CONTRIBUTIONS TO ANALYSES OF MONITORING EARLY SIGNS OF DEGLACIATION CAUSED BY NEVADO DEL RUIZ VOLCANO, MANIZALES, COLOMBIA

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ABSTRACT

The present project studies the glacier area of Nevado del Ruiz volcano in Manizales, Colombia, using OLI images from 2014 to 2019. The main idea is to provide tools that allows us to constantly monitor not only environmental issues, but also social and technical issue. Techniques such as NDSI and NDSII indices, minimum distance supervised classification and K-means unsupervised classification were used. The minimum distance supervised classification and both indices provided the best results. The techniques were inefficient in the images where clouds were abundant.

INTRODUCTION

In the past years, the field of natural hazards has been deeply studied, specifically in Colombia. Due to its geography and topography, this country is susceptible to various natural phenomena.

The mountain range of Colombia is characterized by having a topography that contains steep escarpments; these are factors that cause landslides and mass-wasting. Mass-wasting can be caused by other factors; however, this project will be focused on the landslides caused by deglaciation.

The effect of climate change has accelerated the process of deglaciation during the past years, elevated temperatures can cause deglaciation on mountain tops. Thus, two important problems are going to be observed: firstly, increased mass-movement such as avalanches, over-flow of sediment and lahar-flows (for example the lahar-flow that affected the city of Armero in 1985).

When thawing occurs, it is possible that the flow of the drainages increases to a volume such that it is not supported by the dams

and causes them to collapse, or that the water continues to warm up to such an extent that it evaporates at high rates.

The National Park of Los Nevados, located near Manizales, has been one of the most affected victims in recent years by melting ice, one of its representatives is the Nevado del Ruiz Volcano, which has been the protagonist of several events related to mass transportation, especially torrential floods.

Mass wasting occurs when a high volume of water drags at high velocities the sedimentary material that had been trapped in the drainage channels. This is observed when, due to the melting effect, the volume of water increases, therefore also increases the flow and consequently causes the sediment to be dragged. In addition to above, the water that does not run off infiltrates the soil mass, which triggers the occurrence of new mass movements. In short, the thaw is a real problem and can lead to irremediable losses.

Fortunately, technology has provided us with important tools that allow us to constantly monitor, not only environmental issues, but also social and technical issues. Remote sensing has become a strategic ally in monitoring issues whose environmental and social impact have positioned it as an essential tool for analyzing climate change associated with disaster risk management.

The aim is to contribute to the knowledge, prevention and risk reduction on the monitoring of the ice sheets of the Nevado del Ruiz volcano, giving innovative ideas for the creation and implementation of an early warning system.

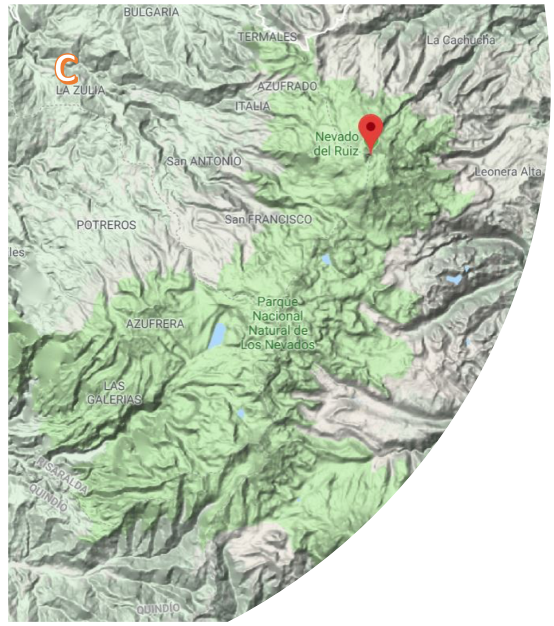

Figure 1. A. Republic of Colombia. B. Caldas Departament. C. Nevados National Park. Source: Google Maps, 2019.

Figure 2. Nevado del Ruiz volcano. Source: Colombian Geological Service, 2019.

The volcano is located at 4 ° 53'43 "N and 75 ° 19'21" W and has an elevation of 5321 meters.
It is classified as an active stratovolcano with two parasitic cones, La Olleta and La Piraña. Its age dates from the Pliocene, as its eruptive history began 1.8 ma.

MATERIAL AND METHODS

The methodology of this project consisted of a series of steps that involved the following:

1. Downloading the volcano images from Landsat 8 OLI by Earth Explorer.
2. Using the ENVI software.
3. Applying NDSI and NDSII indices.
4. Applying minimum distances classification and K-means unsupervised classification.
5. Measuring the snow area of the volcano.
6. Result and Discussions.
7. Conclusions

Satellite and airborne images

OLI images obtained from 2014 to 2019 of Nevado del Ruiz volcano were downloaded from USGS's Earth Explorer. Almost every image contains clouds, which is a problem. However, it was possible to obtain an image from the beginning of each and every year.

Software

The program used to process the images was ENVI (Environment for Visualizing Images).

Processing Images

First, I used ENVI to analyze every image in true color and I applied the square root stretch. This helped me to compare the results I obtained by the indices I applied.

Then, a spatial subset was applied in every image. We generated composite-bands multispectral images, using the visible, near infrared and mid-infrared bands. The panchromatic band was used to enhance the spatial resolution of each image since the resolution of this band is 15 m (Figure 3 to 8). The final result was a new image with a better spatial resolution of the study area.

Then, to understand how data was processed, we need to know that different technics are available to study the snow and ice landscape, for example the spectral indices of satellite images. Another method is using the supervised and unsupervised classifications, because they point out the glacier area in the images. The supervised classification method requires the user to perform a good visual interpretation in order to train the program; this way it will effectively determine different classes on the images. On the other hand, in the unsupervised classification method the software does the job by itself, without requiring the guidance of an user.

In addition to the classifications, we applied two spectral indices:

Normalized difference snow index (NDSI)

$$NDSI = \frac{Green - SWIR}{Green + SWIR}$$

To map-out the snow-ice differentiation in snow-covered areas.

Normalized difference snow and ice index (NDSII)

$$NDSII = \frac{Red - SWIR}{Red + SWIR}$$

To map-out the differentiation of snow and ice in areas covered with snow and ice.

A K-means classification with three classes and three iterations was used. For the minimum distance classification, three regions of interest (ROI) were created:

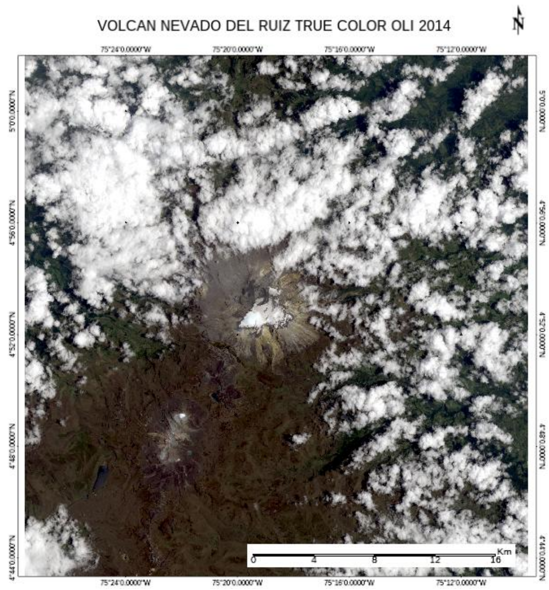

Figure 3. True color image of the volcano (2014)

Snow, Cloud and Ground. The main idea to use this classification was to compare it to the results of the indices, because we want to know if both indices are trustworthy.

Finally, the goal was to measure each area per year, thanks to the indices results, and to prove if there has occurred a decrease in snow each year. ROI provides a measuring tool (figure 9) where we can define all the areas of the resulting images to determine the snow in km^3.

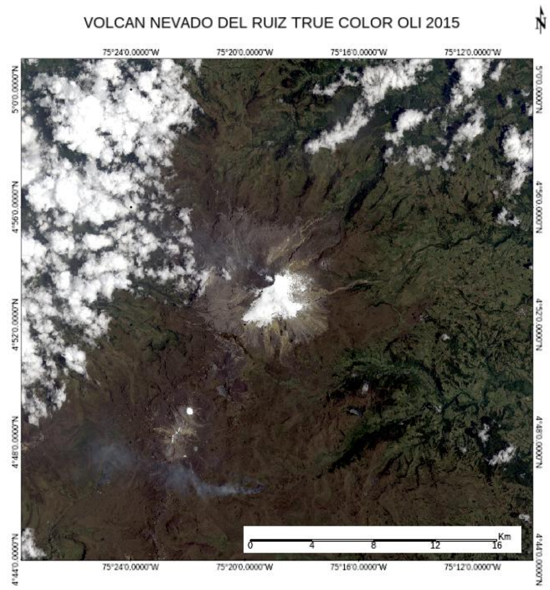

Figure 4. True color image of the volcano (2015)

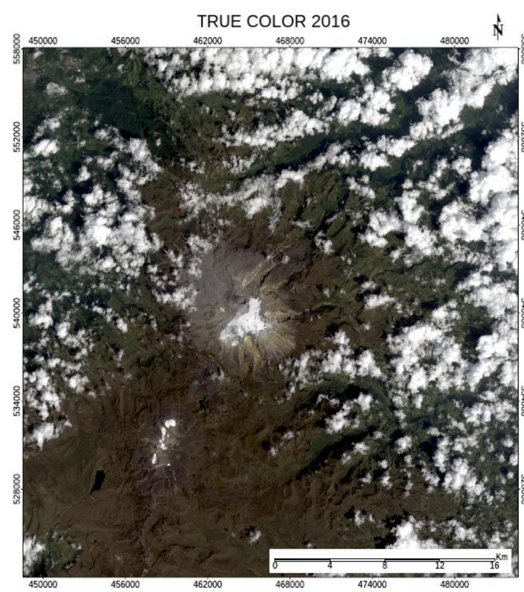

Figure 5. True color image of the volcano (2016)

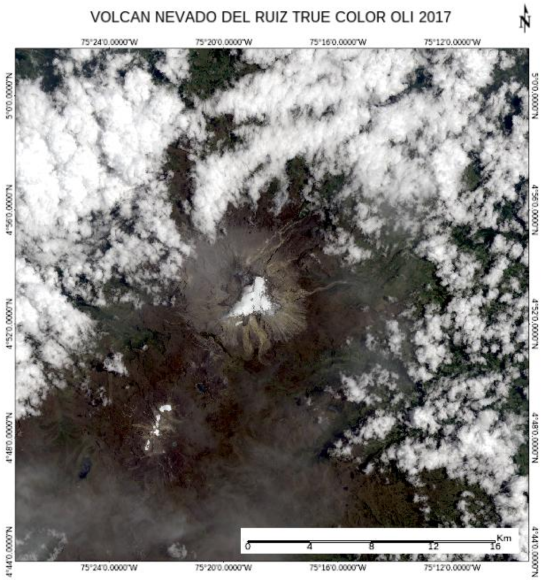

Figure 6. True color image of the volcano (2019)

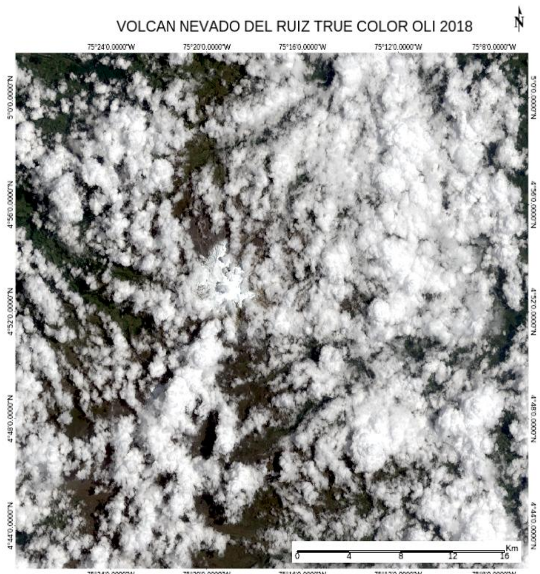

Figure 7. True color image of the volcano (2018)

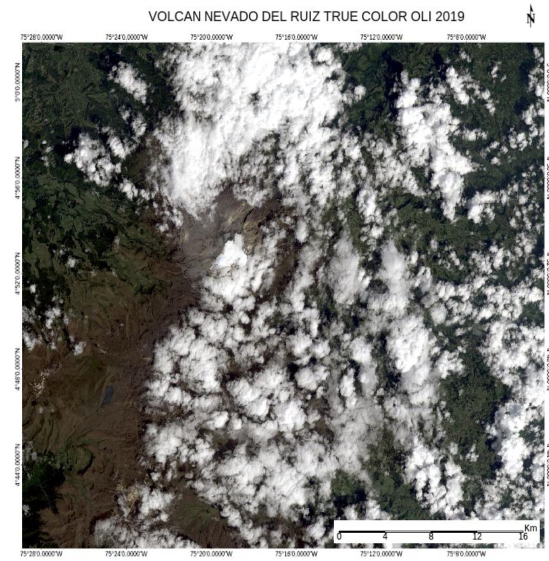

Figure 8. True color image of the volcano (2019)

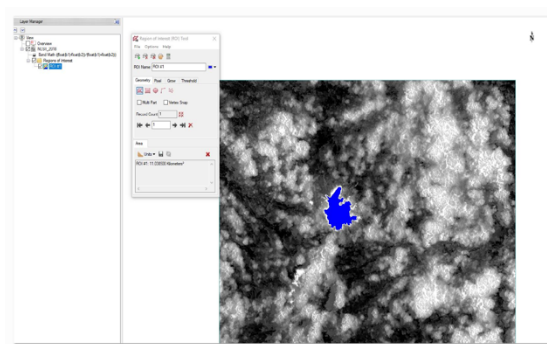

Figure 9. ROI measuring tool

RESULTS AND DISCUSSION

The snow area of the volcano is difficult to study because the presence of clouds around and inside the volcano in OLI images is too common, however NDSI and NDSII indices are able to filter most clouds. The Minimum classification help to filter clouds and to effectively identify the snow area, in contrast the K-means method was unable to identify the region of interest.

Both indices result quite convenient, despite the fact that the algorithm confused cloud with snow, like in the 2018 image. This image has the peculiarity that the crater area was covered of clouds, for this reason it is possible that the algorithm confused those clouds with snow, thus resulting in an enormous “snow” area. We also saw that the Min-Dist. technique presented the same problem.

In 2016, Nevado del Ruiz underwent volcanic activity and maybe that is the reason that the snow area was smaller compared to 2015.

Below, all the results are presented:

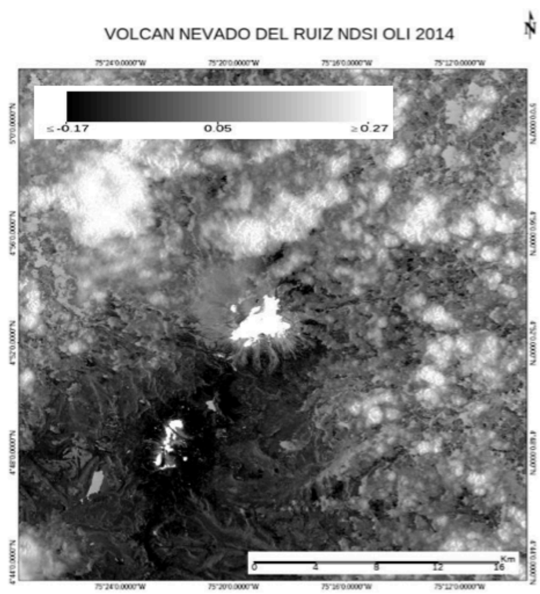

Figure 10. NDSI results (2014)

The index was able to filter the clouds. As we see, the snow is not covering the crater. NDSI shows a value of 0.27, which should belong to snow.

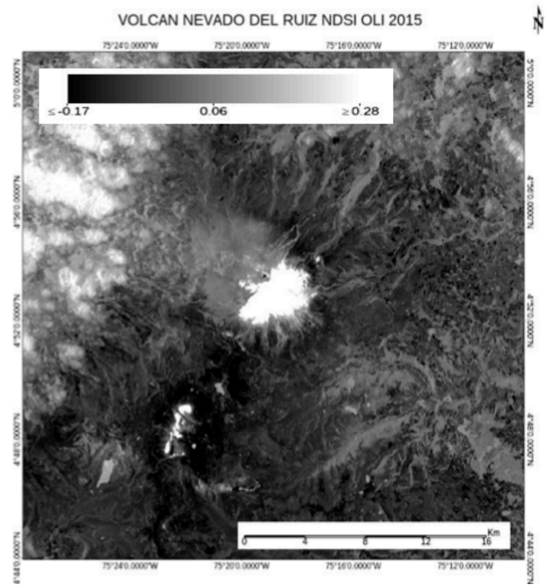

Figure 11. NDSI results (2015)

We see in this year, that the snow area is bigger with respect to the last year. NDSI shows a value of 0.28, which should belong to snow.

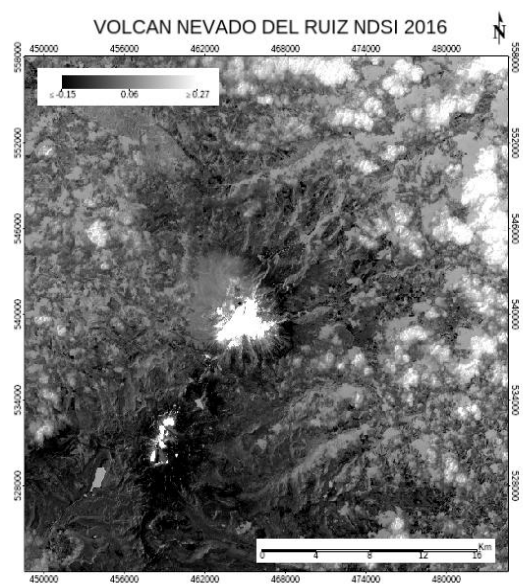

Figure 12. NDSI results (2016)

We can see less snow in comparison to the last image, maybe for the eruption that occurred. NDSI shows a value of 0.27, which should belong to snow.

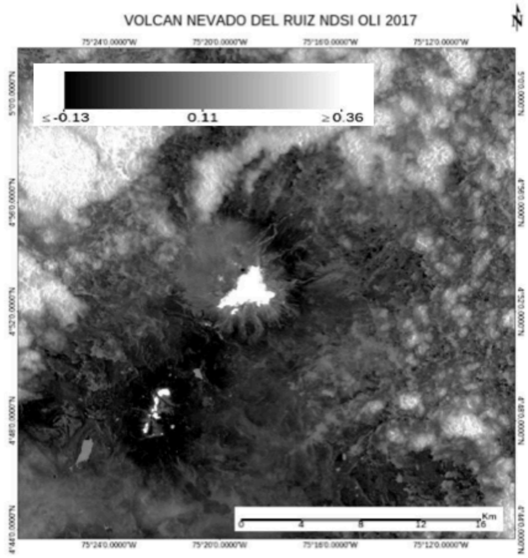

Figure 13. NDSI results (2017)

In this year, the index shows that the snow value is 0.28, but we see the area is quite similar to 2014.

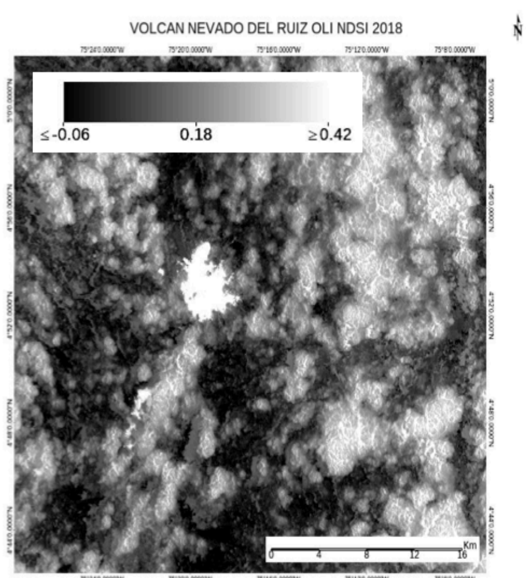

Figure 14. NDSI results (2018)

This is the image where most clouds are present. It also shows the biggest snow area with a maximum value of 0.42.

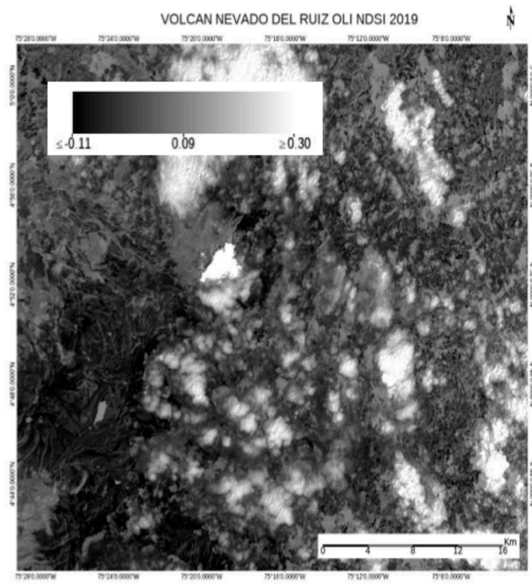

Figure 15. ND NDSI results (2019)

We see that the area is quite similar to 2014. It shows a value of 0.30.

When we applied the second equation (NDSII), the results were very similar to the previous ones.

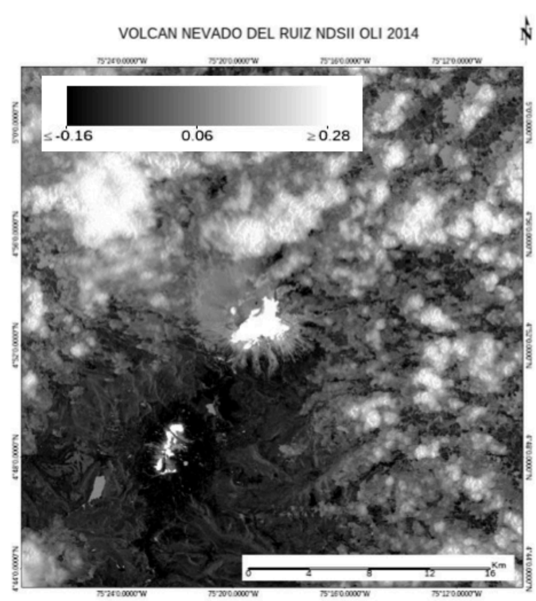

Figure 16. NDSII results (2014)

It shows a snow value of 0.28. As in the previous results (NDSI), the image that belongs to this year is full of clouds.

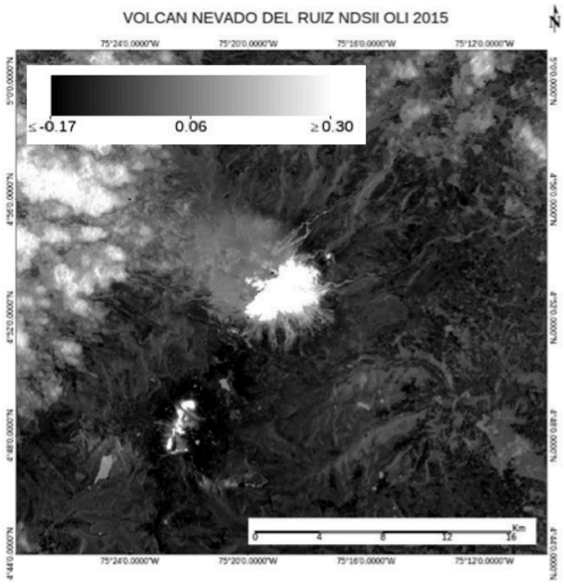

Figure 17. NDSII results (2015)

It shows a snow value of 0.30.

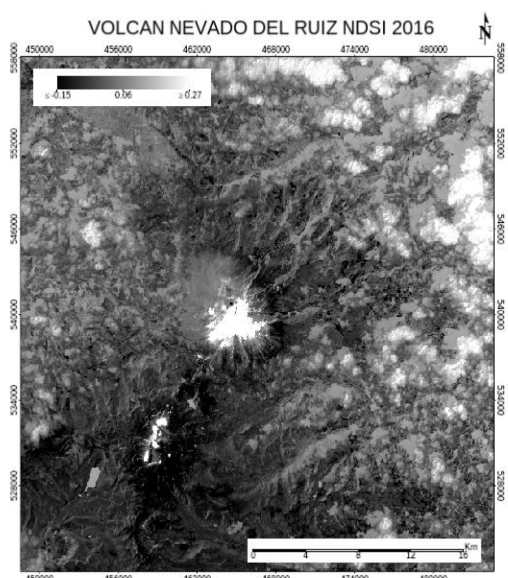

Figure 18. NDSII results (2016)

We can see less snow in comparison to the last image, maybe for the eruption that occurred. NDSII shows a value of 0.27, which should belong to snow.

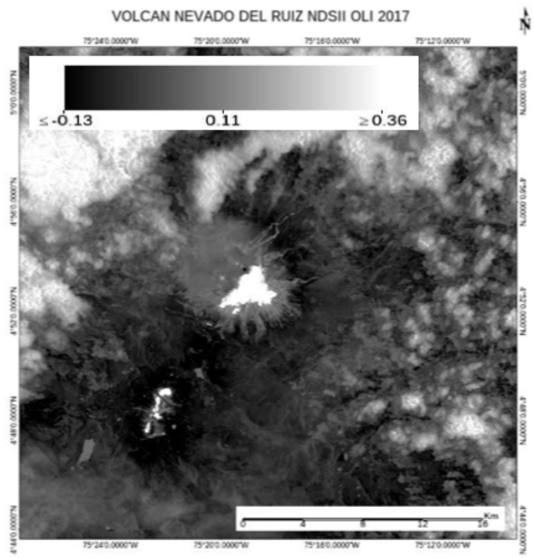

Figure 19. NDSII results (2017)

It shows a snow value of 0.36

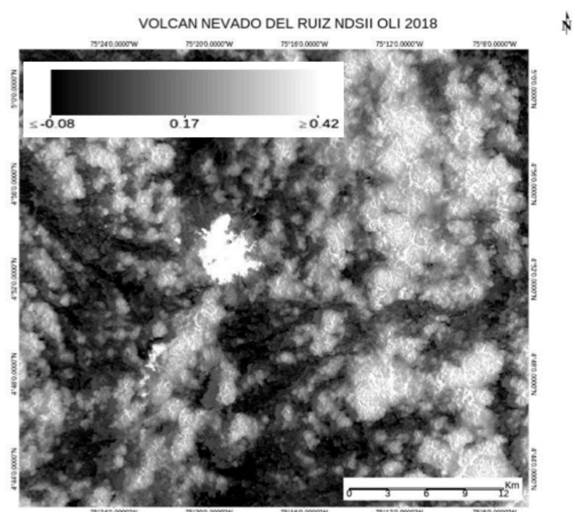

Figure 20. NDSII results (2018)

It shows a snow value of 0.42.

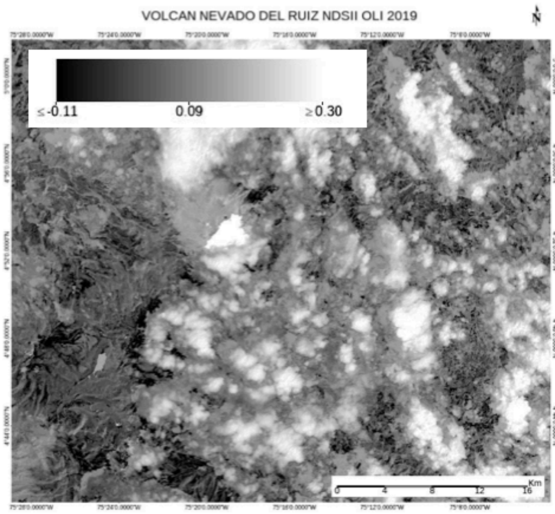

Figure 21. NDSII results (2019)

It shows a snow value of 0.30.

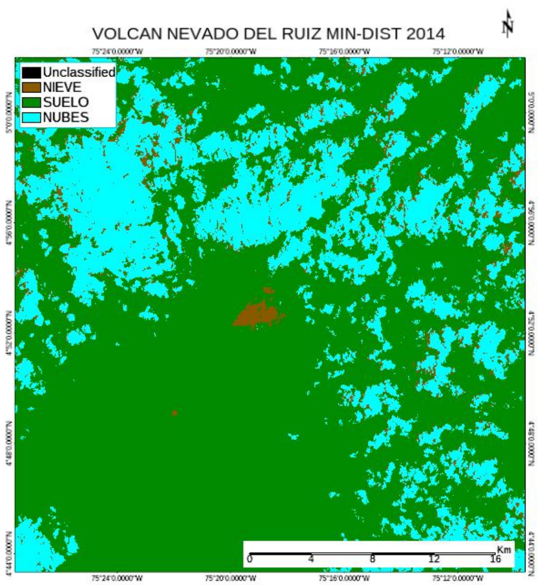

Figure 22. Minimum distance results (2014)

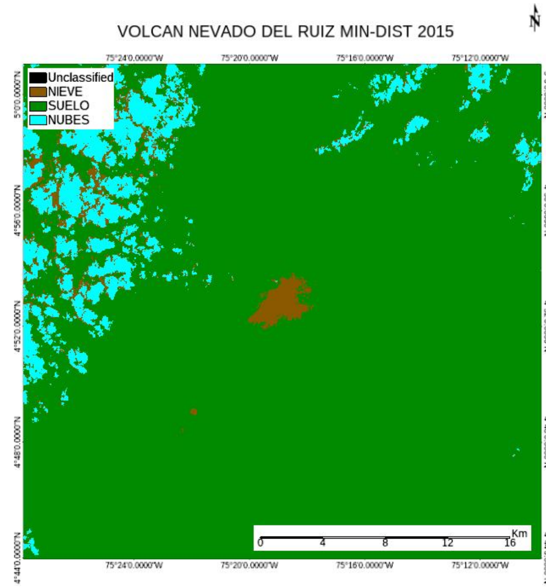

Figure 23. Minimum distance results (2015)

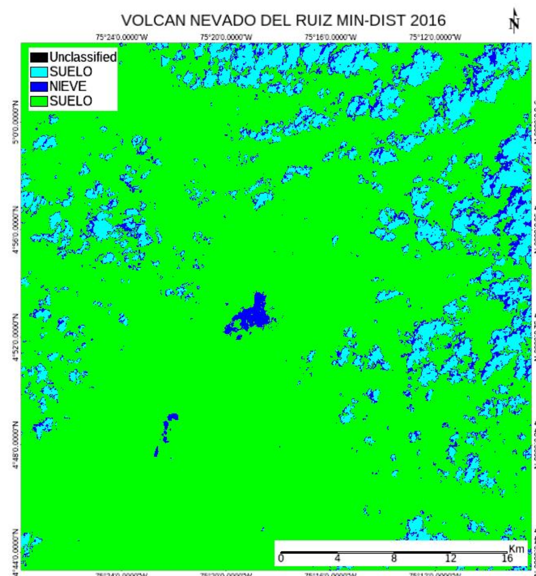

Figure 24. Minimum distance results (2016)

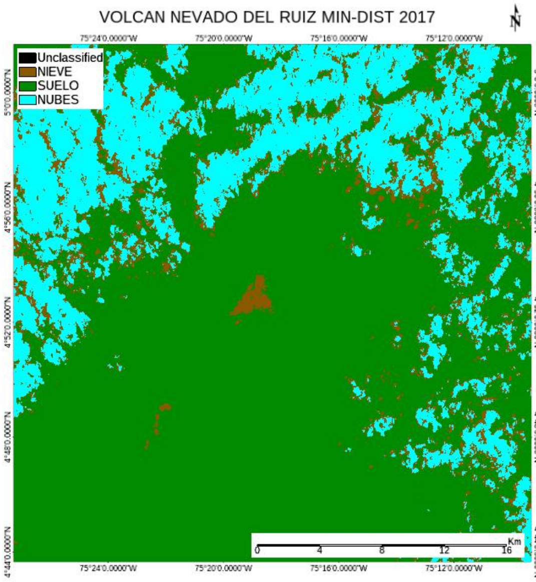

Figure 25. Minimum distance results (2017)

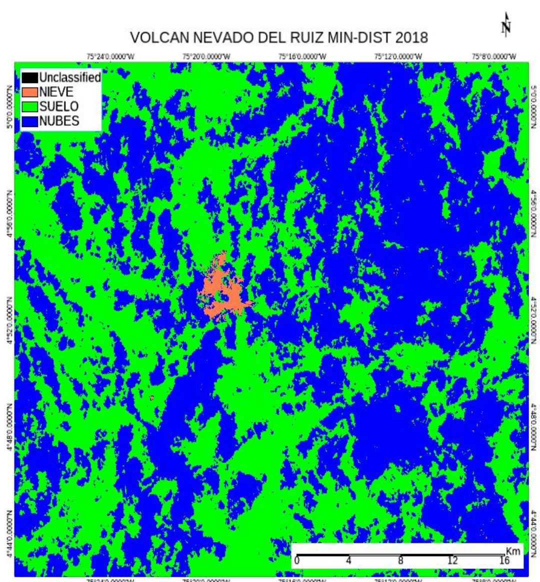

Figure 26. Minimum distance results (2018)

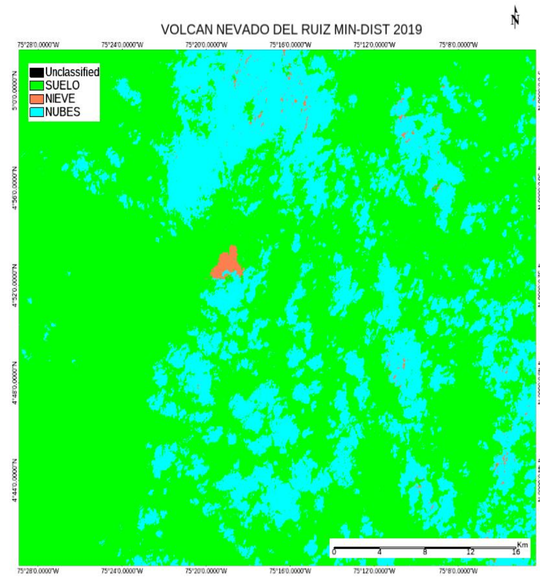

Figure 27. Minimum distance results (2019)

The K-means classification was applied only in two images because it was unable to interpret any classes.

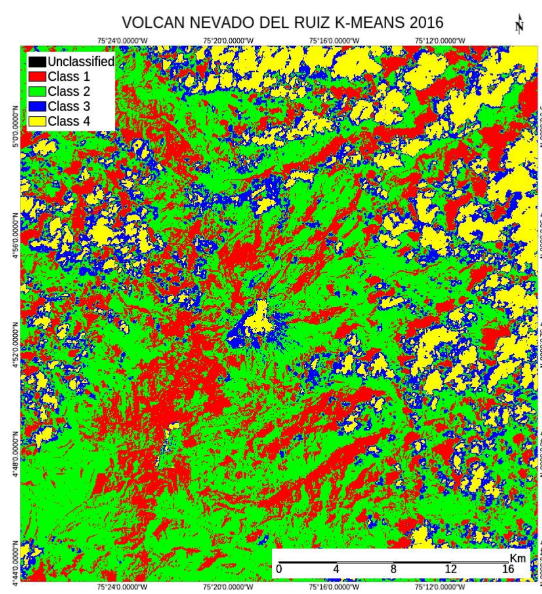

Figure 28. K-means results 2016

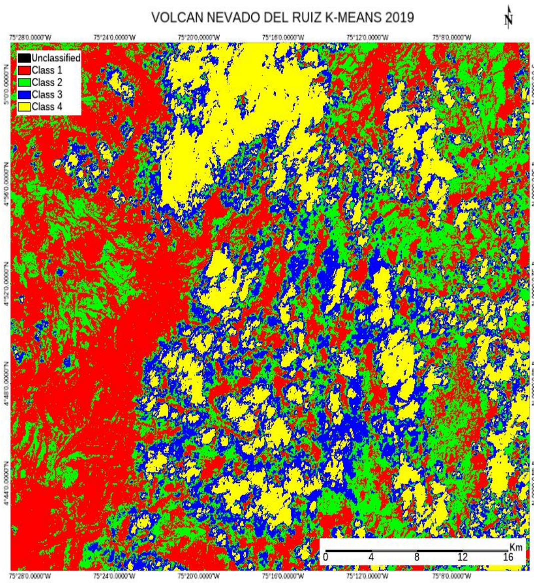

Figure 29. K-means results 2019

Figure 30. temporary variation

CONCLUSION

Thanks to remote sensing techniques, we can explore other branches of sciences. For example, those techniques can be useful to monitor and research nature phenomena, in addition to know how the glacier landscape has behaved over the years.

The temporal analysis shows that in the last five years the snow area was stable, in 2018 the major area was detected but this result was probably negatively affected by the presence of clouds.

The following image presents the percentage of snow of every year (2014 – 2019) in the study area.

Figure 31. snow percent in every year

Although the atmospheric conditions for the selected periods were not favorable, the indices visually presented good results and were able to filter cloudiness to the greatest extent.

The five-year range is a short period to notice a substantial difference in snow area decrease.

The decrease of the snow area is also related to volcanic processes, which does not necessarily imply the phenomenon of global warming.

It cannot be attributed that the reduction of the area is due to climate change, since there are other factors to consider.

Glaciology studies for the area of interest are relatively new and there is no historical record of glacial change.