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Evolution of SO_2 Emissions from Nyiragongo Volcano as Recorded at Rusayo DOAS Station from 22nd May, 2021 to 20th May, 2023

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A B S T R A C T

Nyiragongo and Nyamulagira are two still active volcanoes in the Virunga volcanic chain. However, Nyiragongo remains the most threatening given the human population and goods in its proximity. Given the disappearance of the gas plume and the lava lake in the crater, some residents of the City of Goma and its surroundings were tempted to believe that Nyiragongo was extinct or got dormant after its eruption on 22nd May, 2021. Others have thought that there was an eruptive cycle for Nyiragongo and which should guide estimates regarding the occurrence of a next eruption. This study was conceived to understand, thanks to mini DOAS, the evolution of SO2 emissions as an indicator of the activity of Nyiragongo on a scale of two years after its eruption of 22nd May, 2021.The absorption spectrometry, performed using the Differential Optical Absorption Spectrometer, DOAS, an ultraviolet based instrument settled in Rusayo helped to collect the sulfur dioxide emitted from Nyiragongo during the study period. Results revealed that the longer disappearance period of the SO2 emissions from Nyiragongo (n=98) was recorded from 22nd May to 29th August 2021 directly after the eruption, about three months. At each reappearance of the volcanic SO2 emission during the study period, the average amount recorded where not very different with the amounts observed during other volcanic normal activities. While the lowest average was 297.28 tons/day recorded on 3rd September 2022, the highest average reached 7845.24t/d on 16th January 2022; fortunately, it raised to that extent just the only one day and the trend line for the period remained between 1500 t/d and 700t/d. The longer disappearance could last no more than three months before its reappearance. These observations indicated clearly that Nyiragongo volcano remained active even after the eruption of 22nd May 2021. The volcanic SO2 monitoring should be reinforced and maintained properly to avoid all false considerations about the volcanic activity of Nyiragongo. All signs of volcanic activity should be popularized among all stakeholders of the volcanic risk prevention around Nyiragongo, especially those living in Goma, Gisenyi and the surrounding villages.

Keywords: SO_2, Nyiragongo Volcano, Evolution, DOAS, Rusayo

Introduction

Nyiragongo and Nyamulagira are two still active volcanoes in the Virunga volcanic chain. However, Nyiragongo remains the most threatening given the human population and goods in its proximity. Older lava flows that can be associated with volcanic activities, which have already been the subject of certain scientific studies since 1894, bear witness to a series of ancient gigantic eruptions of Nyiragongo (Pouclet & Bram, 2021). In addition, scientists agree that the well documented and well known eruption of Nyiragongo was that of 10th January, 1977. Among the serious consequences recorded of the latter was loss of human life caused by the volcanic lava flow of which death toll is estimated between 74 and 400 people, and between 800 to 1000 people lost shelter and agricultural land (Jacques Durieux, 2003). The Nyiragongo eruption on 17th January, 2002 was not without human and material damage. It also took the lives of around 140 people and left around 120,000 people homeless and 300,000 people forced to evacuate the city of Goma(Balagizi et al., 2016). As of 22nd May, 2021, Nyiragongo erupted again, the lava flow caused victims again including 32 direct deaths and 450,000 people forced to move; some towards Sake, Bukavu, Uvira and others towards Rwanda(Sabiha Zehraoui and Anna Provodnikova, 2021). Given the disappearance of the gas plume and the lava lake in the crater, some residents of the City of Goma and its surroundings were tempted to believe that Nyiragongo was extinct or got dormant after its eruption on 22nd May, 2021. Others have thought that there was an eruptive cycle for Nyiragongo and which should guide estimates regarding the occurrence of a next eruption(OVG, 2022). In contrary to what many people think in this area, scientific observations consider that a volcano is active if it has an eruptive frequency between ten and one thousand years. While a volcano that has not erupted for five thousand years is considered dormant, after more than ten thousand without erupting, the volcano is considered extinct (Laumonier, Karakas, Bachmann, et al., 2019). There are specific signs that show the level of volcanic activity and warn of upcoming eruptions. These include earthquakes, lava flow in the vicinity of the volcano, expulsion of hot lava and release of gases; to cite only these as indicators (Lindell, 2018). However, not all such

signs are necessarily followed by a volcanic eruption. Statistics from global eruptive data reveal trends that may not be evident in more limited data sets where errors and uncertainties have greater effects (Pesicek, Ogburn, & Prejean, 2021). Like seismicity monitoring, degassing of volatile substances from volcanic systems is a useful tool to monitor the volcanic activity with the aim of characterizing geochemistry, predicting and preventing changes in the level of the volcanic activity (Inguaggiato et al., 2021). Such a geochemical tool was successfully applied by the Goma Volcano Observatory, GVO, to collect the SO_2 emitted by the Nyiragongo volcano thanks to the mini DOAS scanning installed in Rusayo since 2007(Galle et al., 2010) shortly after its eruption on 17th January, 2002. These studies showed that during periods of intense volcanic activity we record 5000t/day of SO_2, or even 15000t/day and that during periods of normal activity we record up to 4000t/day or less. This study was conceived to understand, thanks to mini DOAS, the evolution of SO_2 emissions as an indicator of the activity of Nyiragongo on a scale of two years after its eruption of 22nd May, 2021.

Methods and Tools

The absorption spectrometry performed using the Differential Optical Absorption Spectrometer, DOAS, an ultraviolet based instrument settled in Rusayo helped to collect the sulfur dioxide emitted from Nyiragongo during a period of two years after the eruption of the Volcano on 21st May, 2021.

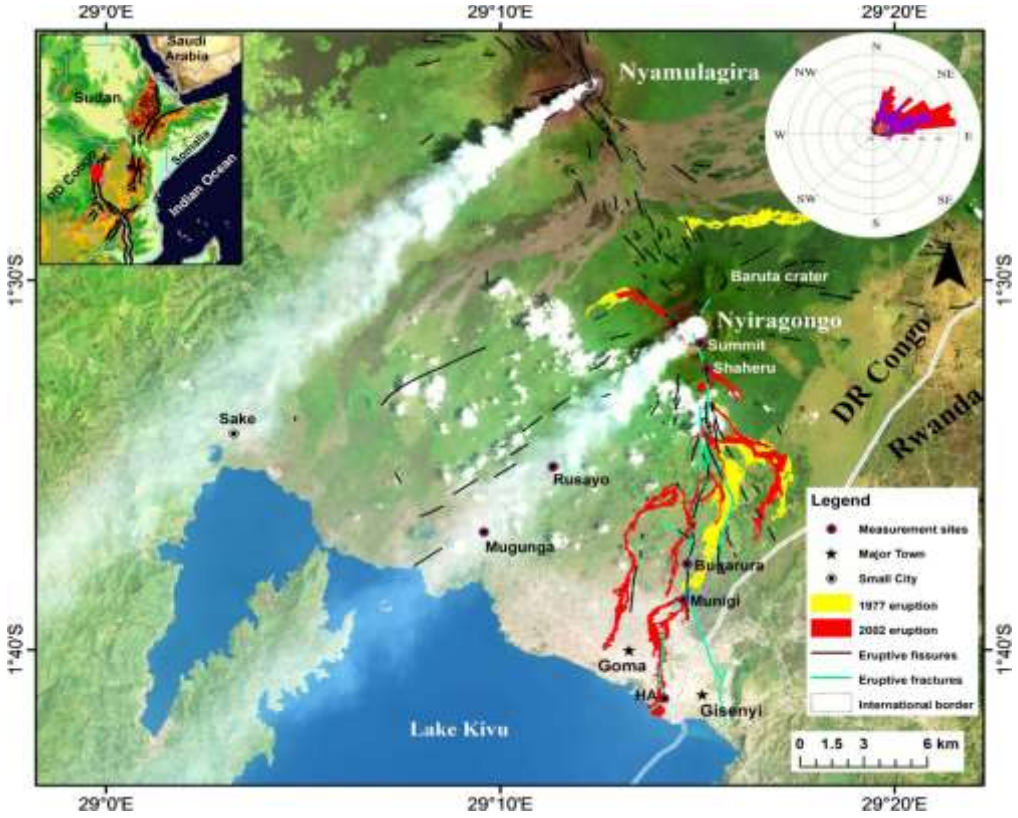

Figure 1. Location of Rusayo DOAS station and space view of plumes venting from Nyiragongo and Nyamulagira permanent lava lakes hosted within their main craters as captured by the NASA Earth Observatory (2015) (Operational Land Imager (OLI) on Landsat 8 (Balagizi et al. 2016).

The scanning mini-DOAS performs the integration of the gas plume from a fixed point, preferably underneath the gas plume, by sequentially aiming the telescope in different directions confined to one plane or cone that intersects the gas plume. The telescope is placed horizontally and aimed at a first-surface UV-enhanced mirror to collect the spectrum. According to the Lambert-Beers law, the light passing through the absorbing gas is attenuated such that the initial intensity, at the wavelength of light beam emitted by the light source and the intensity of light after passing a distance through the gas. Thus, the intensity of the light decreases exponentially with the distance crossed through the gas. Absorption spectroscopy uses this relation to determine the concentration of the gas by measuring initial intensity (Io) and intensity related to a distance made by the light through the gas (I_1)(Arellano, 2014; Galle et al., 2010)

Results and Discussion

Table 1. Observation of SO_2 record from Rusayo DOAS Station

Disappearance & reappearance period	Average SO_2 on reappearance(t/d)	Number of days
22nd May to 29th August 2021	-	98
30th and 31st August 2021	716.54	

1st to 12th September 2021	-	11
13th September 2021	923.92	
14th to 24th September 2021	1407.57	10
26th Sept to 27th December 2021	-	92
28th December 2021	2405.11	
5th to 23rd March 2022	-	20
24th March 2022	1326.01	
10th to 17th April 2022	-	7
18th April 2022	2006.55	
21st April to 13rd May 2022	-	22
14th May 2022	1131.54	
26th June to 2nd September 2022	-	65
3rd September 2022	257.28	

The table above reveals that the longer disappearance period of SO_2 emissions from Nyiragongo (n=98) was recorded from 22nd May to 29th August 2021 directly after the eruption. The second longer period without SO_2 record (n=92) was observed from 26th September to 27th December 2021. The following longer period of SO_2 absence (n=65) was observed between 26th June to 2nd September 2022. The rest of disappearance periods were less than a month and varied between 7 and 20 days. Concurrent reports revealed that the permanent lava lake which is a specific characteristic of Nyiragongo completely disappeared after the eruption. However, a disappearance of three months or even more was not enough to consider that the volcano was becoming inactive, dormant or extinct. The graphic below gives details over the evolution of the SO_2 emissions during the study period.

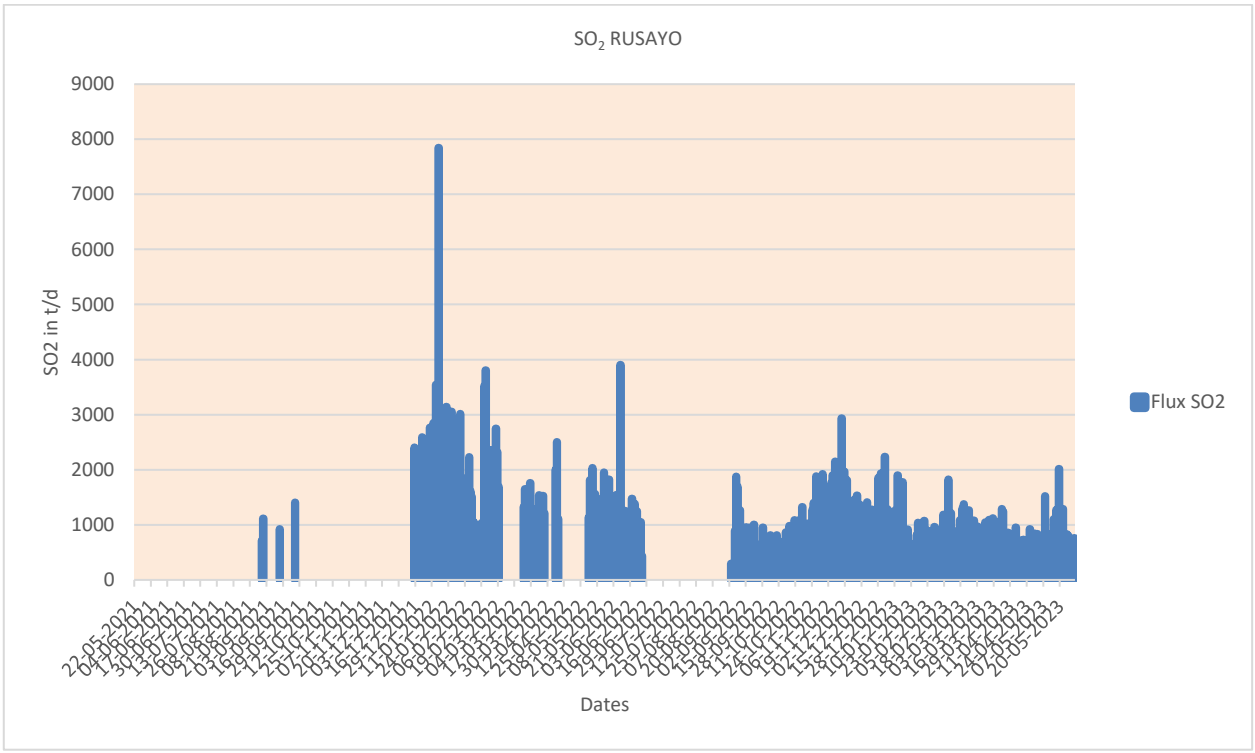

Figure 2. Volcanic SO_2 recorded at Rusayo DOAS Station from 22nd May 2021 to 20th May 2023

Upon examination of the graph above, it is revealed that the SO_2 disappeared after the May 22nd 2021 eruption and reappeared alternatively. At each reappearance of the volcanic SO_2 emission during the study period, the average amount recorded where not very different with the amounts observed during other volcanic normal activity. While the lowest average is 297.28 tons/day recorded on 3rd September 2022, the highest average reached 7845.24t/d on 16th January 2022, and this was a scaring threshold; fortunately, it raised to that extent just the only one day and the trend line for the period remained between 1500 t/d and 700t/d. These observations indicated clearly that Nyiragongo volcano remained active even after the eruption of 22nd May

2021. A compilation of SO_2 emissions recorded from January 2022 to May 2023 revealed a return of a continuing volcanic activity. These and further observations will help to confirm more about the continuation of Nyiragongo volcanic activity.

4. Conclusion

The DOAS Station of Rusayo recorded different periods of volcanic SO_2 emissions disappearance as observed during the period from 22nd May 2021 to 20th May 2023. However, the longer disappearance could last no more than three months before its reappearance. The SO_2 averages were almost similar to those observed during pre-eruptive volcanic normal activities. The highest and scaring average was observed on 16th January 2022. Fortunately, it occurred the only one day. These observations indicated clearly that Nyiragongo volcano remained active even after the eruption of 22nd May 2021. The volcanic SO_2 monitoring should be reinforced and maintained properly to avoid all false considerations about the volcanic activity of Nyiragongo. All signs of volcanic activity should be popularized among all stakeholders of the volcanic risk prevention around Nyiragongo, especially those living in Goma, Gisenyi and the surrounding villages.

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