



## **Environmental and health impacts of Nyiragongo and Nyamulagira Volcanoes, East Africa**

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Nyiragongo and Nyamulagira, only  $\sim 14$  km apart, are the Africa's most active volcanoes. The two volcanoes are located in the Virunga volcanic field, western branch of the East African Rift System, in the eastern Democratic Republic of the Congo. Since  $\sim 1880$ , Nyiragongo has erupted 2 times (1977 and 2002) and Nyamulagira at  $\sim 44$  times with eruptions that can last up to 26 months, and have both produced long lava flows, emitted huge gases, ash and Pele's hair that have impacted both the human health and the environment. During the 2002 eruption Nyiragongo released tons of products into the atmosphere, with estimated fluxes of up to 147 kt/day of  $\text{SO}_2$  and 9.3 kt/d of  $\text{CO}_2$  while on the other hand, the cumulative  $\text{SO}_2$  emissions from 15 eruptions of Nyamulagira between 1980 and 2006 are estimated to  $\sim 27 \times 10^6$  tons, which sets the Virunga among the  $\text{SO}_2$  hot spots of the world. Since May 2002 Nyiragongo's permanent lava lake has been emitting daily up to 5356.8 tons of  $\text{SO}_2$ , while Nyamulagira has shown an intermittent presence of a lava lake since the early April 2013. Virunga volcanic plume impacts the environment both at regional and global scales. The plume is in fact often dispersed over wide areas where it may degrade the quality of air and influence climate; e.g. during the November 27 - December 12, 2006 Nyamulagira eruption, the plume crossed central and northeast Africa, Saudi Arabia and eventually reached India. At local scale, studies we have conducted revealed that volcanic emissions impact water quality as they are the primary source of the dissolved loads in both rain and surface waters. Rainwater of pH as low as 3.1 has been recorded, which is the consequence of the continuous input of acidic volcanic gases. High bulk atmospheric deposition fluxes are observed in the region, with values up to 24.6 t km<sup>-2</sup> yr<sup>-1</sup> for fluoride and to 176.6 t km<sup>-2</sup> yr<sup>-1</sup> for total dissolved substances. Both the deposited major and trace elements may accumulate in the soil and plants and subsequently impact the human health. Fluoride is also at high concentration in the rivers and springs in the volcanic field, with values up to 6.9 mg/L; which is  $\sim 5$  times higher compared to the WHO limit for drinking water. The areas experiencing high rates of F deposition and high F concentrations in surface waters also coincide with the locations of villages and cities and towns where endemic dental fluorosis is found. Such a relationship is explained by the use of F-rich water in all domestic activities, including as drinking water, in this densely populated region. While the long lava flows principally from Nyamulagira eruptions burn large forested areas, the volcanic gases, ash and Pele's hair negatively impact human health by damaging the respiratory system, and hence cause respiratory illnesses. Nevertheless, the acid rain is still the most harmful challenge for the population, because it severely damages vegetation and has caused lower crop yields and reduces milk production in cattle.