



Evaluation of the Sustainability of the Knowledge Acquired on Volcanic Risks by the Population of Goma Several Years After the 2002 Eruption of Nyiragongo

Bahati Rusimbuka Marcel^{1,*}, Fatuma Esther², Birisawa Ntamuhanga Anicet¹, Muhambikwa Kasiwa Françoise³, Safari Habari Faustin¹, Mapendo Kasiwa Hortense²

¹Department of Geochemistry and Environment, Goma Volcano Observatory, Goma, Democratic Republic of the Congo

²Department of Family Medicine, Groupe d'Entraide et de Solidarité Médicale, Goma, Democratic Republic of the Congo

³Provincial Inspection of Agriculture, Service National des Semences du Nord-Kivu, Goma, Democratic Republic of the Congo

Email address:

rusimbuka3@gmail.com (B. R. Marcel)

*Corresponding author

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Abstract: This study was done from November 2019 to March 2020 and aimed to assess the level of knowledge of the population of Goma about volcanic risks and volcanism several years after the Nyiragongo volcano eruption in January 2002. The population of Goma and the surrounding villages is exposed to volcanic hazards, both during eruptive and non-eruptive activity. To conduct the research, a survey questionnaire has been used to collect data from the population. The data collected in the field reported that the major part of the population of Goma has already experienced an eruptive episode and has already attended an awareness session on volcanism. The location of the sensitisation, the content of the sensitisation message, the process, the language as well as the documentation used during the sensitisation should be adapted to the target population. Almost the entire population surveyed said that an eruption of Nyiragongo is possible and presents enormous dangers for the population of Goma and its surroundings. This population also knows that in the event of an eruption, they will refer to the message of the political and administrative authorities to adopt responsible behaviour. Three-fifths of our respondents have information on the contingency plan applicable to the city of Goma.

Keywords: Volcanic Risks, Sensitization, Volcanism, Goma, Nyiragongo

1. Introduction

Volcanism around the world remains a public health concern in areas geographically affected by the phenomenon. Throughout the world, as a result of volcanism, entire regions are devastated, which does not leave mankind untouched by this phenomenon.

In the last two centuries, demographic expansion and extensive urbanization of volcanic areas have increased the exposure of our society to volcanic hazards. [15]

There are about 1500 active volcanoes on the planet, at the foot of which more than 450 million people live [Chester et al. 2001; cited by Julie Morin]. More than 500,000 deaths are attributable to volcanism during the historical period [Blong

1996; cited by Julie Morin]; and 5.6 million people were affected by an eruption in the 20th century [Witham 2005; cited by Julie Morin]. Leone [2007; cited by Julie Morin] highlights a lack of feedback on this type of disaster. [8]

Most volcanic hazards affect only areas within a few miles of a volcano. Volcanic ash, however, can affect areas thousands of miles from its source. [12]

Volcanic eruptions represent some of the most climatically important and societally disruptive short-term events in human history. Large eruptions inject ash, dust, sulfurous gases (e.g. SO₂, H₂S), halogens (e.g. HCl and HBr), and water vapor into the Earth's atmosphere. [1]

The increase in atmospheric CO₂ concentrations during the last deglaciation may be ascribed to enhanced volcanism and carbon emissions due to unloading of active magmatic

provinces on continents. The deglacial rise in atmospheric CO₂ points to a mutual feedback between climate and volcanism mediated by the redistribution of surface masses and carbon emissions. [13]

The Global Volcanism Program at the Smithsonian summarizes the abundant active volcanoes, and paucity of knowledge concerning volcanic activity. “Africa has the highest percentage of volcanoes that are undated but known to be Holocene, reflecting the early stage of detailed geologic studies. Africa leads the world in lava lake production, with 9% of its eruptions—all at Nyiragongo and Erta Ale—having exhibited this uncommon characteristic.” [6]. Increasing pressures of growing populations, famine, and civil unrest have led to migration into new areas, including the flanks of active and dormant volcanoes.

Eruptions from Mount Erebus also represent a significant point source of gases and aerosols to the Austral polar troposphere, including affecting the ozone layer [14].

In 2002, a Nyiragongo volcanic eruption in the Congo destroyed 25% of the city of Goma and forced the evacuation of 500,000 people; a series of damaging earthquakes and multiple volcanic eruptions in the Afar region of Ethiopia have been ongoing since September 2005; a magnitude 7.0 earthquake struck Mozambique in 2006; a rifting event with associated volcanic eruption of Oldoinyo Lengai occurred in the Natron area of northern Tanzania in July 2007, causing an ash plume to rise several km into the sky. The plumes from the 2006 Nyamulagira (Democratic Republic of the Congo) eruption and the 2007 Jebel al-Tair (Yemen) eruption both reached the Pacific ocean, creating hazards to aviation. High alkaline contents of African magmas lead to low-viscosity, fast-moving lavas (e.g., Nyamulagira, Oldoinyo Lengai). Mantle volatiles (mainly CO₂) lead to catastrophic degassing events at Lakes (e.g Lake Kivu) high and continuous gas emissions at active volcanoes (e.g. Nyiragongo and Oldoinyo Lengai) and dry cold CO₂ vents in regions of historic volcanism (e.g., Rungwe). High CO₂ and CH₄ concentrations in the crust also leads to seismic hazards possibly facilitating brittle failure in the crust and possibly, upper mantle. These events and observations highlight the need for basic research into past and present volcanism and rifting processes in East Africa. Such efforts will form the framework in which to develop and support capacity-building, regional networks and observatories in East Africa for the evaluation, monitoring and communication of volcanic and seismic hazards. [7]

In January 2002, Nyiragongo volcano erupted 14–34_106 m³ of lava from fractures on its southern flanks. The nearby city of Goma was inundated by two lava flows, which caused substantial socioeconomic disruption and forced the mass exodus of the population, leaving nearly 120,000 people homeless. Field observations showed marked differences between the lava erupted from the northern portion of the fracture system and that later erupted from the southern part. [11]

The crisis was of concern in neighboring Rwanda, which received the spontaneous exodus of hundreds of thousands of fugitives from Goma, and which was directly menaced, although not invaded, by the easternmost lava flows moving toward the Rwandan town of Gisenyi [Kasereka *et al.*, 2002;

Tedesco *et al.*, 2002; Komorowski *et al.*, 2004; Baxter *et al.*, 2004; P. Allard *et al.*, Final report of the French-British scientific team submitted to the Ministry for Foreign Affairs, Paris, France, Foreign Office, London, United Kingdom and respective Embassies in Democratic Republic of Congo and Republic of Rwanda, Paris, unpublished report, 24 pp., 2002, hereinafter referred to as Allard *et al.*, unpublished report, 2002].

Very fast lava flows were produced from the highest portion of the fissure system above and inside the ancient Shaheru crater, south of the presently active Nyiragongo cone. Fortunately, the lava flows which entered the town of Goma were more slowly advancing, giving time to the inhabitants to escape. For this reason, only about 160 people were reported to have died, about 60 of them in the explosion of a fuel tank in the days immediately following the eruption [Baxter *et al.*, 2004]. At the end of the eruption, about 15% of the town had been destroyed, corresponding to an area of approximately 3.8 km². About 120,000 people had lost their houses, and about 250,000 were displaced as a result of the eruption [Baxter *et al.*, 2004]. [4]

The city of Goma and its surrounding villages (Democratic Republic of the Congo, DRC) are among the world's most densely populated regions strongly affected by volcanic hazards. In 2002, Nyiragongo volcano erupted destroying 10–15% of Goma and forced a mass evacuation of the population. Hence, the 1.5 million inhabitants of Goma and Gisenyi (Rwanda) continue to live with the threat of new lava flows and other eruptive hazards from this volcano. [2]

The city of Goma, located at 15 km south of Nyiragongo, was only a small town with 50,000 inhabitants when the 1977 eruption occurred. Following several humanitarian disasters, the Rwandan genocide in 1994 [Tedesco, 1995, 2002/2003], and the subsequent civil war that is still ravaging the country (1996 to present), Goma has expanded to the north toward the volcano, with a major influx of people from the very insecure surrounding countryside.

Currently, the population of Goma is 500,000. With Nyiragongo volcano located only 15 km from the city, it is impossible to ignore the multiple volcanic hazards that the inhabitants of Goma are now facing. [11]

The volcanic risk is quite evident, as the ancient flows that historically reached Goma attest it. The fact that eruptions seem to be occurring more and more frequently on the flanks of the volcano opposite Goma is an additional preoccupation element. Finally, the probable presence of a magmatic reservoir located under the Goma city, as mentioned in 2002, is alarming, as some of the eruptions of 2002 were even located in the city. As we have seen, this city is located exactly in the axis of the Albertine Rift. In this context, the volcanic risk must be considered as major. In general, lava flows are not really a danger for the population. In the case of Nyiragongo, with its very fluid lava flows and the rather steep slope towards Goma, the risk must be taken into consideration even though the volumes are generally small. Trials to divert lava flows have sometimes been successfully carried out (Eldfell in Iceland, Etna in Sicily). In general, the course of the flows can be fairly well predicted. Some areas could probably be identified on the probable course of the flows and could be arranged to slow down the flows, which are generally

small in volume. Finally, gases represent a real risk, especially as they may be of volcanic origin (SO_2 , CO_2) in particular, but also of limnic origin. The releases observed in Lake Kivu during the eruption of Nyiragongo in 2002 alerted scientists to the risk of a limnic eruption. These releases of CO_2 and CH_4 have already taken place in the city. Methane, present in sufficient quantities to cause its self-inflammation, is the cause of many violent explosions under roads, in gardens, near airport runways, in garages and hotels... There is therefore physical continuity, along cracks and fractures, between the methane and carbon dioxide reservoirs and the city. One of these cracks was discovered under a church (Kanisa La Mungu church) in the city centre. It is also possible that there is contamination of the groundwater and that it is involved in the dissemination of these gases in a certain area around the lake. This risk of water pollution should be taken into account in any civil protection action plan. To set the record straight, each litre of water in Lake Kivu contains 2 litres of gas (1/6 methane and 5/6 carbon dioxide), i.e. 1,000 times more gas than in Nyos! Is it useful to remember that carbon dioxide, which is heavier than air, is uncoloured and odourless? Its toxicity starts at 3%. Its presence at 15% causes a sudden loss of consciousness; at 25%, it causes respiratory arrest which results in death. Similarly, methane is uncoloured and odourless. Like CO_2 , it can cause asphyxiation by taking the place of oxygen in the air. It is also extremely flammable. [9]

That year (2002), people died in the city of Goma (DR Congo) because of the volcanic eruption. In order to prevent these deaths, awareness campaigns were organised by international organisations to inform the population on how to behave in the event of a volcanic eruption (of the Nyiragongo volcano). In reality, to limit the risk to a minimum, the assessment of the frequency and intensity of the threat should include not only the human potential exposed but also "the way in which individuals and organisations in the threatened community are likely to react". [10]

The role of the administrative and political authorities must then be integrated; as they will have to take both urgent and unusual initiatives in an unsuitable decision-making context (e.g. the risk of encroachment of different administrative levels is particularly high). [10]

In order to determine the level of knowledge of the population of Goma about volcanism, this study is being

carried out. It will be able to inform us about the community participation or not of the populations living in the city of Goma, which is directly facing the volcanic threats of the Virunga chain in general and of the two active volcanoes, Nyamulagira and Nyiragongo in particular.

2. Materials and Method

2.1. Study Environment

This study was carried out in the Democratic Republic of Congo; North Kivu province; Goma city. Goma is the capital of the province. This city comprises eighteen quarters; it is bordered by the Republic of Rwanda to the east, Masisi territory to the west, Nyiragongo territory to the north and Lake Kivu to the south.

The city of Goma is home to more than one million inhabitants. Our study took place from November 2019 to March 2020.

2.2. Study Population and Sample

Our study was carried out in a descriptive, quantitative way in order to assess the sustainability of the knowledge acquired about volcanic risks by the population of Goma several years after the eruption of Nyiragongo. Inhabitants of all ages were our target in the surveys. Data was collected through a survey questionnaire and processed and analysed in SPSS and Excel.

2.3. Sample Size and Data Collection and Analysis Technique

The study sample was taken on the basis of the LQAS (Lot Quality Assurance Sampling) system, which is a statistical method of sampling by batches. The study population was represented by 120 (one hundred and twenty) subjects. The data were collected using a personal questionnaire administered to the participants. The questionnaire was handed out to the inhabitants who were willing and able to cooperate and who were free to fill in and hand over the questionnaire already completed. The data were analysed in PASW18 (Predictive Analytics Software) and arranged in Microsoft Excel.

3. Results

Table 1. Socio-demographic data.

Variable	Characteristics		
	Category	Frequency	Percentage (%)
Age range	<=19 years old	12	10.4
	20-39 years old	78	67.8
	40-59 years old	21	18.3
	>=60 years old	9	3.5
Profession	State agent	12	6.1
	Humanitarian	11	9.6
	Student/Student	56	48.7
	Dealer	12	10.4
	Other (liberal)	29	25.2

Looking at this table, we can see that more than half of the respondents are aged between 20 and 39, i.e. 67.8%; most of the

respondents are students (48.7%), followed by the category of self-employed people (25.2%).

Table 2. *Sensitization about volcanism.*

Variable	Characteristics		
	Category	Frequency	Percentage (%)
Have you ever witnessed a volcanic eruption?	Yes	78	65.0
	No	42	35.0
Have you ever attended an awareness-raising event on volcanism?	Yes	64	53.3
	No	56	46.7
Content (message) of awareness raising	Unsatisfactory	11	17.2
	satisfying	18	28.1
	Good	24	37.5
	Very good	11	17.2
	Unsatisfactory	11	17.2
The place for awareness raising	satisfying	20	31.3
	Good	31	48.4
	Very good	2	3.1
	Unsatisfactory	4	6.3
The process of awareness raising	satisfying	17	26.6
	Good	24	37.5
	Very good	19	29.7
	None	1	1.6
	Unsatisfactory	11	17.2
The choice of language used	satisfying	7	10.9
	Good	23	35.9
	Very good	22	34.4
	None	26	40.6
	Unsatisfactory	10	15.6
The quality of the documentation provided	satisfying	11	17.2
	Good	6	9.4
	Very good	11	17.2
	Unsatisfactory	9	14.1
	satisfying	5	7.8
The quality of the presentations	Good	42	65.6
	Very good	8	12.5
	None	2	3.1
	Unsatisfactory	2	3.1
	satisfying	22	34.4
Relevance of the information presented	Good	12	18.8
	Very good	26	40.6
	A better understanding of volcanism	27	42.2
	New knowledge	24	37.5
	The possibility of exchanging with others	13	20.3
What awareness has brought you:	Yes	56	87.5
	No	8	12.5
Are you satisfied with this awareness?	Radio and/or Television	20	31.3
	GVO (in the field)	26	40.6
	Internet	5	7.8
Where do you get your information about volcanism? (What channel has been used to raise awareness about volcanism)?	School	4	6.3
	Friends	9	14.1

Of the 120 subjects surveyed; 78 subjects (65%) said they had already experienced a volcanic eruption; 53% of them said they had already attended an awareness-raising session on volcanism.

Subjects (64) who had already attended an awareness-raising session on volcanism rated the content (message) of the awareness-raising session (37.5%), the venue (48.4%), the conduct of the awareness-raising session (37.5%), the choice of language used in the awareness-raising session (35.9%), and the quality of the presentations (65.6%) as good; they gave a very good rating to the relevance of the

information conveyed by the awareness-raising message (40.6%); they stated that they had not received any documentation relating to volcanism during the awareness-raising session (40.6).

During the surveys, about half of the subjects already sensitised told us that the sensitisation had given them a better understanding of volcanism (42.2%), new knowledge about volcanism (37.5%); the subjects (87.5%) admitted being satisfied with the sensitisation. The Goma Volcano Observatory (GVO) remains the most dominant informant (40.6%) followed by the media: radio and television (31.3%).

Table 3. Knowledge about the Nyiragongo volcano.

Variable	Characteristics		
	Category	Frequency	Percentage (%)
Do you know people or services in the city that you could turn to for help/assistance/information in case of suspected volcano risks?	Yes	64	53.3
	No	56	46.7
If yes, which one	ICCN	2	3.1
	MONUSCO	7	10.9
	GVO	44	68.8
	Radio	11	17.2
Do you think it is possible that Nyiragongo could erupt again?	Yes	111	92.5
	No	9	7.5
What drawbacks do you know about the volcanic eruption?	Loss of life and property, pollution and destruction of the environment	102	85.0
	Increase/increase in gas concentration in Lake Kivu	7	5.8
	Increased gas concentration in Mazuku	11	9.2

It emerges from this table that 53.3% of our respondents have information on the services authorised to provide reliable information on the volcanic activities of Nyiragongo; especially in the case of suspicion of related risks.

Nearly $\frac{3}{4}$ of the respondents (68.8%) declared that the Goma Volcano Observatory is the service empowered to provide information on volcanism, followed by the media (radios) with 17.2%.

Almost all respondents (92.5%) confirmed that it is possible that Nyiragongo could still erupt.

More than $\frac{3}{4}$ of our respondents (85.0%) told us that a volcanic eruption has disadvantages such as loss of life and property, pollution and destruction of the environment; 9.5% said that an eruption would lead to an increase in the concentration of gases in the Mazuku.

Table 4. Attitude and Contingency Plan.

Variable	Characteristics		
	Category	Frequency	Percentage (%)
In the event of a volcanic eruption of Nyiragongo, what behaviour would you adopt?	Going home to join the children/Parents/brothers	16	13.3
	Go to MONUSCO	7	5.8
	Go to Gisenyi	20	16.7
	Go to Sake	6	5.0
	Follow the instructions of the politico-administrative authorities	71	59.2
In your opinion, can a lava flow occur in your neighbourhood?	I'm sure that no	2	1.7
	I don't think so	10	8.3
	Yes I think it is possible	94	78.3
	I'm sure that yes	14	11.7
	No never	7	5.8
Are you afraid of the volcano?	Yes, but only when the eruption was announced...	58	48.3
	Yes, all the time	55	45.8
Do you feel you are being told the truth about the risks you are exposed to?	Yes	111	92.5
	No	9	7.5
Have you ever heard of the contingency plan in the event of an eruption of Nyiragongo?	Yes	73	60.8
	No	47	39.2

It emerges from this table that more than half of the respondents (59.2%) agree that in the event of a future eruption, instructions from the political-administrative authorities should be followed in order to adopt a certain behaviour.

Three quarters of the respondents (78.3%) proved their conviction that in the event of a new eruption of Nyiragongo, it would be possible that the lava flow would reach their neighbourhood; 11.7% told us that it would certainly reach the neighbourhood.

Nearly half of the subjects surveyed said they were only afraid of the volcano when a possible eruption was announced (48.3%), compared with 45.8% who were permanently afraid of it. Almost all of the respondents (92.5%) said that they feel

they are being told the truth about the risks to which they are exposed.

More than half of the respondents (60.8%) said they had already heard of the contingency plan in case Nyiragongo erupts again; and the rest (39.2%) had no information about it.

4. Discussion, Strength and Limits

4.1. Discussion

This study attempted to develop an assessment of the sustainability of the knowledge of volcanic risks acquired by the population of Goma several years after the eruption of Nyiragongo. The study focused on the population of the city

of Goma, which was represented by a sample of 120 people who volunteered to take part in the survey.

The majority (65%) of the respondents said they had already experienced a volcanic eruption and just over half (53%) had already attended an awareness-raising session on volcanism.

It is essential to adapt public information campaigns to people's perceptions of risk [5]. Subjects which attended an awareness-raising session on volcanism: 48.4% rated the location of the awareness-raising session as good, the content of the awareness-raising session (37.5%), the conduct of the awareness-raising session (37.5%), the choice of language used by the awareness-raisers (35.9%), the quality of the presentations (65.6%); they gave a "very good" rating to the relevance of the information conveyed by the awareness-raising message (40.6%); 40.6% stated that they had not received any documentation relating to volcanism during the awareness-raising session.

Awareness-raising remains the single most important issue in the response to natural disasters. The relevance of the message (information) conveyed is a cornerstone of risk and disaster management; in this case a volcanic eruption. During our surveys, the data collected joins those found by Morin and Lavigne who found that in Grande Comore, 88% of the people interviewed liked to receive preventive information. [8]

In our surveys, we found that 87.5% were satisfied with awareness. The Goma Volcano Observatory (GVO) remains the most dominant informant (40.6%) followed by the media: radio and television (31.3%).

Slightly more than half of the respondents (53.3%) have information on the services empowered to provide reliable information on Nyiragongo's volcanic activities; nearly $\frac{3}{4}$ (68.8%) cited the Goma Volcano Observatory. Almost all (92.5%) are aware that an eruption of Nyiragongo is possible; and has drawbacks (85%); 9.5% correlate a volcanic eruption with the rise of the mazuku.

More than half of the respondents (59.2%) will follow the instructions of the political-administrative authorities in the event of an eruption for adopting safe behaviour.

More than half of those surveyed (59.2%) agreed that in the event of a future eruption, instructions from the political-administrative authorities should be followed in order to adopt a certain behaviour.

More than three quarters of the respondents (78.3%) are convinced that in the event of another eruption of Nyiragongo, it would be possible that their district would be affected by lava.

Nearly half of the subjects surveyed said they were only afraid of the volcano when a possible eruption was announced (48.3%), compared with 45.8% who were permanently afraid of it. Almost all of the respondents (92.5%) said that they feel they are being told the truth about the risks to which they are exposed.

We found that 45.8% of the respondents are afraid of the volcano; this is in line with the result published by Julie Morin who found that 38% of respondents are afraid of Karthala.

More than half of the respondents (60.8%) said they had

already heard of the contingency plan in case Nyiragongo erupts again; and the rest (39.2%) had no information about it.

Our results are slightly lower than those found by D. K. Bird et al who found in their surveys that participants were warned (89%) about procedures in case of emergency (contingency plan). Fifty-nine point two percent of our respondents stated that in the event of an eruption of Nyiragongo they would follow the instructions of the political-administrative authorities; these results are lower than those found by D. K. Bird et al who found that seventy-one percent of participants described the evacuation procedure well and stated that they would put it into practice. In their surveys, 19% said that in case of emergency they would stay at home; while we found 13.3% with this opinion. [3].

The age of our respondents leads us to the conclusion that more than half were in the 20 to 39 age group, i.e. 67.8%; most of the respondents were students (48.7%), followed by the category of liberal professionals (25.2%).

4.2. Strength and Limits

This study can be interpreted in the light of its points and limitations. The use of questionnaires, the fact that this study assessed individual factors, including the knowledge and attitudes of the population of Goma about volcanism, and the variables in this study can be considered a major strength of our study. However, other factors such as practice and attitudes as well as knowledge of the contingency plan were studied to verify the degree of knowledge and attitude of the population of Goma about volcanism several years after the eruption of the Nyiragongo volcano and its passage through the city of Goma.

In addition, not using enough literature on this topic due to the unavailability of published data in the Study Area and across the region (province) could be mentioned as a limitation.

5. Conclusion and Recommendations

5.1. Conclusion

Based on the results of the surveys we found, we conclude that the majority of the population of Goma that constituted our target has already experienced at least one volcanic eruption and awareness of volcanism. Almost all of the respondents are aware that an eruption of Nyiragongo is possible; and has its drawbacks. Three-fifths of the population would follow the instruction of the political-administrative authorities in the event of an eruption to adopt safe behaviour.

More than three-quarters of the respondents are convinced that in the event of another eruption of Nyiragongo, their neighbourhood could be affected by the lava. Nearly half of those surveyed said they were afraid of the volcano only when the eruption was announced and about half were afraid of it all the time. Almost all of the respondents from the population of Goma said that they feel they are being told the truth about the risks to which they are exposed.

Three-fifths of the respondents said they had already heard about the contingency plan in case Nyiragongo erupts again; and the remaining two-fifths had no information about it.

5.2. Recommendation

The Congolese Government, international agencies and non-governmental organisations should develop strategies for permanent information on the risks linked to volcanism in the Virunga region in general and the city of Goma and its surroundings in particular. This permanent information would be made possible through mass awareness sessions; accessible to a good number of the population of Goma, in the language adapted and mastered or understood by the majority of this population at imminent risk from Nyiragongo.

Conflict of Interest Statement

All the authors do not have any possible conflicts of interest.

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