Health Implications of Volcanic Ash and Gases from Eruptions at Mount Nyiragongo and Mount Cameroon, Central Africa

ABSTRACT

Aims: To assess the prevalence of respiratory, ocular, and skin diseases in communities exposed to volcanic activity at the flanks of Mount Nyiragongo (MN) and Mount Cameroon (MC).

Study design: This study utilized a mixed-methods approach, incorporating focus group discussions (FGDs), questionnaire surveys, and a review of outpatient department (OPD) registers.

Place and Duration of Study: Conducted between 2017 and 2019 in Goma and Karisimbi Municipalities (DR Congo) and the Limbe Health District (Cameroon).

Methodology: Two workshops were held in Goma and Batoke with 40 participants each. Supplementary data were collected through questionnaires from 738 participants in Goma and 400 in Limbe. Hospital data on respiratory, ocular, skin, and gastrointestinal diseases were obtained from 11 health facilities in Goma, Karisimbi, Nyiragongo, Sake, and Limbe, covering the years 1997 to 2006. The study focused on the 2002 MN and 1999/2000 MC eruptions.

Results: Significant increases in respiratory diseases (asthma and bronchitis) were observed, with over 4000 cases in MN and affecting over 30% of the population in MC. Ocular diseases (conjunctivitis and blindness) saw over 800 cases, impacting more than 25% of the population. Skin diseases (dermatitis) recorded over 600 cases, affecting over 35% of the population. Increased incidences of diarrhoea (79.96%) and gastroenteritis (75.9%) were reported in MN communities.

Conclusion: The prevalence of respiratory, ocular, skin, and gastrointestinal diseases varied across health districts, highlighting the need for targeted public health interventions.

Keywords: Gastro-intestinal, Goma, Health district, Limbe, Ocular disease, Respiratory ailments, Skin disease

1. INTRODUCTION

Products from volcanic eruptions around the world such as volcanic ash (i.e. pyroclasts with diameter < 2 mm) and gases (e.g. SO_2, H_2O, CO_2, H_2S, HCl, and HF) can cause significant impacts on human health [1][2][3][4][5][6][7][8][9][10][11]; infrastructure [12][13][14]); grazing animals and agricultural produce [8][12][15][16][17]); and water resources[18]. They also present serious risks for airplanes and airport operations [19][20][21]. The most dangerous fractions of ash are those in the size range of <1 μm and < 0.01 μm, which pose a threat to the lungs when inhaled [4], and further cause eye and skin irritations [5]. Furthermore, prolonged residence of volcanic aerosols in the atmosphere can influence global climate [10][22][23][24]. These volcanic gases (e.g. $SO_2 = H_2SO_4$ and $CO_2 = H_2CO_3$) have the potential to dissolve in water and fall as acid rain in the form of aerosol [25]. After an eruption, ash deposits are remobilized by wind or human activities for decades [4][5][6][26][27][28][29][30]. These gases (e.g. SO_2) have also been observed to adhere on the surface of ash particles. Once inhaled, they may cause asthma and other respiratory tract diseases [4][11]. These aspects thereby increase the health risk from exposure which may continue long after volcanic activity had ceased.

The population resident at the flanks of active volcanoes have been known to experience volcanic ash and gas exposures during, and following an eruption. For example, after the 18th of May 1980 Mt St Helen eruption, it was registered that areas with high levels of airborne ash experienced a three-fivefold increase in emergency room visit for respiratory conditions of asthma and bronchitis [31]. Similarly, the 1996 diffuse volcanic ash fall from Mt Ruapehu, New Zealand, may have contributed to increased mortality observed in the time period after the ash fall in the city of Hamilton found 166 km from the volcano [32]. Furthermore, increased cases of acute respiratory tract infections (e.g. asthma, bronchitis) and eye problems were reported in hospitals and health centers after major volcanic eruptions at Mt Kelud volcano in East Java, Indonesia [14]; Mts Ruapehu (New Zealand) and El Reventado (Ecuador) [33][34]; Cerro Negro volcano (Nicaragua) [35]; Mt Sakuragima (Japan) [36][37]; and Montserrat volcano [38]. Epidemiologic studies conducted in the communities affected by ash fall and gas from these volcanoes showed that, the number of patients with acute bronchitis and respiratory infections significantly increased soon after the ash fall from these eruptions.

1.1 Background

Mount Nyiragongo (MN; Fig. 1a) forms part of the Western Branch of the East African Rift Valley System [39]. This volcano is a stratovolcano with an elevation of 3,470 m situated ~15 km north of the town of Goma and Lake Kivu found west of the border with Rwanda [40]. It is also the second most active volcano in the Virunga Volcanic Province (VVP) after Nyamuragira [39]). Its historical eruptions can be dated back to 1977, 2002 and recently 2021 [11][41]. The surroundings around MN have been described to contain extremely high concentrations of sulphurous gases (SO_2) linked to both passive degassing from its large persistent lava lake and active eruptions [10][11][39][42]. Most of MN eruptions are effusive in nature characterized with high levels of SO_2. It's 22 May 2021 eruption for example, spewed ash, sulphurous gases and lava that forced over 300,000 people out of a million people that inhabit the city of Goma to flee for their lives [11]. In addition to sulphurous gases, carbondioxide (CO_2) escapes through fractures on the volcano's flanks and settles in depressions due to its density killing people and animals which come in contact with it, thus its local reference as '*mazuku*' ("evil winds" in Swahili) [11][39][42]. Despite the threat posed by the ash and gases released from MN's eruptions, the health impact they pose to both man and animals remain under-studied with just a few contributions as that of [10] which was limited to just respiratory problems only on human health and restricted to Goma municipality.

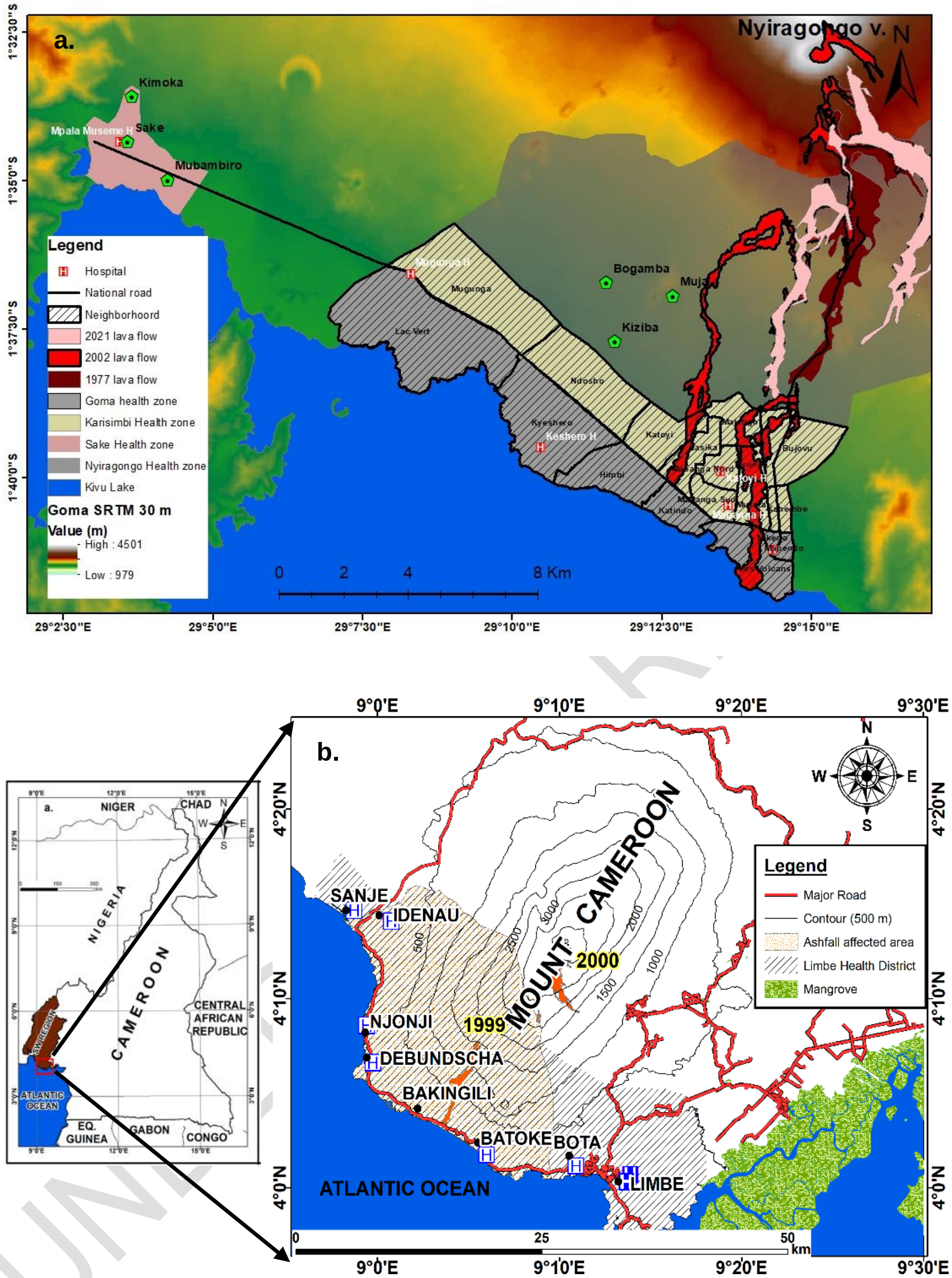


Fig. 1. Maps showing: a) Mount Nyiragongo, the 4 Health Districts, sampled communities, 2002 lava and the sampled hospitals; and b) Mount Cameroon situating the Limbe Health District, sampled localities, health facilities and lava flow fields of the chosen eruptions (1999/2000). Inset: map of Cameroon showing the location of MC

Mount Cameroon (MC) form part of the chain of volcanoes that make up the Cameroon Volcanic Line (CVL) (Fig. 1; [43]). MC has erupted 7 times in the last ~120 years with its most recent eruption being the 2000 eruption [43] and the most destructive being the 1999 eruption

[8][44]. Eruptions from MC are characterized by two phases: a mild explosive phase that principally spews ash and volcanic gases (SO_2, HCL, HF, H_2S) and a quiet or effusive phase that produces long lava flows that get to settlement areas [8][43][44]. In 1999 for example, the ash and gases produced affected the coastal communities found in the SW flank of the volcano [8][45][46]. The short- and long-term impacts registered in these communities included: skin and eye irritations, contamination of water sources; destruction of food crops; a rise in the number of people with breathing difficulties, poor crop yields, lung disease, blindness, abdominal illnesses, death of grazing animals and fishes, and drop in marine coral [8]. Additionally, high fluoride levels erupted from MC [47], contaminate tephra, which probably caused the poisoning of livestock (grazing animals) and humans [27]. In both humans and livestock, ash particles may cause abrasion of the cornea. The health impacts registered for this eruption by [8] were mainly obtained from questionnaire administration (80 in total) and not corroborated with hospital data. In addition, just a few (4 in total) localities in the Limbe Health District were chosen for this study.

1.1.1 Justification

This paper therefore dwells on two main eruptions one each from MN and MC in a bid to understand the relationship that exists between respiratory, ocular and skin irritations with volcanic ash and gasses from these eruptions; and the coping measures utilized by the affected population. It goes further in the case of MN, to assess the impact of ash and gas on agricultural yield, water resources and the health of grazing animals which is an aspect that had previously been covered at MC by [8]. The chosen eruption at MN is the 2002 eruption (Fig. 1a) due to the following reasons: the large volume of sulphurous gases (SO_2) it produced during this eruption [48]; the fact that 3 months prior to the 2002 eruption, a small dark ash plume with emissions of water vapour (H_2O) from old eruptive cracks and fractures was detected [40]. Also, by January 4th, which was a few days before the eruption proper, emissions of a dark plume were also observed. Lastly, a few hours before the eruption proper on the 16th of January, 2002, a pilot flying north of MN perceived a strong smell of sulphur [40]. Prior to its January 2002 eruption, there had been very few quantitative observations of gas emissions from Nyiragongo, however, an estimated 15–31 kt total SO_2 discharge was recorded during the 2002 eruption [40]. The scope for analysis was extended to purposively select communities found within 4 main health zones believed to have significantly suffered from volcanic ash and gas emissions linked to this eruption (i.e. localities in Goma and Karisimbi municipalities (2 health zones found within Goma city); the territory of Nyiragongo (a municipality/health zone out of Goma) and Sake (a city/health zone in the Masisi territory linked to Goma by national road, found 27 km West of Goma)) (Fig. 1a).

At MC the 1999 and 2000 eruptions were chosen and considered as one because of the following reasons: [44] referred to the 2000 eruption as a continuation of the 1999 eruption which resulted from aborted 1999 vents that became eruption centres in 2000 (Fig. 1b). Secondly, [44] cited heightened and sustained seismic activity during the period separating the eruptions; similarity in eruption behaviour for both events; and the reactivation of the 1999 vents during the 2000 eruption. The choice for these eruptions are: the 1999 eruption which began on the 28th of March and the 2000 eruption which began on the 28th of May, were both characterised by explosive vents that emitted gases and tephra of all sizes that extended several metres away from the vents [43][44]. Secondly these eruptions released a dense cloud of ash-laden plumes at heights of 200 and 350 m which due to the prevailing winds dispersed the ash-sized material in the south-western flanks of the volcano as far as Idenau considered to be the furthest coastal town in the Limbe Health District at the flanks of the volcano [43][44]. The scope of the study here included 6 selected communities within the Limbe Health District area (Fig. 1b) which were most affected by tephra and gas from these eruptions.

1.1.2. Study Aims

This study aimed to assess the prevalence of respiratory, ocular, and skin diseases in communities exposed to volcanic activity at the flanks of Mount Nyiragongo (MN) and Mount Cameroon (MC). The following objectives were investigated for this research: 1) assess the prevalence of respiratory, ocular and skin diseases between 1997 to 2006 (flanks of MN) and 1998 to 2006 (flanks of MC) which re presents the period before, during and after the 2002 and 1999/2000 eruptions in selected communities at the flanks of MN and MC respectively; 2) assess the impact of volcanic ash and gases on agricultural practices and water resources in communities at the flanks of MN; and lastly 3) assess the coping strategies used by the communities at the flanks of MN and MC to combat the impacts of volcanic ash and gasses. This was achieved with the aid of primary data generated from workshops through focus group discussion (FGD) sessions; questionnaire administration, which was corroborated with hospital data obtained from hospitals and health centres in the study communities within Nyiragongo, Goma, Sake and Karisimbi Health zones (MN) and 6 communities within the Limbe Health District (MC). Since volcanic ash and gas impacts has direct implications for disaster risk reduction policy and practice due to its extensive nature, there is urgent need to: anticipate long-lasting severe impacts on people's wellbeing; in a bid to plan flexibly to respond to high spatial and temporal variability in impacts; and to be cognizant of communities' adaptations and actions to maintain livelihoods when undertaking external interventions.

2. MATERIALS AND METHODS

2.1. Study Design

This study made use of the transdisciplinary research approach using a mixed research method which combined elements of the quantitative and qualitative research designs. From its conception and design phase, focus group discussion sessions were held in the form of workshops with major stakeholders from the scientific and non-scientific sectors of the studied communities. The discussions held at the pre-design phase led to the design of the research questions and objectives investigated in this study.

The tools used in the realization of these research goals involved focus group discussion sessions (FGD; workshops) held in Goma and Batoke after the co-design phase in 2017. These discussions were centred on the research objectives. A second series of workshops were held in Goma and Limbe city, Cameroon in 2019 to release the findings generated from field analysis and hospital data. These findings were corroborated with the workshop findings and a way forward proposed to the stakeholders in the respective workshops held in DR Congo and Cameroon. The FDG sessions were followed by the distribution of questionnaires which addressed all the research objectives. The sample size used in the selected communities at both the flanks of MN and MC were calculated using the Slovin's formula assuming a precision of 5 % (Eqn 1; [49]).

$n = N/(1+N(e)^2)$--- Eqn. 1

Where n= Sample size; e=margin of Error and N= Population size.

The city of Goma and its environs which include Karisimbi, Nyiragongo and Sake is estimated to have a population of ~ 1,000,000 inhabitants [11]. This number increases to ~1.5 million people when the inhabitants of neighbouring Kisenyi (Rwanda) are added to it [42]. For the calculation of sample size using the Slovin's equation, a total of ~ 1 million people were considered for the 4 health zones in DR Congo. This gave a total of 1000 persons as the sample population. However, in the distribution of questionnaires, just 738 persons fully participated in this study. This was linked to the fact that this study was limited to specific communities within the 4 health zones which does not represent the entirety of the population and also due to the insecurity issues in the area. Limbe health district has a population of ~ 120,000 people distributed in 8 health areas within a surface area of 545 km_2 with a population density of 220 people per km_2 [50]. This total population was used to calculate the sample size for questionnaire administration in the Limbe Health District giving a total of 400 participants who all fully participated in the study.

Prior to administration of questionnaires, in the sampled communities at the flanks of both MN and MC, informed consent was sought from the different participants. Hence, data collection was made retrospectively. Ethical clearance was not required in the collection of data using questionnaires within the 4 health zones at the flanks of MN. This was because those involved in the collection were staff from the Goma Volcano Observatory (OVG) who had already establish a protocol with the population, thus the use of their vehicles during this exercise served as a cover for the study. In addition to the use of their vehicles, the OVG field investigators were issued mission orders that were endorsed by the mayors and traditional chiefs of Goma, Karisimbi, Nyiragongo and Sake health zones. The acquisition of hospital data was facilitated with an authorization letter obtained from the Goma Provincial Health Division. At the flanks of MC, ethical clearance for questionnaire administration was obtained by the field investigators from the institutional review board of the Faculty of Health Sciences, University of Buea. Administrative authorization to conduct the study was obtained from the Dean, Faculty of Sciences /Health Sciences, at the University of Buea. These authorizations were used to obtain permission from the District Medical Officer (DMO) in Limbe. The permission from the DMO was used to obtain permission from the Chief Medical Officers (CMO) of the various health areas and from the traditional rulers to be able to have access to community households and administer questionnaires.

2.2. Study Area and Duration

This study was carried out within four health zones situated at the flanks of MN: Goma, Karisimbi, Nyiragongo and Sake (Fig. 1a) between 2017 and 2019. In each of the health zones, the following communities were targeted for questionnaire administration: Munja, Kiziba, Bogamba (Nyiragongo); Mikeno, Kyeshero, Lac Vert, Les Volcans, Kahembe, Mapendo, Himbi, Katindo (Goma); Sake, Mubambiro (Sake); Kimoka, Mabanga South, Bujovu, Kasika, Virunga, Katoyi, Mugunga, Majengo, Ndosho, Mabanga North (Karisimbi). Data was also collected from 6 hospitals within these 3 out of the 4 health zones: Keshero and Charité hospitals in Goma; Katoyi, Mabanga and Mugunga hospitals in Karisimbi; and Mpala Museme hospital in Sake. No health data was collected from the Nyiragongo health zone because this is a politically insecure (constantly surrounded by armed groups) zone that had witnessed a lot of destruction, thus no health archives are left in their hospitals. However, we were able to get some information from questionnaire analyses. The inclusion criteria used to choose hospitals and health centres at the flanks of both MN and MC was centred on the fact that these health units had existed before 1997 and were still operational at the time of the study.

In Cameroon, the study was carried out in the Limbe Health District, South West Region of Cameroon which includes the city of Limbe and all the coastal communities living at the flanks of MC (Fig. 1b). However, for this study the targeted localities included: Down Beach Limbe, Bota, Batoke, Sanje, Njonji, Bakingili, Debundscha and Idenau (Fig. 1b). The targeted health units included: the Mile 1 Regional hospital within Limbe city; the Down Beach hospital Limbe; and Bota, Batoke, Debundcha, Njonji and Idenau health centres. The Regional Hospital in Mile One, Limbe was selected because it is the main hospital in the Limbe Health District area that has the capacity to handle all diseases. The selected health centres on their part were based on their presence in the volcanic ash and gas affected areas for the 1999/2000 eruptions.

2.3. Data Collection Methods

2.2.1. Focus Group Discussion (FGD)

This study was initiated with workshops organized in the form of focus group discussion (FGD) sessions held in the city of Goma (MN) and the town of Batoke (MC) found in the South West Flank of MC, Cameroon in 2017 (Fig. 2). The goal of these workshops was to get information from major stakeholders in the selected health zones/district on the health implications of volcanic ash and gases from MN and MC on the population and coping strategies used by the population. The major stakeholders included: regional governors; Goma Volcano Observatory (OVG); University of Buea; Government Delegates and Mayors from Municipal Councils; Regional Delegation of Health; Urban Planning; Civil Protection; Red Cross; Media and the Civil society (this included representatives from the community, traditional rulers and the clergy). A total of 40 persons were present in each of the workshops held. Information obtained from these workshops were supplemented with questionnaires and hospital data for the selected diseases collected from recognized health facilities within Goma, Karisimbi, Nyiragongo, Sake and Limbe health zones (Fig. 1ab) between the periods of 1997 to 2006 (which represents the periods before, during and after these eruptions). The target population included people of the age group from 18- to > 60 years. The focus was to evaluate the health impacts of volcanic ash and gases on the population living within the Goma, Karisimbi, Nyiragongo, Sake and Limbe Health Zones in Democratic Republic of Congo and Cameroon respectively. Further emphasis was laid on the impact of volcanic ash and gas on agriculture, water resources and the health of grazing animals in Goma.

2.2.2. Questionnaire Administration

Prior to questionnaire administration, the study participants at the flanks of both volcanoes had the objectives of the study explained to them in a language best understood by them at the time of questionnaire administration. Confidentiality was maintained using locality codes and respondent ID codes to replace the names of participants. The questionnaires were also pre-tested in Goma (MN), Batoke, Debundscha, and Down Beach Limbe (MC), validated before full administration.

The participants in the 4 health zones at the flanks of MN and in the 8 selected communities within the Limbe Health district found at the flanks of MC were selected randomly for questionnaire administration. This took place face-to-face through the use of semi-structural interviews using close-ended questions to ascertain accuracy. The inclusion criteria of selection for the respondents at the flanks of both volcanoes were: 1) the individual must have lived in the community for at least 18 years at the time of the study and had witnessed these eruptions; 2) be a traditional authority, indigene or migrant who moved into these communities within the time frame of these eruptions; and lastly 3) be 18 years and above. These questionnaires were designed in simple English (MC) and French (MN) languages with most questions having multiple choice answers for the respondent to make a choice. In the context where the participants were uneducated and could not understand English (MC) or French (MN), the surveyor translated the question and answers to the local languages used in these communities (i.e. Pidgin English for communities at the flanks of MC; and Lingala to communities at the flanks of MN) and filled or ticked the appropriate answer.

A total of 738 questionnaires were administered within the four health zones at the flanks of MN: 19 % (141) in Goma; 41 % (299) in Karisimbi; 28 % in Nyiragongo (203) and 13 % in Sake (95). Of the 738 respondents, 341 were male (52 %) while 375 (48 %) were female with majority in the age range of 26-45 years (53 %). The statistics for the other age groups were: 18-25 (12 %); 46-60 (24 %) and > 60 (8 %). Out of this number 42 % of them were married; 29 % were cohabiting; 11 % were single; 10 % widow/widower and 5 % were divorced. The dominant occupation of the respondents was petty businesses (73 %) and just 1 % were farmers. A significant proportion of the respondents had lived in the area between 20 to 29 years (34 %) and 10 to 19 years (23 %). However, up to 30 % of the respondents had lived in the area in the period between 30 to > 70 years.

In the 8 communities at the flanks of MC, a total of 400 questionnaires were administered with an equal proportion of 12.5 % (50 persons each) respondents in each of the localities. Out of this number 54 % were male and 46 % female with majority in the age group of 26-45 years (62 %). The other age groups were 18-25 years (20 %) and 46 to > 70 years (18 %). A total of 93 % of them had attained formal education. Since the studied eruptions occurred 15 (MN) and 18 (MC) years before this present study, it was assumed that probable bias and possible recall bias occurred due to the long duration of these events.

Fig. 2. Photographs taken in workshops held in Goma (DR Congo) and Batoke (Cameroon) respectively in 2017 showing: a) the Regional Governor of Goma at the time (Centred), the Director of Goma Volcano Observatory (OVG; left) and the former Dean of Faculty of Science, University of Buea (right); b&c) working sessions (FGD) at Goma with project members and workshop participants; d) a cross-section of the participants present at the Batoke workshop; e&f) working sessions (FGD) at the Batoke workshop

2.2.3. Outpatient Department (OPD) Review

A retrospective cohort study involving document review was used to collect secondary data from hospital records on prevalence of respiratory illnesses, ocular problems and skin irritation at the flanks of both MN and MC. The secondary data document review collection began with a simple random sampling of all health institutions at the flanks of MN and MC. After this sampling, government owned health institutions were chosen for hospital data collection because they had a fairly good archive than the private owned institutions and had also been in existence long before the sampled eruption scenarios.

At the flanks of MN, hospital data was collected from 6 hospitals: Keshero and Charité in Goma; Katoyi, Mabanga and Mugunga in Karisimbi; and Mpala Museme in Sake. The period of data collection was from 1997 to 2006. Despite this, in 1997, health data for the sampled illnesses was available only in Katoyi hospital found in Karisimbi. In 1998 and 1999, health data was available in just two hospitals: Katoyi and Mabanga both found in Karisimbi. In 2000 and 2001, health data was available in three hospitals namely: Katoyi, Mabanga and Keshero (Goma). In 2002 and 2003, health data was available in four hospitals: Katoyi, Mabanga, Kashero and Charite. In 2004, health information was available in five hospitals: Katoyi, Kashero, Mabanga, Charite and Mpala Museme (Sake). It was only in 2005 and 2006 that health data was available in all the six sampled hospitals: Katoyi, Kashero, Mabanga, Mugunga, Mpala Museme and Charite. Within and out of the scope of the sampled diseases, in the hospitals at the flanks of MN, the prevalence of 8 diseases were targeted (also applicable to MC): bronchitis, asthma (respiratory); blindness, conjunctivitis (ocular); dermatitis, bone deformation (skin); gastroenteritis and teeth coloration. The last two diseases were investigated only in communities at the flanks of MN because during the FGD session held in Goma in 2017, it was mentioned that people suffered from abdominal disorders after consuming ash contaminated water. Also, it was also cited that high amounts of particular gases such as fluoride in water resources at Sake caused teeth coloration and bone deformation.

In the Limbe Health district which defines the area found in the South West flanks of MC considered to be the area most affected by volcanic ash and gases from the 1999/2000 eruption [43][44]; hospital data for respiratory, ocular and skin diseases were collected from 5 health institutions: 2 in Limbe city (Mile One hospital and Down Beach health centre); 1 health centre each in Bota, Batoke and Sanje (Fig. 1b). The period of data collection was initially set to run from 1998 to 2006. However, due to poor record keeping there existed unavailability of complete hospital records from which more information would have been obtained and sourced. Thus, for respiratory and skin diseases, data was analysed for three years only: 1998, 2000 and 2006. While for ocular problems, just two years had consistent data: 2000 and 2006. Irrespective of this limitation, the available data gave a good representation of the period prior to, during and after this eruption.

Hospital data collected at the flanks of both MN and MC involved a review of outpatient department (OPD) registers collected using a pre-designed form. This form was divided according to the diseases under study, months, years and localities. In the chosen years, data was collected based on the number of respiratory, ocular, skin, gastroenteritis and teeth coloration disease cases. Confidentiality was maintained using ID codes to replace the names of the patients. Hospital data collected was summarized at the end of each working day.

2.4. Data Analyses

Data analyses for the administered questionnaires was conducted using descriptive statistics and running of frequencies on demographic variables to assess the characteristics of the sampled population and to examine fluctuations in the trends of diseases across the years. The data was entered on Epi info, exported to excel 2013 and imported to SPSS Version 20 for formatting and analysis. For hospital data analysis, the number of cases that reported to the hospital were then calculated and plotted on a graph. This was correlated with the years in which eruptions occurred in the sampled communities at the flanks of MN and MC to assess the variation before and after these eruptions. Statistical tables, graphs and histograms displaying the variation of variables were generated using Microsoft excel.

3. RESULTS

3.1. Respiratory Ailments

In communities at the flanks of MN, the studied participants were of the opinion that respiratory diseases were more prevalent before the 2002 MN eruption than after the eruption (Fig. 3a). The principal diseases cited were bronchitis and asthma. The trend showed that bronchitis was significantly higher before the 2002 eruption. Corroborating this data with hospital data collected from the 6 hospitals at the flanks of MN revealed a reverse trend that highlighted that positive cases of bronchitis significantly increased in the year of the eruption and after the eruption when compared to the cases that existed before the eruption (Fig. 3b). Asthmatic cases were almost negligible prior to and in the year of the eruption which did not deviate much from the respondents' perception. However, it witnessed a significant increase after the eruption (2003-2006) based on the recorded positive cases (Fig. 3b). At the flanks of MC, 24.4 % of the respondents mentioned that they suffered from respiratory diseases prior to the 1999/2000 eruption. This percentage slightly increased to 30 % for those who suffered from respiratory ailments after the eruption. Corroborating this with monthly hospital data collected from hospitals in the SW flank of MC, revealed a similar trend where positive cases of respiratory ailments were reduced prior to the eruption and significantly increased in the period during and after the eruption with the exception of the months of July, September and November (Fig. 3c)

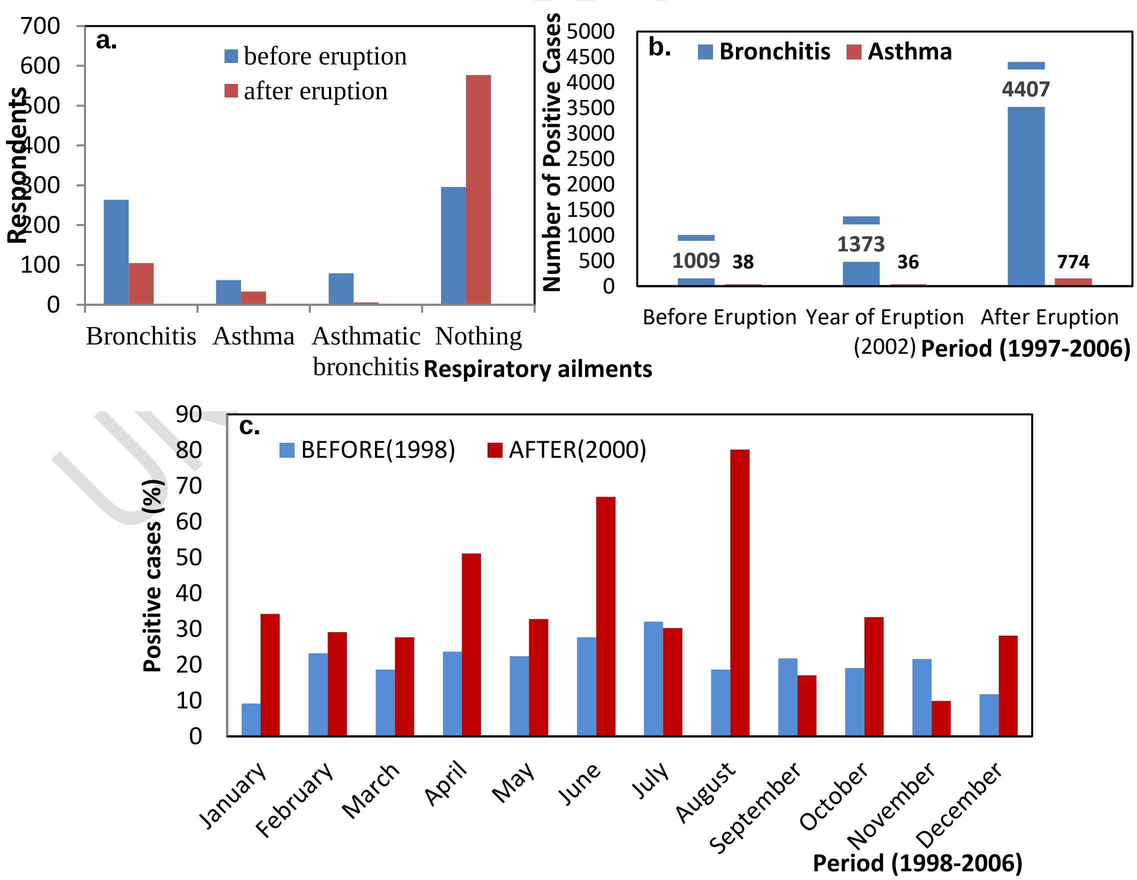


Fig. 3. Prevalence of respiratory tract diseases in localities at the flanks of: a) MN based on the population's perception; b) MN following hospital records and c) MC obtained from hospital records

3.2. Ocular Diseases

The population at the flanks of MN experienced an increase incidence of eye diseases after the 2002 eruption with conjunctivitis being the leading illness based on the respondents' observation (Fig. 4a). This finding perfectly corroborated with data from hospital records which revealed a high prevalence of conjunctivitis during and after the eruption (Fig. 4b). Additionally, positive cases of blindness increased after the eruption. This implies that blindness can be attributed as a long-term impact of volcanic ash. In communities situated in the SW flank of MC, 26 % of the participants mentioned that they suffered from eye diseases prior to the 1999/2000 eruption. This percentage slightly increased to 28 % during and after the eruption. Corroborating these findings with hospital data revealed that positive cases of ocular diseases significantly increased during and after the eruption from January to August (Fig. 4c). This number dropped in the months of September and October, and were completely absent in the months of November and December when compared with the pre-eruption values.

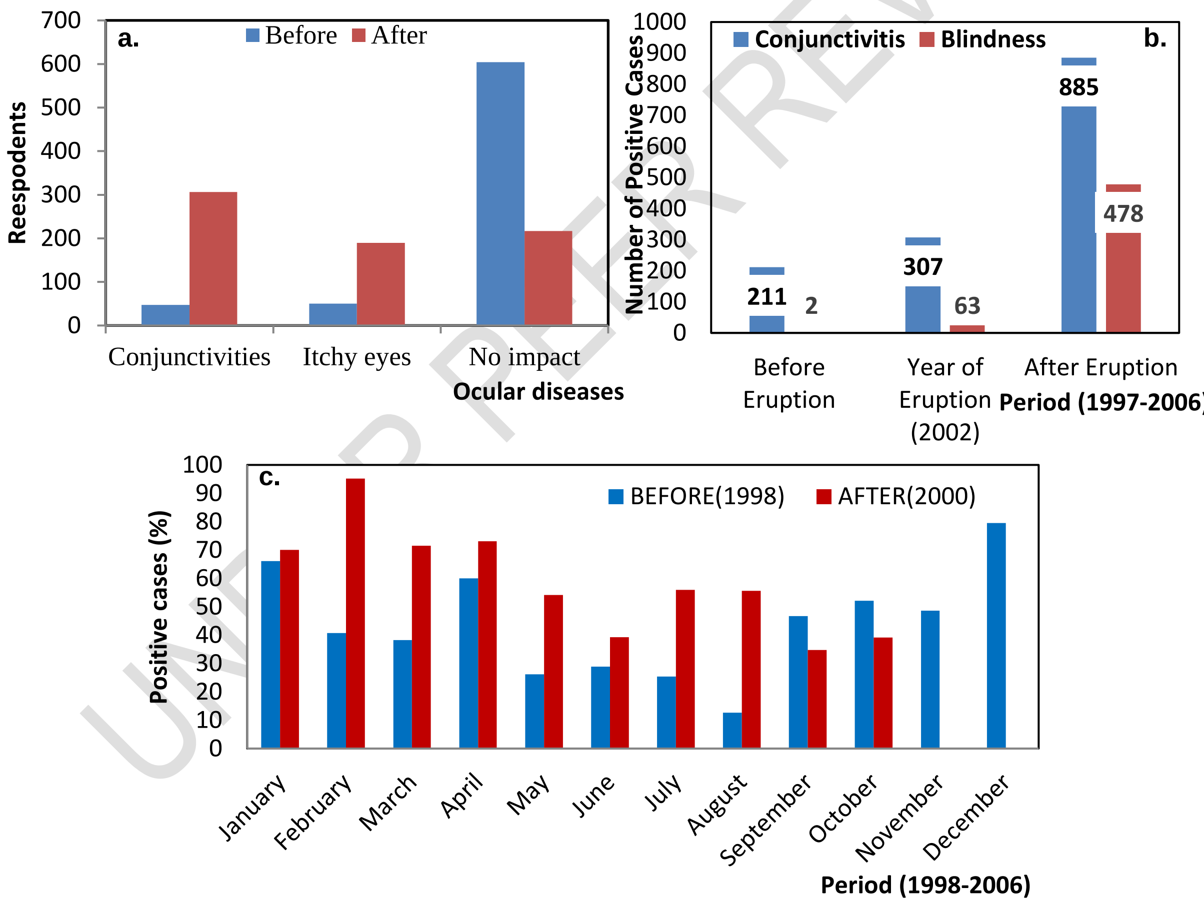


Fig. 4. Prevalence of ocular diseases in localities at the flanks of: a) MN based on the population's perception; b) MN following hospital records and c) MC obtained from hospital records

3.3. Skin Diseases

The participants at the flanks of MN experienced a mild degree of skin diseases prior to the 2002 eruption which significantly reduced during and after the eruption (Fig. 5a). Corroborating this with hospital data showed a reversed trend where there was a continual increase in the positive cases of dermatitis (itchy skin) during and after the eruption (Fig. 5b). In the West Coast communities at MC, 33 % of the respondents suffered from skin diseases prior to the eruption. This percentage dropped to 29 % during and after the eruption. Corroborating this with hospital data showed a rise in the prevalence of skin diseases in the months during and after the 1999/2000 eruption at MC (Fig. 5c).

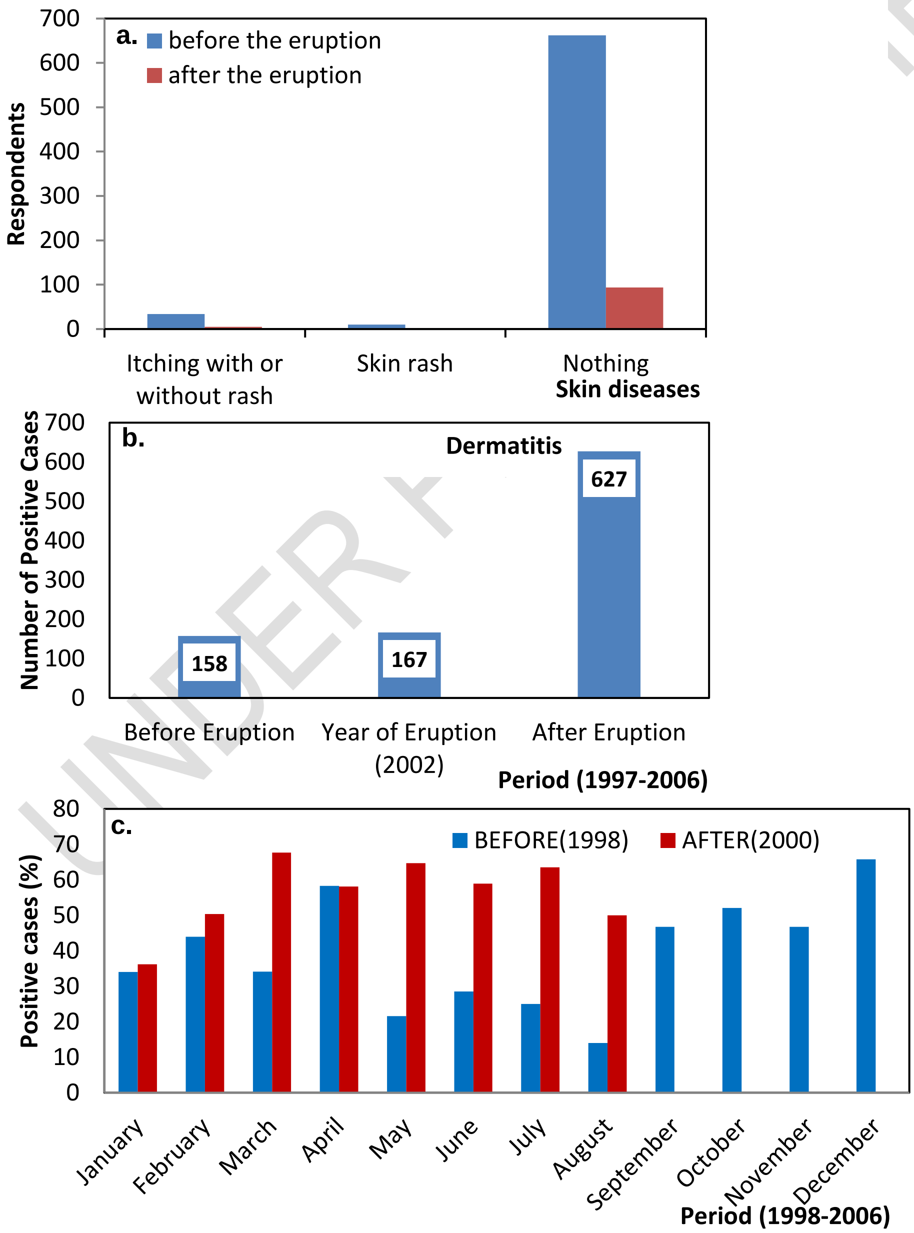


Fig. 5. Prevalence of skin diseases in localities at the flanks of: a) MN based on the population's perception; b) MN following hospital records and c) MC obtained from hospital records

3.4. Gastrointestinal Diseases

In the communities at the flanks of MN, the respondents mentioned that open water sources were contaminated with ashfall during the 2002 eruption of MN, which resulted to increased occurrences of diarrhoea (79.96 %) and gastro- enteritis (75.9 %) tract disorders as illustrated in Fig. 6a. The respondents' findings perfectly tied with the results generated from hospital data which revealed the prevalence of gastroenteritis (diarrheal disease) during and after the 2002 eruption MN (Fig. 6b). Fluoride contamination in the form of fluorosis (teeth colouration) and arthritis (bone deformation/malformation) reduced during and after the MN 2002 eruption following the participants responses (Fig. 6c). This perfectly corroborated with hospital records that registered a maximum of 4 cases each for bone deformation during the eruption and fluorosis after the eruption (Fig. 6d).

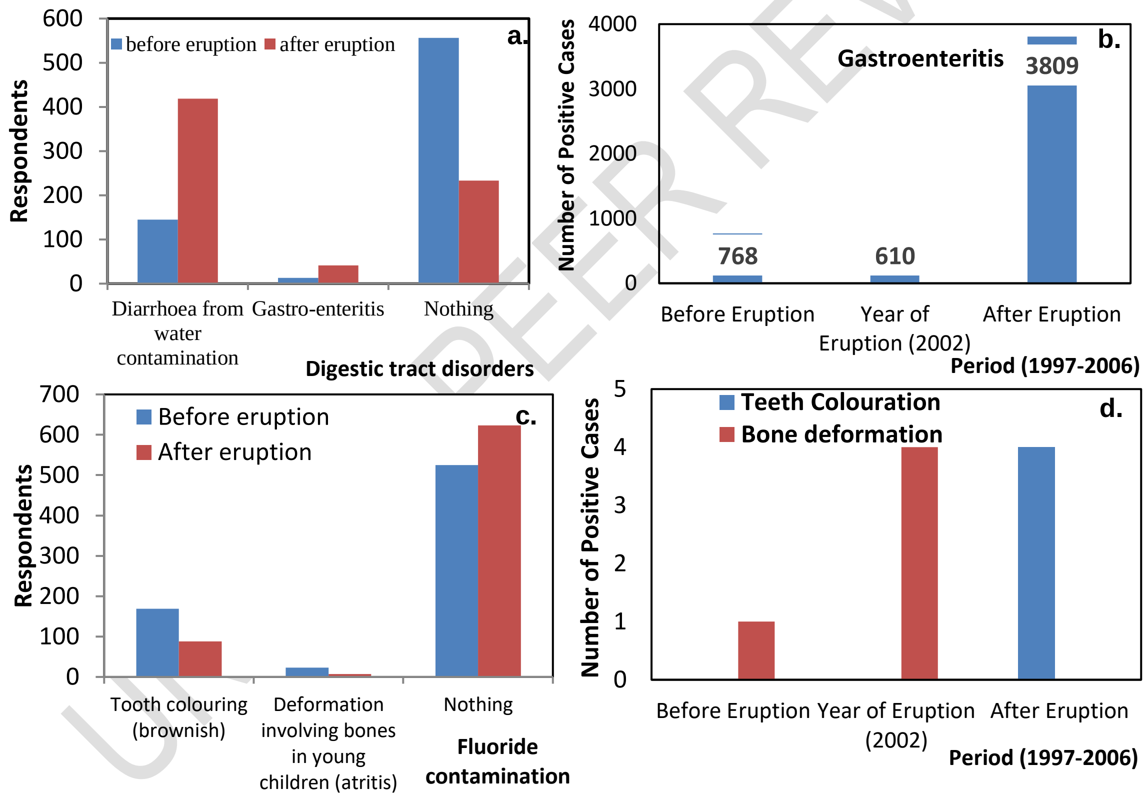


Fig. 6. Prevalence of diseases caused by water and soil contamination of volcanic ash and gases in localities at the flanks of MN showing: a) trend of digestive tract disorders based on the population's perception; b) trend of digestive tract disorders following hospital records; c) trend of fluorosis and arthritis based on the population's perception; and d) trend of fluorosis and arthritis from hospital records

3.5. Impact of volcanic ash and gases on agricultural practices and water resources in communities at the flanks of MN

The agro-pastoral activities carried out by the farmers (1 % of the total participants) in the area included: poultry farming (46 %); subsistence agriculture (28 %); goat rearing (13 %); piggery (8 %); cattle rearing (4 %) and plantation agriculture (1 %). Poultry farming and subsistence agriculture were the main agricultural activities carried out in the sampled communities at the flanks of MN. In terms of the accumulated thickness of volcanic ash as estimated on farmlands, 35 % of the respondents' cited thicknesses of ≥ 30 cm, while 51 % cited thicknesses within the millimeter scale. The accumulated ash on farmlands was observed for a period of 1-6+ years during and after the 2002 MN eruption (Fig. 7a). However, maximum estimated ash was within the 1 year-period following the eruption as cited by 74.4 % of the respondents (Fig. 7a).

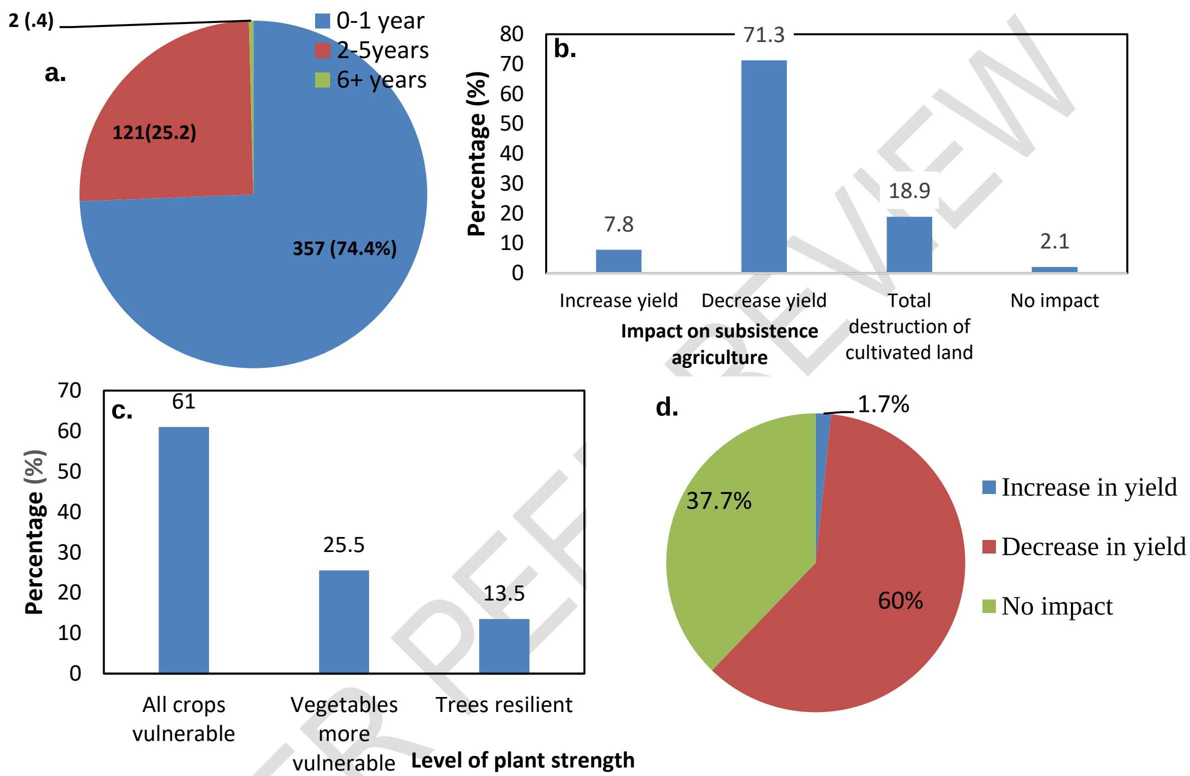


Fig. 7. Illustrations in localities at the flanks of MN showing: a) duration of accumulated volcanic ash on agricultural land; b) impact of volcanic ash on subsistence agriculture; c) vulnerability and resilient assessment of crops to volcanic ash; and d) impact of volcanic ash and gases on pasture/grazing land

Further enquiries revealed that the accumulated ash on farmlands resulted to a significant decrease in crop yield as mentioned by 71.3 % of the respondents (Fig. 7b). However, a small percentage (7.8 %) witnessed increased yield while a handful of the sampled population experienced total destruction of their farmland. Further assessment showed that those who completely lost their crops were vegetable and cereal farmers. These vegetables included beans, cabbages and cassava leaves. Cereal such as maize and sorghum were classified to be the most vulnerable by 25.5 % of the population (Fig. 7c). However, tuber crops such as sweet potatoes, cocoyams, cassava tuber and others such as banana trees were considered more resistant to volcanic ash, thus only experienced reduced yields as cited by 71.3 % of the respondents. The crops that experienced an increase in yield were fruit trees such as mango, pear, and the eucalyptus tree which were found to be resilient to volcanic ash as cited by 13.5 % of the respondents. However, as cited by the majority of the respondents (61 %) all crops have a certain degree of vulnerability to volcanic ash. The accumulated ash also affected pasture land (Fig. 7d) as grasses were found to be vulnerable to volcanic ash which led to decrease yield as cited by 60 % of the respondents (Fig. 7d). Assessing the impact of loss/contamination of grazing land by volcanic ash and gases revealed that it led to the death of 15 % of grazing animals; ill-health of 3 % and relocation of 9 % of the animals. Notwithstanding, 73 % of these animals survived the ordeal.

A total of 91 % of all the open water sources which included: hand dug wells, springs, streams, lakes and rivers used by the population for domestic purposes were affected (Fig. 8). This finding perfectly corresponded to the increased number of skin diseases and gastrointestinal diseases suffered by the population as revealed by hospital records during and after the eruption.

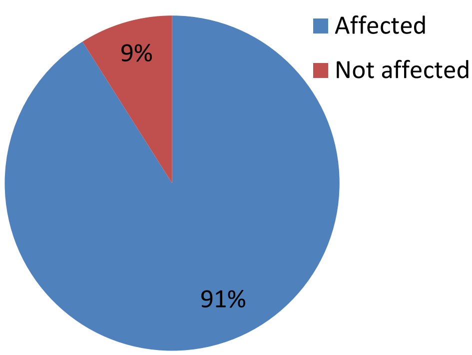


Fig 8. Impact of volcanic ash and gases on water sources

3.6. Coping strategies used by the communities at the flanks of MN and MC to combat the impacts of volcanic ash and gasses

From the stakeholders' workshops held on the 28th of August, 2017 in collaboration with the Goma Volcano Observatory with a total of 40 persons, the population of Goma did very little or almost nothing to protect themselves from the volcanic gases and volcanic ash released during the 2002 eruption. This lack of coping strategies could be attributed to the fact that majority of the workshop participants attested that the population had some peculiar perception that made it difficult for them to take any measures against these hazards. For example, they perceived *mazukus* (CO_2 gas in high concentration) as ancestral urine / rites; evil spirits that bring death; toxic substances deposited by foreigners to hide precious resources and tribal boundaries; whereas volcanic ash was considered as the product that resulted from the quarrel between two traditional chiefs. For fluorine contamination in Masisi (Sake) the population there considered the impact of fluorine (brown stains on teeth) as their tribal identity. Further analysis was carried out in the field to get the respondents view, 36.6% of the population choose relocating to safer sites during volcanic eruptions to avoid the impact from volcanic ash and gases. However, majority (63.4 %) were not for relocation due to the following reasons: economic (could not afford it); family ties; and optimistic that they will not be impacted.

From the stakeholders' workshop that was held on the 17th of August 2017 in Batoke (Limbe Health District) with a total of 40 persons that included health personnels, majority of the participants attested that they were ignorant as to the measures to take during the eruption to prevent the inhalation of ash particles. Others said they were advised by the emergency team managing the disaster to do the following: use locally made palm oil to smear their nostrils with as well as drink it to reduce the impacts of the inhaled ash; place a wet cloth or handkerchief around their nostrils; bath with warm water in case of itchy skins; use detergents to bath children (all these applied to the West Coast communities moving from Batoke to Idenau that were not resettled). For those in the locality of Bakingili where evacuation took place, resettled persons still sneaked to visit their farms in the ash-affected areas, thus had to follow the advice given. Further analyses from field respondents carried out in the communities at the flanks of MC revealed that, 63 % of the population stayed in place and persevered from the adverse consequences of the ash; while 37 % flee.

4. Discussion

4.1. Interpretation of Results

From the graph (Fig. 9a), the number of cases of the eight selected illnesses (i.e. bronchitis, asthma, conjunctivitis, blindness, dermatitis, gastroenteritis, fluorosis and bone deformation) investigated from hospital records at the flanks of MN has been on a rise from 1997 to 2006. Seven of these diseases with the exclusion of blindness, witnessed a sharp increase in the number of cases in the year of the eruption followed by a sudden drop in 2003. However, this drop was still slightly higher than in 2001 prior to the eruption. After 2003, the number of cases of all the 8 illnesses seem to have been on an increase, with bronchitis and asthma topping the chart. A major observation made was that blindness only appeared in hospital records after 2002. Fluorosis and bone deformation were the least prevalent diseases prior to, during and after the 2002 eruption. From the graph, it is established that volcanic ash and gases have a higher affinity for respiratory tract and skin diseases, with moderate to low impact on ocular and digestive tract diseases. Their prevalence (bronchitis and gastroenteritis) is shown to peak during the eruption and remained high 4 years after the eruption.

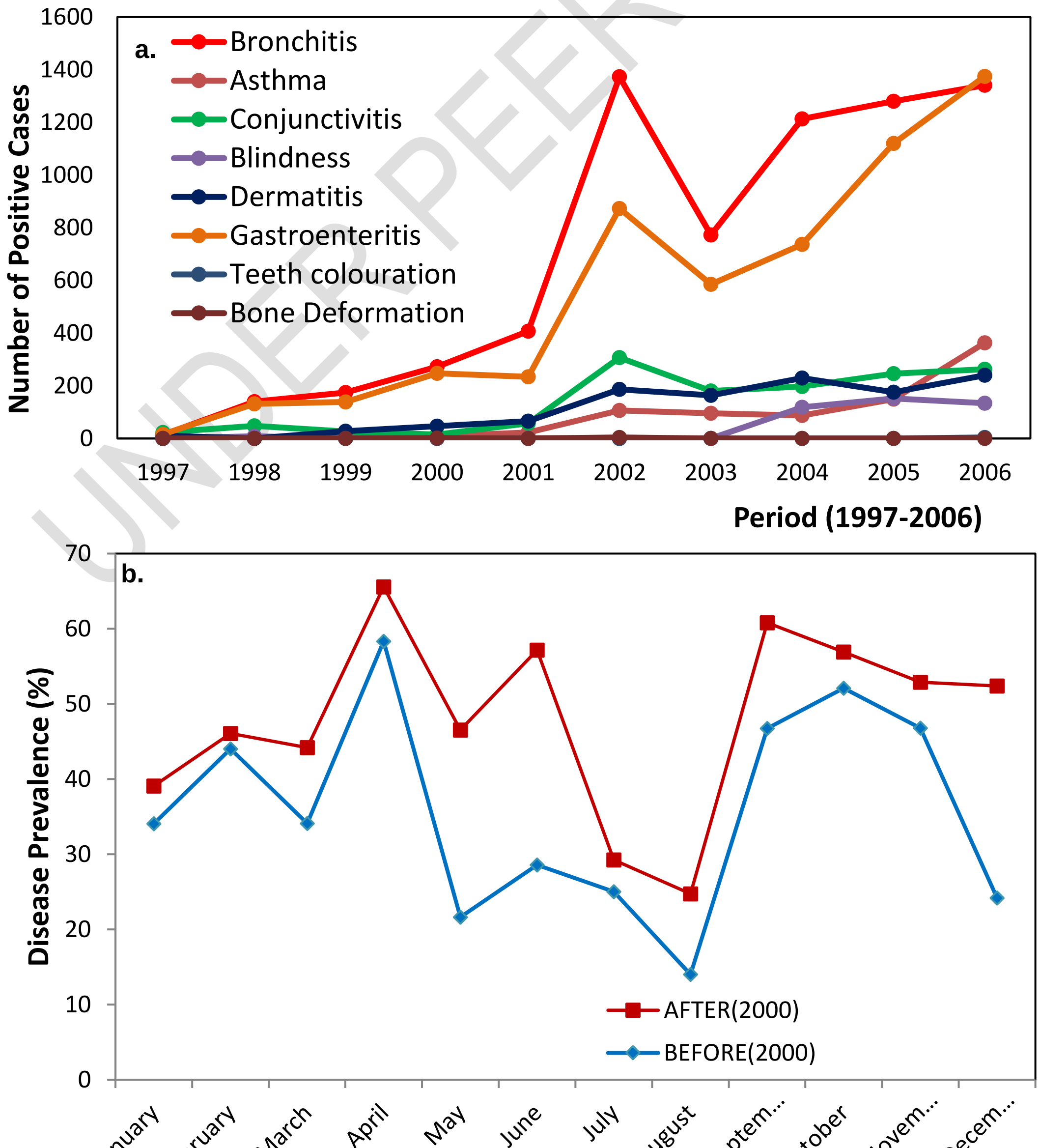
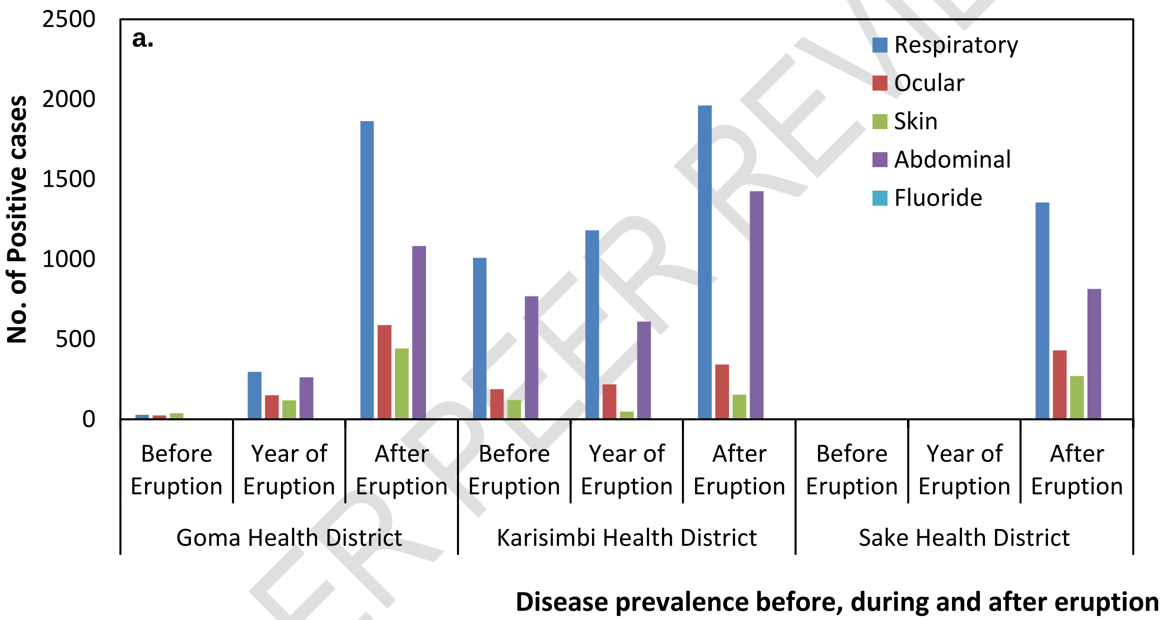


Fig. 9. Trends in number of cases of selected respiratory, ocular, skin, gastrointestinal, dental and bone diseases in: a) localities at the flanks of MN (e.g. Goma) for the period 1997 – 2006 and b) localities at the SW flanks of MC for the period 1998-2006.

In the localities found in the SW flank of MC, hospital records showed a prevalence of all the health diseases (respiratory, ocular and skin) after the eruption (Fig. 9b). This variation showed high positive cases recorded during the months of January - April and from September- December with lower positive cases recorded within the months of June - August each year. Three main diseases were recorded amongst victims of the 1999/2000 volcanic eruption: eye diseases such as conjunctivitis known as ocular disease; respiratory disease such as asthma and bronchitis and skin irritations and rashes. Amongst these diseases, skin irritation registered the highest prevalence as cited by 31% of the sampled population. This was closely followed by the respiratory, eye and other indirect health problems. Further analysis included a cross tabulation for localities and the effects of the hazards they experienced before the eruption. It was realized that the population in Bakingili were more affected by respiratory ailments prior to the eruption (33 %); Batoke experienced more of skin diseases (27.3%); Idenau population experienced both eye and skin diseases though to a lesser extent then Bakingili; the population in Njonji also experienced more eye symptoms than any other health effect and lastly, the community of Sanje experienced both respiratory and skin diseases than any other health effect sampled in this study. The findings revealed that where respondents lived and the hazards experienced are 1.5 times more likely to have occurred during the eruption than before the eruption with P=.03, CI=1.04-2.3. Furthermore, there was no significant change after the eruption with the locality and the health effects experienced as the hazards were fairly distributed in the population after the eruption.

Further analysis of the hospital data in relation to disease prevalence per health district revealed that Sake health district at the flanks of MN was the most affected owing to the fact that none of the sampled ailments were registered prior to and during the eruption (Fig. 10a). However, the statistics revealed that these diseases sprung up in 2004 and significantly increased after the eruption with respiratory ailments alone recording ~ 1355 cases, while abdominal diseases followed suit with a total of 814 cases. The highest case of blindness was also recorded at the Sake health district (~ 207 cases). The absence of positive cases of fluoride contamination in the form of brownish stains on teeth in Sake contradicts with the workshop findings which cited communities within the Sake Health District to be characterized with the highest cases. This absence could be linked to the fact that the inhabitants in this health district see the tooth stains as their tribal mark thus, it is not considered an ailment that requires hospital consultation. In the Goma health district, all the sampled diseases were significantly low prior to the 2002 eruption. They increased during the eruption, and escalated after the eruption (Fig. 10a). Goma health district registered the highest cases for ocular and skin diseases after the eruption (Fig. 10a). Karisimbi health district on its part is said to be the health district that was characterized with the highest incidences of the sampled diseases prior to, during and after the 2002 eruption (Fig. 10a). This could be tied to the fact that Karisimbi Health District is the only district where hospital data was collected from 3 hospitals consistently from 1997-2006. In this health district, fluoride contamination in the form of brownish stain on the teeth and poor bone deformation were found to be highest during the year of the eruption when compared to the other health districts. This health district also registered the highest cases of respiratory tract and abdominal diseases after the eruption.

At the flanks of MC, since just one health district (i.e. the Limbe Health District) was involved, further analysis was carried out following the hospitals and health centres from where health data was collected. The statistics revealed that positive cases of respiratory tract diseases were diagnosed in a large number of patients (> 2000) during the months of July following the eruption at the Mile I, Bota and Down beach hospitals (Fig. 10b). Mile I hospital is the largest hospital in the region and has all the expertise and all 3 hospitals are found within Limbe Municipality. Batoke and Sanje (Fig. 10b) are found in the West Coast of Limbe that represent the area most affected by the 1999/2000 ashfall. However, since these are rural communities, they have just health centres with few equipped staff and technology. Because of this, positive cases for respiratory tract diseases recorded in these health centres were low (~ 100 to 1500 cases) when compared to the hospital cases. This could be attributed to the fact that people prefer large equipped hospitals to health centres. Thus, majority of those living at the West Coast made consultations but in the main hospitals found in Limbe city. Diagnosis for ocular and skin irritation was significantly low in all the hospitals following the eruption with the highest number of positive cases (470) registered in the Batoke health Centre (Fig. 10b).



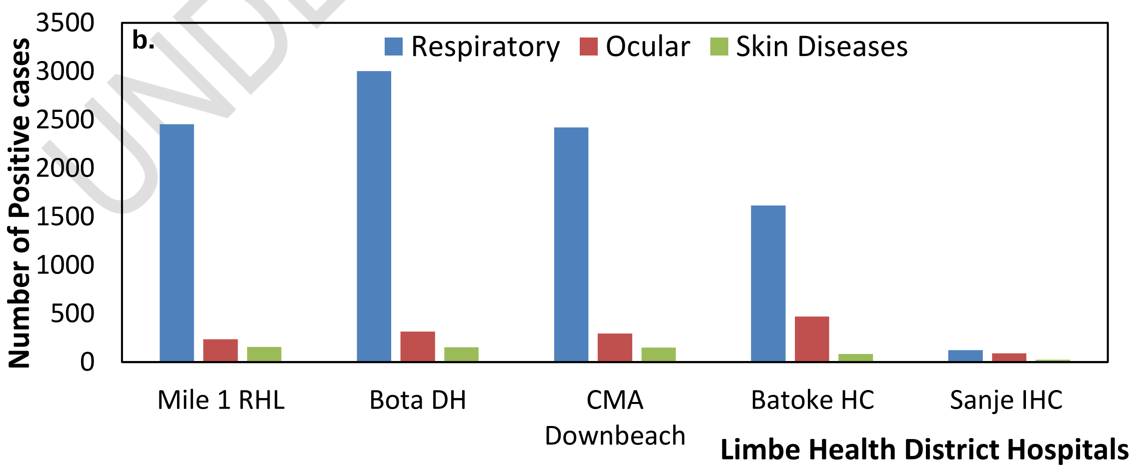


Fig. 10. Records of disease prevalence in: a) the 4 health districts at the flanks of MN; and b) hospitals and health centres in Limbe Health District at the flanks of MC

4.2. Comparison with other studies and health implication

Findings from this study revealed that respiratory ailments such as asthma and bronchitis significantly increased during the period of the sampled eruptions and in the years following these eruptions in communities at the flanks of both MN and MC. The exposed population at the flanks of MN and MC also experienced an increase incidence of ocular diseases during and after the sampled eruptions. Conjunctivitis was cited as the leading eye disease both from respondents' perception and hospital data. Positive cases of blindness significantly peaked in the years following the MN 2002 eruption. Positive cases of skin diseases (dermatitis) also increased during and after the sampled eruptions on the populations living in the sampled health districts at the flanks of MN and MC. Increased cases of gastrointestinal diseases such as diarrhea and gastro- enteritis were also reported in communities at the flanks of MN linked to ingestion of ash contaminated water from the 2002 eruption of MN. Fluoride contamination in the form of fluorosis (teeth colouration) and arthritis (bone deformation/malformation) linked to the MN 2002 eruption was negligible during and after the eruption. According to [51], volcanic ash can disrupt life in two main ways: create air pollution as a consequence of the resuspended ash carried by wind; and secondly, continuous emission from long duration eruptions may affect air quality for months or longer. Both of them have implication of causing health risk. [35] study on the health effects of volcanic ash on residents using data obtained by the national epidemiologic surveillance system showed that households within and near the source of the hazard generally show an increase in diseases as opposed to distant households.

Baxter et al. [52] further revealed that inhabitants living at the flanks/vicinity of Mt. St Helens volcano, suffered from severe respiratory track diseases after the fourth week of its 1980 eruption which is similar to the findings of this study. Bradshaw et al. [53] equally had similar findings after working with the Mt Ruapehu eruption of September 1995. One of the direct health impacts of the volcanic ash released during the December 9, 2019 eruption of Whakaari/White Island volcano, New Zealand on the Downwind communities was the exacerbation of respiratory diseases [9]. Nicole's [11] study on the multiple health hazards of volcanic eruptions revealed that volcanic ash exposure increases hospital admittances for acute respiratory tract ailments such as asthma and bronchitis following an eruption. Studies carried out by [10] in Goma showed that the incidence of acute respiratory symptoms and other diseases peaked after the 2002 Nyiragongo Eruption in localities < 26 km to the volcano. In communities at the flanks of MC, [45] and [8] constated the same phenomenon in communities in the downwind direction during and after the 1999/2000 eruptions. Results from [38] studies in Montserrat where a survey of asthma diagnosis, respiratory symptoms and bronchoconstriction was examined in school aged children 8-12 years and above 13 years after exposure to volcanic ash for 12 months, indicated that, the higher the exposure the more the cases with respiratory symptoms as was observed in the sampled communities at the flanks of MN particularly in the Karisimbi Health District. This study [38] revealed that children who had lived in areas with moderate or heavy exposure to ash reported more respiratory symptoms and use of health services for respiratory problems than children who had never lived in these areas. Thus, making volcanic areas an endemic zone for respiratory tract diseases.

A study carried out by [54] on the population residing close to Mt. Sakurajima (an active volcano) in Japan, revealed that persons living in the high ash exposure area showed ocular symptoms more often than those in the low-exposure area similar to the findings of this study.

They also constated that years of active volcanic eruptions were linked to years with a high frequency of ocular symptoms in persons found in the high-exposure area. The major ocular disease cited was conjunctivitis which was described as: redness, discharge, foreign body sensation, and itching of eye. Fraunfelder et al. [55] after the 1980 Mt. St. Helens eruption revealed that persons who were already suffering from ocular diseases had the most frequent ocular complaints. However, further investigation attested that no long-term ocular effects were noted secondary to volcanic ash exposure at Mt St. Helens. This contradicts the results obtained in hospitals at the flanks of MN that registered incidences of blindness which only appeared in the years following its 2002 eruption believed to be a long-term ocular effect. Barsotti et al. [5] constated that the presence of volcanic ash in the atmosphere reduces visibility which may produce potential problems for traffic movements.

In Carlsen et al. [56] study following the 2010 Eyjafjallajökull volcanic eruption in Iceland, it was observed that the likelihood of having symptoms related to tightness in the chest, cough, phlegm, eye irritation and psychological morbidity symptoms during the last month of the eruption was higher in the exposed population. They also observed that respiratory symptoms such as cough, dyspnoea (i.e. difficult breathing or shortness in breath), prevalence of underlying asthma and heart disease were more common in the exposed population in the year following the eruption. This trend is same as what was observed at the flanks of MN and MC. Hlodversdottir et al. [57] further carried out a long-term health assessment of the impact of the Eyjafjallajökull volcanic eruption on children. Findings from this study revealed that among the exposed children, no significant decrease of respiratory symptoms was detected between 2010 and 2013. This statistic corroborates with the fact that respiratory, ocular and skin diseases prevalence remained high 3-5 years after the 2002 and 1999/2000 eruptions from MN and MC respectively. However, the limitation in our study was that children were not isolated during data collection to enable us know the most affected age group as in Japan [36], Quito (the capital of Ecuado)[2], Eyjafjallajökull [57], Montserrat [38] and Tajogaite in La Palma Island [58]. Research findings from these studies have established that children (particularly those younger than 5 years) are most vulnerable to volcanic ash impacts that usually manifest in the form of asthma and bronchitis two to three weeks into the eruption.

Wantim et al. [8] established that a few persons who drank ash contaminated water at the flanks of MC suffered from diarrheal diseases based on respondents' perception. Hospital data at MN revealed that gastrointestinal disease prevalence rose during the eruption and has been on the rise 5 years post-eruption. According to [58], some components of ash such as: SO_4, F, Cl, Na, Ca, Ba, Mg, and Zn are water-soluble. Their presence in water in concentrations above the recommended ones may pose health risk for humans and livestock as was observed during the Tajogaite 2021 eruption in La Palma Island, Spain. Fluorine (F) was confirmed to be the element with the greatest health threat during this eruption. Eruption products at both MN and MC are characterized with very high F content [47][48]) which explains the high incidences of gastrointestinal diseases exhibited by the exposed population and the affected livestock. At the flanks of MN, accumulated ash affected farm and grazing land which resulted to a significant decrease in crop yield particularly vegetable and cereals and led to the death of some grazing animals. It was constated that all crops have a certain degree of vulnerability to volcanic ash, however tuber crops are more resilient. Volcanic ash also affected 91 % of all the open water sources at the flanks of MN used as potable water sources for domestic, industrial and agricultural purposes. Tephra on vegetation causes physical damage, and sustained coverage may result to longer-term physiological responses [15][16]. Tephra deposits on soils may also alter their capacity to exchange gas, water and heat with the atmosphere or may have a specific chemical effect, such as nutrient input or acidification, on sensitive soils, thus this explains the reduced yield of some of the crops at the flanks of MN. Bustillos et al. [59] reported that when Mt Tungurahua (Ecuador) erupted in 1999, farming communities faced the problem of ash fall destroying their crops as well as the chemistry of the soil. This caused farmers to shift their production to more ash resistant crops such as potatoes and onions. A similar shift in crop type was observed after the eruption of Merapi (Indonesia) in 2006 [26]. These findings are similar to the results of this present study specifically in communities at the flanks of MN where a majority of the respondents (88.4%) said most of the crops are vulnerable to volcanic eruption and 71.3 % of the respondents admitted to a decrease in crop yield after the 2002 MN eruption. Agriculture is also dependent on water. Small quantities of volcanic ash can disrupt water quality which intends affects agricultural yield and grazing animal health [16][60]. Bitschene [61] reported that 5 to 6 million sheep died as a result of Mt Hudson (Chile) eruption. Their death was associated to physical properties of the ash and the fact that the cattle fed on overgrazed pasture causing them to be weak [62]. This is in line with findings from this study where over 14.6% cattle died and were relocated to other areas for survival due to a decrease in pasture land by 60 % caused by carbon dioxide gas in communities at the flanks of MN.

The communities at the flanks of MN and MC do little or nothing to escape from the effects of volcanic ash. However, fleeing the environment or migrating was seen to be highly recommended by these communities. DREF [63] noticed that the 2002 MN eruption, caused massive population movement into the border city of Gisenyi in Rwanda. In communities at the West Coast of MC affected by volcanic ash, [8] reported cases of persons who left the area and have never returned till date. This scenario is different from what happened at Goma, where majority of the population that flee into Rwanda returned a few weeks later, thus the greater impact of volcanic ash in these communities.

5. CONCLUSIONS

This study goes to confirm that there is a direct relationship that exists between volcanic ashfall and gases and human health deterioration. This study has revealed that the number of persons with respiratory, skin and ocular diseases generally increase during and after volcanic eruptions at Mounts Nyiragongo (MN) and Cameroon. The prevalence of these diseases varies from one health district to the other. The prevalent respiratory tract diseases included: asthma and bronchitis. For ocular diseases, conjunctivitis dominated with few cases of blindness observed at the flanks of MN only in the long term. From the workshops held and from respondents' perception, this study brought forth the realization that the local communities within Goma, Karisimbi, Nyiragongo, Sake and Limbe Health Districts are aware of the impact of volcanic ash and gas to their health and that of their livestock. A large part of the sampled population at the flanks of both volcanoes expressed good knowledge on the health effects of these eruptions based on the reports obtained from the workshops and the responses to the questionnaires administered on the field. However, a lot of concerns regarding the safety of these population in case of future eruptions were identified based on their ignorance in handling the impacts from volcanic ash exposure. This study has shown that the number of people that get infected with respiratory, skin and ocular diseases generally increase during and after an eruption due to the fast transportation of the ash particles by wind.

As a recommendation, the health condition of the local population can be more assured if the local governments (i.e. local and city councils) at the flanks of these volcanoes can set aside a stand by medical rescue team to act during such crises period. This will help the victims to belter protect themselves from getting in contact with the ash. Safety camps should also be constructed to accommodate victims and properly orientate them on how to protect themselves from inhaling dust particles mixed with ash. Lastly, the population should avoid getting in contact with the first rains following major eruptions as it is likely to be acidic due to the concentration of the dissolved ash and gases, which can also provoke skin infection. For the collection of OPD data in health facilities at the flanks of both volcanoes, it was realised that, most of the sampled health institutions did not have consistent records for the sampled illnesses. It was further observed that the health facilities where the records were consistent, had the limitation that the data were poorly structured and not stratified according to years. We therefore recommend that these health facilities should provide a separate room meant for file storage along with shelves to make retrieval easy, and a focal point/person appointed uniquely for this task. Secondly, instead of the manual registers/records, hospital data could be stored in electronic form to facilitate retrieval and analyses.

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CONSENT

There was no major risk in participating in the survey. Study participants had the purpose of the study explained to them in a language they best understood at the time of recruitment. Confidentiality was maintained using ID codes to replace the names of participants.

ETHICAL APPROVAL

Ethical clearance to conduct this study was obtained from the institutional review board of the Faculty of Health Sciences, University of Buea (590-06) while the administrative authority to conduct the study was obtained from the Dean of that Faculty and at Goma respectively. A second authorization was collected from the Regional Delegate of Public Health for the South West Region required to collect hospital data from the District Medical Officer (DMO) in Limbe and the directors of all the sampled hospitals.

Disclaimer (Artificial intelligence)

We hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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