Monitoring and Predicting Future Eruptions of Mount Cameroon: A Requirement for Ensuring Sustainable Development in Communities within the Area (SDG11, SDG17)

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Abstract

Over 500,000 people inhabit the flanks of Mount Cameroon (MC) compose of 2 cities, 3 towns and 63 villages. MC is one of the most active volcanoes in Africa. Hazards from its 1999 eruption (lava flows, earthquakes and volcanic ash) caused significant environmental and infrastructural damage and affected the wellbeing of this community. To attain SDG 11 (Targets11.5 and Indicator 11.B.2), there is an urgent need to monitor hazards from this volcano. This entails building and maintaining partnerships towards the implementation of SDG 17 (Targets 17.3, 17 6 & 17.9). This study examines the extent to which recent North-South and South-South partnerships, through a USAID PERIPERI-U and a Swedish (SIDA) LIRA2030 grants have contributed towards the partial attainment of these goals, such as, in the development of the first Earthquake Building Code and Building Regulations in the area, and the construction and partial equipping of a Volcano Monitoring Laboratory. Funding from these partnerships has also been used for capacity building of students; research training of staff in Belgium, Algeria, and in the USA; organisation of workshops and focused group discussions on communities' perceptions of the eruptions of this mountain, how the hazards affect development in the area, and the coping strategies of the communities during eruptions. It is hoped that more partnerships will be established and used to provide clear messages for policy makers and stakeholders and equally ensure confidence building on the communities, aimed at ensuring the implementation of these Goals within this area and beyond by 2030.

Keywords: Mount Cameroon, volcano monitoring, perception, training, building code, partnership

Introduction

Volcanic eruptions are large scale natural processes which are sources of concerns for populations living on the flanks of active volcanoes. This is because volcanic hazards from a single eruption range from deadly earthquakes, lava flows, tephra and volcanic gases as has been observed for eruptions at Mount Cameroon (Suh et al., 2003; Wantim et al., 2011). During the past decade, an average of 60 volcanoes erupted each year, around 20 of which were erupting on any given day. Statistics as per the Smithsonian/USGS Weekly Volcanic Activity Report (May, 2021) showed that there were 47 ongoing eruptions of active volcanoes globally. Some of these, such as Erta Ale in Ethiopia, are persistently active.

Research in volcanic monitoring has progressed in recent decades through the use of models and laboratory experiments. However, such research has been limited to a few volcanoes located in industrialized countries (e.g. Mounts Etna (Italy), Mount St Helens and Kilauea (USA)). For example, the onset of 2018 Kilauea's eruption was successfully forecasted in weeks leading to the event by the Hawaiian Volcano Observatory (Neal et al., 2018). Over two-thirds of potentially active volcanoes in the world are poorly known and unmonitored (Simkin and Siebert, 1994).

A vast majority of these active volcanoes are found in developing countries that lack the equipment, skill, and manpower to monitor them. For example, the 22 May 2021 eruption of Mount Nyiragongo, in the Democratic Republic of Congo produced lava that destroyed approximately 1000 homes, killed ~ 32 people, and displaced over 450,000 people (IFRC, 2021; UNHCR, 2021). Regrettably, that eruption was not predicted due to the failure of effective monitoring from the Goma Volcano Observatory. Both constant and continuous monitoring of these volcanoes in order to avert such surprises on the communities who are exposed to their hazards is relevant.

In Africa, potentially hazardous volcanoes are mostly found along the East-African Rift System (EARS) and the Cameroon Volcanic Line (CVL; Fig. 1) (Ayonghe and Wantim, 2016). Three of these volcanoes: Ol Doinyo Lengai (Tanzania), Nyamulagira and Nyiragongo (DR Congo) all found along the EARS are presently erupting (GVP, 2022). The CVL on its part is a major tectonic feature in West-Central Africa that runs SW-NE following a major left-lateral fault system that extends for more than 2000 km, from Pagalu Island in the South Atlantic Ocean into West-Central Africa (Fitton, 1980; Fig. 1). The continental segment includes Mount Cameroon (MC) which is the largest and presently the most active volcano along this line (Fig. 2). A number of crater lakes are also present along the CVL. Some of these lakes exhibited disastrous outgassing three decades ago (e.g. Lakes Nyos and Monoun) killing people and livestock (Lockwood et al., 1988; Kusakabe et al., 2000).

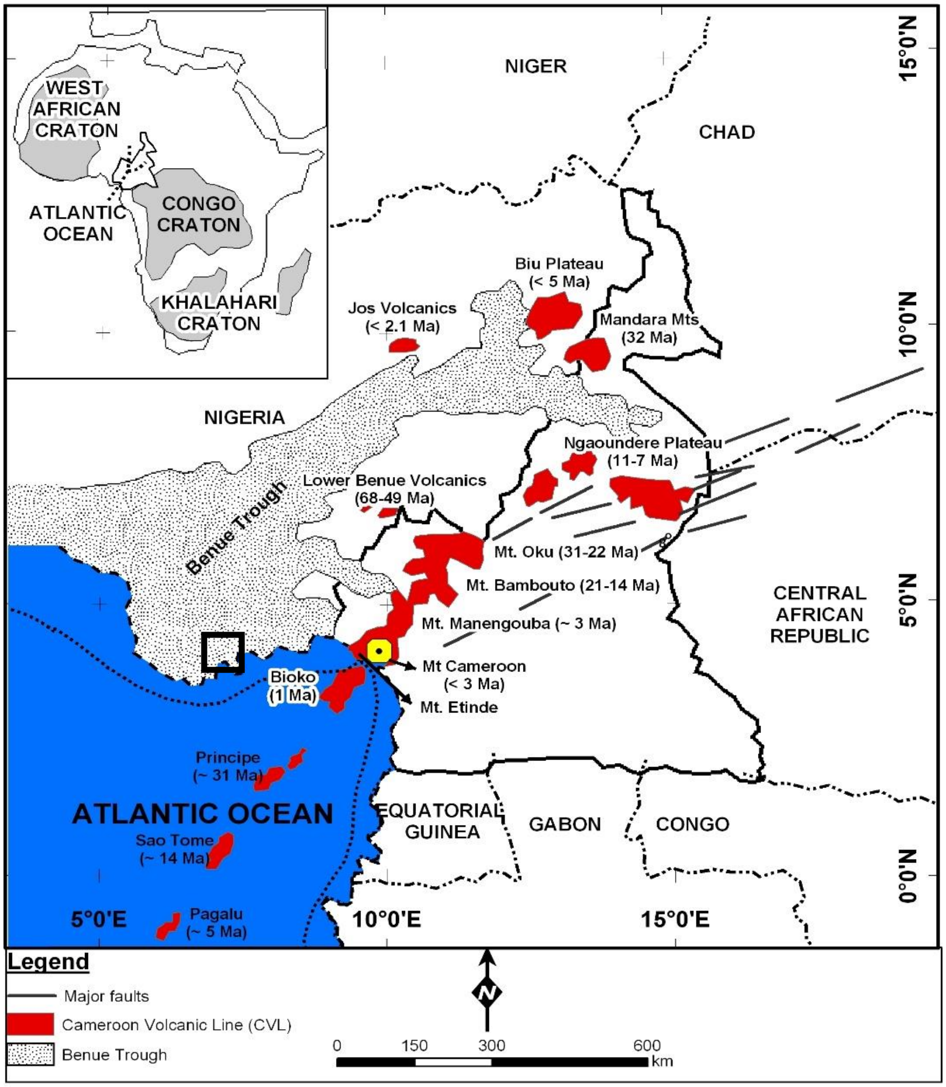

Fig.1. Sketch map of Cameroon showing Mount Cameroon (square) and the Cameroon Volcanic Line (CVL) modified after Marzoli et al. (2000); Inset the CVL and Cameroon within the African Continent (Wantim et al., 2011).

Description and Setting of the Study Area

Mount Cameroon (MC) is a steep elongated volcano (Fig. 2a), 4095 m high above sea level, characterized with over 340 cones, underlain by successions of overlapping lava flows (Suh et al., 2003; Mathieu et al., 2011; Wantim et al., 2013). MC is considered the most active volcano along the CVL having registered a total of 9 eruptions between 1800 and 1871 (1807, 1825, 1835, 1838, 1852, 1865, 1866, 1868, 1871) (Deruelle et al., 1987) and 7 eruptions between 1900 and 2000 (1909, 1922, 1954, 1959, 1982, 1999 and 2000) (Ruxton, 1922; Fitton et al., 1983; Suh et al., 2003; Njome et al., 2008; Wantim et al., 2011, 2013). The principal hazards from its eruptions are lava flows (Fig. 2b), which usually cause major disruptions in the socio-economic life and livelihood of the population living on and around the flanks. Lava flow from its 1999 eruption for example resulted in a humanitarian crisis which included: the evacuation of over 600 people from the coastal village of Bakingili (Fig. 2b) which was situated along the path of the lava flow field. This lava also destroyed agricultural land and plantations which served as major sources of livelihood for the population. In addition, lava destroyed a major road infrastructure that linked the population in the SW and NW flank of the volcano (Wantim et al., 2018). Ash falls from this same eruption destroyed crops, polluted potable water sources, and caused major health concerns to the inhabitants living in the West flank. Earthquakes that accompanied the 1999 eruption also destroyed over 60 houses in the city of Buea, displacing approximately 250 people (Wantim et al., 2018).

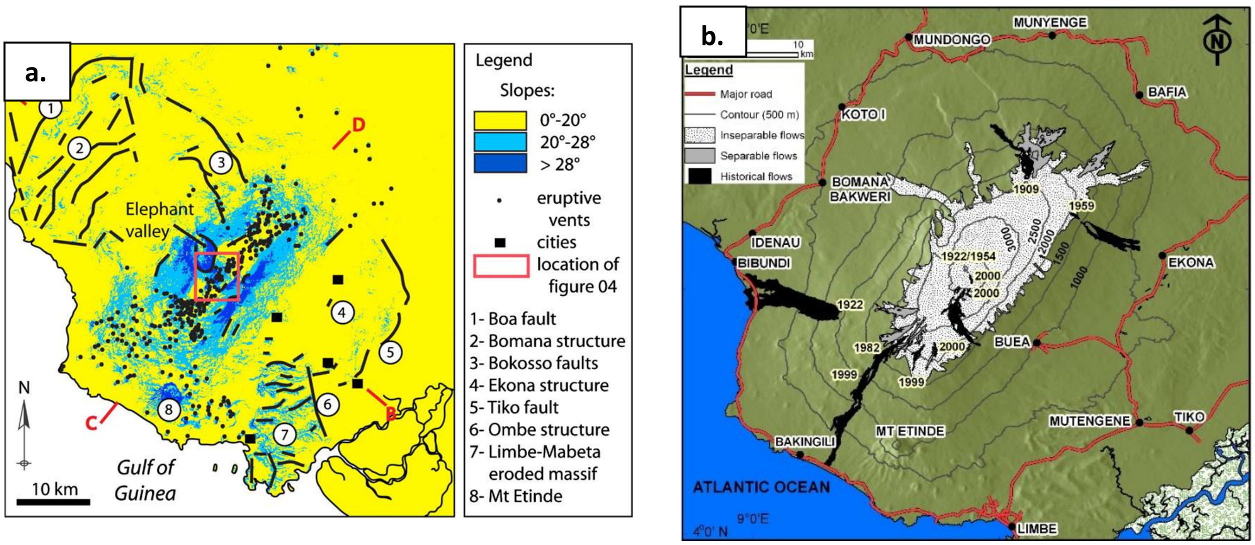

Fig.2. Digitised maps of Mount Cameroon showing a. its main geological entities, lineaments, eruptive vents and faults (Mathieu et al., 2011) and b. historical lava flows with some towns and villages (Wantim, 2011)

Even though a permanent seismic network of six stations was set up at the flanks of MC in 1984, following its 1982 eruption to monitor regional and distant earthquakes, unfortunately, the 1999 and 2000 eruptions were not predicted due to failure in detecting the micro and strong earthquakes which usually precede eruptions from this volcano. With the recent reactivation of activity along the CVL following the December, 2019 earthquake at Sao Tome (Fig. 1) characterized with a magnitude 5.5 which was widely felt across Central Africa with Cameroon inclusive, there is an urgent need to begin monitoring activities from this active volcano relevant for sustainable urbanization by 2030. This is because estimates made by Bonne et al. (2008) and Wantim et al. (2011) gave a return period of between 11 and 14 years for these eruptions. It is now over 21 years since its last eruption in June 2000.

Based on the existing documentation, eruptions from MC are most often accompanied by seismic earthquakes before, during and after the eruptions (Ubangoh et al*.,* 1997; Ateba et al., 2009). The earthquakes start as swarms of tremors produced by magma as it rises through rocks towards the surface and then build up to strong earthquakes with intensities of between IV-VII on the Modified Mercalli Intensity scale. These eruptions are most often accompanied by the release of gases which include Sulphur-dioxide, increase temperature of gases from vents and of water bodies on the mountain. Even though volcanic eruptions are difficult to predict, but progress has been made through volcanic surveillance in order to reduce the impact of its hazards on society (Brown et al., 2015). Monitoring these precursory parameters will therefore help predict future eruptions at MC, which host 2 cities, 3 towns, and over 63 villages at its flanks characterised by increasing population caused by the presence of several higher institutions of learning such as the University of Buea, companies and plantations.

Statement of Problem

In Africa, regardless of improvements in monitoring technologies, the rapid population growth where most active volcanoes are located, has ensured an increase in the vulnerability of the populations and their property to hazards from these volcanoes during the 21st Century. One of the focus of SDG 11 is to protect the poor and people in vulnerable situations from disasters by 2030. Improvements in eruption forecasting are accordingly critical for combating this situation, for reducing injury and loss of life and for minimizing the detrimental effects on local economies and on the fabric of society including developmental projects. However, basic information about the character of past volcanic activity is lacking for most of these active volcanoes on the continent, where priority is most often given to alleviating poverty and combating disease, and funding post disaster activities, rather than monitoring and mitigating adverse impacts of volcanic activity which will go a long way to ensure good health and well-being (SDG3) and build sustainable cities and communities (SDG11).

The population of major cities, towns and villages on the flanks of MC has significantly increased during the last 20 years. As per the census results of 2005 (BUCREP, 2010), approximately 350,000 people inhabited the major cities, towns and villages around MC. This number is believed to have doubled during the last decade. The population in the city of Buea at the time was ~ 130,000 people (BUCREP, 2010) being the most populous at the flanks of MC (Fig. 2b). This number increased to 300,000 people in the city of Buea alone by 2013 (BUCREP, 2013). This increase was initially linked to the presence of major higher institutions of learning in the area which has been on the rise since the creation of the University of Buea in 1993. However, population increase as from 2016 to present, is linked to the influx of internally displaced persons fleeing other parts of the South West and North West Regions of the country who are more affected by the on-going civil strife in Southern (Anglophone) Cameroon. This has led to the influx of people who have never experienced any of the eruptions from MC, lack total awareness of its hazards, and who in the event of such an occurrence, will face difficulties to cope with the resultant hazards, thus increasing the need for sensitization and monitoring.

In addition, located on the flanks of this volcano are important infrastructures of social, economic and administrative importance which are exposed to the hazards linked to eruptions of this volcano which need to be protected. These include: the Prime Minister's Lodge (serves as a monument), the Governor's Office, the University of Buea and other Higher Institutions of Learning, several primary, secondary and high schools, the Head Office of the Cameroon General Certificate of Education Board (GCE) Board, the Nigerian Consulate, several Ministerial Departments, the Municipal Council of Buea, several hospitals, hotels, and several structures housing important corporations and businesses. The *Société Nationale de Rafinerie* (SONARA) located on the SW flank of this volcano is the only oil refinery in Cameroon. Economically, it is one of the country's most important sources of revenue with its production of refined fuel in 2010 estimated at about 70,000 barrels per day. Agro-agricultural complexes which include palm, rubber, banana, and tea, cover an estimated area of 435 km^2 and a majority of them are exposed to lava flow hazards as witnessed at Idenau in 1922 and at Bakingili in 1999.

The pertinence of this study is therefore based on the vulnerability of the population which has been growing exponentially during the past two decades. Increase population is synonymous to increase construction of major infrastructures (e.g. storey buildings) that do not comply with building regulations in the area.

To effectively attain the goal of SDG 11, which targets at significantly reducing the number of deaths and the number of people affected and substantially decreasing the direct economic losses caused by disasters which is relevant to build sustainable urbanization by the year 2030, there is thus an urgent need to provide inexpensive but effective techniques to monitor these volcanoes and assess their hazards.

The information to be provided from the laboratory will be a vital input for volcanic risk reduction, cost-benefit analyses, and prioritization of developmental programmes and its relevance and usefulness for early warning and disaster preparedness by all members of the communities living and working on the flanks of this mountain. There will be confidence building on the community who will know the existence and vital importance and usefulness of the activities of this Laboratory. The effective monitoring of this mountain in an attempt to reduce the impacts of its hazards on the community thereby ensuring sustainable development in the area therefore matters.

The cost saving advantage of the study will accordingly be based on the sensitisation of policy makers, stakeholders, and the local communities on the respect of building norms which can withstand the earthquakes, and the use of results from the ground-based monitoring approaches for possible prediction of future eruptions and to create awareness on coping strategies which are essential for developmental plans. Thus, the study will provide clear messages for policy makers and stakeholders, and useful information for disaster preparedness and environmental protection from the hazards which are associated with eruptions. It will be used to close the large research gap on vulnerability assessment by the academia in the country by ensuring the needs and aspirations of the communities.

It will provide a useful building guide, design and regulations, regarding volcanic hazards in this area where building decisions are presently taken based on assumed and unscientific parameters. Thus, infrastructure operators will be knowledgeable of likely impacts from volcanic hazards from this mountain. This will guarantee sustainable development in the cities, towns, and communities by 2030.

This study therefore sought to assess the role played by the USAID PERIPERI-U and LIRA 2030 partnerships in attaining SDG11 and 17 relevant to build resilient cities at the flanks of active volcanoes.

Objectives

Main Objective

Assess the role played by USAID PERIPERI-U and LIRA 2030 partnerships with the University of Buea to build resilient cities to volcanic risk at the flanks of Mount Cameroon.

Specific Objectives

1. Examine the role played by the USAID PERIPERI-U and LIRA 2030 partnerships in the design and development of the first seismic earthquake building code in the Mount Cameroon area.

2. Assess the role played by USAID PERIPERI-U and LIRA 2030 partnerships in the acquisition of the population's perception on volcanic risk at the flanks of MC.

3. Evaluate the contribution made by the USAID PERIPERI-U and LIRA 2030 partnerships in capacity building of staff and students towards volcano monitoring at MC.

Methodology

A Review of Partnerships and their Relevance towards the Implementation of the Goals

The methodology used in this study has been based on the two main partnerships below which were signed between North-South and South-South partners and hosted by the Disaster Risk Management Unit at the University of Buea.

1. A USAID sponsored Partners Enhancing Resilience to People Exposed to Risk- Universities (PERIPERI U) on Disaster Risk Management (DRM), signed in 2016 but ended abruptly in 2019, and

2. A SIDA sponsored Leading Integrated Research for Agenda 2030 (LIRA 2030) which lasted from 2017 to 2019.

The approach has involved a review of the partnerships above which during the past six years have been instrumental in the acquisition of funding, expertise exchange, technological advancement and infrastructural development which have all been useful towards monitoring the hazards from MC, for capacity building and for research and socio-economic development of the communities within the Mount Cameroon area.

Population Perception on Volcanic Risk Based on Focus Group Discussions with Communities

The perception of the population and the associated health risks that result from the resultant hazards from MC was obtained using focus group discussions organized through workshops held in the cities of Buea, Limbe and Batoke (Fig. 2b). These discussions which were held with a total of 50 persons in Buea, 35 in Limbe and 35 in Batoke in 2017, targeted key stakeholders from the scientific and non-scientific sectors that included: the Regional Governor, City and Municipal Mayors, Media, Health Personnel, Civil Defense, Red Cross, Urban Planning, Scientific Research, Civil Society (traditional rulers, clergy and quarter heads). The discussions at these workshops and related sessions examined the perception of the participants during the focus group discussion sessions, on the causes of eruptions of Mount Cameroon, the resultant health impacts on the population and the coping strategies used by the population to reduce the impacts.

These workshops served as platforms of awareness raising of the population to volcanic hazards and their consequences on property and health. They were principally sponsored by the Leading Integrated Research for Agenda 2030 (LIRA 2030) research grants. The LIRA 2030 Africa programme seeks to build capacity of early career scientists in Africa to undertake transdisciplinary research and to foster scientific contribution to the implementation of the Agenda 2030 for Sustainable Development. In our context, our project fostered contribution in the field of disaster risk management targeting SDG 11. It also fostered South-South partnership (SDG 17) as we worked in collaboration with partners from the Goma Volcano Observatory in the Democratic Republic of Congo where a similar study as at Mount Cameroon was carried out as an example of a South-South collaboration in the implementation of this goal.

Construction of a Volcano Monitoring Laboratory at the University of Buea Campus

The non-functional seismic observatory that was built and equipped in Ekona (Fig. 2a) found on the NE flank of MC in 1984, prompted the need for the construction and equipping of a new building to monitor activities from MC. Even though eruptions from this active volcano have so far not led to any direct fatality, there is an urgent need to monitor them due to the exponential population growth and increasing infrastructures during the past two decades in order to be able to predict future eruptions and avoid the types of catastrophes seen in eruptions worldwide (SDG 11). This is due to the fact that, there is no visible structure dedicated to using monitoring techniques aimed at predicting future eruptions of this active volcano, and the population is ill informed of the state of this active dome which actually produces swarms of micro earthquakes caused by magma movements at depth which, if properly recorded, could be used to predict imminent eruptions.

The work of monitoring activities from this volcano is to be carried out in collaboration with other relevant experts from the Departments of Physics, Geology, Chemistry and Sociology (FSMS), the Faculty of Engineering and Technology and the College of Technology. Other experts working with this team on assessing the vulnerability of people living on the flanks of active volcanoes of Africa are from Switzerland (University of Geneva), South Africa (Stellenbosch University), Ethiopia, Belgium (Vrije Universiteit Brussels), Sweden (SIDA), Algeria, and the USA (USGS), (SDG17).

International Scientific Research Training on Volcano Monitoring

A series of collaborative scientific research training sessions on fundamentals of volcano monitoring using field and remote sensing techniques was carried out by the corresponding author as summarized in Table 1.

Table 1: Scientific Research Trainings on Volcano Monitoring

Research Training	Institutions	Period	Objectives	Relevance
1) **Postdoctoral Research:** "Investigating volcanic unrest at Mount Cameroon Volcano, West-Central Africa using Remote Sensing techniques."	Vrije Universiteit Brussels (VUB), Belgium	01/09/2017 to 28/02/2019	Improve volcanic risk assessment and management at MC by using radar and optical satellite images to: 1) Detect and understand periods of unrest by monitoring temperature and gas emission changes from multispectral satellite sensors in an attempt to understand periods of unrest at MC; and 2) Assess the capabilities of satellite imageries in documenting the spectral characteristics of volcanic surfaces (lava flows) and their temporal evolution after emplacement.	Enhance North-South, international cooperation on and access to science and technology (SDG 17)
2) **International training on Volcano Monitoring techniques** (part of postdoc)	- Centre for the Study of Active Volcanoes(CSAV), University of Hawaii in Hilo, USA - USGS Cascades Volcano Observatory,	27th May to 21st July, 2018	- International Training designed to assist developing nations in attaining self-sufficiency in monitoring volcanoes.	Foster North-South partnership and promote the development, transfer, dissemination and diffusion of environmentally sound technologies to

	Vancouver, Washington State	developing countries (SDG 17).

In a broader perspective, the main purpose of research at VUB summarized in Table 1 can be used to improve the volcanic risk assessment and management at MC.

The method of study involved desktop study, short technical trainings, modelling and writing of publications. Technical training involved short trainings on the analysis of satellite images carried out in Belgium (Liege; the use of Sentinel data) and by the USGS, Hawaii, USA and lava flow modelling using the Q-LavHA model (see Mossoux et al. 2016 for more details on the model) . The research also involved the analysis of survey data collected in Cameroon regarding the impact of the 1999 eruption and associated earthquakes.

The training at Hawaii coincided with the 2018 eruption of the Kilauea Volcano there (Neal et al. 2018) that destroyed over 800 homes. The presence of an on-going eruption made it possible for the participants of the course (who were all from developing countries (Latin America, Philippines and Africa with active volcanoes) to observe and even practice first-hand how such disasters can be managed with sophisticated monitoring techniques such as drones and competent staff. Coincidentally, the other African participant attending the course came from the Goma Volcano Observatory, DRC with whom we were partnering (SDG17) for the LIRA project. Our presence at this training, emphasized the need to develop techniques to monitor these very active African volcanoes and limit the impact of their hazards in the community.

Creation of the First Disaster Risk Management (DRM) Post-graduate Programme in Central Africa

One of the objectives of the USAID sponsored PERIPERI U project was to establish a DRM postgraduate programme at UB. The aim of this action was to help build the capacity of young men and women to address the different risks (volcanic risk inclusive) that characterize the Mount Cameroon Region in particular and Cameroon in general. The Periperi U UBuea Consortium successfully launched and is presently running an MSc degree programme in Disaster Risk Management under the Unit of DRM in the Centre of Disaster Risk Management (CEDIM). The programme successfully took off in January 2019 (academic year of 2018/2019) with a total of 17 registered students for the first batch. Thirty percent (30 %) were full time workers working in the Ministry of Territorial Administration, Ministry of Environment and Nature Protection, Buea Municipal Council, Academic Office of the University of Buea, Non-governmental Organizations, Contractors and Consultants while 70% were full time scholars.

A professional HND programme on DRM will be taught online from October 2022 to mainly full-time workers in several Ministerial departments, Municipal councils, Non-Governmental Organizations, and other Institutions.

The Design of the Mount Cameroon Earthquake Building Code

The relevance of such a code for socio-economic and sustainable development of the area is evident. The realization of this code entailed developing South-South partnerships (SDG 17) with countries such as Algeria that already had an existing earthquake building code. This partnership was established through the Periperi U network of African Universities of which the University of Buea is part of. PERIPERI U is a partnership of African universities (South-South collaboration) that spans across the continent and is committed to building local disaster risk related capacity. Established in 2006, this partnership has grown to include twelve universities from Algiers to Antanarivo, with institutions in Algeria, Cameroon, Ethiopia, Ghana, Kenya, Madagascar, Mozambique, Nigeria, Senegal, South Africa, Tanzania and Uganda. The goal of PERIPERI U is in line with some of the targets of SDG 11 and 17 relevant to reduce disaster risks among African countries through improved national and local disaster risk management. The partners of PERIPERI U believe that this can be accomplished through building and embedding sustainable 'multi-tasking' capabilities in disaster risk and vulnerability reduction capacity building in the 12 selected Institutions of Higher Learning in Africa, consistent with the targets of SDG 11, SDG17, and with global disaster reduction priorities reflected in the 2015 Sendai Framework for Disaster Risk Reduction.

Results

Recent Partnerships and their Relevance for Sustainable Development (SDG11 and SDG17)

These partnerships were aimed at ensuring sustainable development in communities at the flanks of MC, which, from past disasters, are exposed to volcanic hazards such as lava flows and earthquakes which impact society and infrastructures. Modern societies are reliant on dependable functioning critical infrastructure and lifelines, which are vital for effective emergency response and recovery during volcanic eruptions (Grant, 2015). Hence, the partnerships were aimed at ensuring sustainability of cities and communities within these areas, where earthquakes have been of major concerns for policy makers and the communities, especially with regards to conducting developmental projects.

Two partnership agreements on SDG 11 which involved: monitoring and predicting future eruptions of Mount Cameroon and on the health impacts of volcanic and flood hazards around Mount Cameroon (Cameroon) and Mount Nyiragongo (Democratic Republic of Congo). These partnerships involved in a first phase a PERIPERI– U partnership agreement with the USAID on *Hazards and disasters associated with the eruptions of Mount Cameroon*. This project provided funding for: technological transfer, capacity building of the population through workshops and support towards the training of MSc and PhD students. In addition, short courses in GIS were offered to the staff and student population at the University of Buea Campus. It also enabled the design of an Earthquake Building Code for the Mount Cameroon area, infrastructural development and equipping of the Volcano Monitoring Laboratory, and the design of an MSc degree programme and a professional HND programme in Disaster Risk Management. The second project was a Swedish partnership grant on Leading Integrated Research on Agenda 2030 (LIRA 2030) which provided funding which was used for workshops on urbanisation, on health and human wellbeing (SDG 3), food security (SDG 3) and the impacts of climate change on water resources (SDG 6 and 13).

The sensitising of the population on how to cope with future eruptions of this mountain therefore matters in order to ensure sustainable developments within these areas. A recently designed Earthquake Building Code and Building Regulations for the MC area was therefore necessary. The two partnerships above have been useful in these endeavours in equally facilitating the implementation of some targets of SDG3, SDG6, SDG9 and SDG13.

Significance of the Partnerships

The continuous monitoring aimed at predicting eruptions of MC and the associated hazards in an attempt to sensitise the population and prepare them for subsequent disasters will provide opportunities of sensitisation of the population and alerting them in the cases of eminent eruptions and capacity building of students on disaster risk management. Additionally, it is going to ensure that buildings at the flanks of MC are constructed respecting the standard Building Code and Regulations for this area. It will also provide information, which is relevant for investment confidence within the population, amongst other advantages.

The Design of the Mount Cameroon Earthquake Building Code and its Relevance for Sustainable Development

A technical trip was made to Algeria by members of the UB PERIPERI U consortium in February 2018. The aim of this trip was to discuss practical modalities of establishing joint research projects (SDG17) for monitoring and coping with the earthquakes generated during eruptions of MC and develop an earthquake building code for the area. To achieve this, partnerships, a Memorandum of Understanding (MoU) was established with the University of Science and Technology Houari Boumedienne and the Centre for Research in Astrology, Astrophysics and Geophysics (CRAAG) both in Algiers.

The main outcome of the visit included:

1) Members of the Periperi U UBuea team who visited Algiers worked together with the Head of the Division for Seismological Studies at CRAAG, to produce a draft MoU for joint research activities in seismology and Geophysics which was submitted to the Director of CRAAG and the Vice-Chancellor of UB for consideration and signature. This document included the acquisition and setting up of instrumentation for use in research projects and for the training of junior academic staff and students from relevant Faculties and Departments of the University (e.g. Geology, Physics, Environmental Science, Architecture (Faculty of Engineering and Technology).

2) Experts at the University of Science and Technology Houari Boumedienne worked on recommendations for a building code that was presented to authorities within the Mount Cameroon area who are responsible for issuing building permits and follow-up the construction of buildings. The building code will include approaches of reinforcing older buildings through seismic retrofitting in an attempt to make them more resistant to earthquakes.

Following the Algerian trip, the design of this code was realized through short courses and technical meetings held at the campus of UB as summarized on Table 2.

Table 2: Summary of Short Courses and Technical Meetings held to Design and Earthquake Building Code for the Mount Cameroon Area

Events	Date	Participants	Purpose	Relevance
Short Course: 'The design and enforcement of a building code for the earthquake prone Region of Mount Cameroon'	25/06/2019	60 participants that included: - scientists, - structural engineers, - architects, -seismologists, - mayors; and - traditional rulers - administrators - Property owners (landlords)	- Sensitize the population on the: 1) causes and impacts of earthquakes and volcanic eruptions; 2) effects of earthquakes on buildings and related structures; 3) technical knowledge on the underlying principles needed for the design and construction of earthquake resistant structures; 4) usefulness of a building code for the municipalities situated at the flanks of MC.	- Enhance inclusive and sustainable urbanization and provide capacity for participation of all (SDG 11)
Technical meeting: "The design and enforcement of an earthquake building code and building regulations for the councils within the Mount Cameroon	29/08/2019	35 participants: - Scientists - Engineers - Architects - Administrators	To prepare a draft, finalize, and approve the designed building code before it is launched.	- Strengthening national and regional development planning (SDG 11)

Area." Was achieved. After 3 technical meetings.

The Mount Cameroon Earthquake Building Code and Regulations (MOCEBICOR) is the first official building code developed in this area and in Cameroon in general, based on analysis of the intensities of historic earthquakes associated with eruptions of Mount Cameroon (Fig. 3). This code serves as a guide for the design of earthquake resistant structures and general rules for building within the seven Councils around MC. This effort is based on the saying that "earthquakes don't kill people, buildings do". It was accordingly prepared based on the historic characteristics of the earthquakes that normally precede and accompany the eruptions of this active volcano and building regulations based on existing Presidential Decrees, Decisions and other Municipal Legislative Regulations on the subject. The code was accordingly adapted from other freely available building codes on the internet such as the established International Code Council (ICC), the Rwandan building code, the Algerian building code, amongst others. This was based on the known historic seismicity of Mount Cameroon (Fig. 3), which has been shown to have magnitudes of 4.7 on the Richter scale. The geology and soil types of the area and other parameters such as wind and rainfall patterns and altitudes of localities above sea level were also considered in the design of this code.

The building code has been subdivided into two main parts:

- Part I deals with the Earthquake building code proper, which entails engineering and architectural measures that have to be considered when building in the Mount Cameroon area.

- Part II emphasises on building regulations which are the norms and regulations that have been put in place by the government as pre-requisites for the construction of any building.

The launching of the earthquake building code and regulations successfully took place on the 17th of December, 2019. A donation of free copies of the book was made to the seven Councils which are located at the flanks of MC. The way forward after this event comprises of a series of sensitization workshops to be held with engineers and architects who will use desktop experiments and models to demonstrate to the population how to implement the code on the field. It is accordingly expected that the seven Councils within MC area and even beyond, will be bound to implement this code and the associated building regulations based on its effective dissemination and sensitization of the communities within the area.

The strict respect of the building parameters for various types of infrastructure within the areas specified in the building code is imperative if structural damage by earthquakes has to be prevented. This code is accordingly an essential and important tool for ensuring sustainable development within the area.

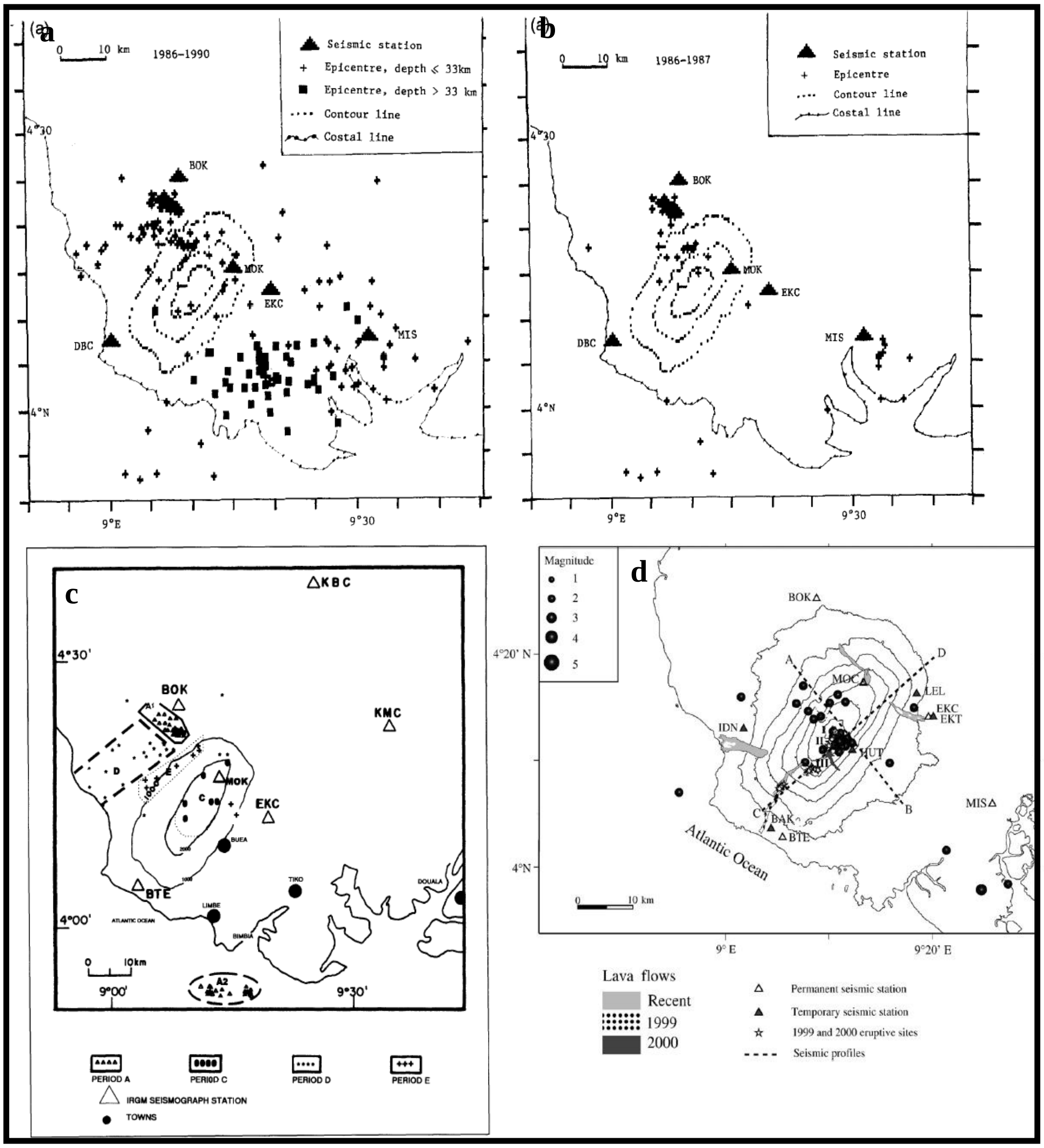

Figure 3. Graphs and maps showing the distribution of epicenters of seismicity at Mount Cameroon for the period a) 1985- 1992; where the dotted lines are contours beginning from 1000 m; ▲ = seismic station; + = depth of hypocentre less or equal to 33 km; ■ = depth greater than 33 km; b) epicentres of the 1986/1987 crustal seismic swarm (a & b are adapted from Ateba and Ntepe, 1997); c) Mapped epicentres of individual swarms in before and after 1989 (Ubangoh et al. 1997); d) seismicity map of Mount Cameroon and volcanic cones associated with the 1999 and 2000 eruptions. Error of epicenter location is 2 km. Also indicated are the sites of recent lava flows and seismic stations. EKT was the only permanent station working during that period, together with the temporary array.

Volcanic Risk Perception

Findings from the focus group discussion sessions held in Buea, Limbe and Batoke on volcanic hazards and their health implications revealed the following. Scientifically, the population perceived that eruptions from MC are triggered by magma and gas ascent. From the indigenous perspective the following causes were mentioned: most of the indigenes living along the flanks of MC believe when the gods of the mountain ("*effasso moto*") are angry, or when a notable dies (in honour of the notable), they spit fire (lava) to their people. For this reason, these communities believe only pouring of libations will appease the gods of the mountain. Most indigenes believe they have strong spirituals ties with "*effassa moto*" who spits fire in the form of lava. The Bakweri indigenes believe that strange mysterious happenings usually take place prior to eruptions, which can be used as indicators of eruption prediction. These include: the death of a notable, trees shed their leaves, observable changes in the colour of plants from green to yellow, changes in animal (antelopes and rodents) usual habitats, longer dry season and strange behaviours of domestic animals (for example dogs bark for a longer time than normal). This used to be the most common way the indigenous people at the flanks of the mountain used to monitor and predict future eruptions.

For the health impacts, majority of it was channeled to volcanic ash which was said to cause the following: ocular problems (blurred vision and conjunctivitis), persons coughed blood when ingested, itching of skin (skin rashes) after taking bath with ash contaminated water, nose bleeding when inhaled in significant quantities, general breathing problems, which some believe later developed into asthma and long term impact of ash on vegetable and medicinal plants feared.

Traditional coping strategies cited against the adverse impact of ash included: consumption of palm oil, using palm oil to soothe itches on skin, staying indoors and avoidance of open water sources for bathing purpose since they have been contaminated with ash. However, some of the indigenous communities at the flanks of MC believe that the use of rituals and incantations in appeasing the gods served as a major strategy to mitigate previous MC eruptions. Others usually gather around a fire during eruptions, and use this as moments to discuss the next possible measures to take. The Bakweri indigenes have settled on the slopes and have interacted with the mountain for a very long time. These indigenes therefore have a wealth of indigenous knowledge, which should be exploited by scientists to help monitor this active volcano.

The UB Volcano Monitoring Laboratory

In 2018, the Volcano Monitoring Laboratory was constructed at the campus of the University of Buea with support from the University, the LIRA 2030 grant and the USAID funded PERIPERI U projects (SDG17). The laboratory is intended for monitoring of precursory activities along the CVL (Fig. 1) which include:

1) Gas Monitoring: collection of water from some selected springs/streams/rivers/craters lakes at the flanks of these volcanoes for water chemistry analyses monthly and/or quarterly;

2) Temperature Monitoring: use thermocouple to identify thermal anomalies from fumaroles and lava lakes monthly and/or quarterly and

3) Seismic monitoring: install a minimum of 6 seismometers at strategic positions at the flanks of these volcanoes to monitor seismicity in the area and locate epicenters of earthquakes prior to eruptions.

All this information is needed to be able to forecast eruptions from active volcanoes along this line and reduce its impact on the population. The laboratory is hosted by the Faculty of Science which has created budget heads for running its research laboratories used for the purchase of basic equipment, such as furniture and stationery. The laboratory has so far been equipped with computers, printers and some basic GIS softwares (Fig. 4) purchased with funds from the USAID funded PERIPERI U and LIRA 2030 grants.

However, proper monitoring has not begun at this laboratory. This process was halted after the construction of the laboratory due to the abrupt stop of USAID funds and the end of the LIRA 2030 project, both in 2019, leaving the laboratory unequipped to perform its functions. The laboratory is fully equipped with GIS facilities but not yet with instruments and equipment which can be used to monitor gaseous emissions, the earthquakes generated by rising magma prior to eruptions and the increase in temperature of water bodies and gas emissions from craters prior to eruption. These are important parameters which are used worldwide to predict eruptions of similar active volcanoes. The sustenance of this center will require constant activities being carried out in the field of disaster risk reduction and management. Thus, the establishment of more partnerships for the realization of these goals matters.

Fig. 4. UB Volcano laboratory in pictures showing a. the front view of the building; b. the secretariat and c. the computer room.

Postdoctoral Research Outcome on Capacity Building for Volcano Monitoring

To be able to detect and understand periods of unrest by monitoring temperature and gas emission changes from multispectral satellite sensors in an attempt to understand periods of unrest at MC, the process included the acquisition of satellite images for the period spanning 14 years from BIRA (Belgian Institute for Space Aeronomy, SDG17) needed to detect Sulphur dioxide (SO_2) gas emission. However, upon analyses of the acquired images at the time of research, emitted SO_2 from MC was negligible, which meant conditions were stable at the volcano.

In addition to this, more fundamental volcano monitoring techniques were acquired during the short training session at CSAV, University of Hawaii, Hilo (6 weeks) and at the USGS Cascades

Volcano Observatory, Vancouver, Washington State (2 weeks). The techniques taught ranged from field, laboratory, modelling and satellite imagery analyses. The field training emphasizes volcano monitoring methods, both data collection and interpretation, which are in use by the USGS. Besides learning to assess volcanic hazards, participants learned the interrelationships between scientists, governing officials, and the news media during volcanic crises. This course served as an introduction to a variety of volcano monitoring techniques, rather than detailed training. The session of this course that was attended fortunately coincided with the Mount Kilauea eruption of 2018 that gave us the opportunity to observe and learn first-hand how to manage hazards from active volcanoes**.**

Further research at VUB focused on improving the volcanic risk assessment of Mt Cameroon. The first set of results involved finishing a study on the “Forensic assessment of the 1999 Mount Cameroon(MC) eruption, West-Central Africa” that began in 2015 which was successfully published by the end of the research period (Wantim et al. 2018). The analysis conducted on the damage associated with the 1999 MC eruption used the FORIN (Forensic Investigations of Disasters) approach launched by Burton (IRDR, 2010). This study aimed at extrapolating information on exposure patterns and unfolding a more articulated overview of vulnerability on the following aspects:

i) systemic, related to the interlinkages among the different sectors that are affected in a region and in cities,

ii) economic, related to the specific fragilities of local activities and the economy of the country, and

iii) social, related to the social structure, and the coping capacity of organizations with responsibility in emergency management as well as the preparedness of different social groups.

This research constituted a first attempt to bridge the gap between different forensic approaches applied to volcanic eruption. A key component of the innovative FORIN method consists in the investigation of the environmental, social and economic consequences of the impacts of the eruption-related hazards (i.e., lava flows, tephra, gases and earthquakes) on people and on multiple sectors, such as infrastructure, economic activities including agriculture, residences and public services.

The second objective of the research targeted the assessment of lava flow risk around MC. It entailed investigating the potential environmental and socio-economic consequences of future lava flow emplacement on the communities living at the flanks of MC. Lava flow hazard was assessed using the Q-LAVHA (Quantum-Lava Hazard Assessment) model developed at the VUB (Mossoux et al., 2016). Q-LAVHA combines existing probabilistic (VORIS; Felpeto et al., 2001) and physical (FLOWGO: Harris and Rowland, 2001) models, with some modifications to refine lava flow simulation in terms of its spatial spread and final length (Mossoux et al., 2016). A major component introduced in the lava flow hazard map used in this study that makes it different from the existing hazard maps from this same volcano is the use of varying effusion rates as input parameters (see Rowland et al., 2005). As observed in the 2018 Kilauea eruption (Neal et al., 2018), lava was extruded at higher effusion rates than previous eruptions from that volcano which was linked to changes in the magmatic plumbing system from the summit to the lower flanks. Mean effusion rates in the last century documented for MC eruptions varied from 5 to 50 m^3s^{-1} (Fitton et al., 1983; Suh et al., 2003; Njome et al., 2008).

Based on this, two scenarios were chosen:

- Scenario I represents the most probable scenario and is linked to documented effusion rates (5, 10, 30 and 50 m^3s^{-1}) from MC eruptions.

- Scenario II takes into consideration eruptions at 100 and 500 m^3s^{-1} and is considered as the upper end member (see Fig. 5).

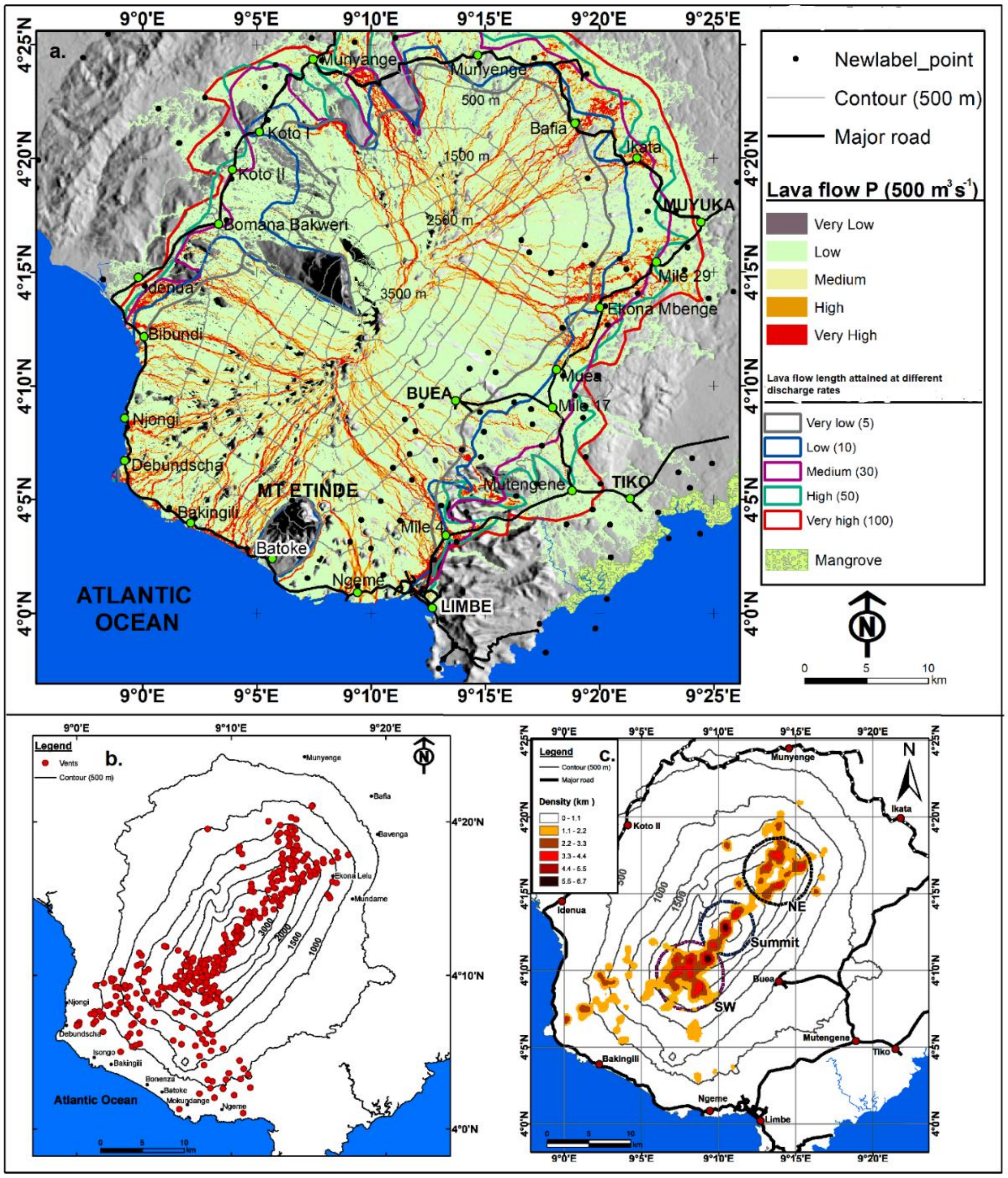

Figure 5: Maps showing: a. lava flow hazard at different eruption rates at MC generated using Q-LavHA model, b. alignments of over 300 vents along a NE-SW fracture network and c. kernel density map produced using a non-homogenous Poisson process that favours modelling of clustered random data with a search radius of 1000 m using all the vents to produce a PDF for lava flow simulations.

The produced lava flow map emphasised the SW, NE and SE habitats to be the most exposed to lava flow inundation taking all mapped vents (340) into account. Major linking roads at the flank of the volcano are susceptible to lava inundation. Lava flow hazard assessment was followed by risk assessment using landcover type and the built environment. MC landcover is depicted by the spatial distribution of natural vegetation (forest and savanna), plantations, agricultural land and built-up or settlement areas mapped from multi-spectral satellite sensors. Individual building infrastructures were systematically digitized from the Java Openstreet Map tool for the different municipalities studied. A total of 45,800 buildings were mapped and analysed in this study: 17,043 houses in Buea, 19,722 houses in Limbe, 1558 houses in Idenua, 6008 houses in Muyuka and 1469 houses in Mbonge municipalities respectively.

Lava from summit vents has the highest impact on the forest and residential areas in the SE flank of the volcano. Built-up areas, farmland and plantations in the Limbe city and Idenua municipalities are at risk from lava inundation from eruptions with effusion rates as small as 5 m^3s^{-1}. Farming contributes to 80 % of the livelihood for the population living at the flanks of this volcano. The most affected landcover in terms of surface area is the forest which is host to timber, non-timber products and endemic flora and fauna species. However, its socio-economic significance when compared to agricultural land is negligible for the affected population. The safest municipality in terms of lava flow impact on building infrastructure is the Mbonge municipality. Here, buildings could only be impacted at effusion rates as high as 500 m^3s^{-1}. In general, the forest, farmland, agro-allied plantations, major linking roads, building infrastructure (commercial, administrative, social, residential) worth millions of US dollars may be impacted in the area.

Since few mitigation and preparedness actions can be taken to protect property from lava flows, the most reasonable solution is to evacuate and remove values from lava flow vulnerable areas. However, due to the sentimental ties attached by the individuals living in these zones, the cost invested in the existing valuables present and the fact that eruptions from MC mostly occur with a recurrence rate of ≥ 10 years interval, convincing these people to leave these hazardous zones is not realistic. The only solution for now is to educate the inhabitants in these high-hazard areas so that they are aware of the potential risks they face and get prepared to respond efficiently to future eruptions that would threaten property and human safety.

Such awareness raising actions took off in 2007 with the initiation of the Belgian sponsored VLIR project (Wantim, 2011) where workshops, training sessions and billboards were put up for the different hazards in the MC region. These efforts have increased through projects like the Periperi U and LIRA 2030.

This study is a continuation of such efforts and the results generated in this study would be transmitted as an awareness action to the different municipalities. Overall, even though lava flow was the hazard considered, looking at the 1999 eruption for example, MC eruptions usually result in multi-hazards with enchained effects (Wantim et al., 2018) that warrants more in-depth study of each of the hazards to be able to properly assess risk from its eruptions.

Unit of Disaster Risk Management

After the creation of the DRM postgraduate programme, the University of Buea was recognized in 2019 as one of the global Centres of Excellence (CoE) on *Hazards and Disasters Research Institutes in Africa* by the Natural Hazards Institute of the University of Colorado at Boulder, USA, as a *Centre for Hazard Monitoring and Disaster Management (CEDIM) (Periperi U)* (https://hazards.colorado.edu/resources/research-centers/africa, based on a National Science

Foundation (NSF) grant to study such academic and research institutions globally. The created programme has so far defended over 30 MSc. theses and presently has a student population of over 40 people (first and second year). It is characterised with a multidisciplinary staff. This team, in collaboration with other experts, designed and launched the first Earthquake Building Code and Building Regulations in the country for the councils within MC. The team has also been actively involved in sensitization work on geological, technological and climate change risks, humanitarian work and consultancy projects. In 2021, the University of Buea granted a Unit for the affairs of this programme which began functioning in 2022. This unit is responsible for the monitoring of MC eruptions and managing of other related disasters in the region and Cameroon in general, which all have an influence on developmental endeavours.

Conclusion

This North-South and South-South partnerships established by the University of Buea between 2016 to 2019, through a USAID PERIPERI-U and a Swedish (SIDA) LIRA 2030 grants have enormously contributed towards the partial attainment of SDG 11 (Targets11.5 and Indicator 11.B.2) in making the cities at the flanks of MC safe, resilient and sustainable. This is clearly illustrated in the role these partnerships played in the development of the first Earthquake Building Code and Building Regulations in the area. Once this code has been promulgated into law, it is accordingly expected that the seven Councils within the Mount Cameroon area and even beyond, will be bound to implement this code and the associated building regulations. The way forward after the establishment of this code into law, will comprise of a series of sensitization workshops to be held where the engineers and architects who were part of this project, will demonstrate to the population how to implement the code on the field using desktop simulations. This will constitute another approach of partnership of the University with its local community.

The construction and partial equipping of a Volcano Monitoring Laboratory at the campus of UB is also a major milestone achieved with the aid of the USAID PERIPERI-U and Swedish (SIDA) LIRA2030 partnerships. Even though real time volcano monitoring have not yet began at this laboratory, it presently serves as a centre for capacity building of postgraduate students in the Disaster Risk Management (DRM) programme, which is also a major fallout from the established partnerships. The creation of the DRM programme at UB, is the first initiative in the whole of the Economic Community of Central African States (ECCAS) which could not have been possible without these established partnerships. Because of the establishment of the DRM programme coordinated by the DRM Unit, staff of the unit have been involved in ECCAS workshops funded by the World Bank in building the capacity of major stakeholders in the ECCAS region on DRR and DRM relevant to build resilient and safe cities. It is therefore imperative to reinforce these partnerships and create more in order to ensure sustainable development approaches in the urban, rural and peri-urban sectors that comprise 2 cities, 3 towns and 63 villages situated on the flanks of this mountain.

Thus, the USAID PERIPERI-U and LIRA 2030 partnerships with the University contributed towards the implementation of the targets of both SDG 17 and SDG 11 for it has enabled the building of a sustainable urbanization around Mount Cameroon which will last until 2030 and beyond. The acquired experience can then be transposed and/or extended to other cities, towns, and village communities within both developed and developing countries on the African continent, and globally which may be vulnerable to similar volcanic risks.

Future Perspectives

1. Sensitization and capacity building on the Earthquake Building Code and Building Regulations: Simplification of the document into non-professional terms so that construction workers will be able to adopt it in their building practices.

2. Equipping and building the Manpower at the Volcano Monitoring Laboratory: develop partnerships (North-South and South-South) to fund the purchase of seismometers, thermocouples, and gas detectors and also train the manpower needed.

3. Usefulness of Monitoring MC: The monitoring process will provide results, which will be used to inform policy makers and the communities about disaster preparedness/evacuation plans. Local partnerships such as those created after the 1999 eruption through grants/subventions from the government could be reinstated. New partnerships will be sought with other government officials, the seven municipalities around the volcano, the private sector, and Ministerial Delegations (Housing, Research, Town Planning, etc.) to ensure social change and sustainable development in the area by the year 2030. The success of such ventures and their sustenance during the next 8 years until 2030 matters because this will:

    a. Enable infrastructure operators to be knowledgeable about likely impacts of earthquakes on buildings in the area,

    b. Provide clear messages for policy makers for consideration in enacting building laws and regulations for the area based on the scientifically identified norms presented in the code.

    c. Build the confidence of the communities and of prospective investors who may like to invest by setting up industries for example, since they will realise the existence of a scientifically monitoring of the hazards from this mountain.

    d. These issues are pivotal for the implementation of SDG11, SDG17 and the other related SDGs in the area and even beyond.

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