UNIVERSITY of RWANDA

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ASSESSMENT OF THE IMPACTS OF NYIRAGONGO VOLCANO ERUPTION ON AIR QUALITY IN NORTH WEST RWANDA(RUBAVU)

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN ATMOSPHERIC AND CLIMATE SCIENCE in the College of Science and Technology

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DECLARATION

I **Nyecumi Bonane,** hereby declare that this dissertation entitled**”** ***ASSESSMENT OF THE IMPACT OF NYIRAGONGO VOLCANO ERUPTION ON AIR QUALITY IN NORTH WEST RWANDA(RUBAVU)*****”** is my original work which has not been submitted or used to any other university or institution as part of class work, presentation or publication. It is my work where other tools which have been used and references consulted, have been mentioned.

Names**: NYECUMI BONANE**

Signature

Date:……/…./2024

DEDICATION

This project is wholeheartedly dedicated to my beloved parents, who have been our source of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. To my brothers, sisters, relatives, mentors, friends, and classmates who shared their words of advice and encouragement to finish this study. And lastly, I dedicated this work to the Almighty God, thank you for the guidance, strength, power of mind, protection and skills and for giving us a healthy life.

CERTIFICATION

This is to certify that master's dissertation entitled "***Assessment of*** **the impact of Nyiragongo volcano eruption on air quality of north west part of Rwanda(Rubavu)**" was carried out by NYECUMI BONANE in partial fulfillment of the requirement for the award of master's degree of science in atmospheric and climate Science in University of Rwanda College of Science and Technology

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Above all, I would like to express my gratitude to the Almighty God who protected me and provided me with all I have, his love and grace on me are so endless that I could not find enough words to thank him in.

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LIST OF ABBREVIATIONS

NAAQM: National ambient Air Quality Monitoring

AQI: Air quality Index

AQG: Air quality Index

EPA: Environmental Protection Agency

HYSPLIT: Hybrid Single Particle Lagrangian Integrated

WHO: word health organization

REMA: Rwanda Environment Management Authority

Du: Dobson Unit

NOAA: National Oceanic and Atmospheric Administration

GDAS: Global Data Assimilation System

RAMP: Region of Aircraft Movement and Parking.

ABSTRACT

Air pollutant which is being accumulated in the atmosphere from different sources such as emission of vehicles, industries, domestic sources and natural sources causes some atmospheric instability where these particle increases temperature in the upper atmosphere and keep it warm as some air pollutant gases reflect back sun's ray which may cause global warming and change ambient air composition. This can seriously impact human health, potentially leading to lung cancer, brain damage, kidney and liver damage, respiratory diseases, and various illnesses, as well as irritation of the nose, throat, eyes, and skin. We simply say that natural sources is one of the source of air pollutants, here we can say example of volcanic eruption that may lead to increased level of pollutant including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and particulate matter. On 22nd may 2021, there was eruption of Nyiragongo volcano in Democratic Republic of Congo. This paper focuses on assessing the impacts of Nyiragongo volcano eruption on air quality of north western part of Rwanda especially in Rubavu District.

This study used different data of air quality of Rubavu district taken from Rwanda environment management Authority (REMA) there is air quality analysis like level of concentration of air pollutants like nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO), and carbon dioxide (CO_2) by taking different time interval to know what was the air quality of the region before eruption and the air quality analysis after volcano has erupted. HYSPLIT Model has been used to simulate spatial and temporal distribution of volcanic gases (air parcel)

CHAPTER1. INTRODUCTION

1.1 Introduction

We habitually talk of air as the first basic need to life where air quality affects public health. We define air quality as the measure indicating the cleanliness or pollution level of the air [1]. Due to the daily accumulation of air pollutants from various sources, the composition of the atmosphere changes, which impacts the environment .The concentration levels of air pollution are influenced not only by the quantities emitted from pollution sources but also by the atmosphere's ability to either absorb or disperse these emissions as reported in [2] [3]. Air pollution concentration varies noticeably, creating distinct patterns that change with location and time due to shifts in meteorological and topographical conditions. Anthropogenic sources of air pollutants include motorized transport, industries, and domestic activities. Natural sources of air pollution include volcanic eruptions, among others. The presence of high levels of air pollutants in the atmosphere is severely impacting both public health and property [4].

Air pollution remains a significant global environmental issue because of its effects on human health, ecological toxicity, meteorological changes, precipitation suppression, and climate change. Therefore, it is essential to evaluate current and future air pollution levels through continuous air quality monitoring [5]. According to 2018 data from the World Health Organization (WHO), over 90% of the global population is exposed to high levels of air pollutants, leading to approximately 7 million deaths annually. Particulate matter, particularly PM10 and PM2.5, is especially concerning due to its association with various health disorders [6],[18]. Nitrogen dioxide (NO2), ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), and carbon dioxide (CO2), along with other inorganic gases such as hydrogen sulfide (H2S), chlorine, ammonia, hydrogen chloride, hydrogen fluoride, hydrogen cyanide, phosphorus oxides, mercaptans, and bromine, are also considered air pollutants [7]. Particulate matter can be categorized into dust, smoke, fumes, mist, fog, and haze. Smaller particles tend to have a longer residence time in the atmosphere. Some of these pollutants are emitted during volcanic eruptions [5],[4] In areas prone to volcanic eruptions, volcanic degassing leads to the emission of various air pollutants , with sulphur dioxide (SO2) being one of the most commonly released gases (besides water and carbon dioxide) [2]. Volcanic degassing has impacts on the environment (acid rain formation, plant damage) and on climate. In humans, SO2 causes irritation of the skin and mucous membranes because of the formation of sulphuric acid (H2SO4), thus leading to acute or chronic respiratory disorders. In a time series study, Kan et al. demonstrated that daily mortality in Shanghai was associated with short-term exposure to outdoor SO_2.The conducted study about health impact of volcano Longo et al, provided an increase in respiratory disease due to Kilauea volcano eruption in Hawaii [7]. In the last century, Nyiragongo has experienced two major eruptions: one on January 10th, 1977, which claimed nearly 500 lives, and another on January 17th, 2002, which resulted in 147 deaths and destroyed between 12,000 and 15,000 houses, leaving hundreds of thousands of people internally displaced [11]. The third eruption on May 22, 2021, resulted in at least 32 fatalities, displaced tens of thousands in the Democratic Republic of Congo, +and heightened concerns about the possibility of future volcanic activity as reported in [8].

1.2 Problem statement

Air pollution is a major factor affecting the quality of life for all living creatures in the environment. It is primarily caused by human activities such as mining, industrial work, construction, and transportation. Natural processes, such as wildfires and volcanic eruptions, also contribute to air pollution [4]. The pollutants that affect air quality can be classified into two main types: gaseous forms and solid forms (particulate matter suspended in the air). Air pollution can lead to both long-term and short-term health effects. Long-term impacts include kidney damage, lung cancer, liver damage, respiratory diseases, and brain damage. Short-term effects, which are temporary, may include illness and irritation of the nose, throat, eyes, and skin

1.3 Relevance and choice of topic

Volcanic air pollution from both emission and extrusive activity can affect large number of populations living closer from near distance to thousands of kilometers away from the source, for long period from days to centuries [9],[2]. Gaseous air pollutants emitted from industries, motorized transport, and indoor sources are major issues in developing cities in Rwanda, such as Rubavu. In middle-income and developing countries, people are often exposed to high levels of air pollution (Engel et al., 1998). Outdoor air pollution accounts for over 3% of the annual disability-adjusted life years (DALYs) lost, according to the 2010 Global Burden of Disease risk assessment, marking a significant increase since 2000 (Lim et al., 2012). Urbanization is a major contributor to air pollution, which in turn leads to various health problems [8]. Volcanic gases pollutants that gave out the greatest potential calamity are hydrogen fluoride, Sulphur dioxide, and carbon dioxide locally. Sulphur dioxide pollutant is dangerous that may even cause acidic rain and air pollution for surrounding region from volcano. And these gases come from lava flows of volcano and even for volcano that may erupt unexpectedly [10].

Volcanic ash from volcano, travels hundreds to thousands of kilometers from volcano erupted. Fresh volcanic ash is aerosol which is dangerous, corrosive and always unpleasant. Though is not highly toxic, it can disturb infants, the elderly, and those with respiratory organ disease [2],[6]. Ash is also dangerous to our eyes because can scratch them, especially when wind is blowing. Ash can exponential reduce grazing livestock production and destroy the installation of drinking water pumps and also water treatment equipment facilities [9]

1.4 Hypothesis

The eruption of Nyiragongo volcano in east Congo would have increased level of concentration of Sulphur dioxide in air constituents.

1.5. Objectives

1.5.1 Main Objective

The main objective of this paper is to evaluate the impact of the Nyiragongo volcano eruption on the air quality in the north western part of Rwanda, specifically in Rubavu.

1.5.2 Specific Objectives

- To analyze air pollutants, present in the atmosphere of the study area
- Provide targets to guide measure towards achievement of reduction of air pollutants releasing.
- To give impressive health base recommendation on air quality of the study area

CHAPTER 2 . LITERATURE REVIEW

2.1 Cause of Nyiragongo volcano eruption

The eruption likely started when a small rupture formed in the volcanic cone, caused by the gradual buildup of pressure and heat from the magma beneath. Over time, this stress would have weakened the structure, and once the rupture occurred, the magma was able to force its way through, triggering the eruption. It's a common phenomenon in volcanic activity where the pressure from molten rock eventually exceeds the structural integrity of the surface, leading to an explosive release.

Figure 1:The_eruption of nyiragongo volcano on 22nd may 2021

Volcanic eruptions can greatly impact air quality, both locally and globally, depending on their magnitude. During an eruption, a volcano releases various gases and particles into the atmosphere, which can directly influence the air quality in nearby areas

Many researches have been conducted on impacts of air quality and even the impacts of recent eruption of Nyiragongo volcano. And consist of some researches conducted globally and locally. the study about scattering of Atmospheric Aerosols in The May 2021 Volcanic Eruptions Over Mount Nyiragongo conducted by Department of Biological and Environmental Sciences, Kibabii University showed that pollutant masses reduced in concentration with distance away from source at ground level [2]. The patterns of volcanic ash columns over the area of study can be applied for aviation purposes even though Dispersion of ash was observed to shift with height or flight levels over the area of study [7]. The findings of the investigation revealed that particles decreased with height up to around 3000 meters above ground level and later increased by height. The study therefore observed changes in particle positions with height over the study area [3]

The Rwanda Environment Management Authority (REMA) has raised concerns that the poor air quality in Rubavu district might not been related to the Nyiragongo volcanic activity as reported in Goma, DR Congo [9],[10],[18]. In response to reports from the Volcanological Observatory of Goma about increased activity from Nyiragongo volcano and warnings against using Lake Kivu water, REMA dispatched a team to assess both the air quality in Rubavu District and the water quality of Lake Kivu [18]. From May 27th to 29th, 2021,this team was in Rubavu District to monitor air quality pollutants related to the Nyiragongo eruption. The monitoring exercise, which operated continuously day and night using solar-powered energy, utilized RAMPS and ATMOTRACK monitors. The targeted pollutants included SO_2, CO_2, CO, O_3, NO_2, PM2.5, PM10, PM1, NH_3, and noise levels, alongside all meteorological parameters such as temperature, relative humidity, pressure, wind speed, and wind direction [8]. The measurements ultimately revealed that the air quality in Rubavu District is currently unhealthy, with elevated levels of pollutants, including particulate matter (PM 2.5). Despite the recent deterioration in air quality, REMA states that this result is not attributed to volcanic activity. Instead, it is linked to anthropogenic sources such as pollution from motorized transport and the burning of wood and charcoal. In contrast, volcanic activity would typically lead to increased levels of sulfur dioxide (SO2) [11]. However, REMA's statement confirms that the water quality of Lake Kivu remains safe, with no observable changes from the long-term average.

2.2 Hysplit model approach

The HYSPLIT model, one of the most commonly utilized Lagrangian dispersion models, was developed by the National Oceanic and Atmospheric Administration (NOAA) in the United States during the 1980s (Cohen et al., 2015). Through several iterations of growing complexity, the present version of HYSPLIT was developed, incorporating a wide range of tools and applications. This evolution has made it one of the most widely used models in dispersion modeling today [15]. The Weather Research and Forecasting (WRF) model is employed to simulate mesoscale meteorological conditions at the event site. These meteorological parameters are then integrated into HYSPLIT, which models the movement of "tracer particles" within the provided meteorological conditions (Hegarty et al., 2013)

2.3 Background of study Area

Rubavu District is one of the seven districts in the Western Province of the country located in north western part of Rwanda, It has a large beach resort and border city .Rubavu covers an area of 388.3 square kilometers. It shares borders with Nyabihu District to the east, the Democratic Republic of Congo to the west and north, and Rutsiro District to the south. The district is located 152 kilometers from Kigali, the capital city. Rubavu District is situated along the shores of Lake Kivu, centered around the city of Gisenyi, and lies just across the border from Goma, a city in the Democratic Republic of Congo, which is approximately a 2 hour and 53 minute drive away . Due to its geographic location and features like Lake Kivu, Rubavu serves as a hub for business and tourism, particularly in cross-border trade with the DRC.The geography of Rubavu District is characterized by diverse rainfall patterns, ranging from 1,200 mm to 1,500 mm annually. The northwestern part of the district is known for its fertile but shallow soils, composed of volcanic ash and decomposed lava. In contrast, the southeastern part has deeper soils that are often poor, acidic, and prone to erosion. Additionally, the district is near Mount Nyiragongo, an active volcano, which experienced a new eruption on May 21, 2021.

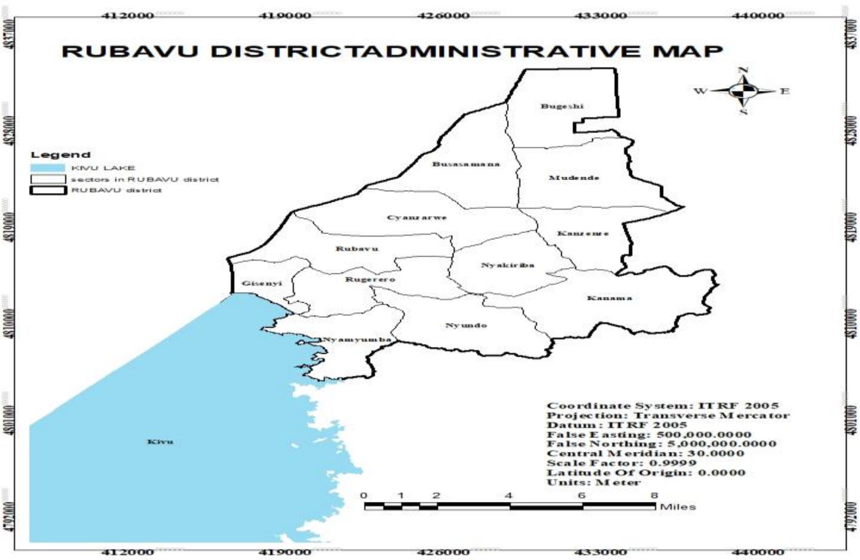

Figure 2:Administative map of Rubavu

CHAPTER 3. METHODOLOGY

3.1. Data collection and site description

To successfully conduct this study, data on air quality standards were required. The analysis included several air pollutants, such as particulate matter (PM2.5 and PM10), sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and ozone (O3) calculated in microgram per centimeter cube taking hourly data from the early January 2021 to end of December 2021. These data were taken from two different sites of Rubavu district that appear to be near the volcano [13]. These data were taken from Rwanda Environment Management Authority(REMA). It has established 23 sites across the country to use instrument based method that collect data to establish a national air quality monitoring network to continuously track and report the air quality index across the country and to enhance the existing climate observatory to improve the understanding of local emissions related to climate change.These data were collected on lake Kivu and Bugeshi Stations as the site lying closer to the nyiragongo volcano [12],[14]. Other data of volcanic ashes that were not provided by REMA, were accessed from online satellite Giovanni-NASA. This is online satellite based approach that were used to give some air pollutant like Ozone(O3) in Dobson unit where one Dobson is 0.01 millimeters thick at a temperature of 0°C and a pressure of 1 atmosphere or is 2.69×10^16 ozone molecules per square centimetre [13]. The volcanic ashes accessed were :monthly dust surface mass kgm^{-3} over Jan-Dec 2021, time averaged monthly CO emission in $kgm^{-2}s^{-1}$, time averaged SO_2 column mass density in kgm^{-2} over April-July 2021, time averaged NO_2 total column in molecule/cm^3 over April-July 2021 [5]. Measurements of the vertical column density (VCD) of SO_2 were gathered using the Ozone Monitoring Instrument (OMI) (Li et al., 2021), The Ozone Monitoring Instrument (OMI) is a spectrometer aboard NASA's Aura satellite that has been used to observe SO_2 levels [9]. HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) was used to simulate the spatial and temporal distribution of air parcels to determine if the trends in volcanic gases and particulate matter have impacted the balance [15]. HYSPLIT is widely used for dispersion and transport modeling across various fields, including radionuclides, wildfire smoke, wind-blown dust, air pollutants, allergens, and volcanic ash (Cohen et al., 2015; Davidson et al., 2009; Hurst & Davis, 2017), Specifically, HYSPLIT is utilized for volcanic ash and gas modeling on a global scale see

To conduct this research, data from the Rwanda Environment Management Authority (REMA) were utilized, including information on air pollutants such as particulate matter (PM2.5 and PM10), sulfur dioxide (SO2), carbon monoxide (CO), nitrogen dioxide (NO2), and ozone (O3) .

3.2. Hysplit model calibration

The HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory model) is a commonly used tool for analyzing the spread of atmospheric pollutants, such as volcanic ash, airborne chemicals, and other particles. It simulates the movement of gases and particles through the atmosphere using meteorological data, along with various physical and chemical principles. The HYSPLIT model was used to simulate the spatial and temporal distribution of volcanic gases and particulate matter following the eruption. It generated results showing the air concentration data trajectories for the study area [15]. Concentration ($\mu g/m^3$) is averaged initiated 1st Jan 2021 over the area of study, at some meters above ground level, at an average integration period of 1 hour and dry deposition rate of 0.1cm per second. The maximum and minimum mass concentrations were generated.

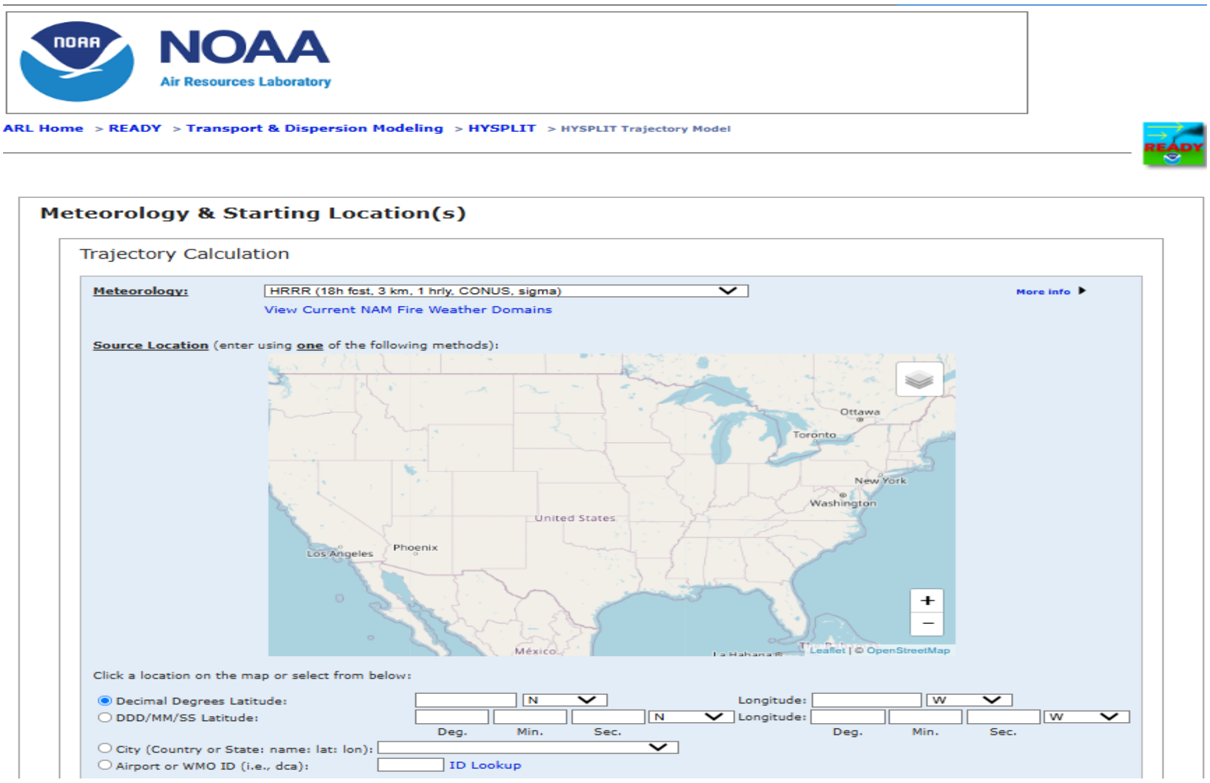

Figure 3:Hysplit model display

CHAPTER 4:RESULTS AND DISCUSSION

4.1 Hysplit model

Hysplit model was used to simulate spatial and temporal distribution of volcanic gases and particulate matter air parcel initiated from week 3 to week 4 of May 2021 over different level of height .

The main simulation parameters are outlined in Table below. Each model run involved a 120-hour forward trajectory using the HYSPLIT model, starting from Rubavu Airport. This 5-day duration is appropriate for capturing the potential long-range transport of air pollutants, as most pollutants tend to settle within a few days [14]. For instance, particulate matter may settle within a few hours to a day, while NOx and SOx can travel for up to three to four days (Seinfeld and Pandis, 1998)

Table 1: Hysplit Model Parameter

MODEL PARAMETER	SETTING
Meteorological Dataset	GDAS
Trajectory direction	Forward
Total Run time(trajectory time)	120hrs
Starting Point	RUBAVU Town
Starting time	00:00UTC
Starting height	1000
Starting height	500
Starting height	100

The results are displayed in the figures. The trajectories of air parcels by height were plotted using the model over the study area under the same conditions as in Figures 4 and 5, with a single mass release quantity. The results are presented in Figure 4 for the week before the eruption and in Figure 5 for the week after the eruption [12].

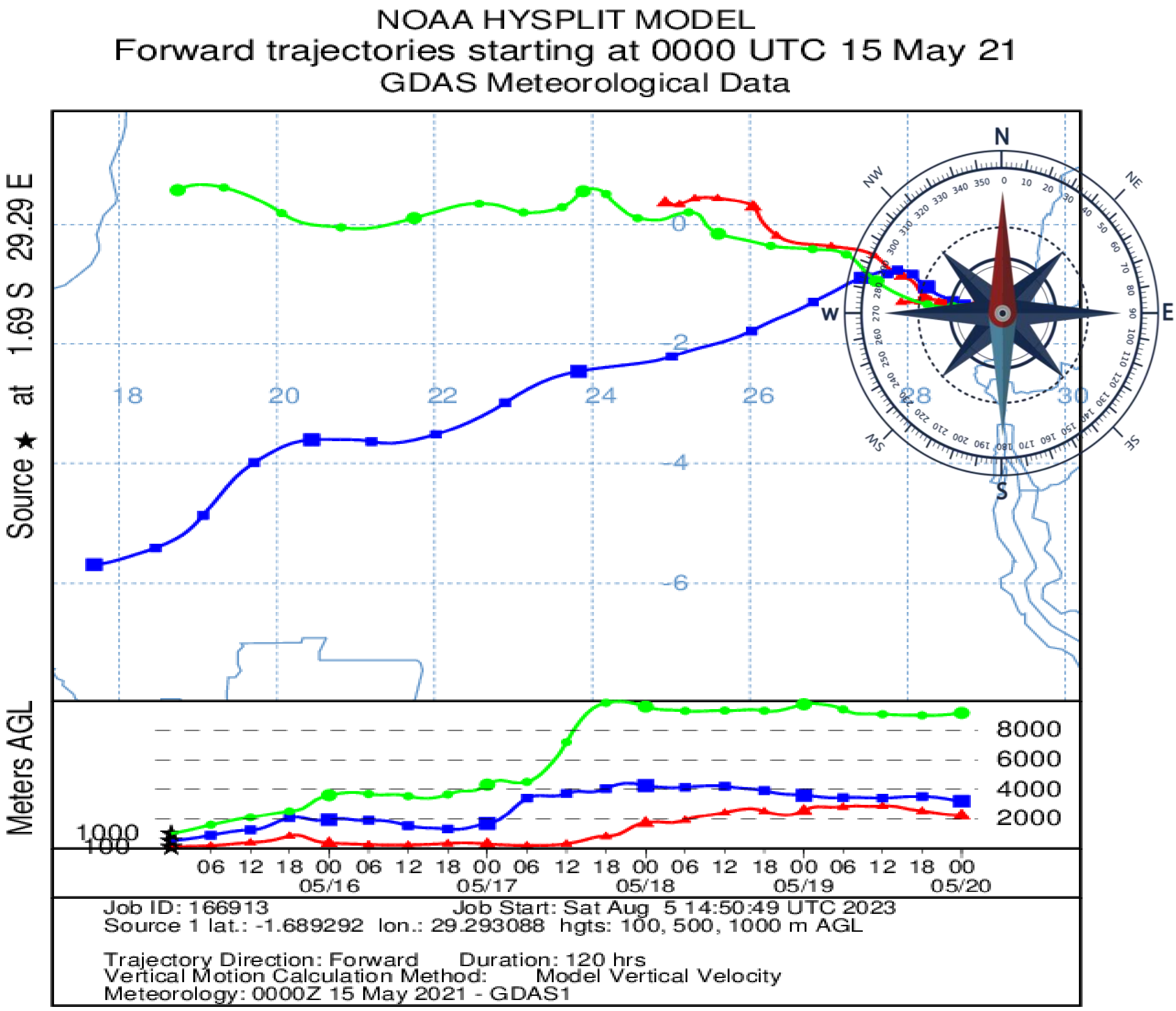

Figure 4:Hysplit trajectory of air parcel for week(15-21 May)before eruption

Each modeling run produced an air parcel trajectory arriving at DRC from Rubavu. Most of the aerial plots indicated that the air parcel paths underwent significant changes in direction, occasionally even looping back on themselves as it is in [8],[13]. To better identify the direction of the air parcel, each path was then analyzed as two 60-hour sub-trajectories. For figure 4, the trajectory is week for pre-eruption15-21st May .The air parcel over the height of 100m air parcel is shown in red color to be rising and directing toward the east from RUBAVU city to Democratic Republic of Congo but suddenly it stops to the third part of division part of time [17]. For the height of 500m air parcel is shown in green color also to be rising directing toward the west from the point of our origin reaching far despite its trajectory is sinusoidal motion changing as sine and cosine curve. For height of 1000m the air parcel is shown in blue color to be descending from the point of our origin reaching far also moving sinusoidaly , although in its inception seemed to little bit rise for a while [8].

The direction for the 0-60 hour sub-trajectory was determined using a compass and then used for cumulative frequency analysis. The compass graphic was used to read the direction of the 0-60 hour sub-trajectory, which would be recorded as West [12]. For calculating and reporting the frequency distribution of air parcel path directions, only the first sub-trajectory (0-60 hours) was considered [15]. This is because an air parcel path labeled as 'West' indicates that the air parcel arrived in DRC from a location west of Rubavu. The same approach doesn't always apply when analyzing the 60-120 hour sub-trajectory, as its origin might change direction, as illustrated in Figure 2, which shows variations at different heights from Rubavu. Additionally, the 0-60 hour sub-trajectory, which tends to start moving toward the West, offers a slightly higher level of accuracy due to modeling accuracy improving with longer simulation times (Rolph and Draxler, 1990)

The direction of air parcel paths alone cannot fully represent the regional influence on DRC's air quality. This is because: 1) It is only possible to accurately determine the direction of air parcel paths arriving in DRC during the last 60 hours of their journey (i.e., the 0-60 hour sub-trajectory), as previously discussed. Therefore, any direction changes made during the 60-120 hour sub-trajectory and the regions associated with them would be overlooked. 2) The 45-degree tolerance band chosen for each compass direction covers an increasingly large geographical area as the distance from DRC increases, making the analysis of regional influence based solely on direction too broad [14],[16]. To address this, the entire 120-hour journey of the air parcel path was analyzed, considering all the states or provinces it traveled through. This approach provided a more complete and precise understanding of the regional influence on DRC's air quality.

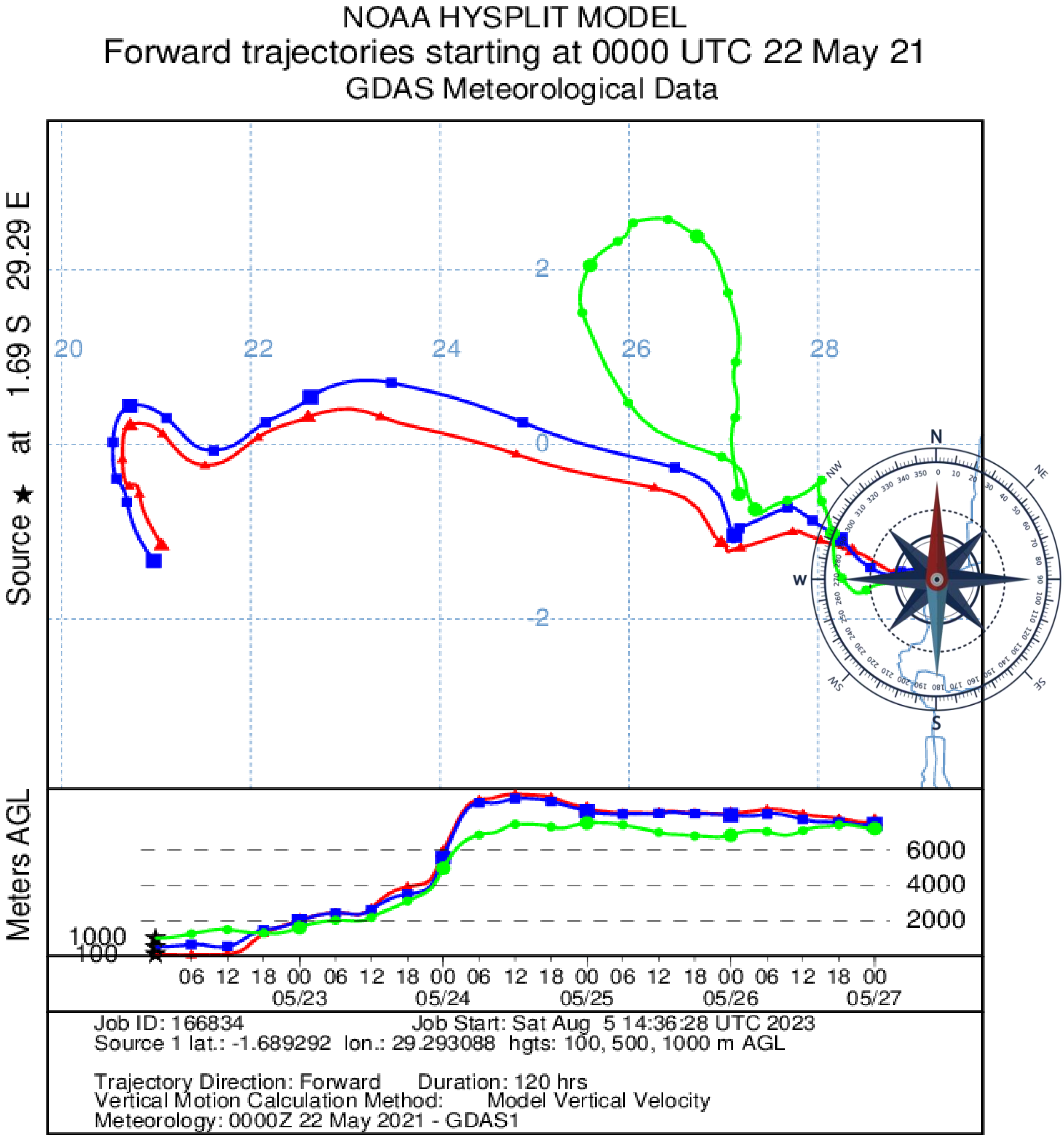

Figure 5:Air parcel for week(22-28 May)during and after eruption

Based on the air parcel direction plots (Figure 5), it is evident that regions to the west of the DRC more frequently influence the DRC's air quality than those to the east, such as Rubavu. This is clearly demonstrated by the analysis of the regions through which air masses traveled before reaching the DRC. Figure 5 also confirms that Rubavu's air quality is most often affected by neighboring states, including Goma and Bunagana, most of which lie to the west (SW, W, NW) [15]. This is primarily due to the dominance of westward winds, consistent with the air mass path direction plots shown in Figure 5 after the eruption [16].

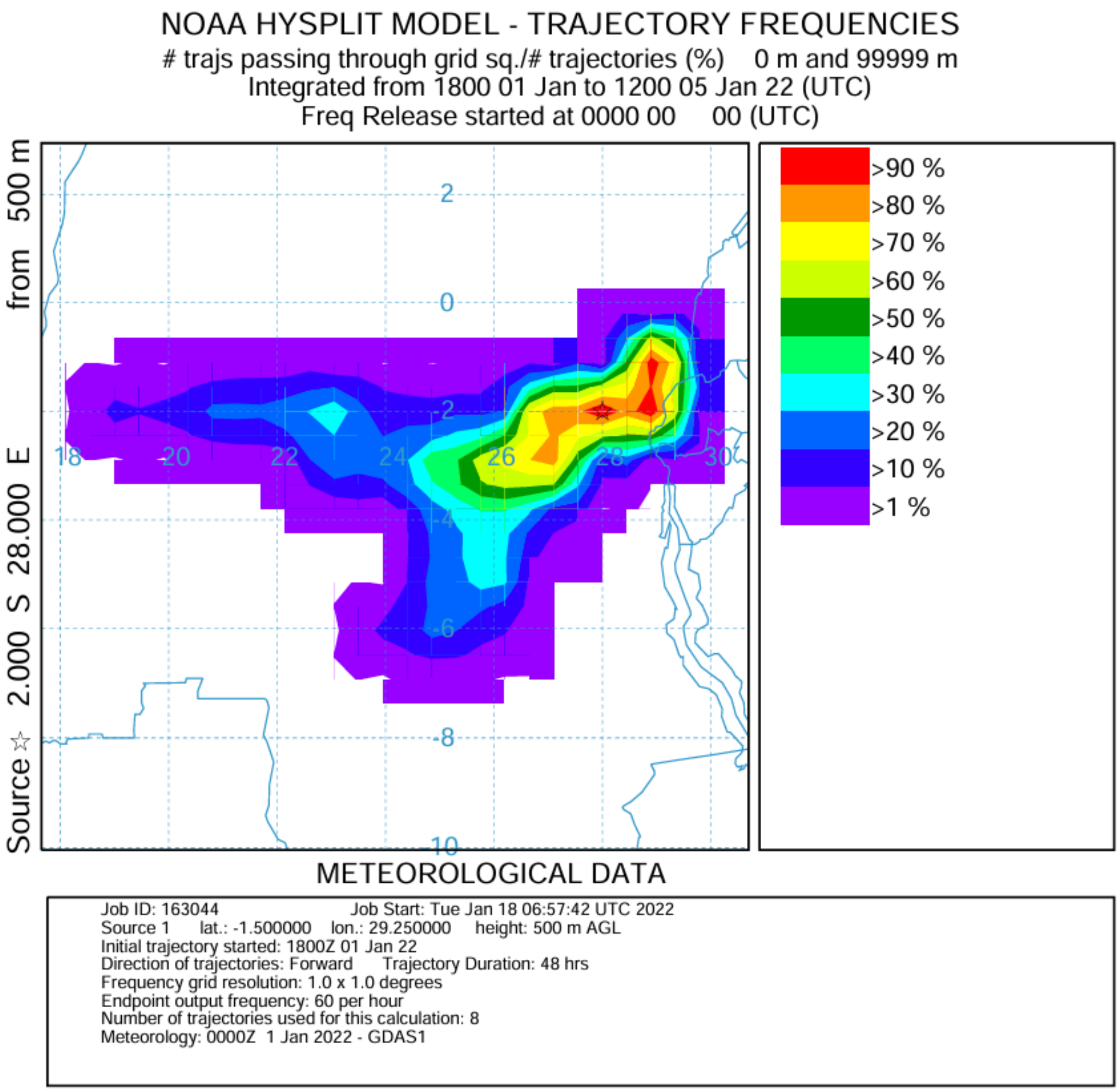

Figure 6:Nyiragongo volcano frequency trajectory

This figure illustrate the forward frequencies trajectories of Nyiragongo Volcano for period of 48hrs at endpoint output frequency of 60 per hour with meteorological dataset GDAS1 at first January 2022.this is showing high frequency from epicenter of the volcano to least frequency as we move outward from epicenter [16]

4.2 Giovanni Mod5

The Giovanni MOD5 system this is an interface within NASA's Giovanni Interactive Online Visualization and analysis tool, specifically designed for working with MODIS (Moderate Resolution Imaging Spectroradiometer) data [4],[11]. MODIS is an instrument aboard NASA's Terra and Aqua satellites, capturing data on Earth's atmosphere, oceans, and land. Researchers utilize Giovanni MOD5 to investigate atmospheric composition, cloud characteristics, and changes in land surfaces over time. Giovanni MOD5 provides access to a diverse array of MODIS datasets, covering variables like aerosols, clouds, land surface, and ocean color, among others [6]. We choose specific data products and time periods for their analysis .The system offers tools for visualizing MODIS data, enabling us to create plots such as time series, area plots, histograms, and maps. It uses-friendly interface that allow easily to visualize complex datasets without the need to download or process the data [7] .Therefore there was volcanic ashes data accessed from Giovanni mod5 due to the limitation that data collected from REMA was incomplete. Giovanni input parameter were time limit, selection of region, type of air pollutant measured and to specify exactly to define the type of output data format. The data results for example of ozone in Dobson unit over the period of year 2021 of the selected region of study looks like this

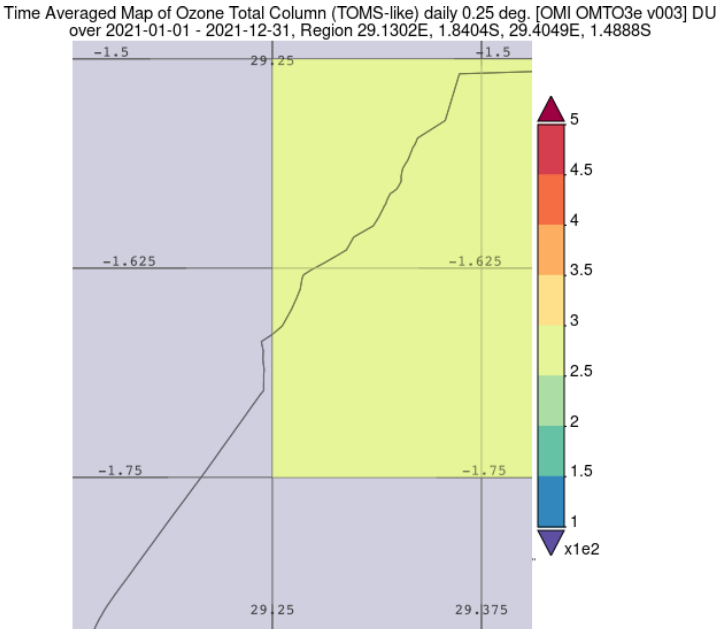

Figure 7: Statellite based result of trends of Ozone(in Dobson) over the year 2021

This means over the period from 1st Jan 2021 to 31st Dec 2021 Ozone gas was between 2.5 and 3 Du. This is not threshold of warning as we can see that this level of concentration is not high

4.3. ANALYSIS OF DATA FROM REMA

Data provided by REMA was extracted from two selected sites of Rubavu District

Table 2:Table showing the station sites for the study area

no	selected stations	location
1	Bugeshi	Rubavu District
2	Lake kivu Rubavu	Rubavu District

These data were analyzed and plotted using excel to see real which dominant air pollutant in the period of eruption as reported in [18]. Also the chart provided the trending rise and descending of the pollutant exactly during the period of eruption where the data from these two sites were averaged in its concentration to be accurate.

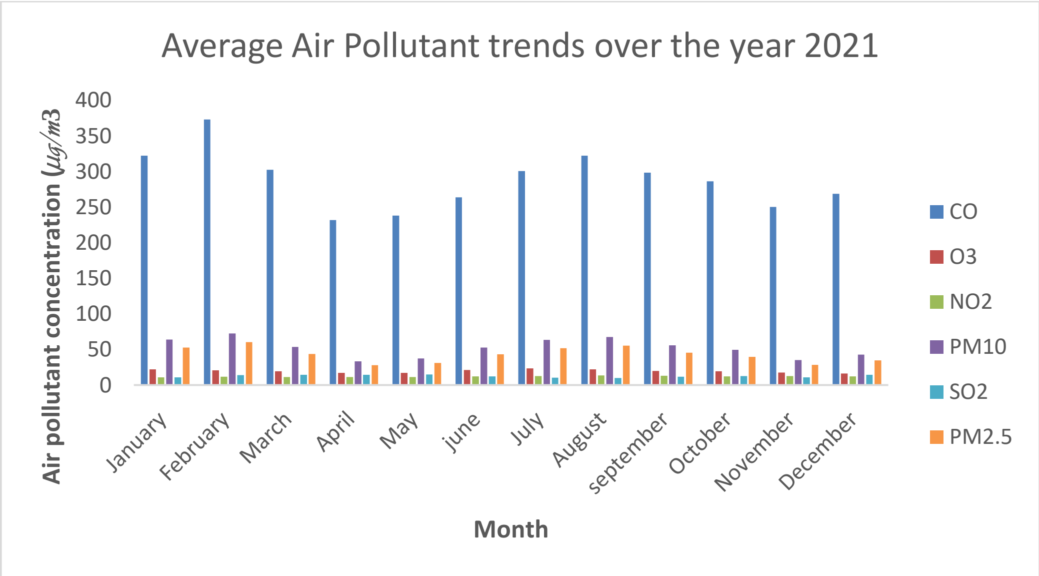

Figure 8:averaged monthly trends of air pollutants over the year 2021

This shows that the concentration of carbon monoxide which is high compared to other pollutants gases, and also the concentration of particulate matter PM10 and PM2.5 is increasing month to month that might have harmed the quality of north western part of Rwanda. This chart also shows that the level of concentration of Sulphur dioxide and nitrogen dioxide is absolutely high over the study area compared to ozone.

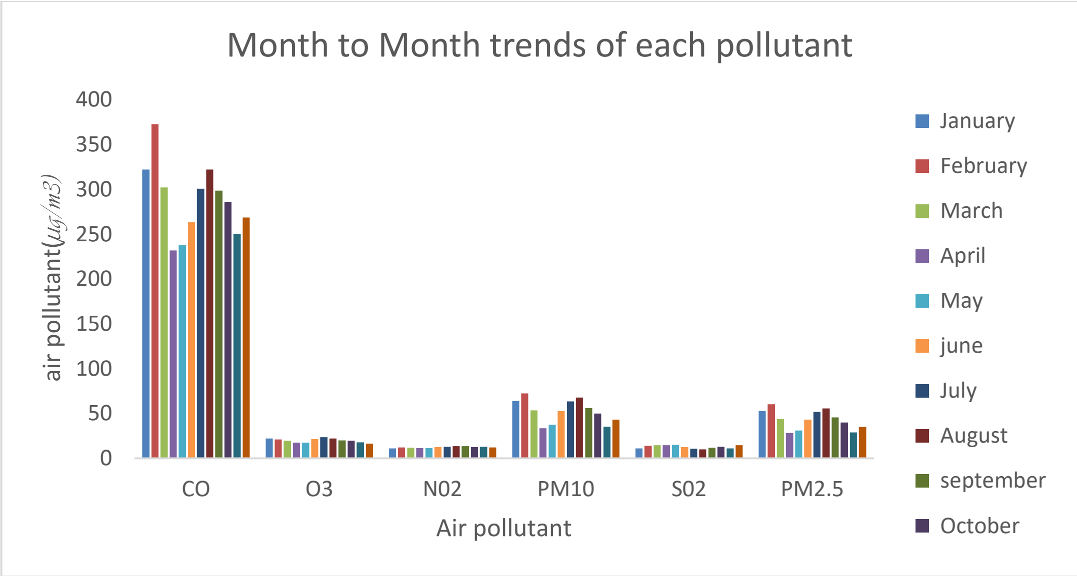

Figure 9:Month to Month trends of each pollutant

This figure clearly illustrates the monthly trends of each pollutant, revealing that carbon monoxide, particulate matter with a diameter of less than 10 microns (PM10), and particulate matter with a diameter of less than 2.5 microns (PM2.5) are the predominant pollutants in the northwestern region of Rwanda

Table 3:Table showing averaged air pollutants of stations of the study area

Station	CO	*03*	NO2	PM10	S02	PM2.5
Lake kivu Rubavu	420.2616	20.76774	14.24581	20.44796	9.600799	18.97838
Bugeshi	288.19	19.9529	12.3438	52.7127	12.7343	43.3333

This table show that air pollutants of these two stations are quite different where station of lake kivu Rubavu seems to have increased level of concentrated pollutants for leading pollutants may be it is because of boarder city

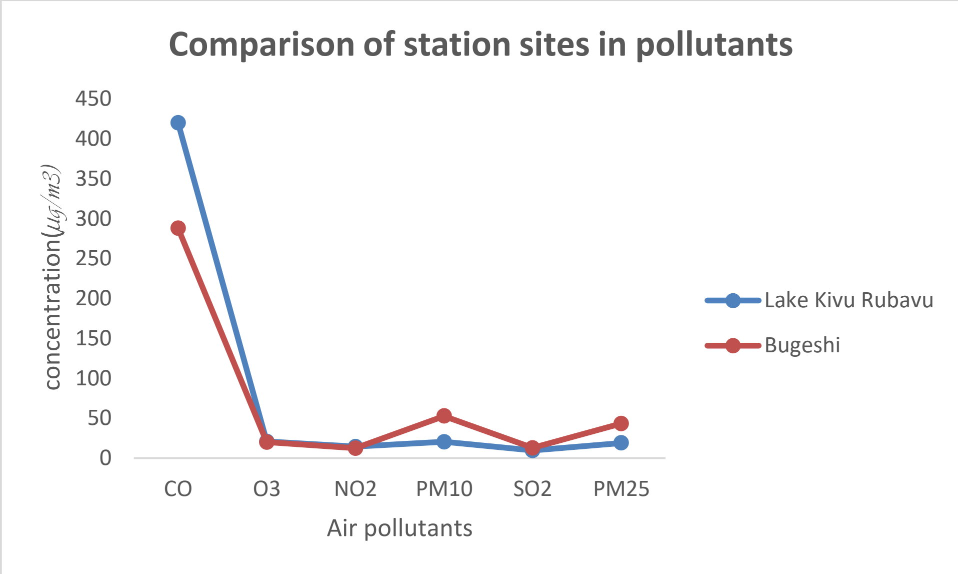

Figure 10:Comparison of station sites in pollutants

This chart shows the annually averaged value of air pollutants over the year of 2021. Here everyone is able to detect that area where lake kivu station is located, is more polluted with carbon monoxide and the region by which Bugeshi station is located, seems to have somehow increased level of particulate matter because it is region closed to volcanic region

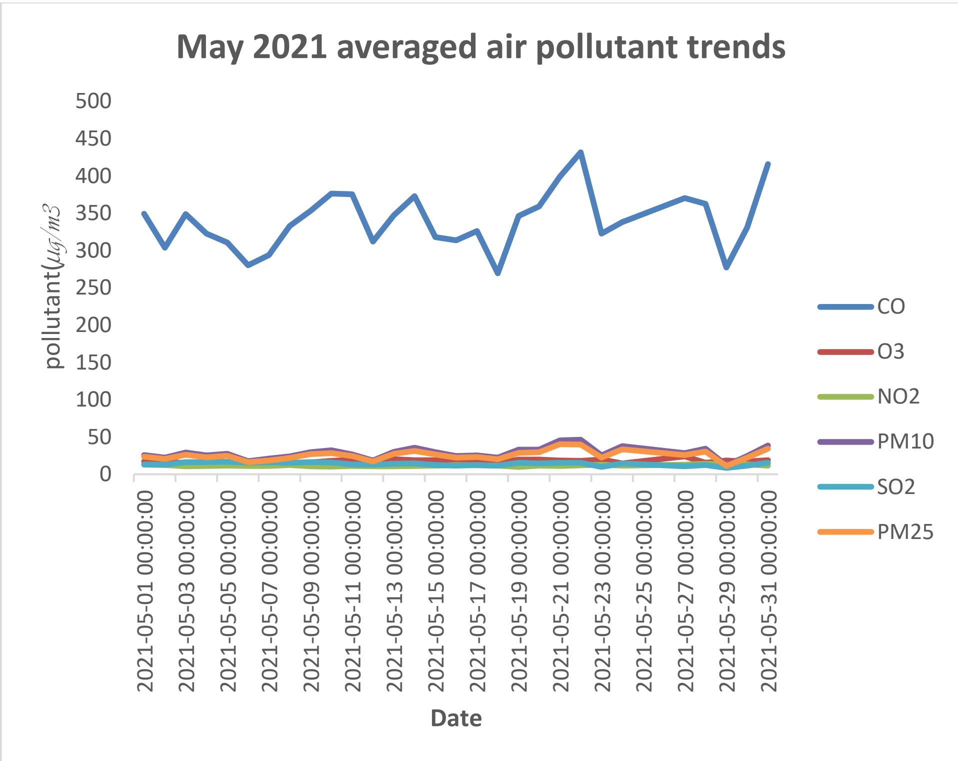

Figure 11:Averaged air pollutants trends over the month of may 2021

This chart shows averaged value of air pollutant over the month of May 2021 as the month in which the volcano erupted in. And it is clear that over the period from 19th to 23rd May, the period of 2days pre-eruption, during eruption, and 1day post-eruption shows clear increases of some particulate matter PM10, PM2.5 and carbon monoxide which might have resulted to eruption of this Nyiragongo volcano. But the effect appears as if the change lasted few days for particulate matter while carbon monoxide persisted whole of the month [15].

Table 4:WHO 2021 Air quality guideline levels compared to 2005 air quality guideline

Pollutant/ $\mu g/m^3$	**Average time**	**2005 AQG**	**2021AQG**
$PM_{2.5}$	**annual**	**10**	**5**
	24 hours	**25**	**15**
PM_{10}	**Annual**	**20**	**15**
	24 hours	**50**	**45**
O3	**Peak season**	**-**	**60**
	8 hours	**100**	**100**
NO2	**Annual**	**40**	**10**
	24 hours	**-**	**25**
$S0_2$	**24 hours**	**20**	**40**
Co	**24 hours**	**-**	**4**

When we compare results of these table with the results of our study area, we can see that the air quality of north western part of Rwanda is at threshold of warning, the air is not standardized that we can avoid long exposure for outdoor activities

4.4 Discussion

The study is aiming at assessing the impact of Nyiragongo volcano eruption on air quality of north western part of Rwanda as we know emission from volcano may change our atmosphere in air constituents as it emits volcanic ash and magma containing some impurities which may warm the air we talk of Sulphur dioxide which may lead to acidic rain, carbon dioxide, and nitrogen dioxide as air pollutant that may rise from volcanic activities as reported in [15]

The concentration of air pollution in Rubavu is likely to be significantly impacted by cross-boundary pollution from the nearby city of Goma, which is situated right next to Gisenyi on the border with the DRC and is known for its very poor air quality. In addition, the poor air quality is also influenced by natural sources, such as the active volcano on Mount Nyiragongo [15]. However, the study showed that the higher altitude of Rubavu cannot be considered a significant factor affecting the existing ambient air quality standards to a concerning extent [8]. From what we have seen as results of this study. we can say the poor air quality of north western part of Rwanda(Rubavu) is not linked to the recent eruption of Nyiragongo Volcano because Rubavu have been experiencing poor air quality even before volcano eruption [2],[12]. Therefore, it can be concluded that the poor air quality is primarily linked to human activities, vehicle emissions, and proximity to Goma city, which is known for its unstable air quality [13].

Chapter 5.CONCLUSION AND RECOMMENDATION

5.1 conclusion

We sum up by giving some recommendation to the policy maker of Rubavu district to adapt targets to guiding measure towards achievement of reduction of air pollutants releasing like reformulating air quality standards measure, to impose rule and regulations on importing vehicles , to set out strategies aiming at reducing emissions from bus lifespan, [16]. to imitate public transport policy systems, to eradicate clear change in use of domestic stoves by providing improved one, to deploy use of renewable energy related as source of generation of energy and to filter manner used in movements across Goma city [18].

5.2 Recommendation

I recommend REMA to increase stations by which data availability will favorize researchers and stakeholders engagement.

I recommend the government to establish national air quality monitoring network server and platforms for Kigali city and its subsidiary cities, that will be the best way of setting ground rules for indoor and outdoor activities and maintain them with data archivism. This will enable the collection of additional information and help identify the sources of poor air quality. It is recommended that REMA monitor changes in air quality over time and evaluate the effectiveness of future strategic measures.

I recommend that policymakers establish cross-departmental air quality monitoring workshops to develop and implement sustainable measures for addressing urgent air quality issues.

I also recommend REMA to Improve data availability if possible at sector level for analyzing norms of air quality for whole country

Additionally, the establishment of air quality monitoring sites with fixed stations is recommended to regularly monitor both ambient and indoor air quality.

Government is recommended to introduce department and school in secondary school even in higher education institution in order to increase number of specialist in air quality monitoring related field.

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APPENDIX

Table1 showing Data collected from Bugeshi station of Study area

Date	CO	O3	NO2	PM10	SO2	PM25
2020-06-22 11:00:00	294.1611	23.66222	10.02111	53.16	14.82556	43.57667
2020-06-22 12:00:00	296.25	22.78	13.14	55.36	15.12	44.84
2021-01-04 17:00:00	416.1471	24.73714	18.45893	70.76964	9.019286	57.72143
2021-01-04 18:00:00	295.9238	17.79375	15.21125	71.52125	14.25875	62.84625
2021-01-05 15:00:00	456.19	17.15	12.965	49.48833	11.79833	38.71333
2021-01-05 16:00:00	354.1425	18.46375	13.865	60.385	13.28813	48.12625
2021-01-05 17:00:00	430.2127	27.26636	16.26773	73.40273	5.598182	61.26273
2021-01-05 18:00:00	459.1748	19.69	16.78304	108.2183	11.96913	97.9187
2021-01-05 19:00:00	650.4614	13.74455	15.85591	190.6373	22.03409	177.0645
2021-01-05 20:00:00	707.423	14.55391	13.76652	196.5348	23.6313	181.5726
2021-01-05 21:00:00	478.6218	16.82591	11.74636	116.6827	14.24227	105.8095
2021-01-05 22:00:00	358.1495	17.72773	11.19636	81.80091	10.35545	70.03318
2021-01-05 23:00:00	296.5022	16.92652	10.41478	88.45739	10.13739	73.92739
2021-01-06 00:00:00	269.5843	18.84391	11.73478	84.51087	9.25	71.65957
2021-01-06 01:00:00	290.0482	20.22273	13.38227	76.66727	8.024545	64.96091
2021-01-06 02:00:00	277.1326	18.55739	10.75957	74.10435	8.748696	61.72739
2021-01-06 03:00:00	253.4827	21.16136	10.24409	73.07227	5.310455	60.33773
2021-01-06 04:00:00	248.4596	20.61696	9.443478	65.88174	6.683043	51.85304
2021-01-06 05:00:00	284.4687	19.59043	11.67174	73.51478	7.669565	60.57739
2021-01-06 06:00:00	289.3523	17.015	11.18318	75.24455	9.125909	62.575
2021-01-06 07:00:00	314.8648	21.24087	12.50696	75.46609	8.852609	63.35435
2021-01-06 08:00:00	299.0126	24.27217	6.17087	65.49826	8.730435	51.01348
2021-01-06 09:00:00	333.7773	26.98136	6.136818	68.57864	6.885909	53.98591

Table 2 Showing data collected from Lake Kivu Rubavu Station of Study area

	CO	O3	NO2	PM10	SO2	PM25
2021-02-15 11:00:00	402.04	11.68667	5.29	54.66667	27.10833	44.11
2021-03-04 18:00:00	514.2384	27.28568	17.63108	50.43784	17.41027	41.73865
2021-03-04 19:00:00	767.1004	21.70532	23.10957	72.02447	25.9034	63.46638
2021-03-04 20:00:00	911.6247	14.48956	20.50289	114.24	33.33267	106.6931
2021-03-04 21:00:00	883.5113	15.08489	15.99333	104.072	32.77378	97.068
2021-03-04 22:00:00	719.4887	14.88936	14.93872	84.01043	28.80447	78.68638
2021-03-04 23:00:00	586.1824	17.3578	15.1612	65.1668	22.3994	54.1126
2021-03-05 00:00:00	479.552	18.52959	13.32143	50.63796	16.84939	41.97388
2021-03-05 01:00:00	468.0933	18.29776	12.24633	50.30816	17.86367	41.64388
2021-03-05 02:00:00	454.9388	16.9674	16.5514	49.2366	17.2792	40.6982
2021-03-05 03:00:00	483.7646	15.6475	14.15958	56.1425	17.58792	45.7725
2021-03-05 04:00:00	477.7727	16.00588	15.32	54.00588	17.01039	44.27667
2021-03-05 05:00:00	453.5467	14.78846	13.02865	53.18962	16.02481	43.51192
2021-03-05 06:00:00	501.306	12.33938	14.3725	58.87	18.605	47.50167
2021-03-05 07:00:00	475.1422	13.1951	12.78569	56.24647	17.77098	45.7451
2021-03-05 08:00:00	490.2039	15.14939	7.447347	59.67408	17.36714	48.17306
2021-03-05 09:00:00	492.7798	21.61583	0.208333	64.19438	16.30979	52.3125
2021-03-05 10:00:00	570.3504	31.25391	3.097826	68.99087	16.72565	57.35304
2021-03-05 11:00:00	545.1711	29.06277	6.334255	64.69766	17.74447	52.06681
2021-03-05 12:00:00	553.2645	31.30213	9.578298	61.37362	17.41191	49.64915
2021-03-05 13:00:00	505.6649	30.07222	6.169778	55.72844	16.49044	45.63222
2021-03-05 14:00:00	476.9648	28.10739	4.652174	43.45739	15.42196	37.00152