Volcanic Ash as a precursor for SARS-CoV-2 infection among susceptible populations in Ecuador: A satellite Imaging and excess mortality-based analysis

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Abstract
The global COVID-19 pandemic has altered entire nations and their health systems. The greatest impact of the pandemic has been seen among vulnerable populations such as those with comorbidities like heart diseases, kidney failure, obesity or those with worst health determinants like unemployment and poverty. In the current study, we are proposing previous exposure to fine-grained volcanic ashes as a risk factor for developing COVID-19. Based on several previous studies it has been known since the mid-eight-tees of the last century that volcanic ash is most likely an accelerating factor to suffer from different types of cancer including lung or thyroid cancer. Our study postulates, that people who are most likely to be infected during a SARS-CoV-2 widespread wave will be those with comorbidities that are related to previous exposure to volcanic ashes. We have explored 8,703 satellite images from the last 21 years of available data from the NOAA database and correlated them with the data from the national institute of health statistics in Ecuador. Additionally, we provide more realistic numbers of fatalities due to the virus based on excess mortality data of 2020-2021, when compared to previous years. This study would be a very first of its kind combining social and spatial distribution of COVID-19 infections and volcanic ash distribution. The results and implications of our study will also help countries to identify such aforementioned vulnerable parts of the society, if the given geodynamic and volcanic settings are similar.

Keywords: Covid-19, volcanic ash, pulmonary and thyroid vulnerability, spatial spreading wave of infection, excess mortality.
Introduction
The COVID-19 pandemic has rapidly expanded around the globe. Latest figures from February, 2021 show that more than 111 million cases and more than 2.5 millions deaths have been officially reported worldwide (John Hopkins Coronavirus Research Center, 2021; Worldometer, 2021). Infections have been detected in every human group, affecting men and women from all ages, being more lethal for elderly people and those with previous health conditions such as cardiac problems, diabetes, obesity and other pre-conditions (Adams et al., 2020). Based on the worldwide reported cases of all countries, Current evidence indicates that the primary mode of transmission of COVID-19 is through direct contact through respiratory droplets that can be projected at varying distances, COVID-19 begins to be distributed mainly by contacts of one person to another by aerosols, and potentially by touching contaminated surfaces (i.e., fomites) (Ong et al., 2020). This infection travels by air, forming droplets with an estimated diameter of 5 to 10 micrometers (µm), and also through droplet nuclei, whose diameter is less than 5 µm (OMS, 2014; Smieszek, 2019). As larger droplets are pulled to the ground rapidly by gravity, transmission of the droplets requires close physical proximity between infected and susceptible individuals, whereas aerosol transmission can occur over greater distances and does not necessarily require that individuals infected as well as susceptible ones are in the same place in the same environment and places like hospitals.

Studies have demonstrated that respiratory droplets can be projected up to two meters (Schneider et al., 2016). In one study, droplets were found on the floor up to four meters from a patient (Guo et al., 2020). A systematic review of studies evaluating the horizontal distance traveled by respiratory droplets found that droplets could travel over two meters and up to eight meters (Bahl et al., 2020). Environmental exposures, such as sunlight, can have significant effects on the viability of SARS-CoV-2. In a rotating drum experiment similar to other studies on the viability of SARS-CoV-2, simulated sunlight (UVA / UVB) was applied to an aerosolized virus through a window of the drum. Results indicated that 90% of viruses are inactivated within twenty minutes in indoor settings, which poses a higher risk of transmission (Schuit et al., 2020).

Epidemiological studies on the transmission of COVID-19 to thousands of secondary contacts in households have determined infection rates ranging from 7 to 23%. For close contacts outside the household, secondary infection rates are less than 1%. (Bi et al., 2020; Cheng HY et al., 2020; Wang Y et al., 2020). The transmission limited to contact outside the household suggests
that the mode of transmission of COVID19 is not by air. The reproduction rate (R0) is less suggestive of airborne spread, since airborne infections tend to have a higher R0. For example, in a systematic review (Guerra et al., 2017), The R0 for measles before vaccination was 6.1 to 27.0, compared to the range of R0 (2 to 3) reported for COVID-19 (Park et al. 2020).

In Ecuador, the official patient zero of COVID-19 appeared in February 2020 and created a first hotspot and a rapid contamination of a high amount of people with corresponding high death rate in Guayaquil and the corresponding province of Guayas, due to a variety of social and political circumstances. Since, the mortality rate raised initially in end of March dramatically, although a strict lockdown was imposed by the governmental authorities on March 16. Due to the difficult economic situation even prior the declaration of the Pandemic, due to a low oil price, fatal policies as well as consequences of a variety of past natural disasters, a stepwise revocation of the lockdown on May 4, allowed local migration and business activities, which inflated once again the virus-spreading situations in urban and rural areas (Anderson, 2016; Jin et al., 2016; Toulkeridis et al., 2017; Wolff, 2018; Hidrobo, 2019; Schodt, 2019; REF). Therefore, Ecuador has had officially the highest death rate by far in South America when compared to deaths per million citizens up to end of June 2020. Additionally, the number of some 6,000 fatalities representing around 370 deaths per million citizens, may be most likely much worse, as various media reported of a surplus of 25 thousands fatalities for the same period of time (March-August 2020) (New York Times, 2020; Heuveline & Tzen, 2020; Sornette et al., 2020; Cepaluni et al., 2020; El Comercio, 2020). This would result for about 1765 deaths per million citizens, having to be unofficially the highest rate worldwide for that period of time. Since, the death pole continued, but not in the same acceleration as previously to spring-summer of 2020 (Table 1; John Hopkins Coronavirus Research Center, 2021; Worldometer, 2021; Instituto Nacional de Estadistica y Censo, 2021).

Therefore, by such circumstances given by the mortality rate in Ecuador, the calculated contagion amount is much higher than the official numbers realized by the national Ministry of health. If the excess mortality has reached more than 45 thousand citizens for the period between March 2020 and March 2021, while the official mortality by COVID-19 has been slightly less than 17 thousand by end of March 2021, than we assume that the contagion is also much higher than the officially stated around 310 thousands for the same period of time. When taking into account that in all official worldwide statistics, there has been a contagion / mortality rate of
2.18%, then the calculated amount of contagion persons in Ecuador will be of at least 2,228 million citizens by the end of March 2021. This corresponds more than 12.4% of the total population of the country. Additionally, based on these calculations of the excess mortality, the deaths per 1 million citizens would reach a rate of about 2720, being hereby slightly lower than the top country Gibraltar in this official statistic with a rate of 2791 (Fig. 1; John Hopkins Coronavirus Research Center, 2021; Worldometer, 2021). Based on such calculations and the aforementioned circumstances of different ways of contagion, it's a matter of simple arithmetic prior to a nationwide successful vaccination, to preview, that the health of the entire country’s population will be compromised in a variety of degrees.

Taken the aforementioned into consideration, it is of the outermost priority to establish which parts of the general population may be most certain affected and hereby strongly confronted by a potential infection by COVID-19. Generally, as demonstrated statistically by a variety of studies, persons who most likely got infected with this virus have been having previous health conditions, such as those with cardiac or diabetic issues, pulmonary weaknesses, obese persons, smokers and elderly persons. Among people with several other similar fragilities or debilities, having in respect to COVID-19 a higher infection and death rate, will be those parts of the population who will need to be in the first priority to be protected based on their high vulnerability.

One of the most underestimated respirable natural hazards is the emission of volcanoclastic material in form of fine-grained volcanic ash. While the precipitation of such material does not necessarily lead to direct death, except it occurs in masses causing asphyxiation or to physical damage due to roof collapse (Cronin et al., 2014; Jenkins et al., 2015; Bourne et al., 2016). Volcanic ash is known to provoke severe pulmonary problems like bronchitis and asthma and usually minor health issues such as ocular, nasal, throat and skin irritation (Beck et al., 1981; Yano et al., 1986; Buist et al., 1986; Baxter et al., 1983; Kraemer & McCarthy, 1985; Yano et al., 1990; Gudmundsson, 2011). Besides pulmonary issues, it has been evidenced that the emission of volcanic ash generates a higher rate of thyroid cancer (Arnbjörnsson et al., 1986; Buist, 1988; Russo et al., 2015). In this respect, compared to other countries around the planet in general and those with volcanic activity in particular, Ecuador, which has a strong volcanic activity in its territory, indicated to have worldwide highest rate of thyroid cancer (Fig. 2; Sierra
et al., 2016; Salazar-Vega et al., 2019). This evidences that the presence of volcanic ash leads to a variety of pulmonary and thyroid weaknesses and are prone to a higher than regular vulnerability towards COVID-19 infections.

Consequently, the current study will allow a new focus on the projection of so far unknown weaknesses of a great part of the Ecuadorian population who lives in areas, which are susceptible to COVID-19, as there an essential part of the population who has been diagnosed with or highly vulnerable to thyroid cancer, a disease which is related to chronic respiratory diseases, which itself is most likely related to the function of the precipitation of volcanic ash. Therefore, we will diagnose areas and the corresponding living population within, which are highly exposed to the emissions and fall-out of fine-grained volcanic material and therefore also being more likely to be susceptible and preferably to be affected by the Sars COV-2 virus. Once such areas may be detected, then more detailed and specific preventive measures should be implemented within a particular epidemiological monitoring.

**Results and discussion**

**a) Worldwide evolution of COVID-19**

The SARS-CoV-2 causing COVID-19 has reached pandemic levels since March 2020 (Cucinotta D, 2020). In the absence of vaccines or curative medical treatment, COVID-19 exerts a huge global impact on public health and health care delivery. SARS-CoV-2 not only causes viral pneumonia but has major implications for the cardiovascular CV system (Zheng, 2020). Patients with CV risk factors including male sex, advanced age, diabetes, hypertension and obesity as well as patients with established CV and cerebrovascular disease have been identified as particularly vulnerable populations with increased morbidity and mortality when suffering from COVID-19 (Driggin, 2020).

Viral respiratory infections represent a very significant part of the morbidity observed in the patient and remain the main cause of death from infectious origin. It remains a major source of global pandemics due to rapid human-to-human transmission through the respiratory tract (Lina et al., 2016). The myocardial damage via the receptor for the angiotensin 2 converting enzyme (ACE2), which cardiomyocytes express in a significant way. This could be the cause of true myocarditis; According to Ruan et al. (2020), the SARS-CoV viral RNA was detected in 35% of
human hearts autopsied during the SARS epidemic. This shows that SARS-CoV can cause ACE2-dependent myocardial infarction.

Angiotensin-converting enzyme 2 (ACE2) is an enzyme of the Renin Angiotensin System RAS that is expressed on the cell surface of many tissues including brain, heart, kidney and type 2 alveolar epithelial cells in the lungs. It is defined as the receptor for the SARS-CoV-2 spike protein, and affect to host cells, however, the affinity of SARS-CoV-2 for ACE2 is 10–20-fold higher than that of SARS-CoV, and induce a high transmissibility (Hoffmann et al., 2020).

ACE2 converts angiotensin II (Ang II) into Ang-(1–7), that lowers blood pressure with vasodilation and by promoting kidney sodium and water excretion (South, et al, 2019), ACE2 shares approximately 60% homology with ACE. ACE converts Ang I into Ang II, which acts at the type 1 angiotensin receptor (AT1R) by increasing blood pressure and inducing vasoconstriction, increasing kidney reabsorption of sodium and water, and increasing oxidative stress to promote inflammation and fibrosis (Sparks et al., 2014).

Although clinical manifestations are dominated by respiratory symptoms up to ARDS (acute respiratory distress syndrome), the virus has a double cardiovascular impact: on the one hand, the infection will be more intense if the host has comorbidities cardiovascular disease and, on the other hand, the virus can by itself cause life-threatening cardiovascular damage. Several data had shown that MERS-CoV could be the cause of acute myocarditis (Alhogbani, 2016). Data obtained from patients infected with SARS-CoV and monitored over a 12-year period argue in favor of a deregulation of lipid metabolism induced by the virus, which could be at the origin of an increase in events long-term cardiovascular disease in survivors without the mechanism being identified at this time (Wu et al., 2017).

People with diabetes have impaired immune-response to infection both in relation to cytokine profile and to changes in immune-responses including T-cell and macrophage activation (Ferlita et al., 2019), and are at increased risk of infections including influenza and for related complications such as secondary bacterial pneumonia, many patients with diabetes can be in poor metabolic control when infected by COVID-19. Poor glycaemic control impairs many aspects of the immune response to viral infection that lead to infection in the lungs (Critchley et al., 2018). In most cases diabetes is associated with obesity that is a risk factor for severe
infection (Huttunen and Syrjänen, 2010). During the influenza A H1N1 epidemic in 2009, the disease was more critical and had a twofold duration in the patients with obesity who were then treated in intensive care units compared with the background population (Honse and Schultz-Cherry, 2019). People with obesity also have mechanical respiratory problems, with reduced ventilation of the basal lung sections increasing the risk of pneumonia as well as reduced oxygen saturation of blood (Dixon and Peters, 2018).

Diabetic complications like ischaemic heart disease and diabetic kidney disease may complicate the situation for people with diabetes, making an increase of the severity of COVID-19 disease and the need for special care such as acute dialysis. Some studies show that COVID-19 could induce acute cardiac injury with heart failure, leading to deterioration of systemic circulation (Li et al., 2020).

Furthermore, inflammation plays a critical role in the progression of crystal-caused disease and can be seen in patients with particle-induced lung disease (Mossman, 2013). A study from (Dostert, 2008) have shown that exogenous particles such as asbestos (asbestosis) or crystalline silica (silicosis), activate the NLRP3 inflammasome. The NLRP3 inflammasome detects crystalline warning signs that can occur during autoinflammatory diseases, and environmental diseases, such as silicosis or asbestosis (Hornung, 2008). IL-1 cytokines are potent mediators of innate immunity in response to exposure to crystalline silica (Driscoll, 2008) and have been implicated in the pathophysiology of human and experimental diseases (Huaux, 2007).

Damby demonstrates the propensity of volcanic cristobalite to activate the NLRP3 inflammasome, following a series of conclusive toxicological investigations of ash from recent major eruptions. The NLRP3 inflammasome has become a central mechanism in mediating cellular responses to various endogenous and exogenous signals and particles related to environmental and lifestyle diseases. Given the established danger posed by respirable crystalline silica in occupational settings, the ability of volcanic ash to stimulate the release of IL-1β by macrophages in vitro, and the observation that the instigation of chronic crystalline silica disease depends on NLRP3 (Damby, 2018, Mossman, 2008)

The researchers demonstrate that SARS-CoV-2 causes severe lung pathology by inducing pyroptosis (Yang, 2020), a highly inflammatory form of programmed cell death (Cookson,
This type of cell death is called piroptosis, which is carried out by macrophages and other immune cells of the immune system causing symptoms such as lymphopenia (Panesar, 1985) that blocks an effective immune response to the virus.

As the molecular biology of SARS-CoV-2 is still being studied, inflammatory mechanisms similar to SARS-CoV-1 are known. A viral protein encoded by ORF8b interacts directly with the inflamasome NLRP3 (leucine-rich repeat of the nucleotide binding domain (NLR) and receptor 3 containing the pyrin domain) (Shi, 2019), which activates the adapter protein ASC and caspases 4, 5 and 11. Simultaneously, it induces proinflammatory cytokines (eg IL-1β and IL-18) (Man, 2017). Therefore, it is necessary to inhibit pyroptosis by acting on NLRP3, in the lungs. The mechanisms of inhibition of NLRP3 have been studied (Zahid, 2019), and melatonin acts as an inflammasome inhibitor of NLRP3 (Ma, 2018). In the bacterial pneumonia model, LPS-induced mouse model, melatonin was shown to successfully inhibit pneumonia by interfering with the NLRP3 inflammasome, protecting macrophages from pyroptosis (Zhang, 2016). Other publications also demonstrate that melatonin can be an effective inhibitor of pyroptosis and associated pathologies (Wang, 2019).

Chong-Shan Shi, demonstrate that SARS-CoV can activate the NLRP3 inflammasome in macrophages through ORF8b. Although SARS-CoV abortively infects macrophages / monocytes, there may be enough ORF8b to affect the integrity of the lysosome, autophagy pathways, and NLRP3 inflammasomes. Unlike macrophages, SARS-CoV productively replicates in lung epithelial cells. These cells also express NLRP3 and can assemble NLRP3 inflammasomes. In humans infected with SARS-CoV, the full impact of ORF-8b on the pathways we delineated in this study is likely on the pulmonary epithelium. ORF8b may contribute to cytokine storm and inflammation activation that occurs during severe SARS-CoV infection (Chong-Shan, 2019). In the future, live virus clearance studies are required to assess the effects of ORF8b-mediated intracellular aggregates and ORF8b-mediated activation of NLRP3. However, here we identify novel mechanisms through which ORF8b can contribute to the pathogenesis of SARS.

In general, Sars CoV2 infection can be transmitted through respiratory droplets, which are 5-10 microns (µm) in diameter (OMS, 2014). According to the available data, the COVID-19 virus is...
transmitted mainly between people through contact and respiratory droplets (Liu et al., 2020), of a person with respiratory symptoms (e.g., cough or sneeze), due to the risk of mucous membranes (mouth and nose) or conjunctiva (eyes). In addition, transmission can occur through fomites droplets in the immediate environment of a person infected (Ng et al., 2020). Airborne transmission of the COVID-19 virus may be possible in specific circumstances and locations where procedures are performed or treatments that can generate aerosols such as: endotracheal intubation, bronchoscopy, open aspiration, administration of a drug by nebulization, manual ventilation before intubation. However, there has been some evidence that the COVID-19 virus can cause intestinal infection and be present in faeces (Zhang et al., 2020), although no fecal-oral transmission has been reported.

The measures to avoid a contagion is a correct hand washing with high frequency with soap and water or with an alcohol-based hand sanitizer of at least 70%. Keeping a distance of at least 2 meters (6 feet) between persons and on particular between those who cough, sneeze, and have a fever, while performing a disinfection of inanimate surfaces with disinfectants as often as possible.

The WHO has received reports that the existence of variants of SARS-CoV-2 and that these cause changes in transmissibility, clinical presentation and severity, or if there is an impact on the diagnosis, therapeutics and the protection of vaccines. Reports mentioning virus variants from the Kingdom of Denmark, the United Kingdom of Great Britain and Northern Ireland, and the Republic of South Africa have raised interest and concern about the impact of viral changes (Table 2).

These three variants share a specific mutation called D614G (Korber et al., 2020; Zhang et al., 2020). It provides the variants the ability to spread more rapidly than the prevailing viruses (Bin Zhou, 2020; Volzs, 2021). As of December 30, of 2020, variations have been reported in another 31 countries. Therefore, it is important that genomic surveillance be conducted in order to identify and characterize the variants of the virus and how these influence the severity of COVID-19 cases, while the efficacy of vaccines and treatments and this is still being evaluated by the scientific community (Hartley et al., 2020; Galloway et al., 2021; Quéromès et al., 2021).

b) Volcanism and the distribution of volcanic ash in Ecuador
Ecuador is a country with an extremely high density of volcanoes in its continental as well as insular territory (Toulkeridis, 2011; 2013; Toulkeridis and Angermeyer, 2019). The Galapagos archipelago as result of hot spot geodynamics possesses more than 3000 mostly extinct volcanoes, while the Ecuadorian mainland counts with more than 250 volcanoes due to the subduction of the Nazca plate below the South American continent (Toulkeridis, 2011; 2013). From the Galapagos, an aseismic ridge of extinct volcanoes called Carnegie, are transported above the oceanic Nazca Plate towards the continent, where its subduction gives rise to the NNE-SSW striking volcanic chains of Ecuador (Lonsdale, 1978; Pennington, 1981; Coltorti and Ollier, 2000). In both environments only a minor amount of the existing volcanoes are active, but their activity contemplates with a variety of volcanic hazards including the massive emission of fine-grained volcanic ash amongst other threats (Toulkeridis et al., 2007; Padrón et al., 2008; Ridolfi et al., 2008; Padrón et al., 2012; Toulkeridis et al., 2015; Toulkeridis, 2016; Vaca et al., 2016; Toulkeridis, T., & Zach, I. (2017; Rodriguez et al., 2017; Parra, 2019; Echegaray-Aveiga et al., 2019). In continental Ecuador there are 19 active volcanoes, of which five have been erupting in several occasions during the last 22 years (Smithsonian Institution Global Volcanism Program, 2021). These five erupting volcanoes have been Sangay, Tungurahua, Guagua Pichincha, Reventador and Cotopaxi (Fig. 3). Sangay has a permanent activity with higher intensities in 2004-2011, 2013 and 2016 as well as strong intensities in 2018-2021 (Global Volcanism Program, 2021a). Tungurahua erupted after 80 years of tranquility in 1999 and continued to be erupting with minor interruptions until 2016 (Global Volcanism Program, 2016a). Guagua Pichincha has been occasionally erupting between 1999-2001 and in 2009 (Global Volcanism Program, 2016b). Reventador volcano erupted after 1976 in 2002 and continued with major interruptions until 2021, while Cotopaxi has been very active only in 2015 (Global Volcanism Program, 2016c; 2021b). In all these periods, all five volcanoes have emitted fine-grained volcanic ash in a variety of amounts and reach (Vaca et al., 2016; Toulkeridis and Zach, 2017; Toulkeridis et al., 2020; Aviles-Campoverde et al., 2021). These eruptive phases were able to be observed from space due to the Satellite Imagery of the Satellite Services Division of the National Environmental Satellite, Data, and Information Service (NESDIS) since September 1999. Hereby, the distribution of the volcanic ash has been traced by the available data for the corresponding areas of Ecuador allowing to evaluate the fall-out areas by this volcanic hazard. Based on this, some 8703 satellite images have been evaluated between September 1999 and
January of 2021, which allowed to characterize the area of influence of the volcanic ash precipitation, being the origin of a high amount of previously described health vulnerabilities and damages or interruptions of strategic infrastructure (Toulkeridis and Zach, 2017; Aguilera et al., 2018; Echegaray-Aveiga et al., 2019; Toulkeridis et al., 2020).

Such fine-grained volcanic material has an amplified range in composition as well as in morphologies due to a variety of genetic processes during the rise of the magma and its subsequent fractionalization prior eruption (Eichelberger, 1995; Nemeth et al., 2003; Karbowska and Zembrzuski, 2016). We have taken samples in different, regular time periods of all active volcanoes of which some results have been published elsewhere (Toulkeridis et al., 2015; Vaca et al., 2016; Aguilera et al., 2018).

A field emission gun scanning electron microscope (FEG-SEM), brand TESCAN model MIRA3 was used to characterize all the samples. Chemical analysis was performed using EDX technique with a BRUKER detector XFlash 6130, resolution 123 eV for Mn alpha. This was done using a double adhesive layer of carbon tape on SEM stubs. To ensure conductivity of the samples, morphology analysis was done applying a gold coating of around 20 nanometers using a Sputter coater QUORUM Q150R. The main elements analyzed were Na, Mg, Al, Si, P, K, Ca, Ti, Mn, Fe. Other elements are detected but lower than limit detection. The compositions of ashes of Pichincha, Cotopaxi, Reventador, Sangay and Tungurahua volcanoes are listed in table 3. Elements as Ti, P and Mn have a % weight concentration lower than 1.5%.

All volcanic ashes have Si composition upper than 40\% wt, which is an aggressive element for human lungs. SEM pictures showed that ashes are quite inhomogeneous in their morphology. Size is quite dependent of the distance of the sampling and could be from some nanometers to millimeters. As an example, from last Cotopaxi explosion, size was from 10 nm to 300 um at 20km distance from the crater, and a mean size 113.5 um. Except of the Cotopaxi volcano, all other fine-grained pyroclastic material has been juvenile. The 101 days of expulsion in 2015 of volcanic ash of Cotopaxi volcano has been exclusively of reworked material due to the fact that it has been originated by hydrothermal processes (Toulkeridis et al., 2015; Vaca et al., 2016). Therefore, the reworked fine-grained pyroclastic material of Cotopaxi volcano was of angular to sub-angular morphologies, while the predominant material of Sangay, Reventador, Guagua Pichincha and Tungurahua volcanoes has been varied from rounded to sub-angular shapes.
The continental volcanoes of Ecuador are oriented perpendicular to the subduction zone along four NNE-SSW arcs, within the western volcanic cordillera, the Interandean Valley, the Cordillera Real and the Subandean Basin. The evaluation of the distribution of fine-grained volcanic material of the five active volcanoes has been based on 8979 satellite images (September 1999 – March 2021), indicate a preferred direction being mainly towards the western side of their location. Hereby, the predominant angle with above 60% of all possible directions of the ash distribution has been between 250 and 290 degrees (Fig. 3). All other directions occur as well, but obviously to a minor degree, of which the eastern directions are the very less of all. Volcanic ash precipitation in southern regions and cities such as Cuenca and Loja or coastal cities such as Guayaquil occur occasionally, but these are less frequented and therefore minorly affected areas (Fig. 4).

Not every contact with a corona infected person leads to an infection, while the risk of transmitting the virus or its mutants, or even become infected may vary on a variety of situations. However, the dominant factor is the dose of the virus and certainly the closeness and contact to an infected person (Ortiz-Prado et al., 2020). Therefore, it’s a simple matter of time when in an area like Ecuador with very little or almost none preventive measures an increasing number of persons will be infected the Corona virus and their mutants. During a second or even third infection wave, the most vulnerable persons will have less and less opportunities to be excluded of contagions. The risk is particularly high if measures to reduce or limit the outbreak have been given up way too early, due to countermeasures to avoid the increasing economic crisis like occurring in Ecuador (Adams-Prassl et al, 2020; Friedman et al. 2020). The progressing infections occur also to a variety of reasons, such as fatigue, social and economic backgrounds, fatal sense of security amongst many others. This phenomenon has been observed and documented worldwide (Dubey et al., 2020; Heitzman, 2020; Islam et al., 2020). Another fundamental aspect is based on the unsolved technical and economic issues in hospitals and their intensive care units, especially in Latin America. Such problems existed prior the pandemic, and has worsened since (Remuzzi and Remuzzi, 2020; Rello et al., 2020; Sasangohar et al., 2020).

Based on the aforementioned, a new aspect of worsening the situation of the public close to volcanic ash emissions may be compared to those reported of air contaminated areas, which also increase the vulnerability to the Corona virus (Wu et al., 2020; Bontempi, 2020; Urrutia-Pereira
et al., 2020). The most affected Ecuadorian public however, will be the persons who are living and working in the shadow of the ash fall out westwards of the main concentration of the active volcanoes, being within the Highlands, the Inter-Andean Valley and the coastal regions, as indicated in the current study (Fig. 3-5). For those persons, it is imminent to prevent to be more susceptible towards a contagion of Covid than people in areas with less contamination due to the absence of volcanic ash emissions.

**Conclusions**

SARS-CoV-2, which is transmitted in a variety of forms, is a deadly virus with a death rate of some 2.18% in respect to the infected amount of people. Ecuador has been so far the second strongest affected country worldwide by the global COVID-19 pandemic, when counting deaths per million citizens based on the calculated excess mortality rates.

The precipitation of volcanic ash is responsible for a variety of health issues, which particularly are able to affect pulmonary areas and thyroids, areas which are preferably infected by SARS-CoV-2 and the corresponding mutants. Based on the evaluation of the geospatial distribution of the fine-grained volcanic ash, the continuous spreading wave of the virus and its mutants will most likely affect vulnerable persons westwards of the active volcanoes, within the Highlands, the Inter-Andean Valley and the coastal regions of Ecuador. Therefore, based on this diagnosis and forecast, a variety of preventive measures need to be implemented in order to protect this specific group of the total population.
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Fig. 1. Comparison of official Covid Mortality (OCM) and excess mortality (EM) in Ecuador from February 2020 up to March 2021.
Fig. 2. Activation of the inflammatory protein complex in lung cells due to infection with the Sars Cov 2 virus and possible complications from inhalation of volcanic ash in lung cells and secretion of cytokines that cause inflammation.
Fig. 3: Main direction of volcanic ash distribution within a rose-diagram of the volcanoes Tungurahua (4412 satellite images), Reventador (2744), Sangay (1641), Cotopaxi (151) and Guagua Pichincha (31). All data are normalized to 100 per cent, for each evaluated volcano.
Fig. 4: Main direction and predominant reach of volcanic ashes (light grey colors) in Ecuador based on the activity of the volcanoes Tungurahua (TUN), Reventador (REV), Sangay (SAN), Cotopaxi (COT) and Guagua Pichincha (PIC), with the three most populated cities Quito (Q), Guayaquil (G) and Cuenca (C). Red triangles are further active volcanoes.
a) 13th of March 2020

b) 31th of March 2020

c) 30th of April 2020

d) 31th of May 2020
Fig. 5. The maps represent the monthly death rates per 100,000 inhabitants that have been standardized taking the official data of deaths published as of March 13th, and the population data taken from the projections to the year 2019-2021 made by the INEC, using data from the Census of Population and Housing in 2010. The lowest values of the mortality rate are represented in green and the highest in red, with yellow representing the average values according to the color code of the traffic light adopted by the Ecuadorian authorities.
Table 1. Mortality and excess mortality rates of Ecuador between 2018 and 2021 based on John Hopkins Coronavirus Research Center, 2021; Worldometer, 2021; Instituto Nacional de Estadística y Censo, 2021. Data of February and March correspond to 2020 and 2021

|       | 2018 | 2019 | 2020 | 2021 | Avg 2018-20 | Excess Mortality (EM) | Off. Covid Mortality (OCM) | □ EM and OCM (DEO) |
|-------|------|------|------|------|-------------|-----------------------|----------------------------|---------------------|
| January | 6696 | 6706 | 6699 | 8454 | 6700,3      | 1753,7                | 813                        | 940,7               |
| February | 5751 | 5930 | 6057 | 7652 | 5840,5      | 216,5                 | 0                          | 216,5               |
| March   | 6057 | 6570 | 10030| 10241| 6313,5      | 3716,5                | 116                        | 3600,5              |
| April   | 5778 | 6159 | 20977|      | 5968,5      | 15008,5               | 1180                       | 13828,5             |
| May     | 5883 | 5960 | 10111|      | 5921,5      | 4189,5                | 3847                       | 342,5               |
| June    | 5758 | 5891 | 8997 |      | 5824,5      | 3172,5                | 1828                       | 1344,5              |
| July    | 5977 | 6078 | 10845|      | 6027,5      | 4817,5                | 1835                       | 2982,5              |
| August  | 6104 | 6245 | 10055|      | 6174,5      | 3880,5                | 1327                       | 2553,5              |
| September | 5814 | 6194 | 7991 |      | 6004,0      | 1987,0                | 1105                       | 882,0               |
| October | 5938 | 5976 | 7557 |      | 5957,0      | 1600,0                | 1312                       | 288,0               |
| November | 5799 | 6010 | 7321 |      | 5904,5      | 1416,5                | 783                        | 633,5               |
| December | 6427 | 5712 | 7137 |      | 6069,5      | 1067,5                | 565                        | 502,5               |
| Total   | 71982| 73431| 13777|      | 48565,2     | 16680                 | 31885,2                    |                     |
Table 2: Variants of the Sars Cov 2 virus

| Detection       | Name       | Mutations                      | Date   | Transmisibility |
|-----------------|------------|--------------------------------|--------|-----------------|
| United Kingdom  | B.1.1.7    | 69/70; 144Y; N501Y; A570D;D614G; P681H | 14 Dec 2020 | 50%             |
| South Africa    | B.1.351    | K417N; E484K; N501Y; D614G      | Oct 2020 | 50%             |
| Japan / Brazil  | P.1        | E484K; K417N/T; N501Y; D614G    | Jan 2021 | 50%             |
| California      | B.1.427/B.1.429 | S13I, W152C and L452R           | Feb 2021 | 20%             |
Table 3. Average weight percentages of each analyzed element in wt %, of all ash samples of the studied active volcanoes (Mn<1%, Ti y P<1.5%)

|        | Si    | Al    | Ca    | Fe    | Na    | Mg    | K     | S     |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Pichincha | 47.16 | 17.71 | 8.74  | 9.35  | 5.12  | 2.44  | 5.16  | 1.58  |
| Cotopaxi    | 41.56 | 20.30 | 13.43 | 9.28  | 5.35  | 1.78  | 2.76  | 3.25  |
| Tungurahua  | 45.09 | 17.20 | 10.92 | 10.65 | 4.91  | 2.37  | 4.35  | 1.45  |
| Reventador  | 44.30 | 16.78 | 10.95 | 10.25 | 4.83  | 1.98  | 5.46  | 2.89  |
| Sangay      | 41.06 | 16.67 | 14.20 | 8.64  | 6.03  | 2.77  | 3.90  | 2.58  |