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PHYSICAL AND CHEMICAL CHARACTERIZATION OF VOLCANIC ASH FROM MT. MAYON, MT. PINATUBO, AND TAAL VOLCANO

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Abstract

The recent rise in volcanic activity in Mt. Mayon has put surrounding areas on high alert after the Philippine Institute of Volcanology and Seismology put the active volcano on Alert Level 3. The Department of Health warned that one of the biggest health hazards posed by a volcanic eruption was the numerous respiratory illnesses that ash spewed by an eruption would cause. To break down the possible health hazards posed by the ashes of Philippine volcanoes, samples from Mt. Mayon, Mt. Pinatubo, and Taal Volcano had their chemical composition, particle sizes, morphology, brittleness, and weight measured and compared using Scanning Electron Microscope, Energy Dispersive Spectroscopy, Attenuated Total Reflectance - Fourier Transform Infrared Spectroscopy, brittleness, and sedimentation tests. All three ash samples had similar chemical compositions that were rich in carbon, oxygen, and silicon which could pose numerous adverse effects to respiratory health. They were also observed to feature many particles that measured less than 40 μm; the three samples were also observed to have varying weights with Mt. Pinatubo being the lightest, followed by Mt. Mayon and Taal Volcano which similarly implies high respiratory health risk due to their ability to stay and spread in the air for long periods of time and penetrate deep into the human body. Despite the variation in physical and chemical properties of volcanic ashes from different volcanoes, all three ashes possess relatively similar properties and health risks which suggests that similar ash-safety protocols could be applied.

Keywords: Ash, Volcano, Mayon, Pinatubo, Taal.

Introduction

The Philippines' location inside the Pacific Ring of Fire makes it more prone to volcanic activity than most nations. There are over 24 active volcanoes in the Philippines, most of which are located on the island of Luzon (PHIVOLCS, n.d.). This has caused the Philippines to have a more active history of volcanic eruptions compared to other countries, and history appeared to repeat itself as new came of increased volcanic activity in Mayon Volcano in 2023. Mayon Volcano was flagged under Alert Level 3 by the Philippine Institute of Volcanology and Seismology (PHIVOLCS). Three years earlier in 2020, the Taal Volcano underwent a full-scale eruption.

The general objective of this research experiment is to analyze the physical and chemical characteristics of Philippine volcanic ashes and explore their potential health risks, primarily those originating from Mt. Mayon, Mt. Pinatubo, and Taal Volcano in the Philippines. These three volcanoes pose health risks that are dangerous to humans either by short-term or long-term effects (Aquila et al., 2021; Prasetyo et al., 2021; Martinez-Villegas et al., 2021). The research studied their physical and chemical characteristics using a scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS). An Attenuated Total Reflectance - Fourier Transform Infrared Spectroscopy (ATR-FTIR) was used to identify the substances that were present in the volcanic ash samples. A brittleness and sedimentation tests were conducted to further test the physical properties of each ash sample.

Theoretical Framework

According to the Volcanic Ashfall Impacts Working Group, the physical and chemical properties of volcanic ash could alter the nature and severity of its health effects on humans. Finer particles could potentially penetrate deeper into the human body and block vital airways or damage the lungs, and various chemicals like silica could cause diseases

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like silicosis when entering the body through the inhaling of volcanic ash. These claims are supported by research that found that ash particle sizes could determine an ash's health risk due to volcanic ash risk (Butwin et al., 2020) and that certain metal salts

in the ash could cause them to contaminate surfaces and substances they land on (Wygel et al., 2019).

The findings are the guiding principles of the study as they establish volcanic ash produced by volcanoes as a potential health hazard to humans and that physical and chemical characteristics could affect how much of a hazard it is to humans. However, these characteristics vary widely from volcano to volcano according to the data for the ash of each volcano is different, with each volcano containing distinctive elemental compositions and particle sizes (Dürig et al., 2012; Soto, 2018).

Conceptual Framework

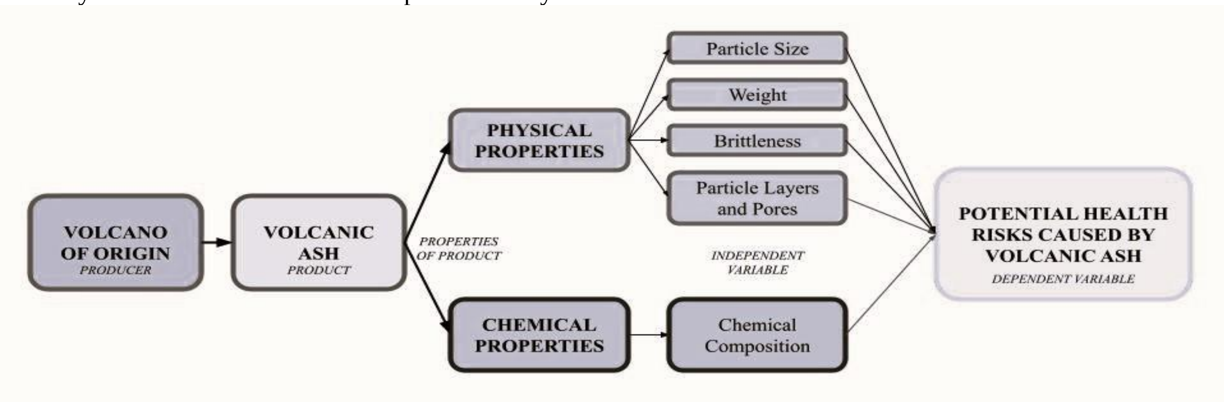

Figure 1: Conceptual Framework of the Study

Statement of the Problem

The presence of active volcanoes in the Philippines leaves many Filipinos exposed to the dangers of volcanic ash to the respiratory system. The Department of Health warns that the ash spewed by a possible eruption of Mayon poses several health risks such as coughing, bronchitis-like symptoms, and eye irritation, among others (Sarao, 2023).

Despite this, few studies explore and compare the physical and chemical properties of volcanic ash from various volcanoes in the Philippines. This presents the opportunity for a study that compiles the physical and chemical properties of volcanic ash from Filipino volcanoes and compares their properties to establish their potential health risks.

Methodology

Research Design

This study will use quantitative data-gathering methods to analyze and compare the various volcanic ash samples. Quantitative data aims to provide more numerical information about the ash such as the concentrations of chemicals in each sample, the sizes of particles, as well as the shape of its particles and morphology.

Materials

The ash samples analyzed were collected from Taal Volcano, Mayon Volcano, and Mt. Pinatubo. The Taal Volcano ash sample used in this study was scooped inside a glass jar a day after the eruption last January 12, 2020. The ash sample from the Mayon volcano was collected last June 2018 in Cagsawa ruins. The estimated distance from the point of collection to the volcano is 28.36 km. The dust was scraped and then put inside the jar as the Cagsawa Ruins were also one of the affected businesses of this volcanic eruption. Lastly, the ash sample from Mt. Pinatubo was collected during the eruption last June 1991. The sample was collected from a roof 125.55 km away from the volcano and funneled into a jar.

Table 1: Details of the Location, Date, and Collection Method of the Ash Samples from Mt. Mayon, Mt. Pinatubo, and Taal Volcano

Ash Sample	Location	Collection Date	Collection Method
Mt. Mayon	28.36 km from the volcano	Jun. 2018	Scraped inside a jar
Mt. Pinatubo	125.55 km from the volcano	Jun. 1991	Funneled into a jar
Taal Volcano	26.38 km from the volcano	Jan. 2020	Scooped inside a glass jar

SEM-EDS Analysis

One of the laboratory equipment used in this study is the Jeol JSM-IT500HR Scanning Electron Microscope. SEM is a kind of electron microscope used for directly inspecting solid object surfaces, and Energy Dispersive Spectroscopy (EDS), is the analytical technique used to characterize materials analytically or chemically (Colpan, 2022). SEM regularly scans a beam of focused electrons over the specimen (Joy, 2022). The much shorter wavelengths of electrons improve the resolution.

Before submitting to the SEM, the samples were filtered through a 100 mesh 0.15 mm sieve to ensure a more uniform particle size. The sieve used in this experiment was borrowed from the Biology Laboratory in the Milagros del Rosario Bldg.

Average Particle Size Measurement

Three different comparisons of ash particles were performed: small, average, and large which recorded the smallest, medium, and largest particle sizes in images produced by the SEM-EDS. They were then compared to one another to determine which Philippine volcano has the largest particle size. ImageJ was used to precisely measure the size of the particles given that all images are within the 100 µm range. This comparison was done in order to determine the dangerous particle size that could lead to different respiratory diseases.

1. **ATR-FTIR analysis**

ATR-FTIR (Attenuated Total Reflectance - Fourier Transform Infrared Spectroscopy) can be used to determine functional groups in molecules by measuring the infrared radiation's absorption throughout a spectrum of wavelengths (Smith, 2011). All three sieved ash samples were processed using Agilent Cary 630 FTIR. Its versatility allows for flexible sampling for the analysis of solids, liquids, powders, and gasses. This procedure was conducted to maximize the number of tests that could be performed on the ash sample. Moreover, this procedure utilizes the addition of the ATR (Attenuated total reflectance) technique which enables samples to be seen immediately in either a solid or liquid state, without further preparation (Hinton-Sheley, 2012).

2. **Sedimentation**

The process of allowing particles suspended in water to separate under the influence of gravity is known as sedimentation. Each unsieved ash sample is weighed to 2.00 g and added to 20 mL of distilled water in a graduated cylinder. Photos were taken in 0 hr, 1 hr, 3 hr, and 24 hr to monitor the samples and to analyze the significant changes.

3. **Brittleness test**

To assess a material's mechanical behavior, particularly its resistance to failure or fracture when subjected to external forces, brittleness tests are carried out. To ascertain how brittle the volcanic ash samples are, the brittleness test was utilized. Each sample was measured at 4.25 g and metal weights were 100 g.

Scope and Delimitation

This research aimed to characterize the different volcanic ash found in the Philippines, focusing on Mt. Mayon, Mt. Pinatubo, and Taal Volcano ash using the SEM, EDS, and ATR-FTIR from the Central Instrumentation Facility (CIF) and laboratory equipment provided by De La Salle University Laguna Campus.

The test and experimentation for the ash samples were done during the months of January - July 2023, the length of 2 terms of the academic year 2022-2023. The research was done at the De La Salle University Integrated School - Laguna Campus using equipment from the campus's Central Instrumentation Facility.

Results and Discussion

SEM

SEM results feature two different prominent results: Its shape, which is presented using figure 2, and its size, which is presented using Table 2. Both of these results aim to present different key functions to characterize the different volcanic ash and differentiate them accordingly.

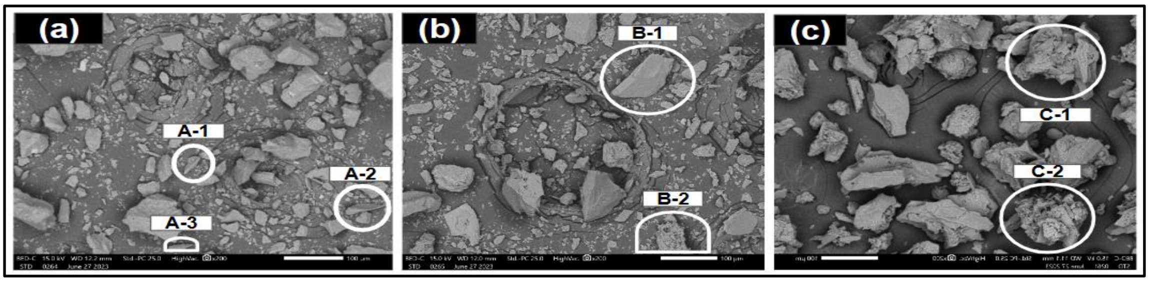

Figure 2: SEM Images and Sharp Particles of Mt. Mayon (2a), Mt. Pinatubo (2b), and Taal (2c) Volcanic Ash

In figure 2A, Mt. Mayon ash is characterized as a non-uniform, irregular polygonal-shaped particle with varied sizes. Mt. Pinatubo ash, on the other hand, is non-uniform, irregularly shaped polygonal but porous in size. Lastly, Taal Volcano ash is slightly porous with a rough surface and globular shape. Figure 3 below zooms in on the particles described.

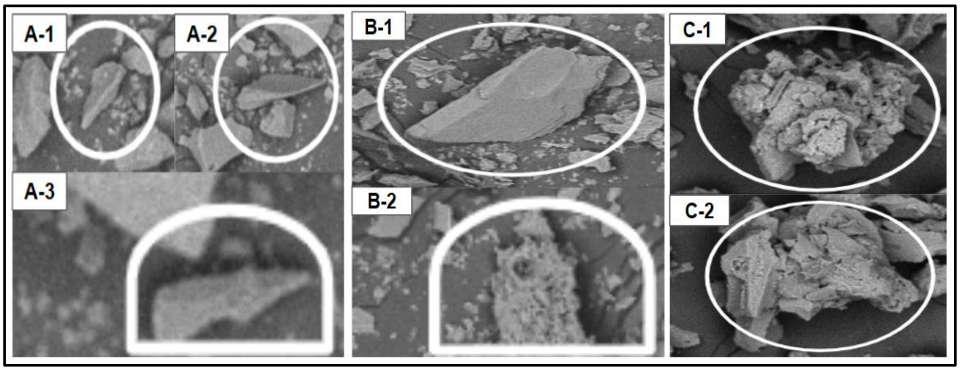

Figure 3: Zoomed-In Images of Sharp and Porous Particles from the SEM Images of Mt. Mayon (3A1 - 3A3), Mt. Pinatubo (3B1 - 3B2), and Taal Volcano (3C1 - 3C2) Ash Sample

In figure 2A, 3A1, 3A2, and 3A3, Mt. Mayon was found to possess sharp volcanic ash particles. Figure 2B, 3B1, and 3B2 featured both sharp and porous particles. Lastly, figure 2C, 3C1, and 3C2 showed Taal ash featuring porous and layered particles more than the others.

1. Comparison of philippine volcanic ash particle sizes (ImageJ)

Three Philippine ash were compared and contrasted using ImageJ software to determine their standard deviations. The experiment on the volcanic sizes was to give information about whether or not the volcanic ash particle sizes are spread wide or not. Table 2 was conducted using the 100 micrometers (μm) range. Since Taal volcano has the least amount of particles according to figure 1, it will then be used as the number of particles to be tested both for Mt. Mayon and Mt. Pinatubo.

Table 2: Particle sizes of Mt. Mayon, Mt. Pinatubo, and Taal Volcano Ash Samples

Test Number	**Mayon (μm)**	**Pinatubo (μm)**	**Taal (μm)**	Test Number	**Mayon (μm)**	**Pinatubo (μm)**	**Taal (μm)**
1	91.426	35.254	139.659	21	37.084	21.633	101.393
2	63.735	27.002	31.719	22	38.759	65.961	38.782
3	72.776	31.06	69.126	23	35.737	30.954	42.764
4	69.682	21.113	33.275	24	29.683	21.448	134.543
5	54.199	21.333	43.571	25	36.603	81.001	27.222
6	38.958	30.171	13.192	26	40.964	26.123	39.753
7	38.767	43.044	21.474	27	34.407	24.925	25.283
8	27.84	34.65	72.231	28	55.248	30.598	111.119
9	38.45	20.485	19.013	29	35.77	25.832	21.094
10	41.476	27.409	51.678	30	25.184	60.518	76.273
11	40.63	88.836	32.24	31	28.456	90.5	58.989
12	38.872	42.706	93.654	32	19.516	35.63	40.254
13	31.866	37.864	29.169	33	30.04	32.066	80.765

14	36.922	24.631	73.96	34	24.197	27.96	136.513
15	64.435	30.219	14.595	35	36.173	24.282	117.972
16	27.649	31.427	35.11	36	27.094	25.844	37.628
17	26.89	19.772	63.625	37	21.783	67.948	17.532
18	27.856	47.136	18.441	38	23.364	25.01	21.784
19	39.88	23.001	72.202	39	27.359	65.523	20.613
20	47.171	23.004	23.482	40	22.028	55.803	91.497
		Standard Deviation	15.587	19.361	36.904		

Given these results from the 40 tests of all volcanic ashes used, it was found that Taal volcano has the widest spread of data and Mt. Mayon has the least amount of standard deviation. This result could only mean that the values are close to the mean, which indicates that the values are spread evenly.

In research done by Horwell and Baxter (2006), ash samples contained 32% of ash having a size < 38 µm. They recorded that between the time the eruption happened up to the 7th month, there was an increase in respiratory symptoms incidence. Horwell et al. (2003b) also studied the respirable effects of two ash particles with a size < 4 µm. In their research, they were also able to conclude that people who received > 0.25 mm of ashfall have a chance to get bronchitis. As such, in relation to Tables 2 ash particles whose size is within the range of 4 µm to 250 µm could cause different health effects to adults and children.

EDS and comparison of chemical composition

Volcanic ashes are metal-rich pollutants that may pose serious health risks to humans. More specifically, it has been found to negatively affect the blood, testes, and liver (Sauzéat et al., 2022). In 2021, Barone et al. found exceeding levels of metallic elements such as nickel (Ni), cadmium (Cd), and arsenic (As) in volcanic ash from Mount Etna, Italy. Moreover, Khazaei et al. (2020) illustrate that gastrointestinal diseases can be attributed to exposure to heavy metals.

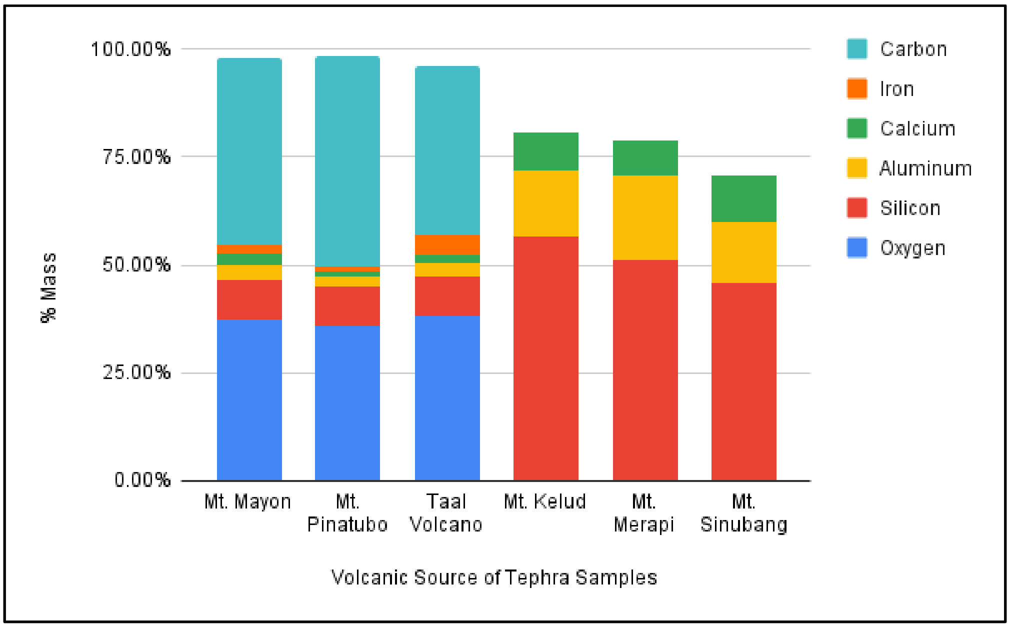

Figure 4: Elemental Composition of Philippine Ash Samples (Mt. Mayon, Mt. Pinatubo, and Taal Volcano) vs. Indonesian Ash Samples (Mt. Kelud, Mt. Merapi, and Mt. Sinubang) from Latif et al. (2016).

Comparing ash from the Philippines and Indonesia, it is apparent that they share roughly the same chemical composition but some notable exceptions could be observed. oxygen (O) and carbon (C) were found in high amounts in all three ash samples from the Philippines while Indonesian volcanic ash did not contain any of the two elements.

Disregarding O and C, both Indonesian and Philippine ash consists mainly of Si followed by, which could mean that both ashes could pose a significant respiratory hazard due to silicon followed by aluminum and calcium. This suggests that both, especially Philippine ash, could potentially develop the health defects associated with silicon and aluminum mentioned above.

However, ash from Taal Volcano contains a significant amount of iron (Fe) compared to other Philippine ashes, which could make Taal ash a more suitable fertilizer than others (Achterberg, et al., 2013). Taal ash also uniquely contains sulfur (S) that is absent in other tested ashes. This could increase Philippine ashes’ due to sulfur compounds presenting a significant health risk (US EPA, 2023).

ATR-FTIR results comparison

To further explore and verify findings relating to the elemental composition of the ash samples, an analysis using the ATR-FTIR was performed.

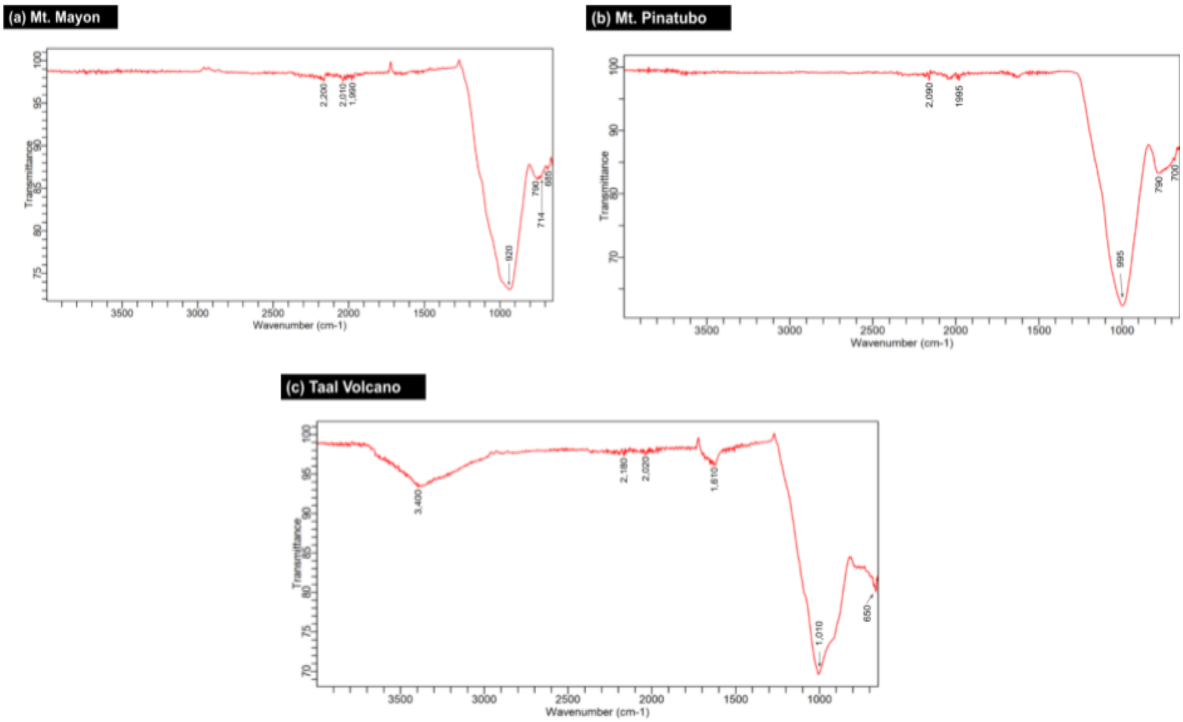

Figure 5: ATR-FTIR Spectrum of Volcanic Ash Samples from (a) Mt. Mayon, (b) Mt. Pinatubo, & (c) Taal Volcano

The ATR-FTIR spectrum of Mt. Mayon, Mt. Pinatubo, & Taal Volcano ash is depicted in figure 5a, 5b, and 5c respectively. The bands of figure 5a, 5b, and 5c observed at 685, 700, and 650 cm^{-1} respectively can be attributed to ring vibrations from Si–O bonds of the silicate network (Tchadjié et al., 2016). The major bands were observed at 920, 995, and 1,010 cm^{-1} from figure 5a, 5b, and 5c respectively, and can be related to the vibration of SiO/Al–O bond of the aluminosilicate framework (Djobo et al., 2016). Moreover, the bands depicted at 1,610 and 3,200 cm^{-1} in figure 5c indicate O–H bonds from the silanol group and water molecules to have undergone stretching and bending vibrations (Tchakouté et al., 2016). Absorption bands found at 1,990, 1,995, and 2,020 cm^{-1} indicate the presence of CO_2 molecules which are formed by the adsorption of carbonates to a glassy phase (Fine & Stolper, 1986).

Sedimentation test

The sedimentation results of the volcanic ash samples are shown in figure 4. The floating ash particles in the water initially gave the samples a hazy appearance after they were poured into the graduated cylinders. After 1 h, the ash sample from Taal Volcano looked clear and had minimal changes until after 24 h indicating it had heavy particles. The other two samples are still cloudy however, the upper portion of the two cylinders is clear. Approximately 20% and 5% clear portion on the top for Mt. Mayon and Mt Pinatubo, respectively. In 3 h, minimal change was observed between the two ash. Nevertheless, the clear portion of both ash increased by ≈ 35% and ≈ 10% for Mt. Mayon and Mt. Pinatubo respectively. Finally, after allowing the samples to rest for 24 h, all three cylinders are clear except for Mt. Pinatubo, with plenty of particles still afloat and the same goes with Mayon Volcano but to a much less extent.

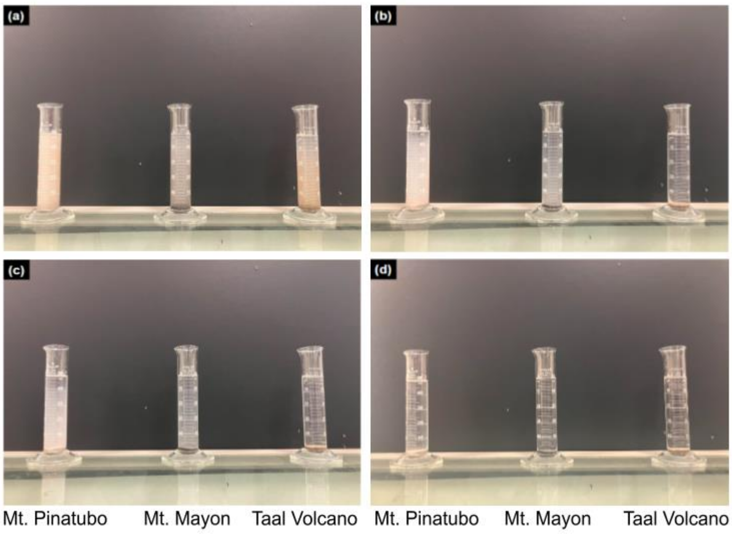

Figure 6: Sedimentation Test Photos of Mt Pinatubo, Mayon Volcano, and Taal Volcano at (a) 0 h, (b) 1 h, (c) 3 h, and (d) 24 h.

Mt. Pinatubo was observed to be the lightest, which could imply that it will stay suspended in the air longer than Mt. Mayon and Taal, making it potentially more hazardous (Mallios et al, 2020). Meanwhile, Taal sunk the fastest with Mt. Mayon in the middle, which suggests that they are less hazardous by contrast.

Brittleness test

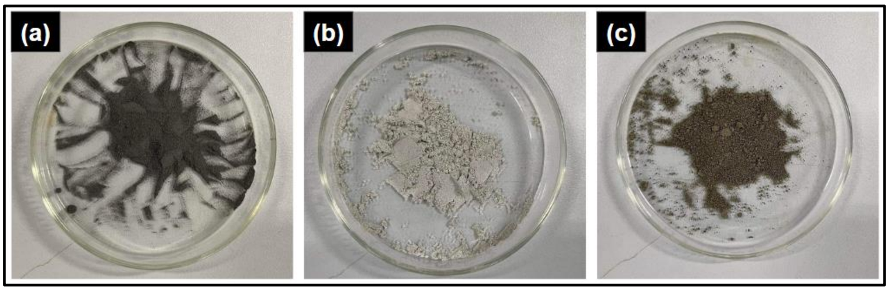

Figure 7: Brittleness Test of Mt. Mayon (a), Mt. Pinatubo (b), and Taal Volcano (c) before the Test

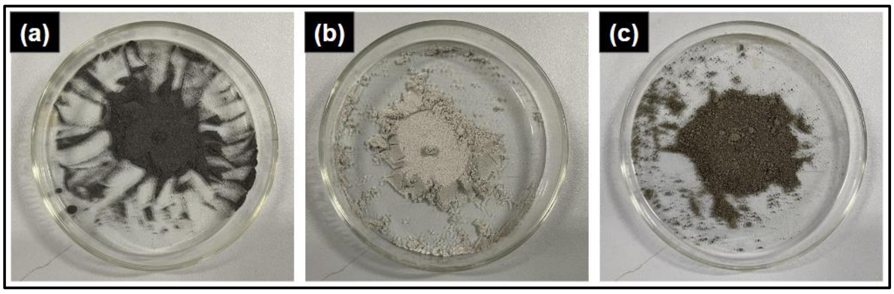

Figure 8: Brittleness Test of Mt. Mayon (a), Mt. Pinatubo (b), and Taal Volcano (c) after the Test

The results from the brittleness test through 100 g weights did not reveal any potential health hazards or lucrative observations from the ash samples.

Conclusion

All three volcanic ash samples were found to possess different characteristics. Sharp particles and irregular shapes were observed in Mt. Mayon's particles while Mt. Pinatubo consisted of porous and polygonal particles. Taal Volcano, on the other hand, was found to contain layered particles while others have a slightly porous and rough surface. As for the particle sizes, it was found that among the three volcanic ashes, Taal volcano has the widest spread as its standard deviation is 36.904 while Mt. Mayon has the least spread as its standard deviation is 15.587. It was also found that ash particles belonging in the range of 4 μm to 250 μm could pose a risk to the health hazards of children and adults.

Volcanic ash from Indonesia and the Philippines were found to exhibit differences in their elemental composition however, they also share several elements. Both sources predominantly consist of silicon (Si), aluminum (Al), and calcium (Ca); however, Philippine ash uniquely contains large amounts of oxygen (O) and carbon (C). In addition, Taal ash from the Philippines displayed an increased presence of iron (Fe) compared to other Philippine samples as well as the distinct presence of sulfur (S). The ATR-FTIR spectrum of Mt. Mayon, Mt. Pinatubo, & Taal Volcano ash indicated ring vibrations from Si–O bonds of silicate network as well as ring vibrations from Si–O bonds of silicate network and SiO/Al–O bond of aluminosilicate framework. O–H bonds from the silanol group and water molecules were also found to have undergone stretching and bending vibrations. In addition, the formation of CO_2 molecules due to the adsorption of carbonates to a glassy phase was observed.

The sedimentation results of the three samples highlight that the volcanic ash from Mt. Pinatubo is the lightest, posing a threat to human health since it lasts longer in the air. After 1 h, the Taal Volcanic ash sank quickly indicating that it is heavy. The samples taken from Mayon and Mt. Pinatubo, on the other hand, remained murky, indicating the presence of lighter airborne particles. The sedimentation rates of the Mt. Pinatubo and Mt. Mayon ash samples converged with time. Their clear portions grew by about 35% and 10%, respectively, after 3 h. Finally, all three samples were clear after 24 h, although Mt. Pinatubo's sample still included a significant number of floating particles, indicating its lightweight nature.

As for the brittleness test of Mt. Mayon, Mt. Pinatubo, and Taal Volcanic, as mentioned in figure 7 and 8, the experiment showed no significant or lucrative findings that could indicate a possible health hazard or use case.

Recommendations

Given the minuscule sizes of volcanic ash particles, their elemental composition, and their density, it is recommended that proper precautions are always taken to minimize the health risks posed by ash fall from Mt. Mayon, Mt. Pinatubo, and Taal Volcano. This is especially critical for areas that are located near active volcanoes. The Volcanic ash samples from the selected volcanoes have been found to contain harmful elements that are easily transported to various locations due to their size and density, posing a health hazard for a vast majority of people. Moreover, this study could help discover other uses for recycling volcanic ash.

Conflicts of Interest

The authors declare that there is no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

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