The Geochemical Properties of Volcanic Materials: After a Year Mt. Sinabung Eruption

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Abstract. Indonesia has many active volcanoes, one of which is Mt. Sinabung in Karo Regency, North Sumatra. Pyroclastic material from volcanoes can provide the nutrients that plants need for the future in varying content amounts. This study aims to identify the chemical properties of Mt. Sinabung ash after the 2019 eruption. A total of 22 ash samples were scattered in the east, southeast, and south sectors within a radius of 3-5 km from the peak of the eruption (research area of 1,676.29 hectares). Samples were analyzed to determine ash pH, available P, cation exchange capacity (CEC), and exchanged base cations of Ca, Mg, K, and Na from volcanic ash. The results showed the Mt. Sinabung volcanic ash had an average value of ash pH (H_2O) was classified as acidic (5.36) in the east, slightly acidic in the southeast (6.06), and south (6.27). The average value of available P in all sectors is very high, while the CEC is still low. In the southeast, east and south sectors, respectively, available P values are: 35.00, 59.37, and 165.96 mg kg^{-1}, and CEC: 12.92, 14.46, and 15.46 $cmol_c$ kg^{-1}. The base cations in this study were Mg > Na > K > Ca classified as very high and very low. The discriminant analysis results showed the chemical properties of volcanic ash in the southeast sector are different from the southern sector, while the eastern sector has similarities in the south sector.

Keywords: Tephra, Nutrient Reserves, Volcanic Ash Chemistry.

1 Introduction

Indonesia has many active volcanoes, one of which is Mt. Sinabung in Karo Regency, North Sumatra. Mount Sinabung is recorded to have a history of eruptive activity that never stops. It happened from 2010, till now after a long sleep since 1600 [1][2]. Pyroclastic material from volcanic eruptions can provide nutrients that plants need for the future. Therefore, volcanic ash serves as a nutrient reserve and along with weathering will release nutrients to the soil.

It was reported the Sinabung volcanic material in 2019 (as soil parent material) had nutrient reserves in the form of MgO, CaO, P_2O_5, K_2O, and SO_3. The total content was from 37,384.17 kg ha^{-1} to 235,794.99 kg ha^{-1} [3]. Then, volcanic ash can significantly supply nutrients to the soil and the soil becomes more fertile [4][5]. According with this statement, nutrients such as Ca, K, Mg, Na, S and P are released into the soil through weathering of volcanic material [6]. In addition, it is also shown by the high average values of C, N, Ca, Mg, K, Na on the soil around Mt. Sinabung, which is an area covered with volcanic ash for 10 years of eruptions that erupt in a fluctuating manner [7].

Recent studies on the chemical properties of Sinabung volcanic ash are lacking and difficult to find. That's because Mt. Sinabung has never stops releasing new volcanic material almost every year, since 2013. Also, the chemical composition and concentration of pedogenic pyroclastic materials showed different amounts. This can be caused by differences in thickness/layer of volcanic material [8], parent mineral content, and weathering processes of the material. Even though the material comes from the same volcanic eruption [9][10]. Thus, in this study we researched the samples of volcanic ash from Mt. Sinabung based on the distribution of the results of the last eruption in 2019. The aim is to identify the chemical characterization of Mt. Sinabung ash deposits.

2 Data and Method

2.1 Information of Mt. Sinabung and Study Area

The research location is in the Mt. Sinabung area, administratively located in Namanteran District, Karo Regency, North Sumatra Province. Mount Sinabung has coordinates 3º 10’ 16.7” N and 98º 23’ 24.66” E with a peak height of 2,460 meters above sea level (m. a. s. l.). After the 2019 eruption, the pyroclastic material formed spread from southeast to south of 1,371 hectares like a pyroclastic fan. This can be seen in Fig. 1 which is monitored via satellite imagery.

Ash sampling was carried out in March 2020 in a disaster-prone area of Mt. Sinabung (3 – 5 km radius from the center of the eruption) with a research area of 1,676.29 hectares (Fig. 2). A total of 22 ash samples were obtained, with 8 samples collected in the eastern and southeastern sectors, and 6 samples in the southern sector. Samples were taken trigonal at 3 random points (±2 m interval) at each sampling location and then composited into one sample. A sampling of ash using a trowel on the top layer/new layer (marked with a different color for the previous layer). The sample was brought to the laboratory, wind-dried, and sieved using a sieve to obtain a fine volcanic ash sample (< 2 mm).

2.2 Sample and Data Analysis

General chemical characteristics of volcanic ash samples analyzed include ash pH, available P, CEC, and exchangeable base cations. Analysis of the pH of the ash with a solution ratio of 1:5 to determine the pH value of H_2O and pH KCl with 1 M KCl. Then measured using a pH meter. The available P was analyzed using the Bray I method and measured by a spectrophotometer with a wavelength of 889 nm. Cation exchange capacity (CEC) was obtained from analysis by leaching using 1 M ammonium acetate (NH_4OAc), extraction pH 7. The leachate from the CEC analysis was followed by measurements using atomic absorption spectrophotometry (AAS) to determine exchangeable base cations.

Fig. 1. Satellite image of pyroclastic material distribution at Mt. Sinabung (9 November 2019)

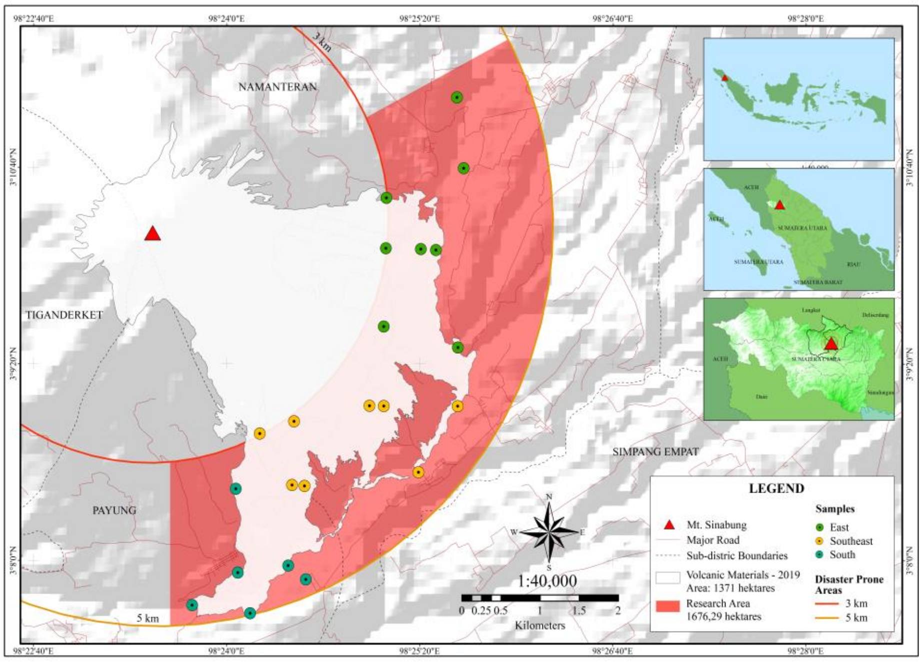

Fig. 2. Volcanic ash sampling location

The measurement data in the laboratory were analyzed using JMP-Pro 14 software and presented based on the grouping of the ash distribution direction and the sampling points, namely east, southeast, and south. The data variables were processed statistically by measuring the one-way function analysis. Then, linear discriminant analysis with canonical plot function was also used on the chemical properties of ash in the three sectors to see the similarity between variables. The chemical characteristics of ash are grouped based on the criteria for assessing soil chemical properties by Indonesian Agency of Agricultural Research and Development [11]. Kriging data processing digital for mapping of Mt. Sinabung ash chemical properties using ArcGIS 10.4.1. software.

3 Results and Discussion

This study obtained data on the chemical characteristics of Sinabung volcanic ash, which were grouped according to the direction of the material distribution (Table 1). However, the characteristics of the ash's chemical properties are influenced by the type of parent material spewed out by the volcano [9]. For example, the Sinabung eruptions in 2016 and 2017 show that the parent material of pyroclastic material is basaltic material with an average SiO_2 oxide content of 49.33% [12]. While the eruption in 2019 is classified as dacite to andesite material with an average oxide content of 51.51-67.51% [3]. From these two statements, it is known that pyroclastic material originating from the same mountain eruption at different times will produce different data on the chemical characteristics of the ash.

Table 1. Chemical characteristics of Sinabung volcanic ash

	Units	Means values					
		East (n = 8)		Southeast (n = 8)		South (n = 6)	
pH H_2O		5.36 ^{a}	b	6.27 ^{sa}	a	6.06 ^{sa}	ab
pH KCl		4.39	a	5.02	a	5.01	a
ΔpH		-0.97	a	-1.25	a	-1.05	a
Available P	mg kg^{-1}	59.37 ^{vh}	ab	35.00 ^{vh}	b	165.96 ^{vh}	a
CEC	cmol$_c$ kg^{-1}	14.46 ^{l}	a	12.92 ^{l}	a	15.46 ^{l}	a
Exch. Ca	cmol$_c$ kg^{-1}	0.27 ^{vl}	a	0.23 ^{vl}	a	0.27 ^{vl}	a
Exch. Mg	cmol$_c$ kg^{-1}	12.59 ^{vh}	a	12.37 ^{vh}	a	12.93 ^{vh}	a
Exch. K	cmol$_c$ kg^{-1}	3.66 ^{vh}	a	3.82 ^{vh}	a	3.82 ^{vh}	a
Exch. Na	cmol$_c$ kg^{-1}	6.64 ^{vh}	a	7.04 ^{vh}	a	6.44 ^{vh}	a

a acid, *sa* slightly acid, *vh* very high, *l* low, and *vl* very low.

The reaction of volcanic ash (pH H_2O) has an average value of 5.36, classified as acidic, and in the slightly acidic category with values of 6.06 and 6.27. The average pH values of KCl were 4.39, 5.01, and 5.02. While the average ΔpH value has a lower value, respectively -0.97, -1.05, and -1.25. This shows the magnitude of the negative charge on the surface of the volcanic ash to bind cations. One-way analysis (see Fig. 3) of pH H_2O and KCl reflects the highest ash pH values in the southeast sector, compared to the south and east with the lowest pH values.

This is closely related to the acidity of volcanic ash, namely gases released during eruptions such as SO_2. If SO_2 in the air is deposited with pyroclastic materials, it has been oxidized to form SO_3. However, new pyroclastic materials generally have a neutral pH, when SO_3 is hydrolyzed it will produce acid aerosols which cause a decrease in the pH value [13]. In line with reports, the weathering of Talang volcanic ash for 2 years reduced the pH value of H_2O to 3.55 from 1.35% of the leached sulfur total [14]. The distribution of pH (H_2O) and deposit of SO_3 is shown in Fig. 6.

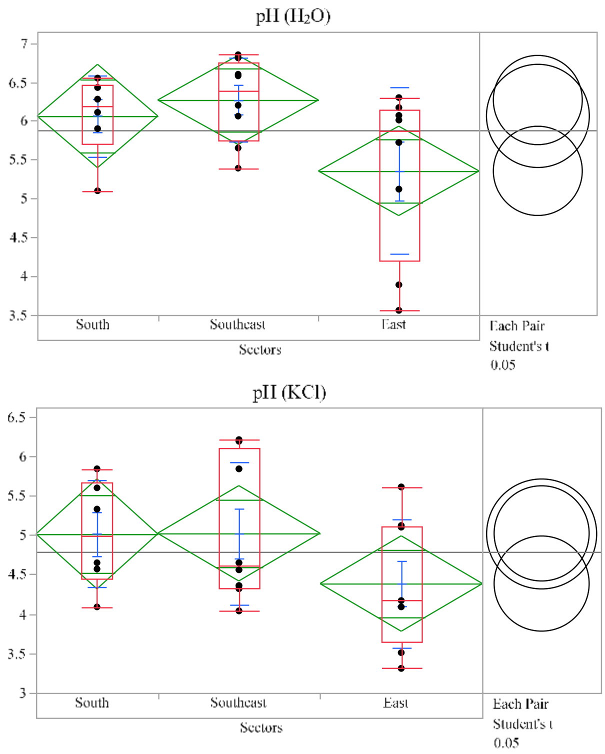

Fig. 3. One-way analysis graphics of volcanic ash pH (H_2O and KCl) in various sectors of the volcanic ash distribution from the eruption center

The average value of available P in volcanic ash is very high, namely 35.00 mg kg^{-1} in the southeast, 59.37 mg kg^{-1} in the east, and the highest in the south was 165.96 mg kg^{-1}; in Fig. 4. The presence of this phosphorus comes from the apatite mineral in pyroclastic/tephra deposits. Reportedly, pyroclastic deposits in Kutcharo-Japan contain P_2O_5 from 300 to 800 mg kg^{-1} in the P-apatite mineral, and phosphorus availability to plants is 70 to 140 mg kg^{-1} [15]. The distribution of available P in the Sinabung pyroclastic material can be seen in Fig. 7.

Sinabung volcanic ash has a low CEC with an average value of 12.92 cmol$_c$ kg^{-1}, 14.46 cmol$_c$ kg^{-1}, and 15.46 cmol$_c$ kg^{-1}. Although classified as low, the average CEC value is highest in the south, and in the southeast the lowest value, as shown in Fig. 4. The low CEC value of volcanic ash has similarities to the CEC on Mt. Anak Krakatau, which ranges from 0.44 – 8.99 cmol$_c$ kg^{-1} with a low to very low category [16].

However, CEC is related to particle size/material fraction, its value will increase with increasing weathering and clay content [17][18]. The distribution of CEC values is shown in Fig. 7.

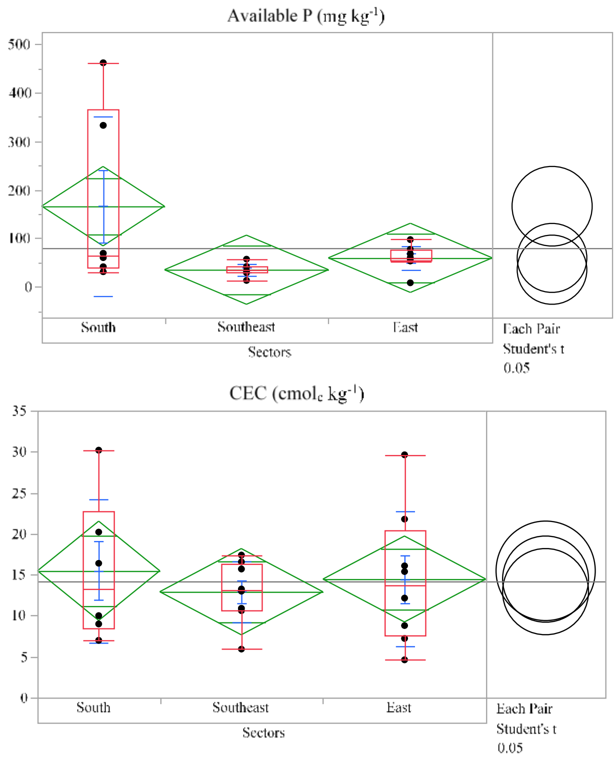

Fig. 4. One-way analysis graphics of available P and cation exchange capacity (CEC) in various sectors of the volcanic ash distribution from the eruption center

Mount Sinabung volcanic material has a number of exchanged cations in the order Mg > Na > K > Ca in all sectors. This cation is classified as very high for Mg, Na, and K cations. But not for Ca which shows a very low value, in contrast to other cation groups (see Table 1). While the results of the one-way statistical test in Fig. 5 show that the average values of Mg, Na, K, and Ca cations in the three sectors (east, southeast, and south) have not significantly different values. For the distribution of cations, see Fig. 8.

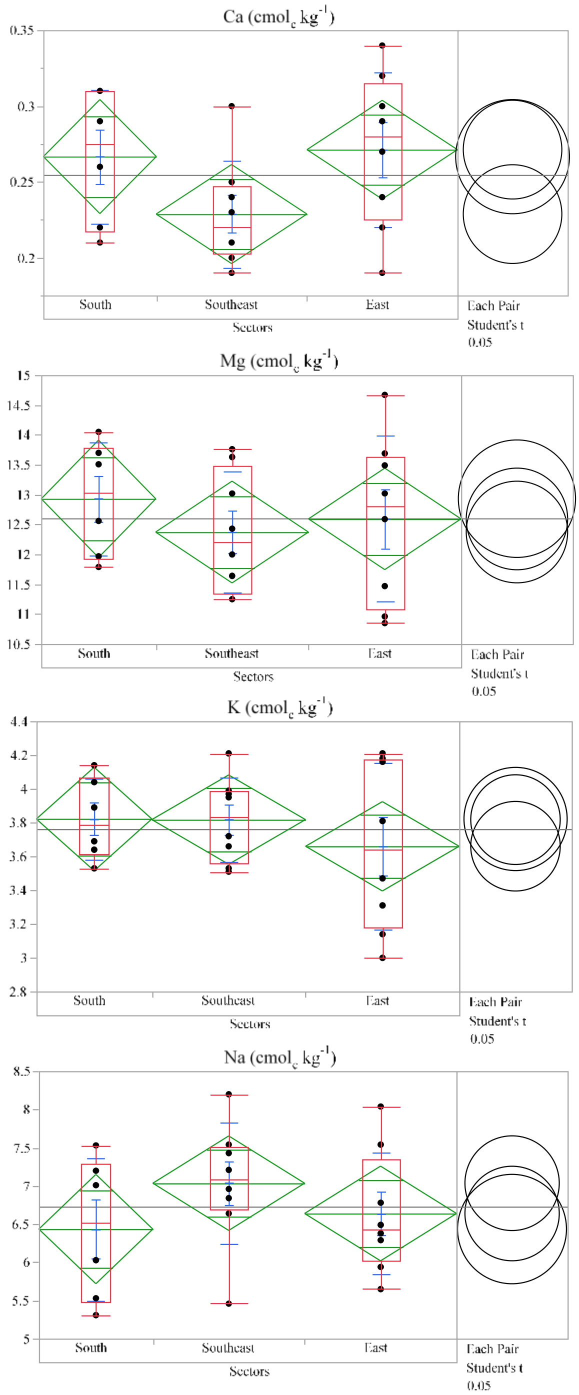

Fig. 5. One-way analysis graphics of the base cations: Ca, Mg, K, Na in various sectors of the volcanic ash distribution from the eruption center

Linear discriminant analysis was carried out to distinguish volcanic ash from 3 sectors of material distribution. From the results of the analysis, it produced clear differences between ash in the east, southeast, and south sectors using a combination of 8 volcanic ash chemical variable data (H_2O pH, KCl pH, available P, CEC, Exch. Mg, Exch. Ca, Exch. K, and Exch. Na) (Fig. 9).

It was reported that chemical groups of volcanic materials could be distinguished by their elemental characterization using multivariate statistical methods [19]. From Fig. 9, shows the chemical characteristics of Sinabung volcanic ash from the southeast sector are different from the south sector. Meanwhile, the eastern sector overlaps with the southeast and south sectors, showing characteristics that have similarities between sectors. From this analysis, it can be seen that the distribution of volcanic material can have different chemical properties even though they originate from the same volcanic eruption.

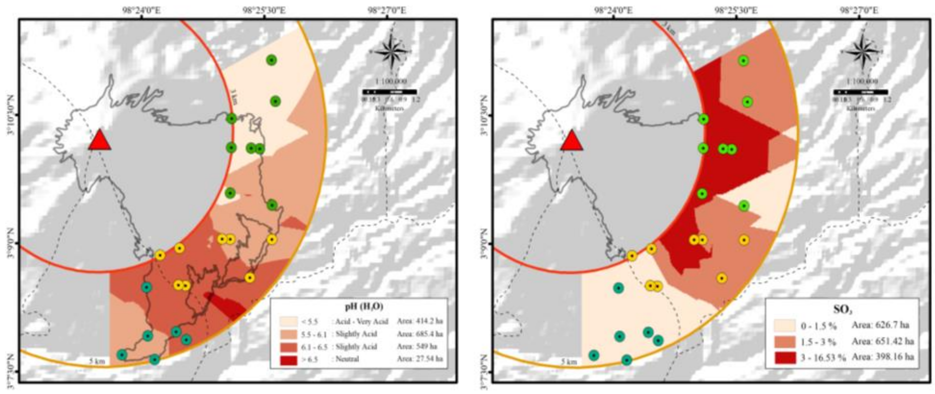

Fig. 6. The distribution maps of pH (H_2O) and SO_3 content in volcanic ash of Mt. Sinabung. Light to dark red color indicates the distribution of the lowest to the highest values

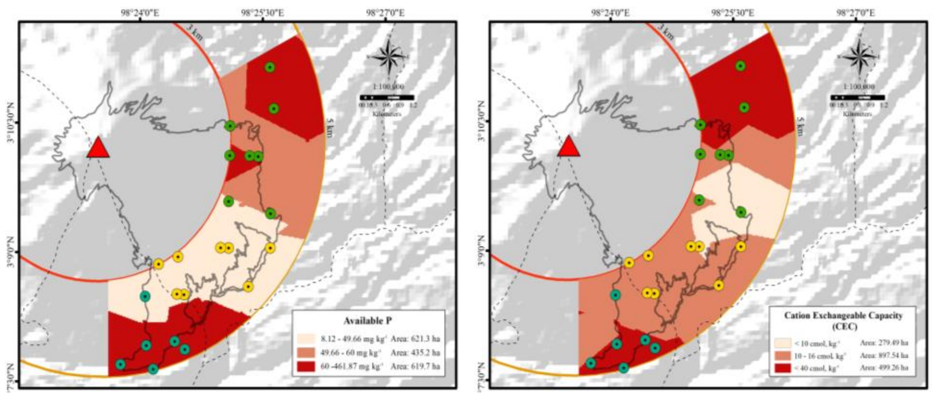

Fig. 7. The distribution maps of available P and cation exchange capacity (CEC) in volcanic ash of Mt. Sinabung. Light to dark red color indicates the distribution of the lowest to the highest values

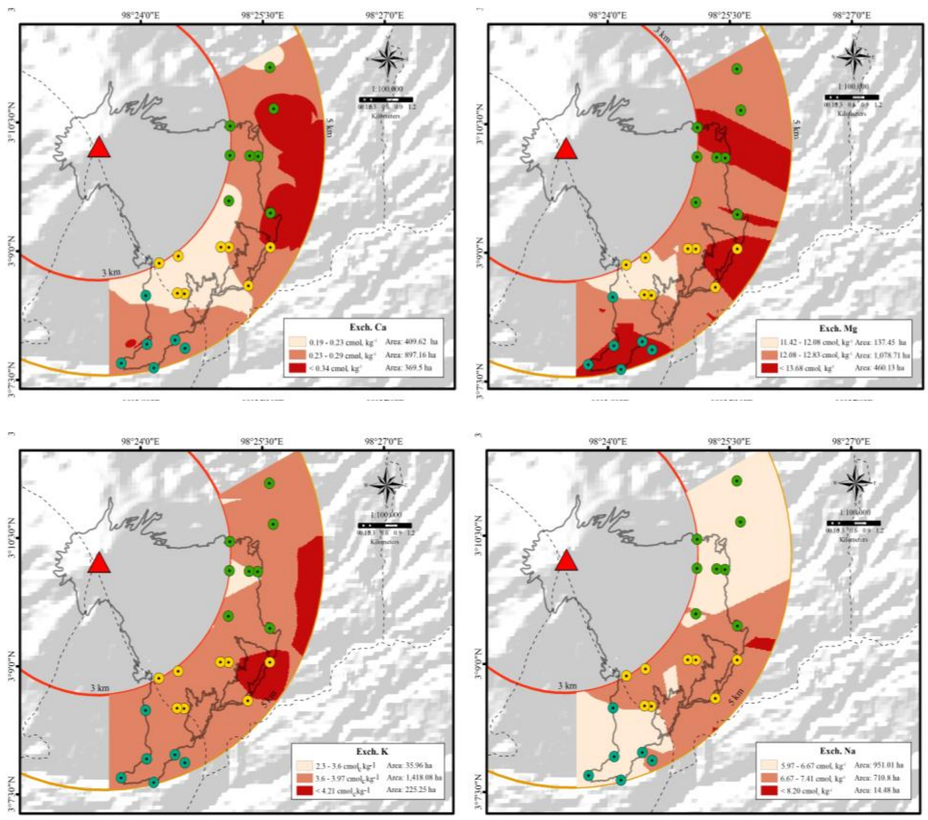

Fig. 8. The distribution maps of base cations: Ca, Mg, K, and Na in volcanic ash of Mt. Sinabung. Light to dark red color indicates the distribution of the lowest to the highest values

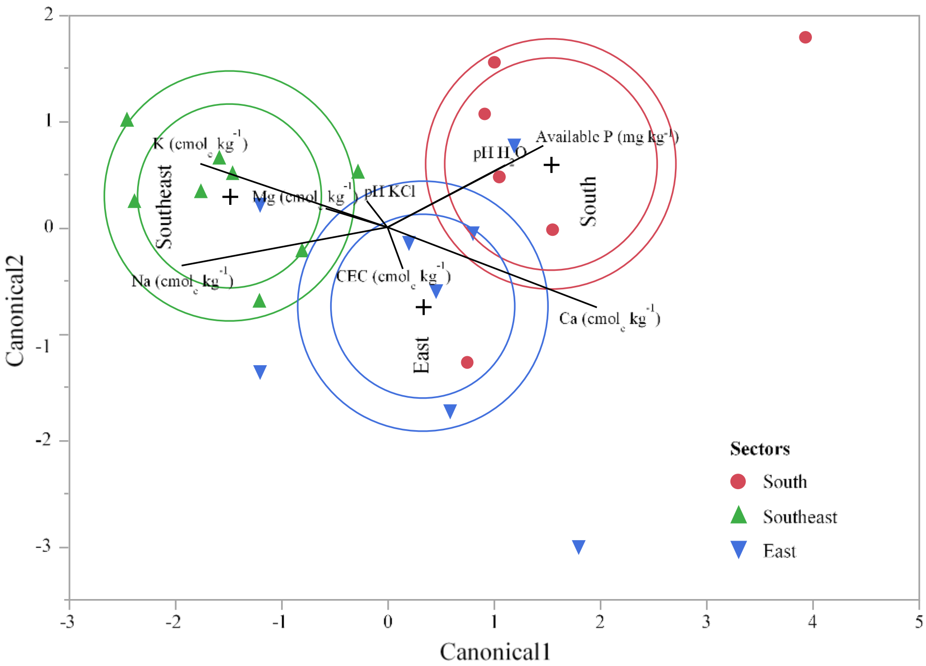

Fig. 9. Differences in the chemical properties of Mt. Sinabung volcanic ash from various sectors of ash distribution

4 Conclusion

Mount Sinabung volcanic ash was classified as acidic (5.36) in the east, slightly acidic in the southeast (6.06), and south (6.27). The available P in all sectors is very high, while the CEC is still low. In the southeast, east and south sectors, respectively, available P values are: 35.00, 59.37, and 165.96 mg kg^{-1}, and CEC: 12.92, 14.46, and 15.46 $cmol_c$ kg^{-1}. The base cations in this study were Mg > Na > K > Ca classified as very high and very low.

The discriminant analysis results showed the chemical properties of volcanic ash in the southeast sector are different from the southern sector, while the eastern sector has similarities in the south sector.

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