Assessment of the Geochemical Weathering Indices of Volcanic Soil After the Eruption from Mount Sinabung in 2020

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Abstract. The weathering process of volcanic material that erupts will release nutrients depending on the type of rock and the level of weathering and then fertilize the soil. The level of weathering of volcanic soils can be measured by calculating the weathering indices to evaluate the stage of soil development, nutrient mobility, and indicate the intensity of chemical weathering in the soil. In this paper, we analyze the total elemental oxides and the degree of weathering of the soil affected by the eruption of Mount Sinabung for 10 years (2010-2020). The samples were taken using the grid sampling method with an interval of 1 km and samples collected as many as 34 samples. In this study, the calculation of the chemical weathering indices includes the Ruxton Ratio, Bases Loss and Desilication Indices (DI). The results of this study indicates that the average total soil oxides are TiO_2 (0.53-0.90%), MgO (0.74-2.48%), K_2O (1.37-1.88%), P_2O_5 (1.40-2.52%), CaO (2.40-3.59%), Fe_2O_3 (4.82-7.91%), Al_2O_3 (23.09-28.60%), and SiO_2 (53.60-59.28%). The average soil weathering indices calculated from the Ruxton ratio is between 1.90-2.61, Base losses is around 3.318-6.991 and Dessilication indices is 1.452-1.916. Based on the results of the research described above, it can be concluded that the soil affected by the eruption of Mount Sinabung has a moderate level of weathering. The level of weathering from highest to lowest is Southeast>South>East>Northeast.

Keywords: Soil Nutrient, Elemental Oxide, Weathering Degree

1 Introduction

Mount Sinabung is one of the most active mountains in Indonesia. Mount Sinabung is located in North Sumatra Province, precisely in Karo Regency. After dormancy since 1600, Mount Sinabung first erupted in August 2010 [1] and is still erupting to that. Of the 127 active volcanoes in Indonesia, Mount Sinabung is the mountain with the longest eruption period [2]. Continuous eruptions cause changes in morphology, topography, deposition of volcanic materials [3]. This has a great influence on the geochemical properties of soil in the vicinity.

The geochemical properties formed are influenced by the types of rocks and minerals. Generally, minerals originating from volcanic activity are dominated by glass volcanoes, which are easily weathered minerals with high levels of porosity and permeability [4]. In addition, volcanic materials contain silica glass which is an amorphous solid of irregularly formed silicate oxide [5]. The parent material which is dominated by the silica-based glass is at the core of the development of volcanic soils [5]. Silica content in Mount Sinabung ash is relatively high. Anda [2] reported that Sinabung ash deposits taken at 4 different years had silica content ranging from 57.78-60.38%. [6] reported that the volcanic ash of Mount Sinabung contains 51.51-67.51% SiO_2 which is classified as basalt to dacite. Rock classification is determined based on Silica content [7]. In addition to having a high silica content, volcanic ash also contains a chemical composition that has the potential to enrich nutrients in the soil.

The basic composition of volcanic ash consists of SiO_2, Al_2O_3, FeO_3, MgO, CaO, Na_2O, and S which will then weathering and increase nutrients in the soil [8]. The process of releasing nutrients contained in volcanic material from an eruption is determined from the level of weathering of the mineral which can be calculated using the calculation of the weathering indices. The weathering indices can provide information about soil development and the mobility of rock constituent elements during the weathering process. Information about the degree of weathering is very useful in the environmental research process [9]. The calculation of the weathering indices is one way to characterize the level of weathering based on the value of elemental oxide [10].

Assessment of elemental oxides can be analyzed using XRF (X-Ray Fluorescence). The results of XRF analysis are widely used to measure the total concentration of elements in the soil that are important for soil fertility [11]. After 10 years of being affected by the eruption, the volcanic material donated to the soil has changed. This article provides information on the geochemical properties of the soil after being affected by the eruption of Mount Sinabung for 10 years. The objective of this study was to assess the total elemental oxide and weathering degree of the soils after 10 years affected by the eruption.

2 Materials and Methods

2.1 Soil sampling and analysis

This research was conducted on Mount Sinabung with an area of 4.517.25 ha. The samples analyzed were 34 samples taken at a radius of 3-7 km from the peak of the eruption (Fig. 1). Soil samples were taken at a depth of 0-20 cm using a belgian drill after the volcanic material on the soil surface was cleaned. Soil samples were taken on pyroclastic material flows, namely the East, Northeast, Southeast, and South. Each area has a different thickness of volcanic ash. In a radius of 5 to 7 km, they are generally located in horticultural planting areas and have undergone various processing.

Soil geochemical properties are determined by the type of rock material. In according to [12], that rock formation affects soil properties which are assessed based on mineral and chemical content which have differences in each region. Based on the analysis of the volcanic ash covering the area around Mount Sinabung, it was found that the composition of SiO2 (51.51-67.51%) belongs to mafic to felsic materials [13].

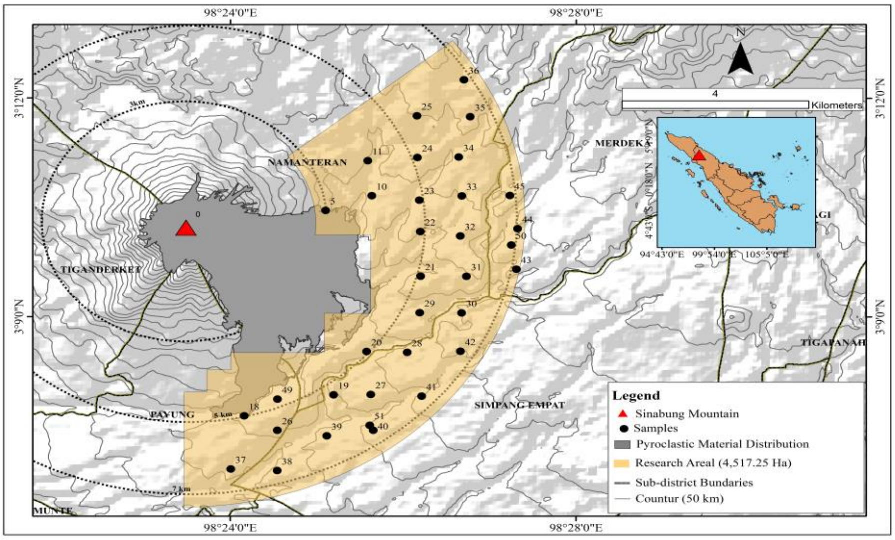

Fig. 1. Soil sampling points affected by the eruption of Mount Sinabung.

The concentration of total elemental oxide was analyzed using the X-Ray Fluorescence (XRF) spectrometer PAanalytical Epsilon 3 for the analysis of geochemical properties. The soil sample used was first dried and then sieved using a 200 m sieve. The results of XRF analysis are widely used to measure the total concentration of elements in the soil that are important for soil fertility [11].

2.2 Chemical weathering indices

Weathering index is a way to measure the condition of volcanic ash at the weathering stage and assess the level of soil fertility so that the levels of soil nutrient sources can be predicted [9]. In addition, according to [8], the weathering index can also provide information about the development of soil and the mobility of rock constituent elements during the weathering process. In this study, chemical indices were evaluated to characterize weathering degrees:

Ruxton ratio

R= SiO_2/Al_2O_3, this method was introduced by Ruxton (1986) who calculated the rate of loss of Silica (SiO_2) with the loss of resistant elemental oxide, namely Al_2O_3 in the weathering process [14]. The reliability of the Ruxton ratio is determined by the uniformity of the parent material, the resistance of aluminum during weathering, the degree of difference between moles of silica to alumina, and the degree of correlation between silica loss and elemental oxide [15]. The range of values in this weathering index is 0-10. The lower the value of the weathering indices, the more optimal the level of weathering and otherwise [9]

Bases loss

Bases loss = Al_2O_3/(CaO + MgO + K_2O), this method connects resistant elemental oxides with easily washed bases. The greater the value of base loss indicates that the Alumina content is getting bigger [14].

Desilication indices

DI= SiO_2/(Fe_2O_3 + Al_2O_3 + TiO_2), is the molar ratio of movable Si to immobile oxides (Fe, Al and Ti) [11]. The lower the DI value, the more optimal the level of weathering [14].

2.3 Geochemical data analysis

Geochemical statistical analysis of the soil samples in this study used the JMP Pro 14 software. The total elemental oxides of the soil samples used were analyzed by discriminant analysis. In addition, the level of weathering is also presented on the kriging map processed using Arc. Map 10.4.1.

3 Result and discussion

3.1 Total elemental oxide

The elemental oxide composition showed a significant negative correlation between Al_2O_3 and K_2O, SiO_2 and CaO (Table 1). This means that when the Al_2O_3 content is higher, the K_2O, SiO_2 and CaO content will be lower. An increase in Al_2O_3 concentration causes a decrease in SiO_2 concentration [16]. The process of losing mobile elements (Ca, Mg and Na) and increasing the concentration of immobile elements (Si, Al and Fe) is the initial stage of the geochemical weathering process of the soil [17]. Furthermore, there is a significant positive correlation between CaO and K_2O. That means there is a linear relationship between CaO and K_2O.

Linear discriminant analysis was used to compare the geochemical elements of the soil affected by the eruption in the East, Northeast, Southeast, and South sectors. There are 7 chemical composition data analyzed using discriminant analysis, namely MgO, Al_2O_3, SiO_2, P_2O_5, K_2O, CaO, and Fe_2O_3. Based on the discriminant analysis, it was found that the land in the Southern sector has a significant difference compared to other sectors. The east sector overlaps the northeast and differs from the southeast.

Table 1. Correlation between total elemental oxide

	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	Fe_2O_3
MgO	1	-0.237	-0.188	-0.089	0.094	0.05	0.296
Al_2O_3	-0.237	1	-0.781	-0.26	-0.735	-0.791	0.381
SiO_2	-0.188	-0.781	1	0.043	0.56	0.729	-0.8
P_2O_5	-0.089	-0.26	0.043	1	0.289	0.164	-0.027
K_2O	0.094	-0.735	0.56	0.289	1	0.784	-0.246
CaO	0.05	-0.791	0.729	0.164	0.784	1	-0.469
Fe_2O_3	0.296	0.381	-0.8	-0.027	-0.246	-0.469	1

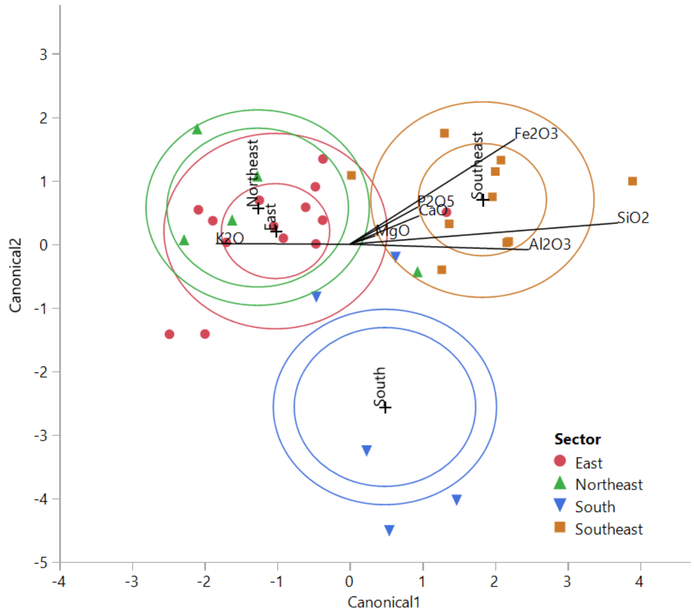

Fig. 2. Differences in total elemental oxides in various sectors

The results of canonical analysis varied with the data, respective-ly: canonical 1: 51.348%, II: 35.878%, and III: 12.775%. then the eigenvalues are 1.9, 1.3, and 0.5 respectively. Significant canonical correlations P < < .0001*, 0.0007* and 0.0588 indicate that there are significant differences between sectors. According to [12], the canonical correlation of P < 0.0001 and 0.083 between the chemical characteristics of the soil has a significant difference.

Table 2. Canonical detail

	Cannonical variate		
	I	II	III
Eigenvalue	1.9	1.3	0.5
Percent	51.348	35.878	12.775
Cum Percent	51.348	87.226	100.000
Canonical Corr	0.810	0.756	0.567
Likelihood Ratio	0.100	0.291	0.678
Approx. F	4.069	3.562	2.468
NumDF	21	12	5
DenDF	69.465	50.000	26.000
Prob>F	<.0001*	0.0007*	0.0588

3.2 Weathering indices

Based on the calculation of weathering levels using the Ruxton (R) method, there are significant differences between the Northeast and East and Southeast sectors (Fig. 3). The average Ruxton index from highest to lowest is East, East, South, and Southeast with values of 2,611, 2,366, 2.166, and 1.902%, respectively. In other words, the highest level of weathering is in the Southeast sector and the lowest is in the Northeast sector. The level of weathering in the research area is still classified as moderate. Following [9] the level of weathering in the research area is still classified as moderate. Weathering indices value close to 0 means it has a weathering level close to optimal [10]. The distribution map of the weathering index based on the Ruxton method is shown in Fig. 4. The distribution map shows that the soil in the Southeast sector has a higher level of Silica loss compared to other sectors.

The volcanic ash on Mount Sinabung is classified as mafic (basalt) to felsic (dacite) material with SiO_2 content (51.51-67.51%) with a total elemental composition of Al_2O_3 (15.54-23.41%), Fe_2O_3 (2.84-10.02%) and CaO (2.94-6.46%) [6]. Ilham [18] reported that the volcanic ash of Mount Sinabung had an oxide content of SiO_2 49.33%; Al_2O_3 15.93%; Fe_2O_3 6.48%; CaO 5.87%. Along with further weathering, the Silica content will decrease drastically because it has more mobile properties than Al, Fe and Ti. Anda [2] reported that the volcanic ash of Mount Sinabung collected from different years (2010 to 2014) had relatively the same SiO_2 content ranging from 57-60%. This indicates that the volcanic ash of Mount Sinabung is relatively resistant to weathering.

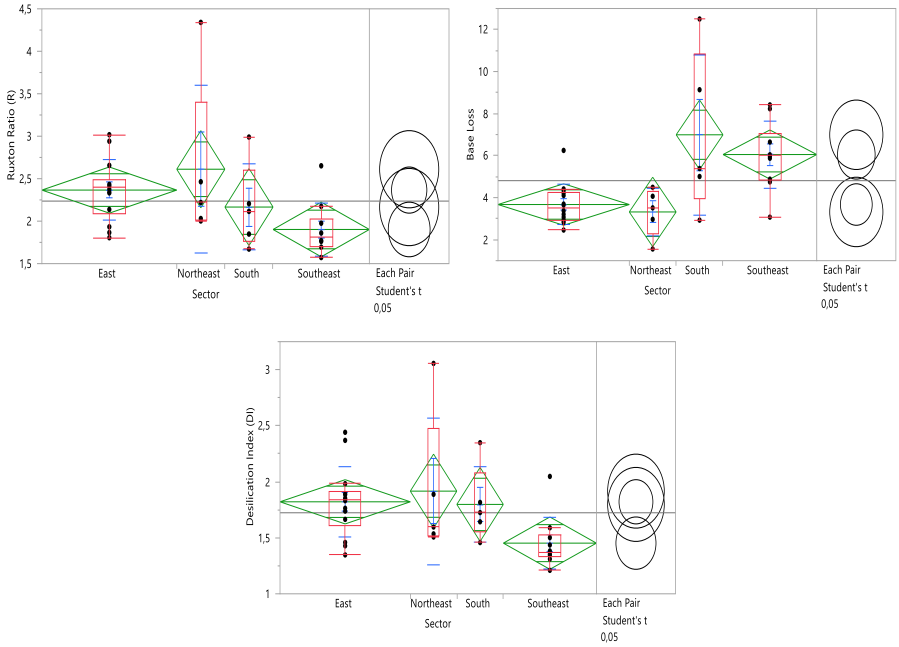

Fig. 3. Oneway analysis of weathering indices by volcanic soil

During the chemical weathering process, there is a loss and leaching of some alkaline minerals from the parent material which causes a decrease in basic elements in the soil. In this study, it was found that the level of loss in the South to Southeast region was relatively the same but significantly different from the East and Northeast sectors. Optimal weathering levels are found in the South and Southeast sectors (6,991 and 6,051), this explains that the base loss in the East and Northeast sectors is lower. Furthermore, soils with high levels of bases loss are dominant in the Southeast to a South sector (Fig.5). According to research [13], the East and Northeast sectors have higher exchangeable Ca and Mg than the South and Southeast sectors. Non-alkaline has the property of being easy to move so that the soil that has lead to advanced weathering has a low non-alkaline content. Ca and Mg and K will decrease in line with the progress of weathering [19][20].

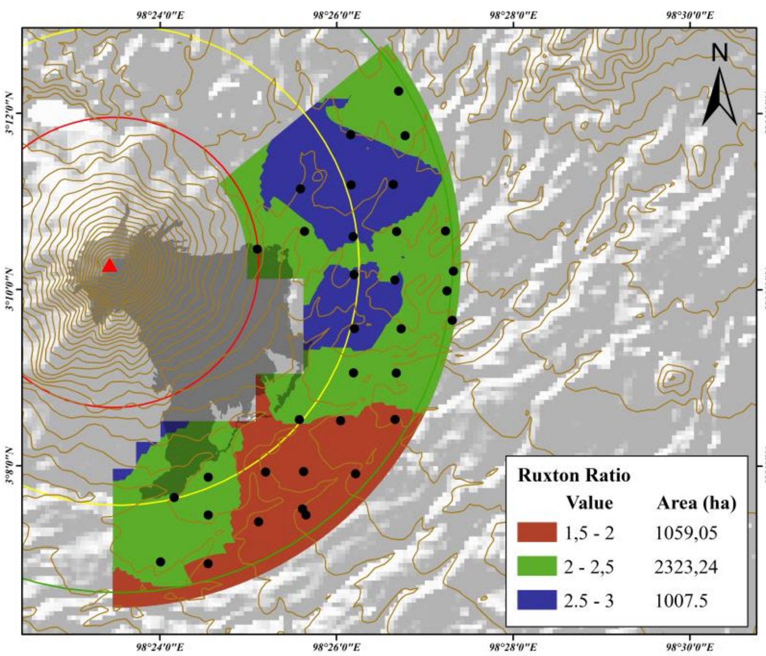

Fig. 4. Weathering indices distribution map based on Ruxton ratio method

The Desilication Index Ratio (DI) is a method used in calculating the weathering index by comparing mobile silica with resistant oxides, namely Al, Fe and Ti. The DI ratio value in the Northeast and East sectors is significantly different from the Southeast with the lowest average in the Southeast Sector (Fig. 3). This shows that the level of weathering of Silica minerals is lower in the Northeast and East sectors compared to the Southeast. The DI ratios with the highest to the lowest scores were Northeast, South East and Southeast with averages of 1,916, 1,821, 1,789, and 1.452%, respectively. Furthermore, soils with high levels of silica loss are dominant in the Southeast to a South sector (Fig.6).

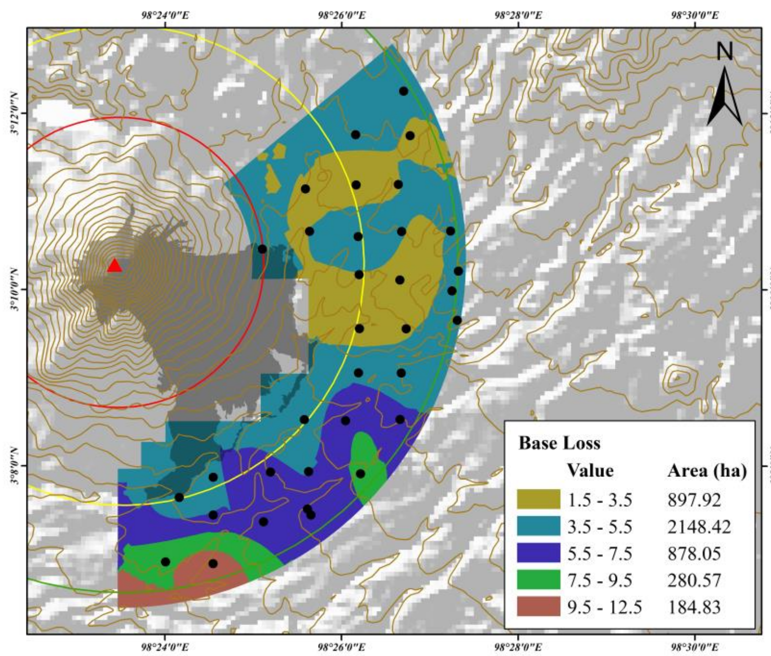

Fig. 5. Map of the distribution of the level of base loss in the soil

In this study, it was found that the lowest total SiO_2 oxide was found in the Southeast sector, which means that the level of Silica loss in the Southeast was higher than in other sectors. According to [11], the higher the Silica ratio, the lower the weathering rate so that the presence of immobile elements (Al, Fe, and Ti) will be low.

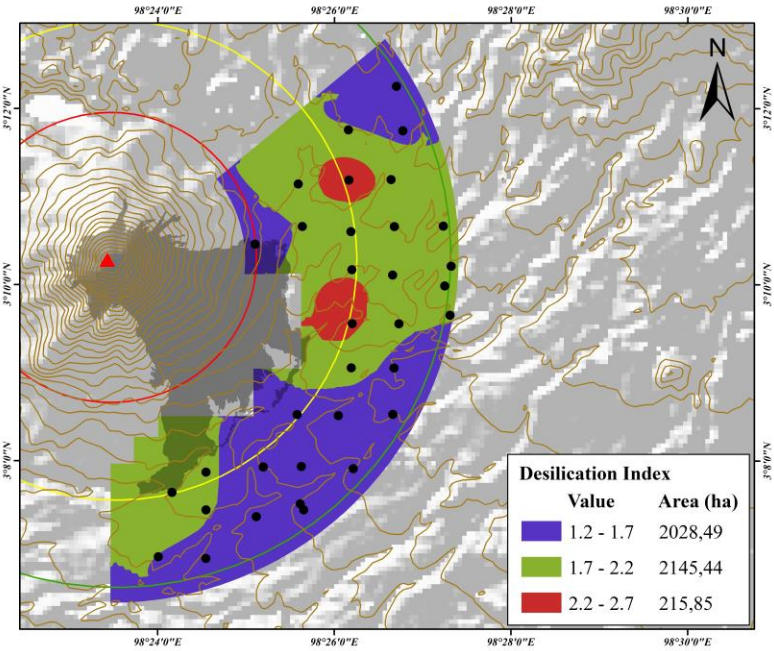

Fig. 6. Weathering indices distribution map based on Desilication indices method

4 Conclusion

Based on the results of the research described above, it can be concluded that the soil affected by the eruption of Mount Sinabung has a moderate level of weathering. The level of weathering from highest to lowest is Southeast>South>East>Northeast.

Acknowledgment

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