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THE IMPACTS OF MT. SEMERU VOLCANIC ASH ON THE NEARBY AGRICULTURAL LAND FERTILITY: A CASE STUDY OF APPLICATION OF BORE-HOLE AND GEOELECTRIC METHODS

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ABSTRACT: An investigation has been conducted, to assess the characteristics of two agricultural lands which exhibit different fertility, in Malang, Indonesia, due to volcanic ash from Mt. Semeru. The assessment was conducted using bore-hole sampling, and the geoelectric method. The results from the XRF analysis of bore-hole data indicate that the two lands have common dominant chemical contents, which are iron (Fe), and silicon (Si), whose concentrations range between 35% to 40% by mass. They also indicate, that at shallow depth, the land of Loc2 has a significantly higher concentration of phosphor (P) than that of Loc1, which is 2.1% compared to 1.2%, and that the concentration of Ca is higher at Loc1 than at Loc2, that is, about 13% to 10%. Other elements of much lower concentrations were also detected at both locations, such as Ti, K, and V. Geoelectric results show that the content of volcanic ash at shallow depths at Loc1 is thicker than that of Loc2. Higher phosphorus concentration obtained at Loc2 may be the cause of its better fertility. The results from the two methods show fairly good correlations, where, for instance, points with high Si concentration are well correlated with high resistivity values, while points whose contents are high in metallic elements have lower resistivity values. The geoelectric method has indicated that fertile land has lower resistivity, compared to less fertile ones. While the geoelectric method may offer less-quantitative results, however, it may play as an efficient complementary method.

Keywords: Volcanic Ash, Land Fertility, Geoelectric Methods, Bore-Hole, Iron, Silicon, Phosphorus

1. INTRODUCTION

Indonesia is known for its hundreds of volcanos, located on many islands in the country, so volcanic eruption is a common feature in the country. Nevertheless, investigating volcanic activity is always a common interest, due to its influences on various life aspects, such as economy, health, agriculture, transport, etc.

In East Java, one of the most active volcanos is Mt. Semeru, which is located within the Tengger-Bromo-Semeru National Park (TNTBS). The TNTBS is located near Malang City, which is the second largest city in the province, with more than 1 million population. Both The TNTBS and Malang City are popular tourist destinations, and, therefore, a volcanic eruption that occurs within this national park can have a tremendous economic impact.

The impact of the volcanic activities of Mt. Semeru on the agricultural sectors could be, mainly, on the productivity of fruit and vegetables, which are commonly grown in the nearby agricultural areas. It is well-known and easy to observe, that the land productivity of areas such as Poncokusumo is lower compared to those of Batu, despite that they are only about 40 km apart.

This research is aimed to assess the physical and chemical property differences, between two areas, one of which is frequently affected by volcanic ash from Mt. Semeru, represented by Gubuk Klakah (GK), in Poncokusumo, named Loc1 (stands for Location 1), and areas which are not, which is represented by Batu (BT), named as Loc2. Another aim of this investigation is to correlate the results obtained from implementing the geoelectric method, and those from implementing the bore-hole sampling method, from which we seek the possibility of developing a novel application of the geoelectric method, to be solely used for land fertility investigation.

2. RESEARCH SIGNIFICANCE

This research is an attempt to investigate the effect of volcanic ash on land fertility, and to correlate results from the bore-hole sampling which is analyzed using an XRF, to those results from the geoelectric method. Results from both methods, naturally, have different properties, where the first one produces fine and precise concentration values, while the second one produces rough resistivity distribution. Correlation from two data groups, however, may reveal how land fertility is related to its electric resistivity, which may lead to the possibility of employing the geoelectric method as a cheap and effective method to assess land fertility.

3. THEORETICAL BACKGROUND

Volcanic ash is a pyroclastic material, which is composed of particles of various sizes, ranging from sub-micrometer scale, to relatively coarse, on the millimeter scale. The geometric shape of volcanic ash particles is generally irregular and tends to have sharp edges.

The main content of magma is silicate materials accompanied by metals, such as iron (Fe). The silicate content in felsic volcanic ash can reach as high as 70% [1]. Witham et al. [2] reported that, from observations on fresh volcanic ash splatter, more than 55 different types of ions were obtained, dominated by Na^+, K^+, Ca^{2+}, and Mg^{2+}, as well as Cl^-, F^- and SO_4^{2-}.

Fresh volcanic particles tend to be spherical, with a diameter of less than 100 μm, and some of them, perhaps, are electrically charged [3]. Its coarse part, with an equivalent diameter larger than 1 mm, can fall during a relatively short time, that is in less than an hour, over a relatively short distance. However, volcanic ash particles whose diameter is less than 1 µm, can stay in the air for days, even months, and can be transported by the wind over long distances [3].

Colleen et al. [3] show that the factors that affect the spreading distance of volcanic ash particles are not only the geometric size (equivalent radius) of the particles but also their geometric shape. A spherical shape, for example, will have the lowest friction compared to other shapes, so that, when a spherical particle is exposed to the same force, it will travel a longer distance.

The fall of volcanic ash on agricultural land will cause disturbances to soil fertility. According to [4], as soon as the volcanic ash falls on the ground, a layer of soil, called Andisol, is formed on the local surface. Andisol soil is soil formed from falling volcanic ash, which has different properties from the soil in its surroundings. Andisol soil, in general, is infertile and tends to make plants not grow well. This is mainly due to its low nutrient contents of nitrogen, potassium, and phosphorus, and due to the presence of toxic elements [4]. Only after experiencing leaching by rainwater, for a relatively long period, the state of the soil can recover to its original state. Ashfall may also change the soil properties, by increasing its sulfur content and lowering its pH, which in turn reduces the availability of phosphate and other essential elements, which may cause crops and plants cannot survive [5]. A study of the influence of volcanic ash on the soil's mineral weathering rate conducted by [6] indicates that volcanic ash could increase the weathering rate, and thus increase the soil fertility. However, because weathering is a slow process, it may take a long time for the weathering products to affect soil fertility.

From an agricultural aspect, volcanic ash accumulated in large quantities, in the future, will form the fertile top layers. However, in the short term, relatively young volcanic ash particles can have a hydrofluoric acid-coated structure, which does not contribute to soil fertility, and can even damage the vegetation.

Geoelectric is one of the geophysical methods that gained great popularity of being used in research or survey because it is simple in operational principle, non-destructive, and relatively easy and cheap to apply.

One of the most popular implementations of the geoelectric method is for seeking groundwater and assessing its pollution. Other assessments that also mostly use geoelectric methods are site investigation, subsurface structural mapping, environmental studies, ore exploration, engineering soil characterization, archaeological investigations, etc.

Geoelectric has weaknesses in that it is only capable of detecting the physical properties of targeted objects, and not capable of directly detecting their chemical properties. Therefore, it is rarely used in the investigation of the chemical aspects of targeted objects. For that kind of implementation, the geoelectric method is quite often combined, or complemented, with other suitable methods. For example, the authors of [8]. in delineating sulfide deposits, used a combination of geoelectric and ground magnetics methods; [9] combined geoelectric method and direct soil analysis to assess the incessant road failure; and [10] combined the geoelectric method and hydrochemical analysis method to assess the impact of dumpsite to the nearby groundwater system. Even, in the cases of assessment of an object, that is completely physical, some investigators still often use the geoelectric method by combining it with another method [7].

4. METHODS

The locations for data acquisition are in a village known as Gubuk Klakah, named Loc1, and in a village in the Bumiaji, City of Batu, named Loc2, as shown in the map, in Fig.1, which displays Java Island and its small section, where this investigation was conducted.

In this investigation, the geoelectric and bore-hole sampling methods were employed, to access the properties of soils, from both locations. From the geoelectric method, we seek the distribution of resistivity values of soil, while, from bore-hole sampling, we seek samples, whose chemical contents will be identified quantitatively.

In geoelectric theory, the resistivity of any medium that conducts electric current is given by the equation

$$\rho = K\,\frac{V}{I} \qquad (1)$$

where K is the geometric factor of the current measurement configuration. This geometric factor, for the Wenner-Schlumberger configuration, for example, can be described by Eq. (2), as follows [11]

$$K = 2\pi\left(\frac{1}{|r_A - r_M|} - \frac{1}{|r_A - r_N|} - \frac{1}{|r_B - r_M|} + \frac{1}{|r_B - r_N|}\right) \qquad (2)$$

All symbols that are written in the formula (2) are related to the configuration presented in Fig. 2.

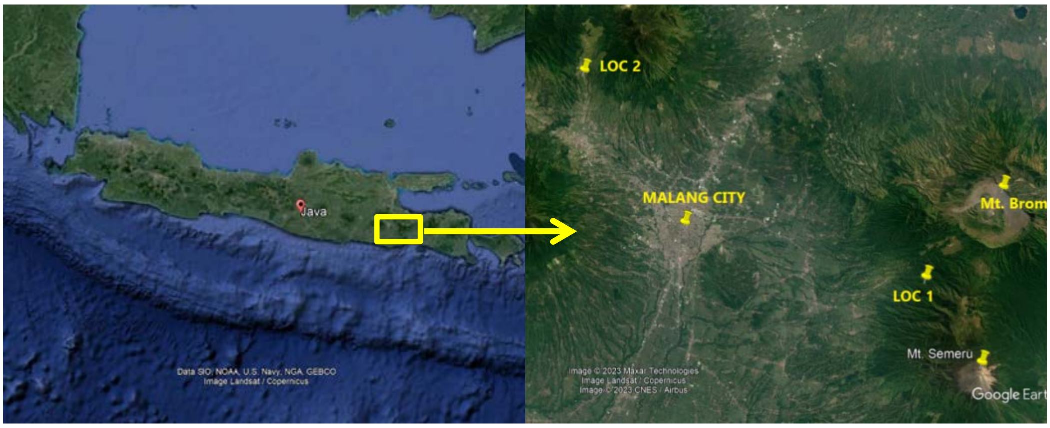


Fig. 1: Map of locations of data acquisitions, named Loc1 and Loc2, in Malang, East-Java, Indonesia

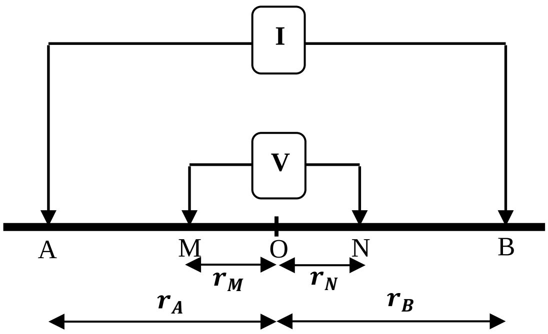


Fig. 2: Electrodes positions in the Wenner-Schlumberger configuration

The Wenner-Schlumberger configuration has relatively moderate sensitivity for vertical and horizontal structural mappings, so the use of the configuration is a good choice. The working principle of this configuration is to vary the distance of the current electrode from the potential electrode, by making it n times of potential electrode distance $(r_M + r_N)$. Because the farther the current electrode is from the potential electrode, the smaller the potential detected by the potential electrode, the measurement sensitivity is, then, maintained by expanding the potential electrode distance from time to time, so that the n needs not to be large. The impact of these changes only affects the calculation curves that will overlap and does not affect the homogeneity of the resistivity of the material. The advantage of this configuration is its ability to detect the inhomogeneous nature of rock layers on the surface, namely by comparing the apparent resistivity values for every change of electrode distance.

The bore-hole samples obtained from various depths are treated by cleaning them from non-soil elements and heating them sufficiently hot, i.e. up to 200ºC, such as to remove the water element in the soil. After that, the samples are sent to the XRF facility, for analysis that reveals their various elements and corresponding concentration and spectra.

5. RESULT AND DISCUSSION

5.1 Result

The results of resistivity from various depths, from Loc1, are compiled in Table 1, with their various lithology interpretations. Similarly, results from lithology interpretations are also provided for data from Loc2, in Table 2

Table 1: Resistivity values, and their lithological interpretations, from Loc1 (Location: $\mathbf{8^o3'4''}$ S, $\mathbf{112^0 6'42''}$E, 1184 m ASL)

Depth Range (m)			Lithology	ρ (Ω m)
0	to	0.27	Soil	188
0.27		0.34	Gravel-ash	14732
0.34		1.80	Gravel-ash	563
1.80		3.10	Tuff	10.7
3.10		3.30	Gravel-ash	704
3.30		7.05	Gravel-ash	459
7.05		18.30	Sandy Tuff	76
18.30		28.60	Sandy Tuff	203
28.60		34.10	Sandy Tuff	228
34.10		49.50	Sandy Tuff	304
49.50		70	Gravel-Ash	1275

Table 2: Resistivity values, and their lithological interpretations, from Loc2 (Location: $\mathbf{7^o48'15.90''}$S, $\mathbf{112^o31'32''}$ E, 1279 m ASL)

Depth Range (m)			Lithology	ρ (Ω m)
0	to	0.6	Soil	207
0.6		0.8	Tuff	10.8
0.8		1.1	Sandy Tuff	312
1.1		2.2	Tuff	16.8
2.2		4	Gravel-Sandy	968
4		9.1	Tuff	25
9.1		13.2	Sandy Tuff	193
13.2		25.5	Gravel	1229
25.5		50	Gravel	877-6718

The lithology interpretation of the resistivity data was made by referring to Fig. 3, where all lateral distances were measured from point GK-3, and measurements were conducted along lines of GK-3, GK-1, and GK-2.

Fig. 3: Map of Loc1 with measurement points.

Lithological interpretations from both locations are presented in

Fig. 4 and Fig. 5, from which one can see how the resistivity of the lands is distributed with the depths.

Fig. 4 represents the lithology modeling for Loc1, which was made along the lines of GK-3, GK01, and GK-2

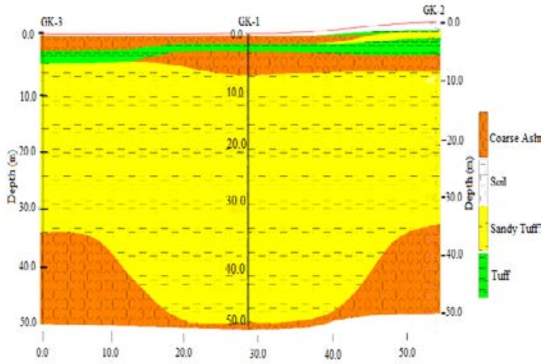


Fig. 4: Lithological interpretation along the lines of GK-3, GK-1, and GK-2

Similar lithological modeling, for resistivity data from Loc2, along the lines of BT-3, BT-2, dan BT-4, gives the result as shown in Fig. 5.

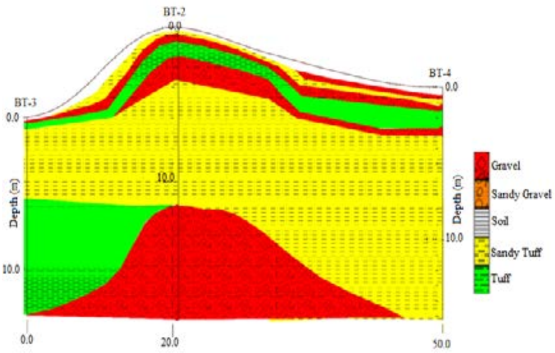


Fig. 5: Lithological modeling along the lines of BT-3, BT-2, and BT-4

The models, as shown in Fig. 4 and Fig. 5, indicate how surface layers for both locations are covered by gravel tuff, in Loc1, and sandy tuff in Loc2. It also can be seen that the gravel tuff layer in Loc1 is much thicker than the sandy tuff in Loc2. This may be a consequence of extensive and frequent ash covering undergone by land in the Loc1.

Plots for results from bore-hole data analyzed by using XRF analysis, for the few largest concentration elements versus the depth from Loc1 are given in Fig. 6. To make a comparison between data from the two locations, a similar plot also is provided for the elemental data from Loc2, which is given in Fig. 7.

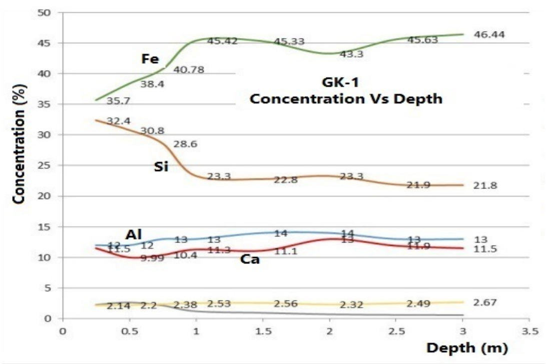


Fig. 6: Concentrations of main elements vs the depth, from Loc1

From both Fig. 6 and Fig. 7 it can be seen that soil content is dominated by Fe and Si. The trend is the same in both plots, where Fe increases with the depth, while Si decreases. Also, in both plots, the Al concentration is always larger than that of Ca. However, while in Fig. 6 Ca increases fairly smoothly with the depth, in Fig. 7 it decreases at some depths, with a slightly larger rate, and tends to increase again at further depth.

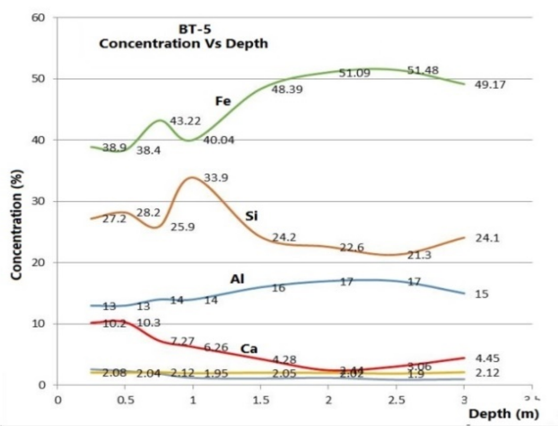


Fig. 7: Concentrations of main elements vs the depth, from Loc2

Fig. 8 presents plots of the lower-concentration elements from Loc1, while Fig. 9, presents similar data from Loc2. Lower concentration elements, from where differences between the two data groups appear, may be suspected as the source of all existing differences between soil characteristics, especially the concentrations of P in both locations. As can be seen from Fig. 8 and Fig. 9, Loc1 has a lower P concentration at the shallow strata compared to P concentration at about the same depth as Loc2.

In the following part, the correlations between results from geoelectric method and bore-hole samplings are shown in plots, as presented in Fig. 10 (a), for Loc1, and in Fig. 10 (b) for Loc2. In both plots, resistivity is given in ohm-m, depth is in meters, and concentration is given in percent.

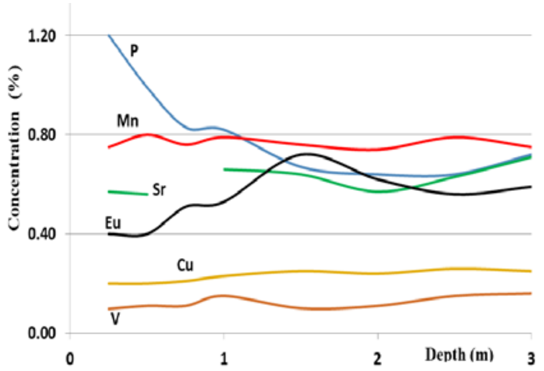


Fig. 8: Plots of lower concentration elements, from Loc1

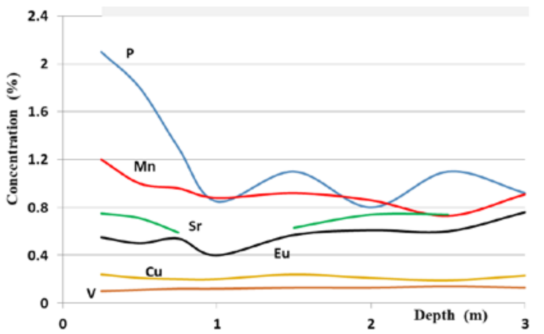
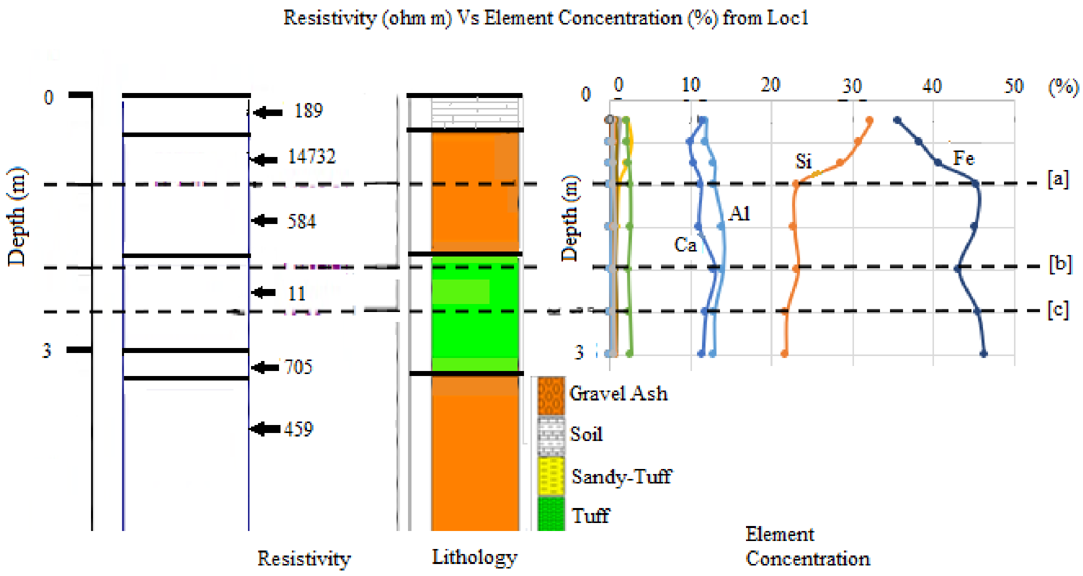


Fig. 9: Plots of lower-concentration elements, from Loc2

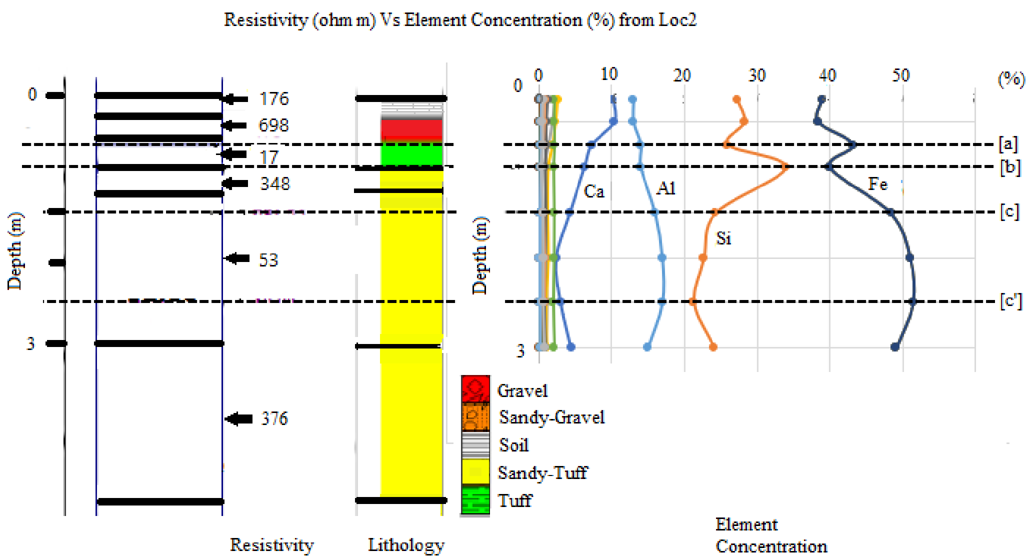
Due to technical and cost considerations, the depths for bore-hole land sampling were conducted only up to about 3 meters each, which is also considered to be sufficient for the main purposes of this study. On the other hand, by using the geoelectric method, through every measurement process, in principle, it is possible to obtain a general description of the resistivity for greater depths. Therefore, if successfully conducted, the geoelectric method may offer an easy, quick, and cheaper method for land fertility assessment. It would be greatly beneficial for those who are conducting an investigation of land fertility measurement for large areas, where detail elemental aspect is not important.

As can be seen from Fig. 10, the left part of the plot is a description of the distribution of resistivity values to a depth of 5 meters, while its right side part is a description of the concentration of chemical elements, up to a depth of 3 meters.

It can be seen in Fig. 10(a), that, one of the dominant elements, namely Fe, is associated with a low resistivity, and dominates the near-surface strata, while another dominant element, namely Si, is associated with a high resistivity value, at a slightly deeper strata.



(a)



(b)

Fig. 10: Correlation between the geoelectric resistivity data, and bore-hole data from Loc1 (a) and from Loc2 (b)

From the depth of about 1 m (along the line [a]) and on, the Fe dominates the Si by more than 20% and is indicated by a drastic drop of the resistivity from 14732 ohm-m to 584 ohm-m, or less. For deeper strata, between 2 and 3 m (between lines [a] and [c]), it can be seen that the resistivity values are, in general, low, which shows the dominance of the Fe over Si. Resistivity results indicate that for deeper points, the trend continues, which indicates the dominance of Fe over Si.

Similar results are indicated in Fig. 10 (b), which represents data obtained from Loc2. Near-surface resistivity indicates the dominance of the conductive material, which is Fe. The stratum at about 0.6 m still indicates relatively low resistivity, although it is fairly larger than that of the near-surface. This may be related to the slightly higher concentration of Si in that zone. At the zone between the lines [a] and [b], for which Fe concentration decreases, while Si concentration increases slightly, the resistivity value also increases, although it is still in the conductive range. At the zone between the lines [c] and [c'], resistivity is low, following the decrease of the Si concentration and the increase of the Fe concentration, as indicated by the bore-hole plot on the right-hand side of the plot. The increase of the resistivity in the zone under 3 m may indicate that the Si may be dominating.

In the study of geochemistry, various chemical elements have been known to have the unique value of their resistivity. In general, Fe, as a metal, is known to be a very good conductor, which means it has low resistivity. Si, on the other hand, has a much greater resistivity due to the fact it is an isolator material. For example, Si has a resistivity of about 10^{-3} ohm m, while Fe has a resistivity of about 10^{-8} ohm m [12].

Perhaps due to phosphorus' much lower concentration, compared to the concentration of Fe or Si, both Fig. 10 (a) and (b), do not clearly exhibit the role of phosphorus in determining the resistivity values. However, both figures indicate that near-surface strata, which are rich in phosphorus, have lower resistivity values, while those strata that are poorer in phosphorus have higher resistivity values.

5.2. Discussion

The resistivity measurement results, as described above, show that the soil layers at Loc1 and Loc2 have similar characteristics, but are distinguished by the presence of a thick layer of volcanic ash at Loc1. The thickness of the soil layer at Loc1 is suspected to be directly related to the activity of the nearby volcano, Mt. Semeru. Loc2 is also relatively close to a volcano, namely, Mt. Welirang. However, Mt. Welirang has been known to be inactive for a long time, for which no volcanic ash spread is recorded.

Bore-hole sample analysis shows that there are common features, in terms of main chemical components contained in samples from both locations, namely Fe, Si, Al, and Ca; and smaller concentration elements of C, P, Ti, K, and V. All of these elements were contained in all analyzed samples. However, there are concentration differences observed from certain elements, which may be the cause of the characteristic difference of the soil in the two locations. At shallow depths, samples from Loc1 generally have slightly lower Fe concentration, but slightly larger Si and Ca concentrations. For example, for the depths between 0.25 m to 0.5 m, samples from Loc1 have Fe concentration ranges from 36 to 38 %, compared to that of samples from Loc2, which ranges from 38 to 38.5%. These concentration differences between the two groups of data, are relatively small, compared to their corresponding values, and, therefore, supposedly do not play important roles in the overall property differences between the two lands. At both locations, the Al and Ca also tend to vary with the depth similarly, and hence can not be the cause of differences in the land properties. The presence of Ca slightly higher concentration in Loc1, recalling that its resistivity is low (4×10^{-8} ohm m [12]), geoelectrically, may not contribute to Loc1's general higher resistivity.

It can be seen from Fig. 8 and Fig. 9, which display the concentrations of non-dominant elements, that, for instance, the phosphorus element (P) at lower depth was more dominant in the sample from Loc2, compared to that of Loc1. For example, at the depth of 0.5 m, the concentration of P at Loc2 is about 1.8%, while at Loc1 is about 1%. At the depth of 1 m, concentrations of P in the two locations, are more or less the same, that is about 0.83%. At a depth larger than 1 m, P concentration in Loc2 varies from 0.85 % to 1.1 %, while in Loc1 it tends to smoothly decrease, from 0.80%, with the depth. In general, it can be seen from Fig. 8 and Fig. 9, that, the land at Loc2 was richer in phosphorus. Phosphorus is naturally contained in the soil. If no volcanic ash were present at Loc1, then, Loc1, and Loc2, which are geographically close to each other, should have phosphorus elements of similar concentration. Perhaps, the presence of the volcanic ash in Loc1 may have been the cause of its lower P concentration, compared to that of Loc2.

Through Figs. 10 (a) and (b) we try to correlate the concentrations of various elemental contents of the rocks with their resistivity values. Fe and Si, as the two most dominant elements, naturally, determine most of the overall resistivity. Their corresponding concentrations, or interplay between them, as indicated in the right-hand side parts of the figures, may have been a factor causing the variations of the resistivity values, at various depths, as indicated by geoelectric results, shown in their left-hand side parts. A stratum, that is rich in Fe, would naturally have lower resistivity, and one which is rich in Si would have higher resistivity.

Electrically, phosphorus is an element whose resistivity is fairly low, i.e., about 10^{-7} ohm m [12]. Although the geoelectric results do not reveal the nature of the phosphorus, however, they indicate that resistivity values seem to be related to its concentrations in near-surface strata. A closer look at the upper left parts of Fig 10 (a) and (b), together with Fig. 8 and Fig. 9, shows us how strata whose phosphorus concentration is larger, have a lower resistivity, and vice versa.

Phosphorus is an important element that determines land fertility, and, geoelectrically, its presence may contribute to low resistivity. Therefore, at least in the case of phosphorus, land fertility may be related to the resistivity of the land, the lower the resistivity, the more fertile the land is. For more general results which may indicate a similar phenomenon, the presence of land-fertilizing elements is needed, to extend the study to a broader scope. In principle, the lower the resistivity the larger the soil nutrient mobility. As indicated in an anion mobility study [14], the larger the mobility of soil nutrients, the more fertile the soil is, as it is easier for the plant roots to absorb the soil nutrients.

6. CONCLUSION

Analysis of the chemical constituents of soil samples from two sites, namely Loc1 and Loc2, showed that, in general, the chemical contents of soil samples from both locations were similar. The concentrations of the main elements in Loc1 and Loc2, such as Si and Fe, do not show significant differences between them. Similarly, at lower concentrations, the calcium concentration in both locations is relatively the same in near-surface strata, and slightly different in deeper strata, and hence is not considered the important cause of fertility differences.

The content of phosphorus (P), an element with a relatively low concentration, is more dominant at Loc2, with a concentration of 2.1% (by mass), compared to its concentration value at Loc1, which is 1.2%. Therefore, their concentration relative difference is fairly high. Differences in such non-dominant elements, mainly phosphorus, are considered to be the cause of the difference in land fertility in the two locations, which may be due to the influence of volcanic ash presence. The low resistivity of phosphorus may contribute to the overall land lower resistivity in Loc2

The correlation of resistivity data, as obtained from geoelectric method, with chemical elemental data, as obtained from the XRF analysis, shows a good result. It can be seen from Fig. 10, that metallic elements correlate with low specific resistance values, while non-metallic elements correlate with various resistivity values, which are generally high. While the geoelectric method does not provide quantitative results, however, it provides qualitative data on how matters are distributed with the depth of the land, which can indicate which chemical contents are dominant amongst the others. Geoelectric results show an agreement between the richer phosphorus near-surface strata and their corresponding lower resistivity values, which means that the more fertile a land the lower its resistivity is. Although, at this stage, we can not expect the geoelectric method to be used solely for land fertility investigation, however, we could employ it as a complementary method to strengthen the results from the bore-hole method, or vice versa, recalling the information it could provide may be useful for the overall investigation results.

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