INVESTIGATION OF VOLCANIC ROCKS ORIGIN ACCORDING TO ORE MINING BY USING OPEN SOURCE GEOGRAPHIC INFORMATION SYSTEMS

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KEYWORDS: Open Source GIS, Ore Mining, Volcanism

ABSTRACT*:* The purpose of this study is to investigate the origin of volcanism which surfaced around Afyon and Kütahya cities and outcropped in the region which has been named as the Phrygian valley in the literature. It is known that, volcanism had occurred during different periods in two different region in the studied area (Şuhut and Bayat Regions-Afyonkarahisar). Making research on these volcanic rocks which were formed during these eruptions, finding their similarities and contradictions are important according to the known mineral deposits in this region. Chemical analyzes of volcanic rock samples which were collected from the field trips were done during the study. Major oxides values of each rock samples were obtained.The regional volcanic rocks database has been established by using data and analysis values of each different samples as an attribute. GIS methods were utilized to interpret the results of chemical analysis. QGIS was used as an Open Source GIS software in this study. Primarily, the distribution of major oxides in the studied area were interpreted. Evaluation of the thin section of each rock samples were done under microscope according to the results of distribution of major oxides. At the end, new potential iron, clay and marble occurrences were tried to reveal which are known as famous metallic and nonmetallic mineral deposits for this region.

1. INTRODUCTION

The Phrygian Valley is one of the major volcanic regions partly located in the Tavşanlı and Afyon zone in western Turkey.In this paper, the study area was also identified not only the geological, petrographical, mineralogical properties but also the chemical and geochemical data. These volcanic rocks are distinguished from other rocks by their characteristic different colors, structure, and typical alteration due to finely occurred clay minerals, different colored opal, and some metallic minerals such as hematite, and limonite minerals. This study deals with Tertiary aged volcanites of the east-southern part of the Phrygian Valley, and the main purpose of this study is to designate geological, petrographical, and geochemical characteristics of Tertiary aged volcanites to correlate these data.

2. GEOGRAPHIC LOCATION OF THE STUDIED REGION

The study area is approximately located 30-40 km northeast of Afyonkarahisar, in the Phrygian valley part of the 600-km long, NW-SE-trending Afyon and Tavşanlı Zone. The area in the border of Afyon and Tavşanlı Zone have been selected as the studied area (Figure 1).

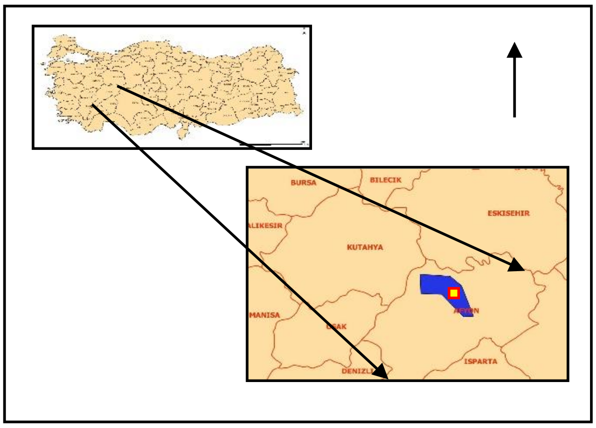

Figure 1. Location map of the studied region

3. TECTONIC ZONE OF THE STUDIED REGION

Turkey is located on an east–west trending segment of the Alpine–Himalayan orogenic belt. It is made up of a number of continental blocks separated by ophiolite suture zones. There are mainly six continental blocks, from N to S (Okay and Tüysüz, 1999, Candan et al., 2005). Western Turkey is divided into the Pontides in the north, which is separated by the İzmir -Ankara Suture Zone from the Anatolide–Taurus Block in the south (Ketin, 1966; Şengör and Yılmaz, 1981; Okay et al.,1996, Candan et al., 2005). The studied region is located between Tavşanlı and Afyon Zones (Figure 2).

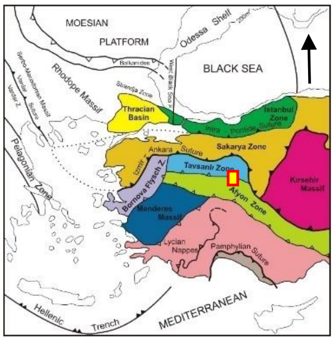

Figure 2.Tectonic location of the studied area (Okay & Tüysüz, 1999)

4. GENERAL GEOLOGY OF THE STUDIED REGION

The oldest lithological unit is metamorphic rocks. The main metamorphic units are from north to south: the Tavşanlı Zone, the Afyon Zone, the Menderes Massif and the Lycian Nappes. The Afyon Zone was regarded to have undergone lower green schist facies metamorphism (Okay, 1984; Okay et al., 1996; Göncüoğlu et al., 1992 Candan et al., 2005). The green schist-facies metamorphism is suggested by the assemblage quartz, albite, chlorite, white mica, less garnet and biotite. The schist unit is conspicuously free of carbonate layers. Paleozoic aged Iscehisar marbles were formed as a result of regional metamorphism (Candan et al., 2005).

Metamorphic rocks are overlaid by the sedimentary and different type of volcanic rocks. In the central part of the Afyon Zone around Kütahya, (Bayat–İscehisar-Seydiler-Gazlıgöl), and Eskişehir (Kırka), this assemblage is exposed as scattered outcrops of varying size. These rocks are seen as Mesozoic and Tertiary aged.

The volcanic rocks outcrop dominantly intermediate-felsic rocks andextend as N-S and NW-SE orientation in the segment of the Phrygian Valley, the south of the İzmir-Ankara suture zone (IASZ) (Kibici et al., 2008, Kibici et al., 2010, Kibici et al., 2015). The volcanics in the Phrygian Valleycan be divided into three regions; Kütahya, Afyon and Eskişehir Region. The volcanic activity both north Afyon Zone and Tavşanlı Zone produced Tertiary aged acidic and intermediate volcanic rock, whereas the south of Afyon Zone's volcanic rocks can be identified as an alkaline character. This paper generally is focused on Afyon Zone's volcanics (Figure 3).

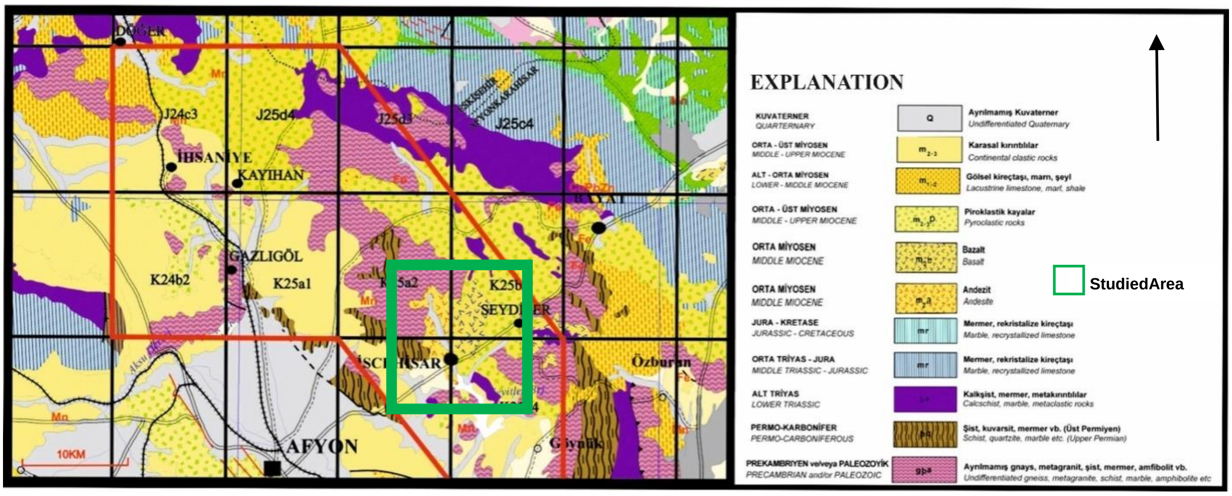

Figure 3. Geological map of the region (General Directorate of Mineral Research and Exploration, 2002)

5. MINERALOGY,PETROGRAPHY and STRUCTURE OF THE VOLCANIC ROCKS

Petrographically, the Karakaya lavas are mainly named as trachyandesite and andesite.These rocks consist of primarily of plagioclase (*oligoclase*), amphibole (*brown hornblende*), clinopyroxene and biotite. Seydiler ignimbrite lavas are mainly named andesite, trachyandesite, and less rhyolite, rhyodacite. These rocks are also consist of plagioclase (*oligoclase, andesine*), amphibole (*brown hornblende*), biotite and quartz. Plagioclase, amphibole, and clinopyroxene and biotite are main phenocrystals of the lavas. Euhedral plagioclase (*andesine*) phenocrystals show polysynthetic twinning and zoning. They have microlitic porphyric texture.

Somewhere, these volcanic rocks show well-developed columnar jointing and flow structure with thicknesses of 10.0 cm. to 120.0 cm. leucitite and phonolite occur in the study area. They are easily distinguished by their physical properties and mineralogical compound. In addition, they have leucite minerals.

Some samples of the volcanic rocks exhibit various degrees of alteration in the studied area. The diatomite and different colored opal deposits (such as yellow, white, brown, dark and light green colored opals) and other alteration products occurred by alteration of rhyolitic and andesitic volcanic rocks in Seydiler and Karakaya, Central Afyon Zone and southeastern-east Phrygian Valley. These diatomite and opals are classified in two stratigraphic levels. These horizon are seen as10 different colors and patterns. They are commercially known as Seydiler–Bayat (Afyon/Turkey) opals in the literature. Pyroclastic eruptive products are presented in this period. They are known as rhyolitic, andesitic and rhyodacitic lavas and they exhibits various degrees of alteration. These volcanic units have been kaolinized, silicified and affected by hydrothermal solutions.

6. METHODOLOGY

6.1. Geochemical Studies

20 representative unaltered samples from the volcanic rocks of Phrygian Valley were examined for petrographical and geochemical analyses. Unaltered samples were selected by using optical microscope studies. These samples are used for the major analysis. Different mineralogical composition and petrographical textures have identified from selected volcanic rocks. According to these mineralogical compounds, volcanic rocks are classified on four groups.

In the volcanic area of Afyon Zone, the activity is marked by aphanitic or weakly porphyritic lava flows. Major and trace element variations show that magma evolution paths were controlled by fractionalcrystallization of plagioclase, hornblende, clinopyroxene, Fe-Ti oxides and apatite.

Petrochemically, both Seydiler and Karakaya lavas exhibit medium-to high-K calc-alkaline character. Some part of Karakaya lavas are composed of basaltic andesite and basalt products with medium and low-K content.Afyon zone volcanic rocks define a compositional rangefrom rhyolite through basalt, and tracybasalt. Seydiler and Karakaya volcanic rocks have a range from nearly 50-62 % SiO_2. The calc-alkaline samples have the highest contents of TiO_2 (0.14-2.18), Fe_2O_3 (1.92–8.49), MgO (0.86–8.84) andCaO (1.28–9.48) and the lowest contents of Na_2O and P_2O_5.

Whereas most of the alkaline samples have the lowestTiO_2, MgO, CaO and the highest Al_2O_3, Na_2O and P_2O_5 values. The sub alkaline samples have intermediate values for all these major oxides (Table 1).

Table 1. Major oxide elements value of the collected samples from the studied area

iscehisar :: Features total: 47, filtered: 47, selected: 0

	Sample	X	Y	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	Ba	Rb	Sr	Zr	Nb
0	G1a	304851	4294066	60.03	0.66	15.31	4.79	0.08	2.43	3.81	2.77	4.8	0.42	528	313.5	654.7	783.8	31.5
1	GI11	304137	4296170	49.69	1.24	15.17	8.07	0.13	5.35	9.39	2.51	3.64	0.62	1568	58.8	778	328.7	29
2	GDI2-9	304723	4296202	49.39	1.32	15.32	8.49	0.17	5.24	8.85	2.07	3.57	0.74	229	169	66.8	104.9	13
3	GDI6	304723	4296203	49.18	1.22	15.59	8.36	0.14	7.12	9.42	2.56	2.24	0.55	487	168.9	147.7	93.8	16.5
4	GI2	304723	4296204	54.95	2.18	11.43	5.85	0.16	6.51	5.08	1.22	9.18	0.71	1605	110.4	798.4	383.7	33.1
5	GI4	304723	4296205	50.81	1.39	15.81	8.07	0.11	4.96	8.96	2.77	3.66	0.69	1500	65.7	845.6	342.1	30.5
6	GDI8	304723	4296206	51.3	1.35	15.38	8.04	0.1	5.73	9.26	2.51	3.41	0.63	1541	58.7	830.2	325.9	29
7	GI5	304723	4296207	50.44	1.36	15.66	7.9	0.11	4.9	7.63	2.45	4	0.69	1872	48.7	951.7	354.6	32
8	GI3	304723	4296210	49.73	1.32	15.28	8.25	0.14	5.72	8.58	2.38	3.61	0.69	1844	97.3	806.4	315.1	26.9
9	GDI2-10	304723	4296211	50.95	1.33	15.6	8.12	0.14	4.52	9.48	2.4	3.54	0.65	1682	185.7	726.8	431	24.3
10	G5a	304723	4296213	57.63	1.93	12.67	5.23	0.04	3.6	4.06	1.4	8.47	0.61	1801	192.9	793.2	461.8	25.2
11	I5	306206	4299358	51.65	1.76	11.77	6.42	0.1	8.41	7.08	2.34	5.82	1.38	2522	188.7	1106.4	815.7	35.6
12	I6	306206	4299360	50.49	1.76	10.32	6.21	0.1	8.84	7.08	1.18	6.99	1.25	2614	142.2	990.9	819.5	35.2
13	I7	306206	4299361	50.93	1.67	11.18	6.67	0.1	8.06	7.26	3.4	3.55	1.5	2595	557.1	1167.7	753.4	34.5
14	I2	307062	4299841	52.07	1.79	11.27	6.69	0.11	6.05	7.46	2.75	5.8	1.46	2546	234.3	1232.2	852.5	37.6
15	I3	307062	4299842	51.92	1.79	11.17	6.6	0.1	6.18	7.37	4.13	3.45	1.47	2583	377.5	1219.4	838.5	37.2
16	I8	306956	4301586	50.05	1.88	11.61	6.39	0.09	6	5.58	1.53	8.62	0.96	1859	235.7	1293.6	882.3	37.2
17	I9	306911	4301719	50.61	1.91	11.91	6.49	0.1	5.89	5.25	1.65	8.74	1.09	1996	233.5	1366.5	857.3	34.5
18	I34	306623	4303689	51.37	1.74	11.41	7.34	0.09	6.25	7.72	4.19	2.19	0.94	827	414	798.7	865.7	44.8
19	I33	307247	4304073	52.8	1.82	11.8	7.46	0.13	5.49	7.41	2.66	5.08	0.92	864	182.7	802.7	905.8	46.6
20	I31	307859	4304461	54.46	1.57	13.97	7.3	0.08	3.43	6.67	2.23	6.17	1.09	2132	153.4	973.9	610.2	26.1
21	I32	307859	4304462	53.19	1.63	14.6	7.45	0.1	3.5	6.72	2.19	5.74	1.15	2304	124.4	1014.8	612.3	26.6
22	I12	300818	4304868	52.85	1.94	10.83	6.02	0.09	9.71	5.44	4.07	3.32	0.73	643	515.7	620.6	1059.2	57.7
23	I13	300906	4304873	52.11	1.87	11.18	5.99	0.09	9.61	5.56	1.79	6.48	0.72	743	281.7	647.8	965.5	53.3
24	I14	300906	4304874	57.07	1.43	12.84	6.67	0.14	3.94	3.27	1.47	2.9	0.61	569	219.8	284.7	625.3	35.8
25	I15	300906	4304875	61.87	0.7	15.79	4.73	0.13	1.46	1.05	0.55	2.82	0.26	606	160.5	127	222.1	17.4
26	I16	300926	4304974	52.51	1.89	11.17	5.92	0.09	9.01	5.47	4.69	2.74	0.77	737	601	675.1	1012.2	55.5
27	I17	300926	4304975	70.16	0.14	13.83	1.92	0.07	0.86	1.28	2.16	4.7	0.02	468	181.9	137.8	105	17.1

At the end of the geochemical laboratory analyses major oxide element values were obtained. The coordinates of each sample point had been get during the field study.

6.2. Geographic Information Systems (GIS)

Geographic information system (GIS) is defined as a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial(Wikipedia, 2016). The important points in this definition are to analyzing and the type of the data which is spatial data. These two points are especially very important for earth scientists. Because geologists are interested about spatial data, must know the coordinate value of it and analyze these data for getting a new map for evaluation and getting the result, solving the problem.

Here, in this study we have interested the distribution of major elements values in this area. We have used Open Source GIS Software for this study. The name of the software was QGIS. The collected samples from the field and analyzed data values from the laboratory were used as an input data for GIS interpretation. The data which were in the Excel format was converted to the comma separated value (CSV) format type. Because QGIS can accepts this format like many others. This format type is selected because it's very easy to make this conversation. Then "Interpolation" which is one of the widely used spatial analysis method in GIS. Spatial interpolation is the process of using points with known values to estimate values at other unknown points (QGIS, 2016). Interpolation was used for this purpose. There are two different interpolation methods in this analysis. One of them Inverse Distance Weighting (IDW) the other one is Triangulated Irregular Networks (TIN). IDW method wasused and the grid distance was selected as 250X250 m. After the interpolation and getting the results, evaluation of major oxide elements distribution was done for the studied area by using GIS methodology.

7. EVALUATION MAJOR OXIDE ELEMENTS DISTRIBUTION ACCORDING TO ORE MINING BY GIS

At the end of the GIS analysis, it's understood that distribution of the SiO_2 content is high at the north of İscehisar district (Figure 4). SiO_2 content is above the 60 % in these region. At the south part of the studied area SiO_2 content is below 50 %. The high content of SiO_2 is related to the occurrence of volcanic rocks (tuff and andesite).

Interpretation of distribution of Al_2O_3 content indicated a low circular zone near İscehisar district (Figure 5). This low circular zone is due to localization of basalt and marble type rocks in this region.

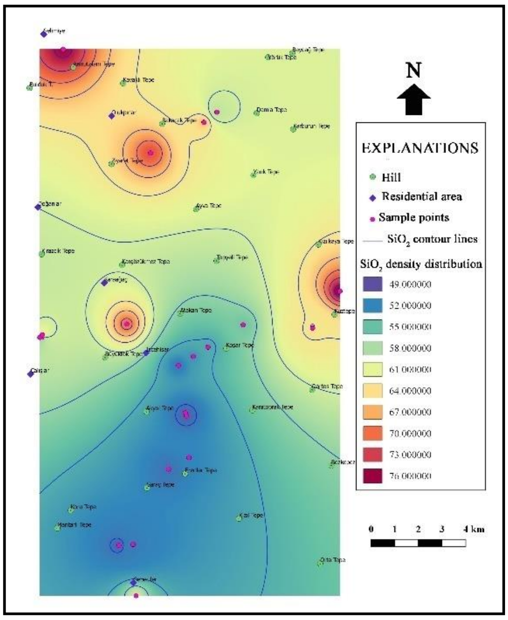

Figure 4.Distribution of SiO_2 content

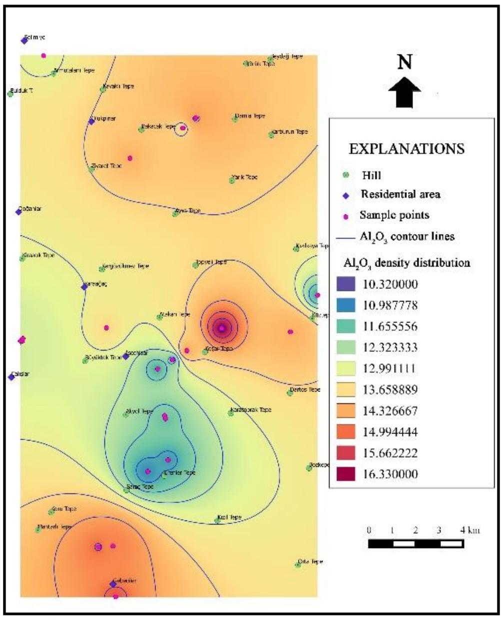

Figure 5. Distribution of Al_2O_3 content

High Fe_2O_3 distribution in the studied area is related with metamorphic rocks such as metamorphic schists (Figure 6). It known that, these rocks have mostly consist of ferro-magnesian (mafic) minerals. Alteration of the mafic minerals are also seen during the field studies. This is another factor that the high Fe_2O_3 content corresponds to high mafic minerals.

High and low Na_2O distributions ofthe studied area are seen ascircular shaped spots(Figure 7). Evaluation of these high and low spotswere correspondto the lithological units in the studied area. Trachy-basalt outcrop which is seen in the SE part of the İscehisar corresponds to low Na_2O content. The rhyolite and rhyodacite outcrops are located nearby thetrachy-basalt contact and the rhyolite and dacite rocks are correspond to high Na_2O content.

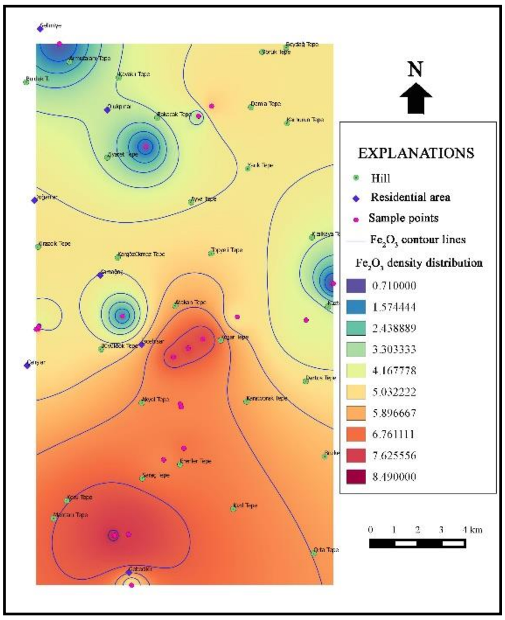

Figure 6. Distribution of Fe_2O_3 content

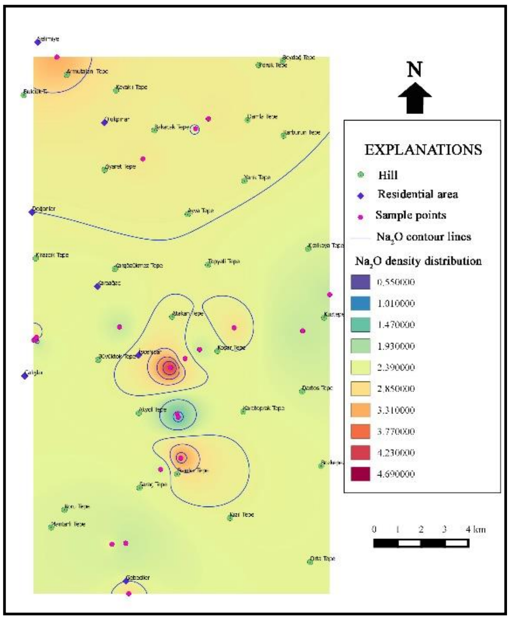

Figure 7. Distribution of Na_2O content

K_2O in the studied area shows the same distribution shape like Na_2O distribution(Figure 8). High and low circular shaped spot distribution of K_2O can be explained by the same result of Na_2O content distribution.Trachy-basalt outcrops correspond to high and rhyolite and rhyodacite outcrops give low K_2O content.

Interpretation of high CaO content is due to the occurrence of the most famous Afyon-İscehisar marbles in the south and the central part of the region (Figure 9). This marble is known as the famous Afyon Marble in the international marble literature. These marbles are seen mostly in the metamorphic rocks.

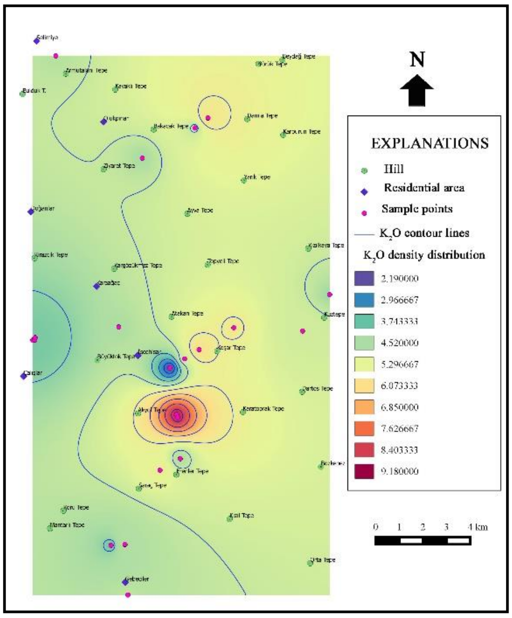

Figure 8. Distribution of K_2O content

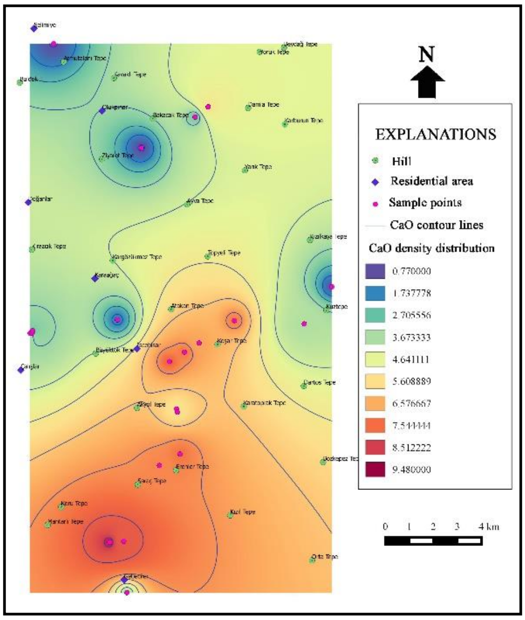

Figure 9. Distribution of CaO content

8. RESULTS and RECOMMENDATIONS

The following results can be get at the end of the evaluation of the GIS study;

- High SiO_2 values correspond to volcanic rocks,
- Low Al_2O_3 values indicates metamorphic rocks and marbles,
- Metamorphic rocks are the indicator of high and volcanic rocks are the indicator of low Fe_2O_3 content,
- High Na_2O and K_2O contents correspond to volcanic and low content to metamorphic rocks.
- The occurrence of marbles in the metamorphic rock shows high and volcanic rocks on the north shows low CaO distribution values.

- It is understood that, there is a high relationship with the chemical analysis results by the GIS and the lithological occurrence of rock units in the studied area.
- Many industrial mineral kaolinite deposits can be seenaround the area where the high Al_2O_3 distribution values were evaluated,
- It is also interpreted that occurrence of marble quarries corresponds to high CaOdistribution values.

The following recommendations can be obtained at the end of the study;

- This type of study must be extend to a larger area than this area.
- Evaluation of chemical analysis results by using GIS for the industrial mineral exploration studies will give more reasonable results.
- Using the distribution of minor and trace elements values in addition to evaluate the distribution of major oxide element values by GIS, will increase the precision and accuracy of the study.

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