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Geochemical heat maps in complex geological structures via using QGIS: Maden (Elazığ) district

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ABSTRACT

Geochemical analysis results are one of the most significant indicators that reveal the characteristics of the geological structures in a region. In particular, the differences in the composition of complex geological structures can be evident in field and Geographic Information Systems (GIS) studies. Turkey includes a character consisting of quite complex features with its geological structure. The Maden (Elazığ) complex has also attracted the attention of many researchers with its complex structure. The Maden Complex also contains basalts, basaltic andesite, andesite, dacite, diabase, and pyroclastic rocks, which are intercalated and lateral-vertical transitive with all these sedimentary successions. Mapping and lithological differentiation of the Maden Complex, which has a very complex structure, is difficult. The geochemical analysis of the samples taken from the field was transferred to the GIS environment with their coordinates. Thematic maps are created to make the geological interpretations in this region cleaner and the field data more predictable. These maps also allow the correlation of major oxides and trace elements. In this study, the geochemical data obtained in the Maden Complex were analyzed in the QGIS program. The geochemistry of the region has been made more understandable and interpreted with heat maps. The diversification of thematic maps, which gives a new perspective to geochemical data, will provide more support to geological studies.

1. Introduction

The Southeast Anatolian Orogenic Belt (SAOB) constitutes the eastern part of the Taurus Orogenic Belt, which is one of the most critical tectonic belts in Turkey, located between the Arabian platform and Anatolian micro-plate (Şengör & Yılmaz 1981; Ural et al., 2015; Ertürk et al., 2017, 2018, 2022; Sar et al., 2019; Yılmaz et al., 2022) This belt is a complicated part of the Alpine–Himalayan Mountain range with numerous distinct characteristics. This region has a complex geodynamic history, with northward subduction and closure of the Tethyan Ocean branch and the collision of various continental blocks. The Southeast Anatolian Orogenic Belt has been studied by many researchers in three belts from south to north (Yılmaz, 1993; Yılmaz, 2019).

(1) During the period from Precambrian to Early Miocene, the "Arabian Platform" consists of a thick autochthonous sedimentary sequence accumulated in the marine environment and the base volcanic rocks.

(2) The "Zone of Imbrication" occurs in the north of the Arabian Platform, forming a reverse fault zone developed in the Late Cretaceous-Early Miocene interval, about 5-10 km in width.

(3) The uppermost central tectonic unit, which includes the Middle Eocene Maden Complex, is the "Nap Zone". These zones are separated from each other by thrust faults. The study area is located north of the Bitlis–Zagros suture zone. It covers the most widespread and the best-observed regions of the Maden Complex, which have an important place in understanding the geodynamic evolution of the region.

Geochemical inputs are applied to clarify many geological problems. One of the powerful practices of these data is statistical and spatial approaches. As it is recognized, many geological studies have been supported by remote sensing and geographic information systems in recent years. These studies are conducted with advanced programs in a computer environment with technology development. Now, many GIS programs are used, and an open-source-coded QGIS program was used in this study.

With scientific advances in spatial analysis techniques, linearity, ore exploration and morphological

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investigations have developed into approximately practical. Geographic Information Systems (GIS) have also been used in many mineral exploration studies and mine probability maps (Porwal et al., 2001; Joly et al., 2012; Lindsay et al., 2014).

The Maden Complex is an extraordinarily significant structure for the geology of Turkey. Major oxide and trace element analyzes were carried out of the samples compiled from the field in this region, which has many complex geological characteristics. The geochemical distribution of this complex region and the relationship between the elements can become more visible with thematic maps in the GIS environment. Heat maps of some of the analysis results of the sample points were created, and discussions on the geological structure were prepared. The spatial geochemical changes of the Maden Complex, which has a very complex structure, will be an important finding for the enlightenment of the geology of the region.

The purpose of this study is the spatial interpretation of geochemical data.

2. Method

Data analysis in geochemical studies requires consideration of both geographic locations and attributes. With the development of computer hardware and software along with technology, an increasing number of spatial analysis and statistical techniques have been integrated into GIS, which makes a great contribution to geochemical analysis studies (Fotheringham & Rogerson, 2013).

At the same time, with the development and application of spatial analysis techniques, problems related to geochemical mapping, mineral exploration, and many geological problems can be solved (Overpeck et al., 2011; Reichman et al., 2011).

The samples collected from the field study are detected via XRF and ICP-MS methods. The major elements were measured by X-ray fluorescence techniques on fused glass beads. Trace elements were measured by inductively coupled plasma-mass spectrometry (ICP-MS). The major oxides and trace element analysis detected by Ertürk et al. (2018) was digitized in the GIS environment, and sample points were located. Afterward, heat maps dwelling on major oxide and trace elements were made.

3. Geological Background

The Maden Complex is situated in the Bitlis-Zagros Suture Zone, including the Zone of Imbricate and Nappe Zone. In the study are the Upper Cretaceous Guleman Ophiolite and the Maastrichtian Lower Eocene Hazar Group thrust over the Middle Eocene Maden Complex. The Guleman Ophiolite crops widely in the east and southeast of Hazar Lake and presents its most typical outcrops around the Alacakaya-Maden districts. Regarding the formation of the Guleman ophiolites, many researchers have stated that the Guleman Ophiolites are products of the Neotethys oceanic crust that began to open from the Upper Triassic between the Pütürge Metamorphites and the Keban-Malatya massifs (Michard et al., 1984; Yazgan & Chessex, 1991). The Guleman ophiolites emplaced on the continental crust towards the south with the closure of the Neo-Tethys Ocean in the Late Cretaceous.

Rizeli et al. (2016) accept that the Guleman Ophiolite was formed in the fore-arc basin at the beginning of the northward subduction of the southern branch of Neo-Tethys.

According to Kaya (2004), the Hazar group consists of a red-brown basal conglomerate at the bottom, and grey, green and light brown coloured sandstone, siltstone, mudstone, shale, marl and limestone towards the top.

For the formation of the unit, researchers such as Özkan (1982), Perinçek & Özkaya (1981), and Aktaş & Robertson (1984) stated that the environment initially presented terrestrial conditions. The units at the base of the Hazar group represent this terrestrial environment and are laterally associated with the Simaki Formation. They stated that the deposition basin gradually deepened with block faults, and the formation was deposited under marine conditions. In contrast, the uppermost Gehroz Formation was pelagic limestones deposited in the shelf environment.

The Maden Complex cropped out over vast regions in Eastern Taurus (Figure 1). The representative field photographs are given in Figure 2.

The Maden Complex also contains basalts, basaltic andesite, andesite, dacite, diabase and pyroclastic rocks, which are intercalated and lateral-vertical transitive with all these sedimentary successions. The brecciation is widespread due to tectonism. Also, the region observes intensive alterations depending on the thrusts and imbrications. The magma constituting the Middle Eocene Maden Complex was derived from a source like E-MORB and N-MORB enriched by previous subduction components.

In addition, this situation shows that crustal contamination processes play an active role in addition to the fractional crystallization of the mechanism that is effective in the development of rocks (Ertürk et al., 2018).

After the Late Cretaceous collision in the region, ophiolites were thrust on the Arabian Plate, and the Pütürge-Bitlis Metamorphic Massifs overlaid the ophiolites, and a significant crustal thickening occurred. The bottom part of the Late Cretaceous subduction zone and Bitlis-Pütürge Metamorphics and the gap formed due to the drifting of the lower ophiolites into the asthenosphere were filled by the asthenosphere. The magma formed by partially melting the adiabatically rising asthenosphere with the effect of the volatiles released from the collapsed part rose and formed the Maden Complex on the Guleman ophiolites (Ertürk et al., 2018).

Perinçek (1978) stated that the Maden Complex was deposited in the deep sea, was complicated by intense tectonics, and gained its present position by moving south as drift covers.

Yazgan et al. (1987) stated that the Maden Complex is volcanism due to intraplate continental subduction, which is formed by partially melting the upper mantle due to post-collisional compressional tectonics.

Ertürk et al. (2018) reported that the middle Eocene Maden magmatism developed in a post-collisional environment by asthenospheric upwelling owing to convective removal of the lithosphere during an extensional collapse.

Yalçın et al. (2020) stated that Cu anomalies in Maden Complex are around Hasenekevleri (Maden-Elazığ) and said that Cu mineralization is in vein type within diabases.

Ertürk & Yalçın (2022) evaluated geochemical analyses in the Maden complex, which has significant geological structures, via the QGIS program. They stated that the major oxides and trace elements show the distribution of the geochemical signatures of the study area.

The spatial geochemistry data in this study will be helpful in interpreting the elemental distributions of the rock groups in the region.

3.1. Petrography

The Maden Complex comprises basalts, basaltic andesite, dacite, diabase, and pyroclastic rocks (Ertürk et al., 2018). Basalts largely crop out in the study area. The volcanic rocks are dominated by plagioclase and pyroxene phenocryst assemblage. They display aphanitic, microlitic, ophitic, subophitic, and intersertal textures (Fig. 3). Basalts are generally greenish, brownish, bearded in colour, and massive, ellipsoidal-shaped pillow lavas and broken pillow basalts.

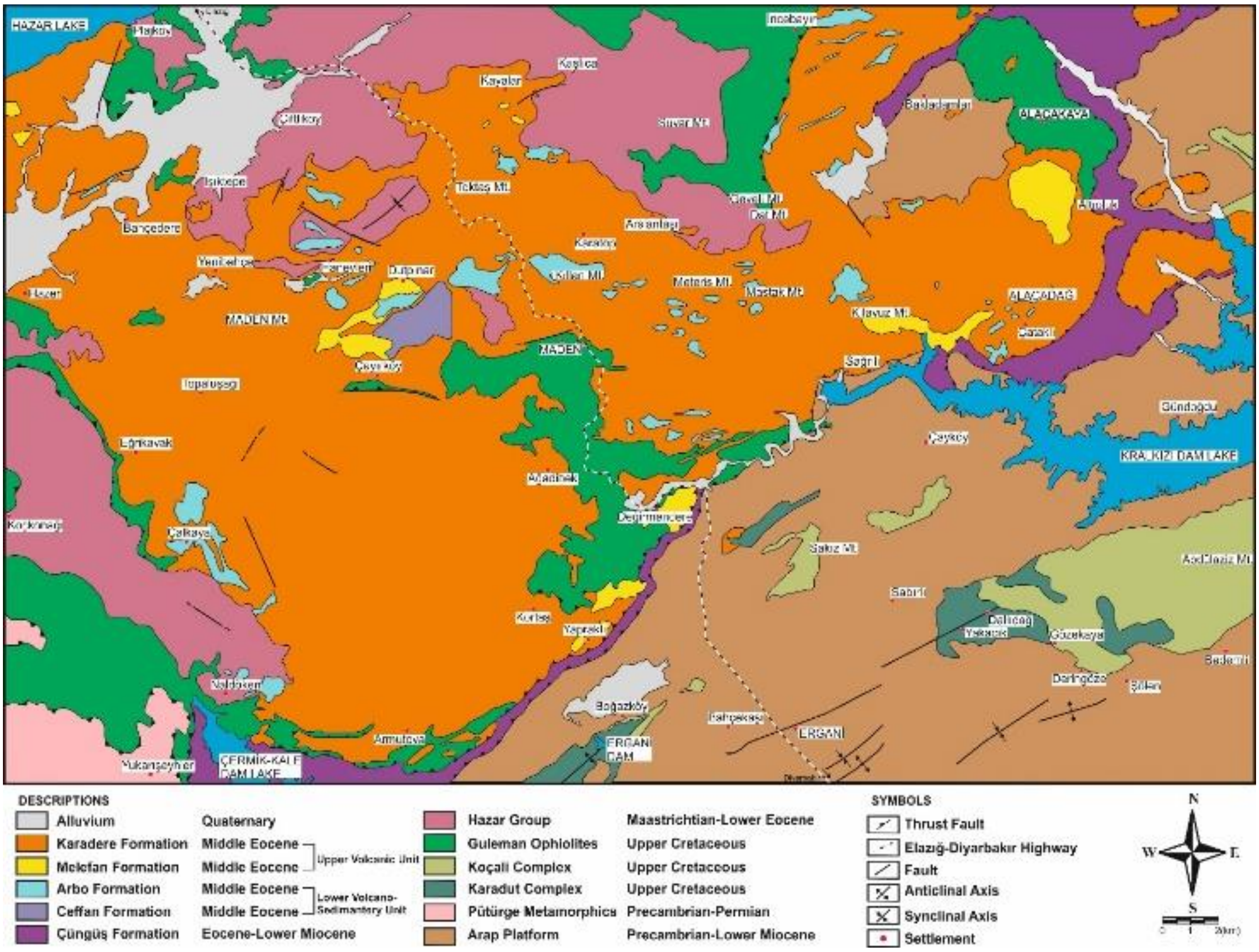

Figure 1. Geological map of the study area (modified from MTA, 2011)

Basalts are intercalated mainly with red cherts and mudstones. Basaltic andesites and andesites are in grey colours compared to basalts, and it is challenging to distinguish macroscopically from basalts. However, it is possible to make this distinction according to petrographical and geochemical features.

The dacites are macroscopically lighter, grey, whitish, and darker than the mafic volcanics and are fine-grained volcanic rocks.

The diabases often cut the basalts. The diabases greenish coloured is medium-grained and varies in thickness.

The study area represents pyroclastic rocks represented by agglomerate, lapillistone, and tuff. The agglomerates are composed of bombs with a grain size of more than 64 mm, and a cement material welds the volcanic parts. The lapillistones have a basic and andesitic composition. The tuffs are fine grain.

As explained above, many rock groups with different characteristics are observed together in the Maden complex. Because of this structure, the geochemical contents of the rocks in this region should be interpreted by overlapping with the spatial data. In this way, the complex structure of the region will be illuminated.

4. Results

4.1. GIS application

GIS and statistical methods have been widely used to analyze the formation, origins and processes of geochemical characters in rocks.

Geochemical data in a region can qualify as typical spatial data when associated with geographic coordinates in any program geographic information system (GIS).

Therefore, data analysis in geochemical studies requires consideration of both geographic locations and attributes. With the development of computer hardware, software, and technology, many spatial analysis and statistical techniques have been integrated into GIS, which greatly contributes to geochemical analysis studies (Fotheringham & Rogerson, 2013).

At the same time, with the development and application of spatial analysis techniques, problems related to geochemical mapping, mineral exploration, and many geological problems can be solved (Overpeck et al., 2011; Reichman et al., 2011).

Many samples were taken from the field in the petrographic and petrological study by Ertürk et al. (2018). Geochemical analyzes of these samples were carried out and used in many clarifications. In this study, a heat map was prepared in the QGIS program to compare and review the attribute information of the sample points.

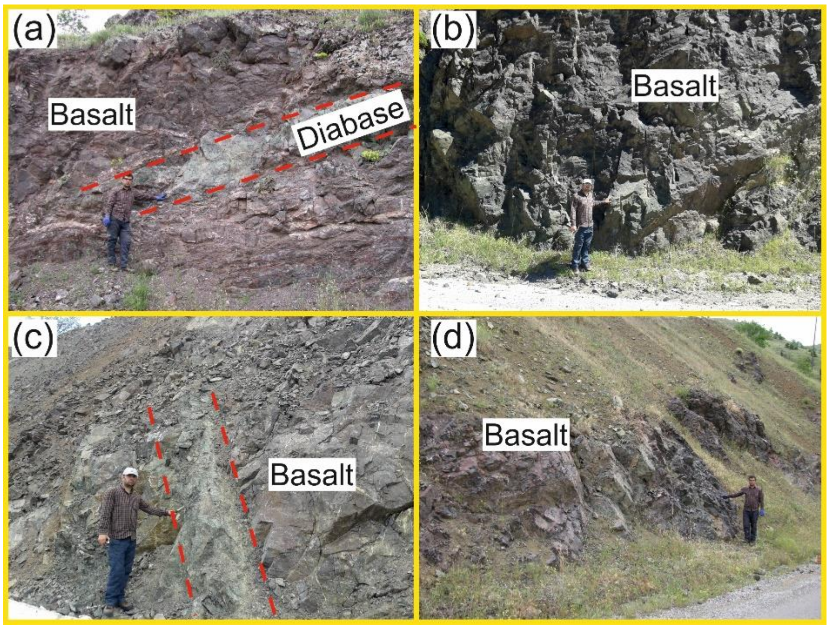

Figure 2. Representative field photographs of the volcanics

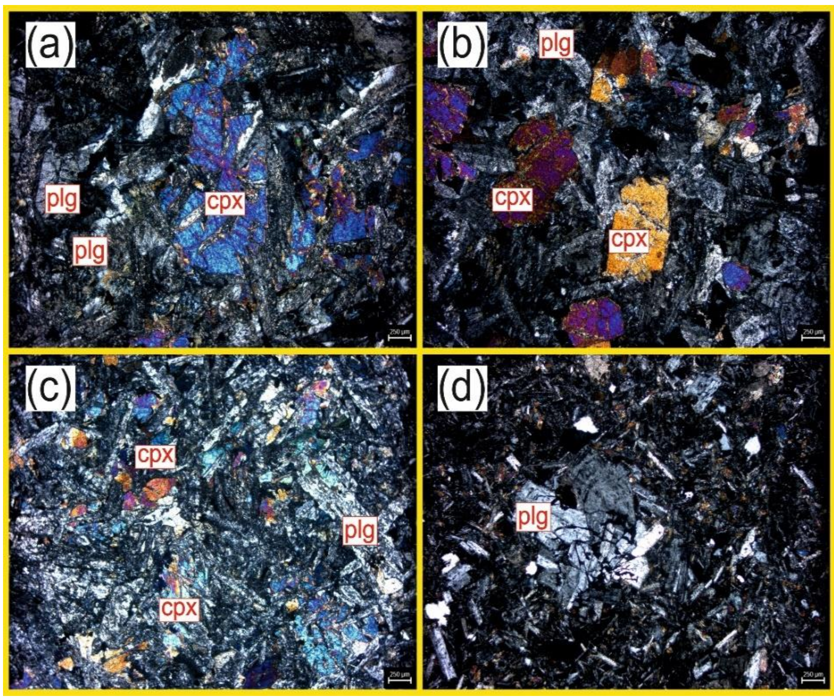

Figure 3. Microscopic views from the volcanic rocks (plg = plagioclase, cpx = clinopyroxene)

In Figure 4, it is seen that the major oxide values commonly show a similar distribution in many samples. SiO_2 is an essential component of minerals that make up many rocks. Other oxides (Figure 4) take place in the structure of silicate minerals together with SiO_2.

The SiO_2 distribution also summarizes whether the rocks are acidic or basic. Higher values represent acidic rocks, while lower values represent basic and ultrabasic rocks. Except for the northeast of the study area, most basic and near-basic rock groups are observed (Fig 4).

Al_2O_3, Fe_2O_3 and Na_2O values from other major oxides show approximately similar distributions and positive correlations with each other (Figure 4).

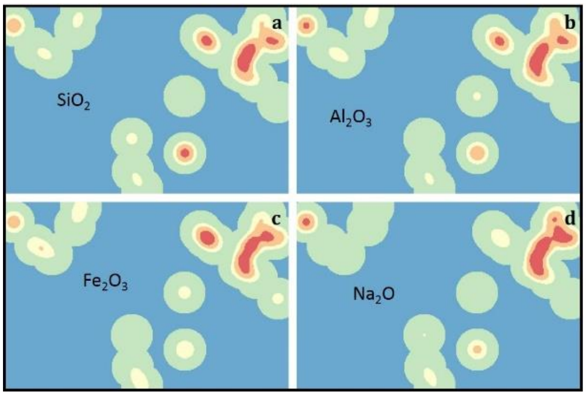

Figure 4. Heat map of the study area via major oxide contents (On each thematic map, the red areas represent the densest regions)

To further elucidate the geochemical data in the region, CaO, K_2O, MgO and P_2O_5 values from other major oxides were also analyzed. CaO values show concentration in more areas than MgO values, while MgO values show concentration in northeastern areas. (Figure 5).

Although K_2O and P_2O_5 values show a similar distribution, P2O5 values also present high anomalies, as in MgO in northeastern areas (Figure 5).

As explained above, the distribution and correlation relationships in the major oxide values indicate that rocks of different origin and characteristics exist in the region. These differences are due to mineralogical change and geochemical character.

The distribution of some trace elements is given in Figure 6. While Cr, Ga and V have a roughly similar distribution, Cu, W and Rb have different patterns. These differences are due to lithology, mineralogy and geochemical differences.

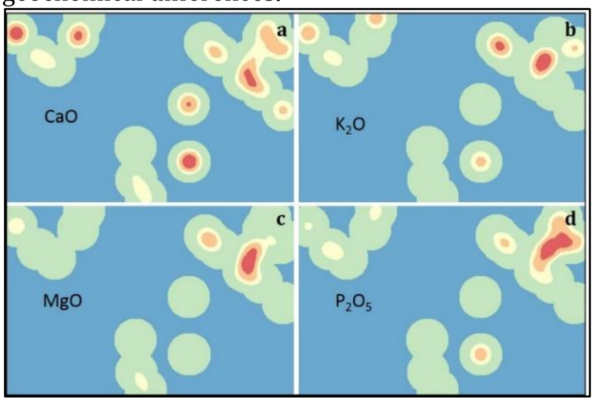

Figure 5. Heat map of the study area via major oxide contents

There are significant Mn mineralizations within the Maden Complex. For this reason, Mn values from trace elements are evaluated and shown in Figure 7a.

The Y values used in many petrogenetic interpretations were also analyzed (Figure 7b). These two elements, which present a similar distribution, offer variation in the central and southern areas.

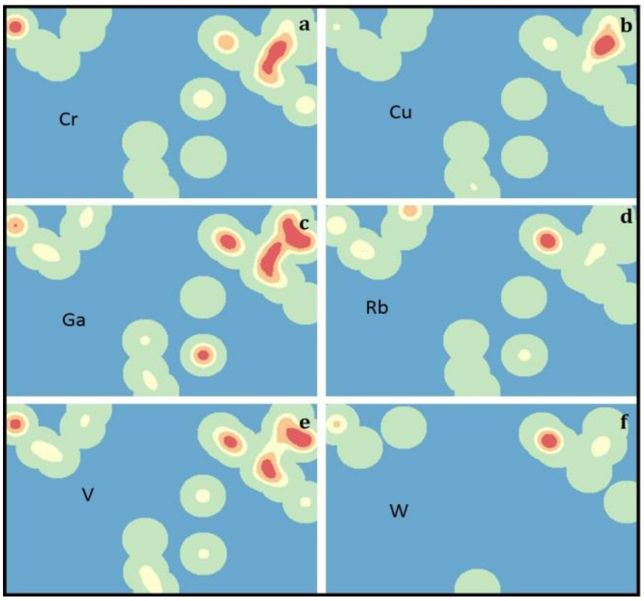

Figure 6. Heat map of the study area via trace element contents

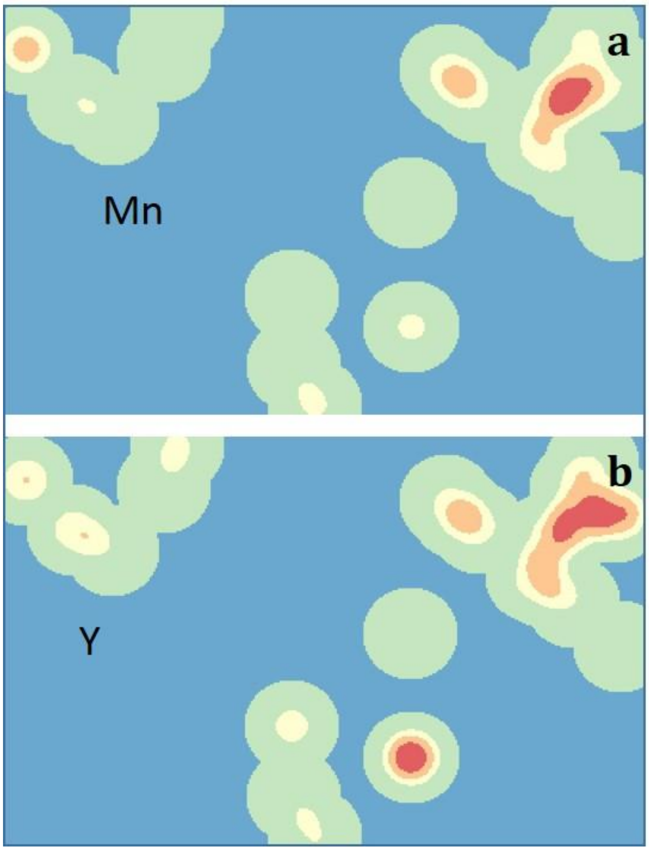

Figure 7. Heat map of the study area via trace element Mn-Y contents

In this study, the regional geochemistry character was digitized in the QGIS program. This digitization was created by evaluating the coordinates and elemental contents of the samples taken with GPS in the field. As it is known, QGIS enables GIS analysis. Thanks to this program, an approach to the character of the study area with a complex geological structure has been provided.

With these studies, the existence of structures with different characteristics should be correlated with field data. Therefore, the information that will be a guide will lead to more meaningful interpretations. Moreover, it is exceedingly challenging to make lithological discrimination in the Maden Complex, where rocks of many different characters are observed closely. For this reason, it is significant to evaluate the data obtained in the field in the GIS environment.

5. Discussion and Conclusion

GIS-based modelling has been proposed in addition to geology-geochemistry studies (Brown et al. 2003; Partington, 2008). This modelling provides a geostatistical approach to the geological structures.

For example, Atakoğlu & Yalçın (2021) explained the statistical properties of Sutlegen (Antalya) bauxite according to their geochemical content and set up thematic maps with the Krigging interpolation method.

Yalçın et al. (2021) created thematic maps in the Geographical Information Systems (GIS) environment by using Adobe Illustrator 2020 program to reveal the spatial geochemical changes of Cu enrichment in the Kuzuluk (Sakarya, Turkey) region. These maps interpreted that the Cu concentration increased as the fault zone was approached and changed into altered zones as it moved away from the fault zones.

In another similar study, U-Th anomalies in the vicinity of Arıklı (Çanakkale) were revealed in the QGIS program (Yalçın et al., 2022). Although the applications described above are mainly mineralization, GIS applications can be successfully applied in petrogenetic interpretations or mapping studies in complex geological structures.

Mapping minerals, elements or oxides based on multi-source geoscience data (geology, geochemistry, and remote sensing) and computer technology is an effective technique that merges information and data-driven production (Bonham-Carter 1994; Zhao, 2002; Wang et al., 2016). For this reason, the data of the study conducted by Ertürk et al. (2018) in the Maden (Elazığ) district were re-evaluated in the QGIS environment. In the evaluations prepared, GIS-based thematic maps correctly exhibit the relationship of the geochemical contents of the study area correctly.

The thematic maps obtained in this study show that geochemical data can be interpreted with the help of GIS in complex geological environments. These and similar studies, which are important for the interpretation of regional geology, can be preferred especially in mineral exploration. For this reason, it will be important to evaluate the data obtained from geological studies in the GIS environment.

Author Contributions

The contributions of the authors of this article is equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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