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Analysis of Heavy Metal Content and Magnetic Mineral Morphology in River Sediments in Bajuin District, South Kalimantan

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ABSTRACT

Bajuin District is a sub-district located in Tanah Laut Regency, South Kalimantan, where there is gold mining around the river basin. Gold mining activities are often a source of pollution, especially heavy metals, to the aquatic environment. This study aims to determine the content of heavy metals and the morphological characteristics of magnetic minerals in river sediments in the gold mining area. Heavy metal content measurement was carried out using *X-Ray Fluorescence* (XRF) instruments and magnetic mineral morphology was carried out using *Scanning Electron Microscopy with Energy Dispersive Spectroscopy* (SEM-EDS) instruments. The results of measurements using XRF in river sediments found heavy metals Fe (2,495.40 – 4,395.83), Mn (51.40 – 70.60), Cr (18.60 – 107.93), Ni (8.03 – 21.87), V (9.33 – 12.77), Cu (5.53 – 13.50), and Zn (4.60 – 6.33) in ppm units. The results of magnetic mineral measurements based on SEM show that magnetic minerals are octahedral and irregular. Meanwhile, the results of EDS measurements show that the main constituent elements of magnetic minerals are Fe and O which indicate magnetic minerals. In addition, elements Al, Si, Sc, V, Cr, Zn, Au, and Hg were also found. The results of this study provide important implications for environmental conditions in Bajuin District, especially related to the potential for increased heavy metal pollution due to gold mining activities around the river.

KEYWORDS: Sediments; heavy metals; magnetic minerals; pollution

INTRODUCTION

Changes in environmental conditions are often caused by mining activities, especially in river ecosystems. The entry of hazardous chemicals and industrial waste containing heavy metals is discharged into the river flow resulting in pollution for the river ecosystem. This activity not only pollutes surface water but also poses a long-term threat to the survival of living things (Hidayati et al., 2014).

Sediment is part of pollution because heavy metals that settle on the sediment can provide information on the origin of heavy metal entry into the watershed. The binding of heavy metals with river sediment occurs when particles settle on the river floor. Bonded metals usually accumulate at the turn of the river or where the flow slows down (Luo et al., 2024; Yi et al., 2011; Sojka & Jaskuła, 2022). The presence of tailings and solid waste discharge into water bodies, as well as surface erosion from mining activities accelerate the release of minerals into river flows. The heavy metals then associate with sedimentary particles and undergo the process of adsorption, coagulation, and sedimentation on the river

bed (Hilson 2002; Zhang et al. 2014).

Research on heavy metal pollution in river sediments in gold mining areas has been widely conducted and shows that mining activities are one of the main sources of heavy metal accumulation in the aquatic environment (Islam et al., 2015). Case studies in various regions show a correlation between gold mining locations and increased concentrations of heavy metals in water and river sediments (Y. Chen et al., 2023; Fashola et al., 2016; Gafur et al., 2018).

Bajuin District is a sub-district located in Tanah Laut Regency, South Kalimantan where there is gold mining around the sub-district river area. Rivers in Bajuin District provide essential ecosystem services as water supply for household needs and agricultural irrigation, food sources and flood management (Lo et al., 2019; Ureta et al., 2024; Vári et al., 2022). Loss or decline in the quality of these functions due to pollution can reduce food security and local public health. The existence of mining activities can certainly cause environmental pollution in the river waters in the sub-district, especially the accumulation of heavy metals as a result of mining activities (Ayiwouo et al., 2022).

Various previous studies have examined the heavy metal content of river sediments in gold mining areas and shown an increase in the concentration of elements such as Fe, Mn, Cr, Ni, Cu, and Zn as an impact of anthropogenic activity. However, most of these studies focus more on quantitative analysis of heavy metal concentrations without comprehensively linking them to the characteristics of magnetic minerals that act as the main carrier phases of these elements. Some studies have also utilized sediment magnetism parameters as an indicator of heavy metal pollution in the aquatic environment, but are still generally limited to the relationship between magnetic properties and heavy metal concentrations in general, such as research conducted by Mariyanto et al. (2019) in the Brantas River sediment shows that heavy metal content such as Fe and Co has a strong positive correlation with magnetic susceptibility values, indicating the dominance of magnetite minerals as the main ferrimagnetic mineral in the river sediment. Other research by Sudarningsih et al. (2023) in the sediments of the Riam Kiwa, Riam Kanan, and Martapura Rivers in South Kalimantan also found that the dominant magnetic mineral is magnetite with a pseudo-single domain (PSD), as well as the relationship between magnetic parameters and heavy metal content such as Fe, Mn, Cu, Zn, and Hg derived from lithogenic processes and anthropogenic activities. In addition, a study by Tiwow et al. (2022) on the Tallo River sediment in Makassar shows that the magnetic susceptibility parameter has a strong positive correlation with the concentration of heavy metals such as Fe, Mn, and Zn, so that the magnetic parameter can be used as a potential indicator in identifying the level of heavy metal pollution in river sediments.

The study of XRF-based geochemical analysis with the characterization of the morphology and composition of magnetic minerals using SEM-EDS is still relatively limited. In addition, variations in geological conditions and mining systems in each region can lead to differences in distribution patterns and associations of magnetic minerals that have not been fully explained, especially at the local scale in South Kalimantan. Therefore, this study was conducted to analyze the characteristics of magnetic minerals in river sediments around the gold mining area and evaluate their relationship with the presence of heavy metal elements. This approach is expected to provide a more comprehensive understanding of the role of magnetic minerals as a geochemical indicator in detecting heavy metal pollution in river sediments influenced by gold mining activities.

The morphology of magnetic minerals can reflect the processes of formation and environmental changes that occur because magnetic minerals often adsorb heavy metals on their surfaces (Liu et al. 2012; Wang et al. 2020). This is due to the presence of hydroxyl groups and specific surface areas in iron oxide minerals such as magnetite and hematite which allow the process of adsorption and surface bonding with various heavy metal

elements. Therefore, magnetic minerals often act as carrier phases that can accumulate and transport heavy metals in sediments of aquatic environments. The magnetic mineral approach is important in pollution studies because changes in the magnetic properties and morphology of minerals can reflect the accumulation of heavy metals from natural sources or anthropogenic activities. Several studies on the morphology of magnetic minerals in river sediment samples show that magnetic mineral morphology can be formed from both lithogenic and anthropogenic processes, as reported by Sudarningsih et al. (2017), Kirana et al. (2024) and Chandrasekaran et al. (2021).

The purpose of this study is to analyze the level of heavy metal pollution and the morphology of magnetic minerals in river sediments in the gold mining area in Bajuin District. The method used is the X-Ray Fluorescence (XRF) chemical method to determine the content of heavy metals at the research site and the rock magnetism method that can be used is the Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) method to determine the morphological characteristics of magnetic minerals in sediment samples. The SEM-EDS method allows microscopic identification of particle morphology and composition of its constituent elements, making it very important in the study of the mining environment. Morphological and magnetic mineral composition information can be used to identify the source of particles as well as distinguish particles derived from natural geogenic processes from particles resulting from anthropogenic activities, including waste or residues from traditional gold processing processes (Dare et al., 2014; Lottermoser, 2010). In the context of gold mining, this analysis also helps to understand the relationship between iron oxide minerals, such as magnetite, and the presence of heavy metals adsorbed on the mineral surface due to mineral processing processes and sediment transport in the river environment (Oldfield, 2007).

METHODS

Bajuin District is located in Tanah Laut Regency, South Kalimantan. Based on the geographical location, Bajuin District is located between 3°35′6.9" – 3°49′55.3" south latitude and 114°47′16.8" – 114°57′50.4" east longitude (Figure 1). Sediment sampling was carried out using sediment grab at ten points in the watershed around the gold mine in Bajuin District with the coordinates as shown in Table 1.

Each point was taken as many as 2 kg of samples using *sediment grab* on the sediment surface referring to the surface sediment collection method carried out by Iizuka et al. (2025) and prepared at the Geophysics Laboratory of FMIPA, Lambung Mangkurat University, Banjarbaru. The sampling points were chosen representative to illustrate the variation in environmental conditions along the river flow, ranging from remote parts of mining activities to areas directly affected by gold mining activities. Location 1 is the point that is furthest from the gold mining area and represents the reference conditions. Location 2 is in the drum area (ore processing), while location 3 is located in the mining activity area. Meanwhile, locations 4 to 10 are located in the upstream part which is still in the river flow system related to the mining area. With the selection of these points, the sample distribution is expected to represent a variation in environmental conditions from unaffected areas to areas affected by mining activities. The sediment sample is dried at room temperature within 36 – 48 hours to lower the moisture content in the sample. After drying, the sample is then crushed using a porcelain slab and then sifted using a sieve with a size of 325 mesh. This sample is used for the measurement of its heavy metal content. Some samples were extracted using a *magnetic stirrer*. The extraction process is carried out by first dissolving sediment samples in the aquifer to form a suspension, then magnetic particles are separated using a magnetic stirring rod which produces a weak magnetic field. Extraction is carried out in stages with a time interval of 5 minutes through the process of removing *the*

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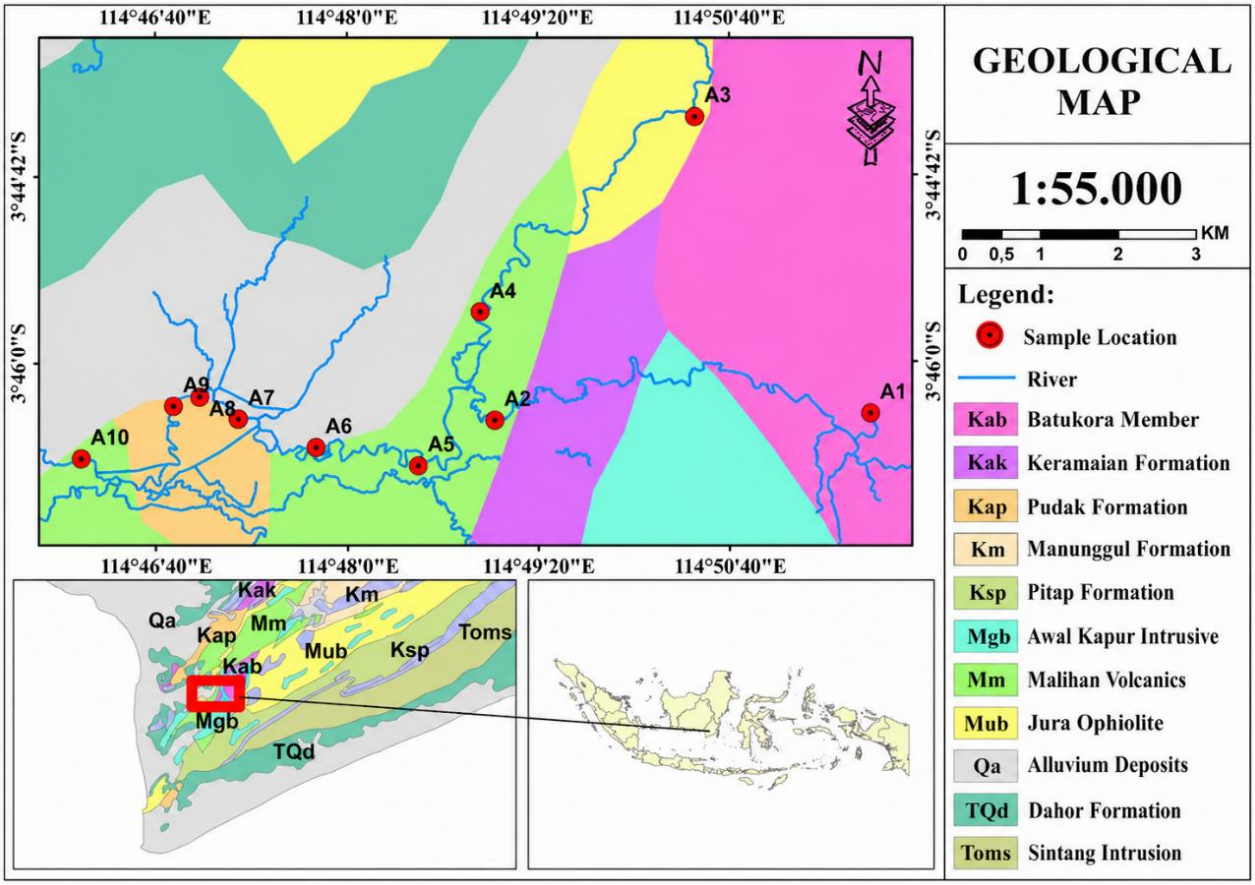

Figure 1. River sediment sampling location at the research site (Modified using ArcGis)

magnetic stirrer from the solution until there are no more magnetic particles attracted. The use of weak magnetic fields aims to selectively extract strong magnetic minerals and minimize the inclusion of non-magnetic minerals. This procedure refers to a method developed by Novala et al. (2019), which emphasizes the importance of strong control of the magnetic field and extraction duration to obtain representative fractions of magnetic minerals. The extracted samples were then used for morphological analysis.

Table 1. Sediment sampling coordinates

Location	Coordinates	
A1	3°46'21.62"S	114°51'39.01"E
A2	3°46'24.20"S	114°49'2.00"E
A3	3°44'17.36"S	114°50'25.75"E
A4	3°45'38.70"S	114°48'55.90"E
A5	3°46'43.12"S	114°48'29.75"E
A6	3°46'35.50"S	114°47'46.90"E
A7	3°46'23.50"S	114°47'14.60"E
A8	3°46'14.30"S	114°46'58.50"E
A9	3°46'18.13"S	114°46'47.54"E
A10	3°46'39.90"S	114°46'9.00"E

The measurement of heavy metal content was carried out using X-Ray Fluorescence (XRF) instruments at the Academic Support Unit (UPA) of the Integrated Laboratory of Lambung Mangkurat University. Calibration of the XRF instrument is carried out using metal molding materials (Potts & West, 2008). Verification of the instrument's performance is carried out before analysis as well as periodically during measurements to ensure the stability of the instrument and the accuracy of the analysis results (Rousseau, 2001). The detection limit of the XRF instrument used in this study is 0.001%, allowing accurate identification of elements in low concentrations. Meanwhile, the measurement of magnetic mineral morphology was carried out using the SEM-EDS instrument at the FMIPA Advance Laboratory, Lambung Mangkurat University.

RESULTS AND DISCUSSION

Heavy Metal Content

Based on the results of the XRF test, river

Table 2. Heavy Metal Content of River Sediments Around the Sub-district Gold Mining Bajuin

Sample Name	Heavy Metal Concentration (ppm)						
	V	Cr	Mn	Fe	Ni	Cu	Zn
A1	12.77	19.87	64.10	4,395.83	8.87	13.50	6.53
A2	11.47	18.60	65.77	4,010.20	8.03	12.77	5.77
A3	12.27	54.67	69.97	3,497.77	21.23	7.60	4.87
A4	10.63	71.03	52.67	3,041.83	21.87	6.93	5.47
A5	9.33	107.93	51.40	2,495.40	14.20	5.53	4.70
A6	10.07	64.53	55.07	3,043.57	19.00	7.60	5.50
A7	10.70	61.10	61.30	2,934.33	18.10	7.17	5.17
A8	10.33	59.77	53.90	3,001.03	18.87	7.33	5.37
A9	9.63	51.93	70.60	2,818.80	17.63	6.63	4.60
A10	10.83	47.00	65.83	3,351.40	21.10	8.90	5.73
MIN	9.33	18.60	51.40	2,495.40	8.03	5.53	4.60
MAX	12.77	107.93	70.60	4,395.83	21.87	13.50	6.53
AVERAGE	10.80	55.64	61.06	3,259.02	16.89	8.40	5.37
Threshold	130[a]	110[b]	1.100[b]	4.000[b]	49[b]	150[b]	460[b]

(a) *Federal Environmental Quality Guidelines* (Canada, 2016)

(b) Consensus-Based Sediment Quality Guidelines (Contaminated Sediment Standing Team, 2003)

sediment samples around gold mining in Bajuin District are as shown in Table 2. The average value of heavy metals was found to be V, Cr, Mn, Fe, Ni, Cu and Zn. The average value of heavy metals showed the order of Fe > Mn > Cr > Ni > V > Cu > Zn. This shows that the elements Fe and Mn are the most abundant metals in the river sediments of Bajuin District, which is strongly suspected to have originated from the weathering of iron and manganese minerals in the ultramafic and manganese rocks that indeed make up the area (Mistikawy et al., 2020; Abbas and Maulana, 2021).

Figure 2 shows the variation in the distribution of heavy metals at each sample point which shows the difference in environmental conditions and the influence of human activities around the research site. In most heavy metals, there is a fluctuation in the levels between sample points with a tendency to decrease the heavy metal content at certain points. The average metal V ranges from 9.33 – 12.77 ppm and Mn 51.40 – 70.60 ppm shows a relatively more stable variation than other elements indicating the presence of fine sediment transport and reduced oxidation processes in the aquatic environment that cause the accumulation of Mn and V in slow flows. These two metals are still far below the threshold with V being 130 ppm and Mn being 1,100 ppm. It is most likely influenced by geogenic sources (rock origin) but under reductive conditions it can dissolve and increase its concentration in groundwater (Ingri et al. 2011; Shaheen et al. 2019).

Cu, Zn, and Fe showed high concentrations of heavy metals at locations A1 and A2. Location A1 is the sampling point that is furthest from the gold mining activity area, so the sediment condition at this location better illustrates the natural condition of river sediment in the Bajuin area. While Location A2 is the location of A2 is a gold ore processing location, where the use of chemicals in the amalgamation process can cause an increase in heavy metal levels in river sediments.

The concentration of Fe in sediments ranged from 2,495.40–4,395.83 ppm, with the highest values found at locations A1 and A2 slightly exceeding the reference value of 4,000 ppm. Fe is a naturally abundant key element in sedimentary systems, especially in regions controlled by geological conditions. When compared to natural conditions in South Kalimantan, the Fe content in the Martapura River sediment is reported to reach the range

of 48,000–68,800 ppm, reflecting the strong geogenic influence of the iron-mineral-rich regional lithology (Sudarningsih, 2021). Compared to this value, the concentration of Fe at the study site was much lower, indicating that the presence of Fe was still within the natural range and did not directly represent the polluted condition. The dominance of Fe in the sediments of this study is more related to the weathering process of ultramafic rocks and the contribution of magnetic minerals such as hematite and magnetite, which are commonly found in iron-rich geological environments (Boula et al., 2022; Choudhary et al., 2024). On the other hand, gold mining activities in the surrounding area still have the potential to play a role in the process of remobilization and redistribution of sediments, which can lead to local variations in Fe concentrations.

Cu metals show a range of 5.53 –13.50 ppm with a threshold of 150 ppm. This value is still far below the safe limit, so there is no indication of copper contamination in the sediment. Copper generally comes from weathering sulfide minerals such as chalcopyrite from gold mining or from anthropogenic sources such as pesticides and waste derived from gold processing tools or materials. Nevertheless, the accumulation of large amounts of Cu can interfere with the metabolism of the organism (Förstner & Wittmann, 1983).

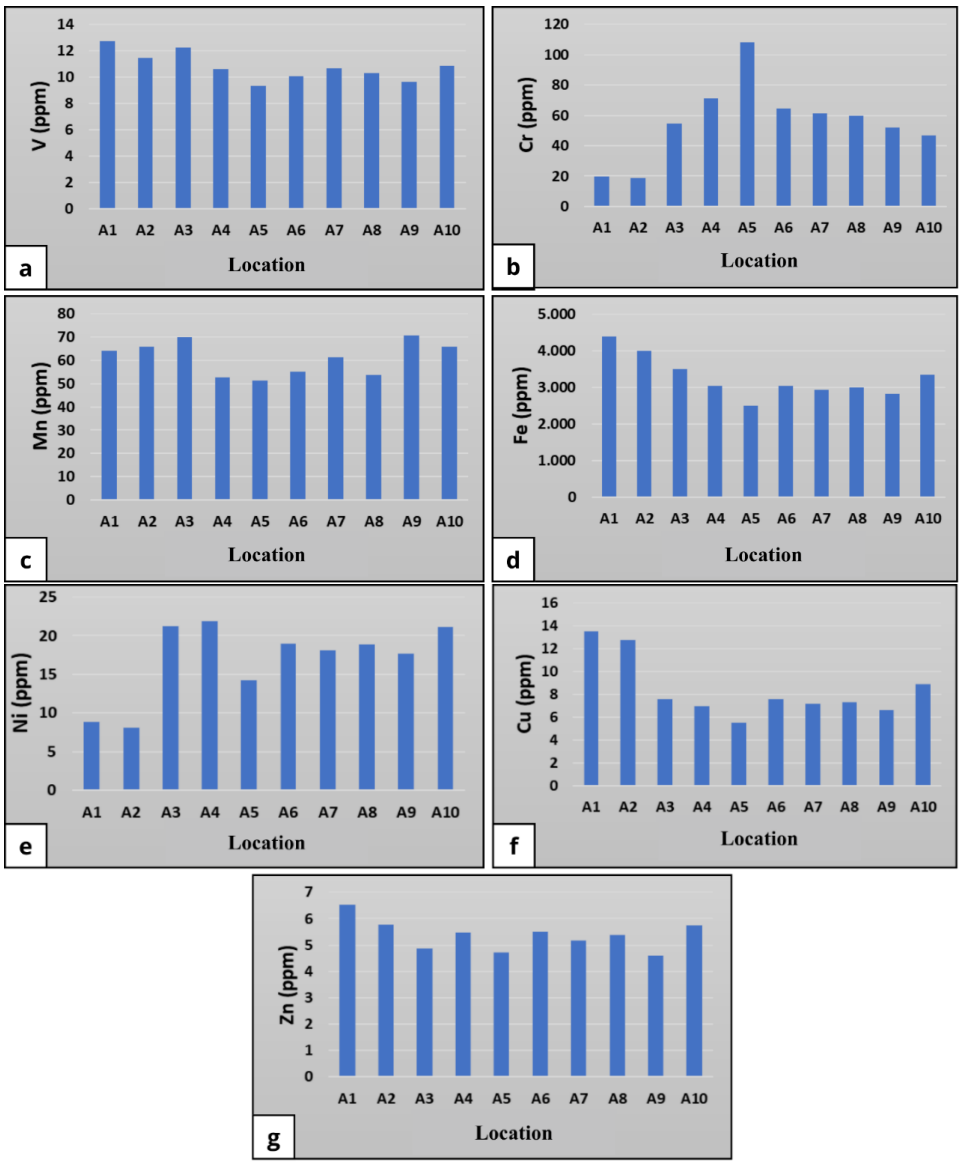

Figure 2. Graph of heavy metal content in each sediment sample

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Zn concentrations are in the range of 4.60 – 6.33 ppm with small variations between points. The concentration of the element Zn is well below the threshold of 460 ppm, indicating that Zn in river sediments is still classified as natural and has not been polluted. Zinc is an essential element for the organism, but it can become toxic if it exceeds certain limits (Kabata-Pendias and Pendias, 2001).

Cr metals range from 18.60 – 107.93 ppm with a threshold of 110 ppm. The high Cr content, especially in A5, indicates the strong influence of gold mining activities that are common in ultramafic rocks in Bajuin or due to the influence of anthropogenic activities such as metal mining residues (Fashola et al., 2016; Oze et al., 2003). The Cr content decreased at points A9 and A10, indicating the effect of dilution of river water downstream (Vaezihir et al., 2022). Meanwhile, Ni ranged from 8.03 – 21.87 ppm with an average of 17.85 ppm well below the threshold of 49 ppm. The highest values at location A2 indicate the influence of nickel-containing minerals and are commonly found along with ultramafic minerals and sulfides in gold mining zones (Arif et al., 1996; Golroudbary et al., 2022).

Morphology of Magnetic Minerals

The SEM photos show that magnetic minerals are octahedral and irregular in shape (Figure 3). Sample A1 is furthest from the area of gold mining activity. Meanwhile, Sample A2 was taken adjacent to the drum of the gold processing site which is directly adjacent to the sub-watershed. The samples A2, A3, and A5 are in the main river flow in the gold mining area.

The octahedral form is more likely to come from a pedogenic process in the form of the formation of natural minerals from the weathering of the parent rock. Irregular shapes can come from a combination of lithogenic and anthropogenic influences (Sudarningsih et al. 2017; Bijaksana et al. 2019). These morphological differences reinforce that river sediments contain a mixture of magnetic minerals from lithogenic processes (parent rocks, reservoir materials) and anthropogenic processes (human activities).

Based on the results of EDS (Figure 3), the elements Fe and O are the main components that make up the magnetic mineral fraction at all observation points. The variation in the content of the two elements shows that there is a difference in the composition of magnetic minerals formed at each location, which is related to the geochemical conditions of the river sediment environment. The presence of Fe and O as the constituent of magnetic minerals indicates that the samples formed are most likely magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3), or hematite (Fe_2O_3). In gold mining areas, the existence of these magnetic minerals generally comes from the weathering activities of iron-rich motherrocks and the influence of anthropogenic processes (Evans & Heller, 2003). An image of oxidation rates with high concentrations of Fe and relatively low O indicates the possibility of dominance of magnetite formed under reductive conditions. On the other hand, a significant increase in O indicates the formation of hematite or goetite reflecting oxidative conditions due to the presence of oxygen supply, waste or microorganism activity (Liu et al., 2012).

The EDS results also show the presence of elements Al, Si, Sc, V, Cr, Zn, Au and Hg. Elements Al and Si indicate the contribution of silicate minerals that may still be carried during the magnetic separation process. The presence of these elements reflects the influence of the materials that make up the parent rocks in the research area, especially silicate minerals resulting from rock weathering from surrounding rocks (Ciobanu et al., 2019; González-pérez et al., 2024).

The presence of Sc, V and Cr in the megnetic fraction shows a close relationship with local geological characteristics. These elements are generally derived from mafic to ultramafic rocks that are rich in ferromagnetic minerals and iron oxides. The presence of these elements supports the geological information of the research area composed of ophiolite rocks and ultramafic rocks rich in chromium and vanadium elements (Mikulski et al., 2022; Venier et al., 2022). As for Zn, it is generally not

from the magnetic mineral structure but is the result of the process of adsorption with iron oxide or the weathering of sulfide minerals derived from mining activities (Bao et al., 2022).

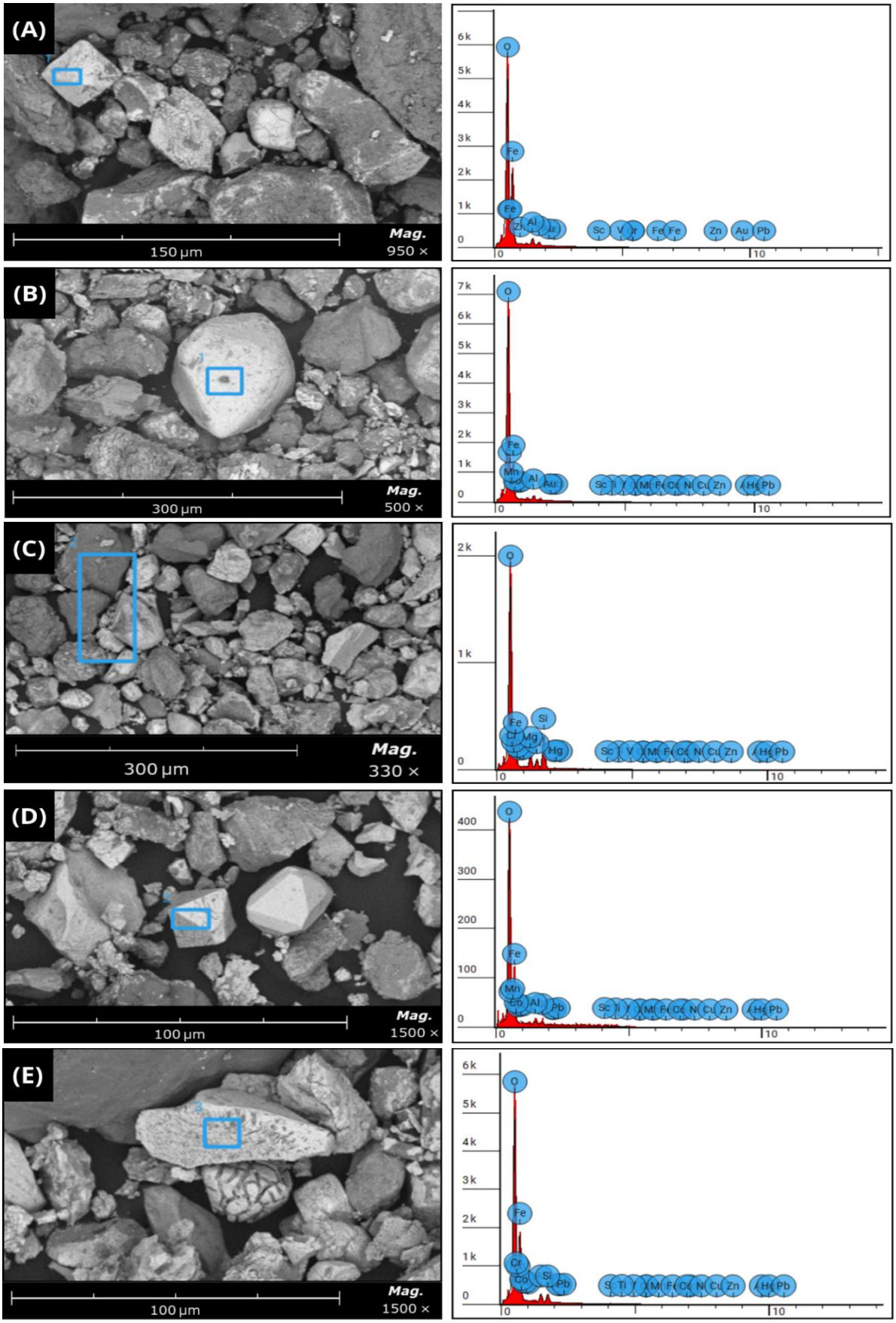

Figure 3. Magnetic Mineral SEM-EDS test results

EDS results that identified the presence of Au and Hg in magnetic mineral fractions showed a relationship between the geochemical processes of magnetic minerals and gold mining activities in the study area. Iron oxide minerals such as magnetite are known to have the ability to absorb various elements on their surface so that they can act as a medium for transporting these elements in river sediments (Jurković et al., 2020). In addition, the presence of Hg in the magnetic fraction indicates an anthropogenic influence related to the gold processing process. In the traditional gold mining process, Hg is generally used at the amalgamation stage to bind gold from ore materials. This situation is in line with research by Arasteh et al. (2023) and Lv et al. (2024) which shows that iron oxide minerals can bind and accumulate heavy metals through the adsorption mechanism as well as surface complexation. Therefore, the presence of Au and Hg in the magnetic fraction can be used as an indicator of the influence of gold mining activities on the quality of river sediments.

CONCLUSION

The heavy metal content in the river sediments in Bajuin District shows the order of the average concentration of Fe > Mn > Cr > Ni > V > Cu > Zn. Heavy metals such as Cr, Cu, Zn, Ni, and V are still below the standard threshold for sediment quality. While Fe exceeds the threshold at points A1 and A2. The influence of heavy metal concentrations comes from the weathering of ultramafic and manganese rocks, as well as the possible influence of gold mining activities around the research site. The morphology of magnetic minerals based on the results of SEM analysis shows octahedral (pedogenic) and irregular (lithogenic and anthropogenic) shapes. This indicates that the magnetic minerals of the river sediment are formed from a mixture of natural processes of the motherrock and the influence of human activities. The results of the SEM-EDS show that the main constituent elements of magnetic minerals are Fe and O, indicating magnetic minerals such as magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3), and hematite (Fe_2O_3). The elements Al, Si, Sc, V, and Cr show strong geogenic source influence from mafic–ultramafic rocks, while Zn tends to accumulate through the adsorption process on iron oxides. The presence of Au and Hg in the magnetic fraction confirms the role of iron oxide minerals as a medium for adsorption and transport of heavy metals, as well as indicating the contribution of gold mining activities.

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