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NICKEL ELEMENT CONTENT DISTRIBUTION IN LATERITE DEPOSITS BASED ON GEOCHEMISTRY USING THE INVERSE DISTANCE WEIGHTING (IDW) METHOD

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ABSTRACT

Administratively, the study area is located in the Sorowako Area, Nuha Sub-district, East Luwu District, South Sulawesi Province, Indonesia. Inverse Distance Weighting is a method used to determine the distribution of Ni element, which is one of the geocomputation methods that uses the concept that the value at a location can be estimated based on how close the location is to existing measured points, with weights given based on the distance. The data used in this study is geochemical data from XRF analysis results on laterite samples in the study area. XRF analysis results show that the Ni content value in the limonite zone tends to be lower than in the saprolite zone, which is caused by the semi-mobile nature of the Ni element, so that the Ni element accumulates in the saprolite zone as a result of the enrichment process. The XRF method was used in the geochemical analysis of the laterite deposit samples, which showed high Ni content in the saprolite zone compared to the limonite zone. Ni distribution in the limonite zone is found in two classes of grade distribution, which are < 1.3% and 1.3% - 1.5%. While in the saprolite zone tends to be more varied, there are six classes of grade distribution, from grade values < 1.3% to > 2.25% distributed in the study area.

1. INTRODUCTION

Indonesia is the largest nickel producing country in the world in 2022 according to the United States Geological Survey (USGS) with a total production of 1.6 million metric tons or equivalent to 48.48% of total world production [1]. One of the largest nickel laterites producing areas in Indonesia is located on Sulawesi Island, precisely in the Eastern Mandala Section. Figure 1 shows Mandala distribution of Sulawesi. The Sorowako area is part of the Eastern Mandala of Sulawesi Island, so that the lithology of the constituents of the area is very likely to occur laterization process. The company that operates in the mining sector, especially nickel laterite in the Sorowako area is PT Vale Indonesia.

The division of mining blocks in the Mining Business Licence (IUP) area of PT Vale Indonesia are classified based on the differences in their characteristics, which are West Block and East Block. The main difference between the two blocks geologically is based on the bedrock, level of serpentinization, and fractures in the rock that will affect the difficulty of mining. In the West Block, the bedrock is predominantly harzburgite with occasional occurrence of the high-olivine dunite bedrock [2]. The study area is part of the West Block area. The purpose of this study is to determine the distribution of Ni element based on the geochemistry using the Inverse Distance Weighting (IDW) method. Other sections will also discuss about the geology of the study area, behavior of geochemical elements, the development of laterite deposit profiles, and the characteristics of the bedrock based on petrography analysis.

The result of weathering of ultramafic rocks such as dunite, peridotite and serpentinite in a tropical climate will form a nickel laterite deposit. The weathering process in the bedrock (laterization) causes nickel to turn into solution and be absorbed by iron oxide minerals that form garnierite in the saprolite zone (Golightly, 1981 as cited in Adi Maulana, 2017) [3]. Olivine, pyroxene and hornblede are minerals that formed the ultramafic rocks, which have a tendency to be dark in color when found in fresh conditions. The process of laterite profile formation begins when the minerals that formed the ultramafic rocks are decomposed which causes the elements to be carried in solution and precipitated residually, where this process proceeds dynamically and slowly [4].

Based on the position of the zones, from the top to the bottom, the laterite profile arranged by the limonite zone, then the saprolite zone, and the lowermost position is the bedrock zone. The limonite zone, located at the top of the laterite profile, is the end product of tropical weathering of ultramafic rocks and a residual concentration of immobile elements. Located above the unaltered bedrock, the saprolite zone consists of boulders partially to completely decomposed under the impact of tropical weathering. The weathering process begins along the surfaces of the joint and fractures and results in the formation of "boulders" within the saprolite zone. The original rock texture is still recognizable and the weathering profile has not collapsed. Located at the very bottom of the laterite profile, the bedrock zone marks the original ultramafic rocks that have not been affected by weathering processes [2]. Laterite profile overview was shown in Figure 2.

Geo-computation is a recent emerging foresight in GIS and geospatial analysis and is very much influenced by recent developments in programming, data processing, and interface design. Geo-computational methods are accepted individually as an effective solution to specific spatial analysis problems and are just now emerging in more general software with widespread use such as remote sensing data analysis, geo-simulation techniques, and visualization tools. Inverse Distance Weighting (IDW) is a method used in determining estimates with data points that have local influence, where the value of the data will decrease if it is directly proportional to the increase in distance. Technically, the IDW method calculates the value at each point in the data space by examining the surrounding areas that has the data. The value of the data in the space is the result of the calculation of the population of sample points around the area [5]. The detailed samples weighted distance in IDW estimation method was indicated in Figure 3.

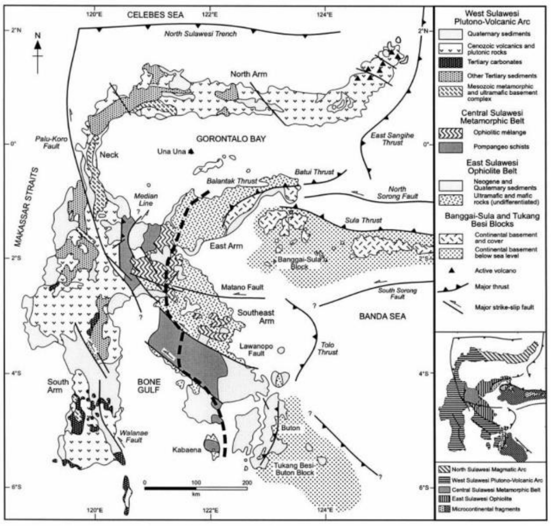
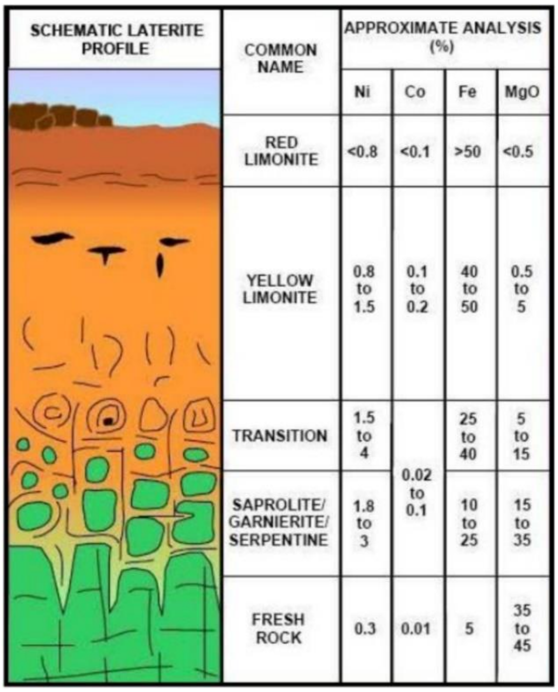


Figure 1. Mandala distribution of Sulawesi (Hall and Wilson, 2000 in Sompotan, 2012) [6]



SCHEMATIC LATERITE PROFILE	COMMON NAME	APPROXIMATE ANALYSIS (%)			
		Ni	Co	Fe	MgO
	RED LIMONITE	<0.8	<0.1	>50	<0.5
	YELLOW LIMONITE	0.8 to 1.5	0.1 to 0.2	40 to 50	0.5 to 5
	TRANSITION	1.5 to 4	0.02 to 0.1	25 to 40	5 to 15
	SAPROLITE/ GARNIERITE/ SERPENTINE	1.8 to 3		10 to 25	15 to 35
	FRESH ROCK	0.3	0.01	5	35 to 45

Figure 2. Laterite profile overview (Elias, 2002) [7]

2. METHODOLOGY

The study method uses data from the field in the form of rock samples, core logging samples, and data from core logging. Rock samples are taken from drilling points in the research area which will then be analyzed petrographically to determine the characteristics of the minerals that form the bedrock. Then the core logging samples will be analyzed using the Xray Fluorescence (XRF) method. The output from the XRF data validation results is the cummulative of Ni content in the limonite zone and saprolite zone which will then be used to create a map of the distribution of Ni elements using the Inverse Distance Weighting method in the ArcMap 10.7.1 application in 2D form. The Inverse Distance Weighting method is an estimation method using a block model-based approach that considers the neighboring points (Latif, 2008 as cited in Langkoke, 2023) [8]. It is interpreted that the amount of similarity between adjacent data points is not significantly different from the distance of unsampled data in between. This correlation is thought to be comprehensible as a function of each point's inverse distance from its neighboring points [9]. The value of geochemical elements based on the results of XRF analysis will also be made in the form of vertical diagrams to see the behavior of elements and the value of Ni elemental which will then be connected to the results of the elemental distribution value.

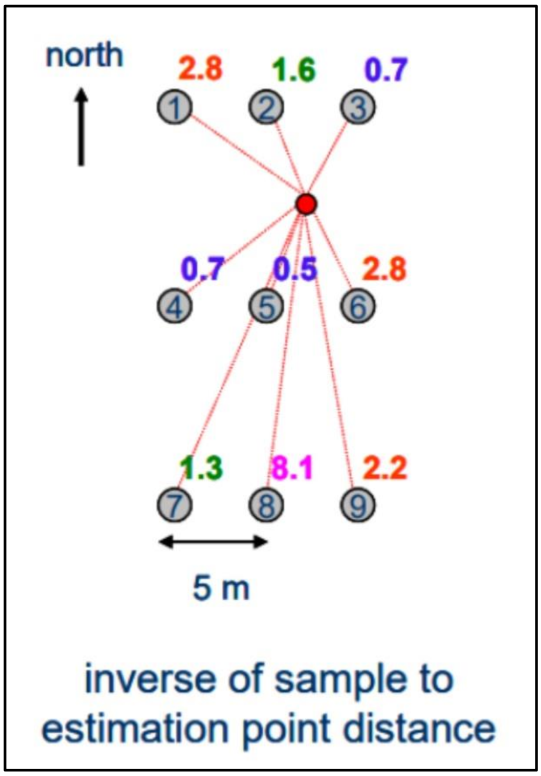


Figure 3. Sample weighted distance in IDW estimation method (Langkoke, 2023) [8]

3. RESULT AND DISCUSSION

3.1 Geology of The Research Area

Geomorphological conditions of the study area reveal quite diverse morphological forms. Based on the lowest elevation point of 660 meters above sea level and the highest elevation point of 740 meters above sea level. Based on morphometric aspects using the absolute altitude classification (Van Zuidam, 1985) the area consists of high hills morphological unit (500 - 1,500 masl). While based on the slope classification (Van Zuidam, 1985) this area has a slope class that is sloping - steep. Based on morphogenesis, there is a high level of weathering characterized by an average soil thickness of tens of meters, so that it can be indicated as a result of the denudation process. The morphology that occupies the study area is therefore generally part of the Denudational High Hills. The presence of structures in the form of fractures filled by quartz veins in bedrock samples produced from drilling is thought to originate from the Matano regional fault.

3.2 Laterite Profile Characteristics

The laterite profile found in the study area are divided into three zones, which are limonite zone, saprolite zone and the bedrock zone. The limonite zone found in meter 1 - 4 has a brownish yellow color with fine grain material size with a very high level of weathering, the minerals found are goethite and hematite minerals. The saprolite zone found in meter 19 - 23 is brownish yellow, gray to greenish with the material size of coarse grain with moderate weathering. The minerals found are goethite and garnierite while the boulders found are dunite rocks. The bedrock zone found at meter 29 - 33 has a greenish gray color with a very coarse grain material size with a low level of weathering. The mineral content is olivine and pyroxine. The rock name is dunite. The detailed laterite profile of the study area was shown in Figure 4.

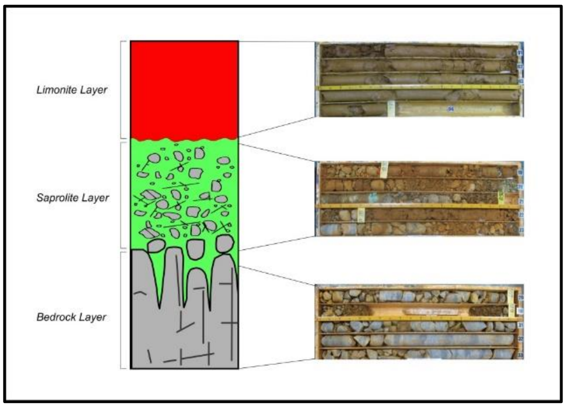


Figure 4. Laterite profile of the research area

3.3 Bedrock Characteristics

Bedrock samples were taken at several drill points which were analyzed petrographically to determine their characteristics based on mineral composition. The results of observations on thin section samples showed that the bedrock are Dunite and Lherzolite type of peridotite based on the olivine content in the Streckeisen classification. The thin section petrographic appearance are depicted in Figures 5 and 6..

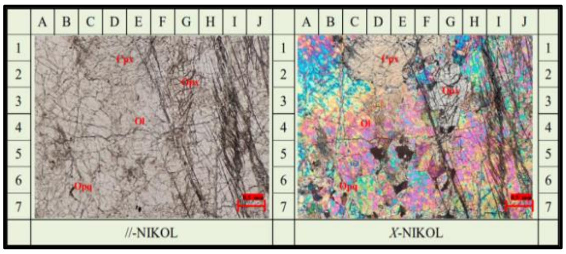


Figure 5. Thin section petrographic appearance of sample C157105

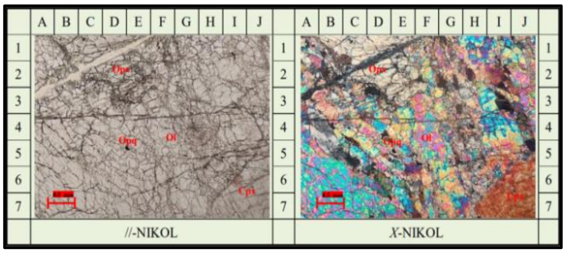


Figure 6. Thin section petrographic appearance of sample C149353

Based on Figures 5 and 6, lithology that composed the research area is Dunite and Lherzolite based on the Streckeisen classification (1974), with an olivine mineral composition of 82% - 92%, following by the clinopyroxene mineral with 7% composition and the orthopyroxene mineral with 2% - 10% composition. Figure 7 shows an ultra mafic rock classification.

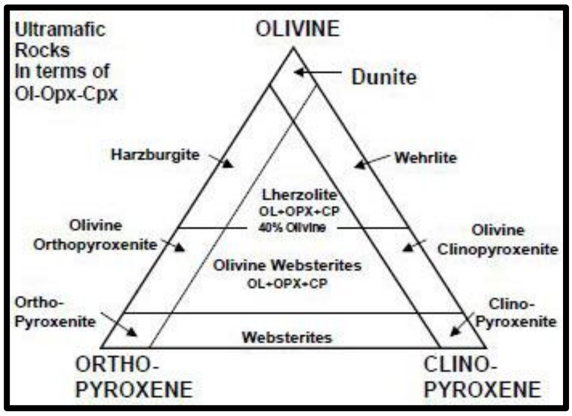


Figure 7. Ultramafic rocks classification [10]

3.4 Deposits Section and Geochemical Profile of Laterite

On the drill hole distribution map, three incision lines were made, which will be used to create a laterite profile cross-section as well as a geochemical vertical profile cross-section. Figure 8 shows drillhole distribution map of the study area in 3 D form which consists of 3 incision line (A-B, C-D, E-F).

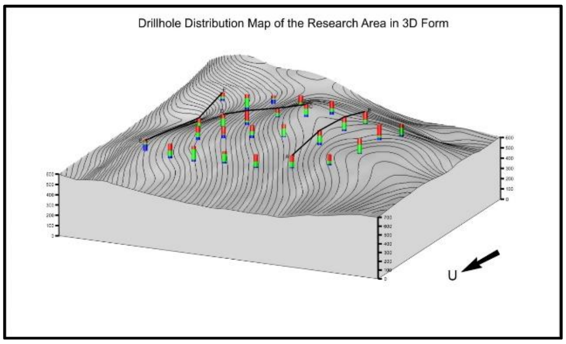


Figure 8. Drillhole distribution map of the research area in 3D Form which consists of 3 incision line (A-B, C-D, E-F)

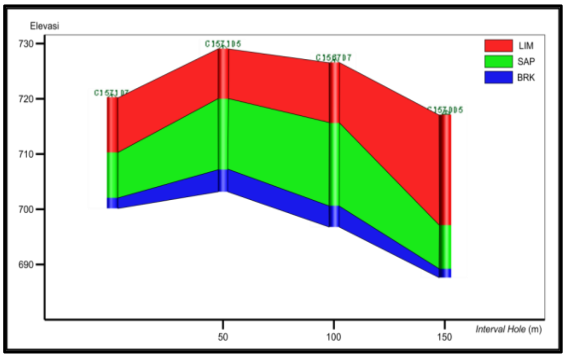


Figure 9. Cross section of laterite deposit profile of section A - B

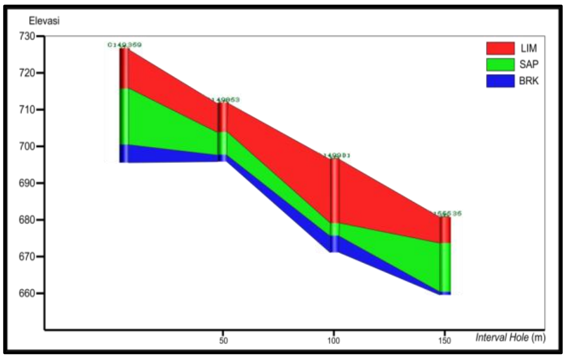


Figure 10. Cross section of laterite deposit profile of section C - D

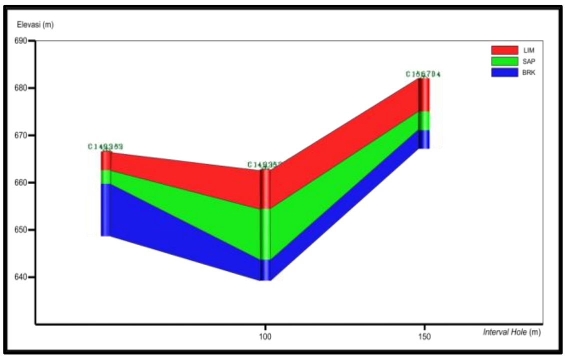


Figure 11. Cross section of laterite deposit profile of section E – F

Based on the cross-sectional image of the laterite deposit profile as shown in Figures 9, 10, and 11, it can be seen that in the study area there is a diverse thickness of the laterite deposit zone at each drill point. This is due to the uneven laterization process, so the thickness of the laterite profile zone at each drill point will have a different thickness.

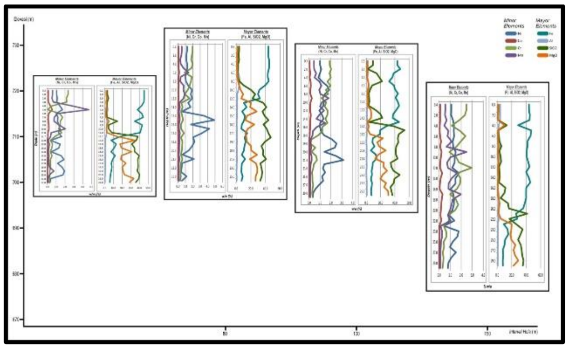


Figure 12. Vertical profile cross section of geochemical elements of section A - B

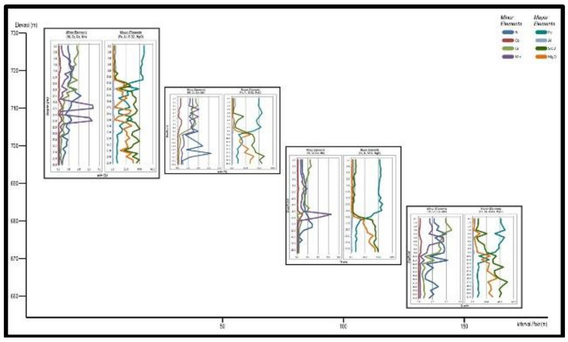


Figure 13. Vertical profile cross section of geochemical elements of section C - D

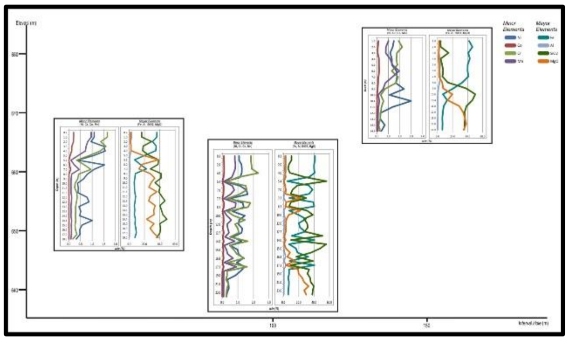


Figure 14. Vertical profile cross section of geochemical elements of section E - F

Based on the cross-section of the vertical geochemical profile of minor and major elements in Figures 12, 13, and 14, it can be seen that the Cr element has a non-mobile nature and is insoluble in groundwater so that this element accumulates a lot in the limonite zone, then decreases in the saprolite zone and decreases further in the bedrock zone. While Ni, Co, and Mn elements have semi-mobile mobility properties or are soluble in acidic groundwater conditions, and no longer dissolve when the pH of the groundwater has become neutral. These elements accumulate in the lower limonite zone to the upper saprolite zone.

The Fe and Al elements accumulate most in the limonite zone. This element will drop significantly in the saprolite zone and even lower in the bedrock zone. Fe and Al levels accumulate the most in the limonite zone, because Fe and Al elements are formed from the results of the oxidation process, have a very high level of chemical weathering, and the characteristics of Fe and Al are not easily mobilized by water media. In the opposite case, MgO and SiO_2 are elements that are easily dissolved during the weathering process and leached to the lower saprolite zone. These elements accumulate the least in the limonite zone, increase in the saprolite zone and continue to increase in the bedrock zone. This is due to the highly mobile nature of the element. The graph clearly shows that as we move towards the bedrock zone, the value of both elements increases. Tables 1, 2, and 3 shows total elements content value of incisions A-B, C-D, and E-F. Figures 15, 16, and 17 shows histogram of total elements content values in each zone of incicion A-B, C-D, and E-F.

Table 1. Total Elements Content Value of Incision A - B

Zone	*Minor Elements*				*Mayor Elements*			
	Ni	Co	Cr	Mn	Fe	Al	SiO_2	MgO
Limonite	1.25	0.124	1.72	0.97	41.42	2.82	5.65	1.87
Saprolite	1.66	0.032	0.63	0.32	14.81	0.81	35.63	17.3
Bedrock	0.58	0.004	0.32	0.1	7.33	0.57	36.55	28.13

Table 2. Total Elements Content Value of Incision C - D

Zone	*Minor Elements*				*Mayor Elements*			
	Ni	Co	Cr	Mn	Fe	Al	SiO_2	MgO
Limonite	1.31	0.174	1.64	1.21	41.02	3.21	5.3	2.02
Saprolite	1.32	0.06	0.61	0.55	15.11	0.91	32.45	18.8
Bedrock	0.5	0.004	0.29	0.1	7.11	0.45	35.13	26.94

Table 3. Total Elements Content Value of Incision E - F

Zone	*Minor Elements*				*Mayor Elements*			
	Ni	Co	Cr	Mn	Fe	Al	SiO_2	MgO
Limonite	1.24	0.11	1.56	0.84	35.98	2.63	14.3	2.9
Saprolite	1.43	0.05	0.8	0.33	18.51	1.21	33.32	11.3
Bedrock	0.49	0.004	0.29	0.098	7.26	0.43	39.48	30.82

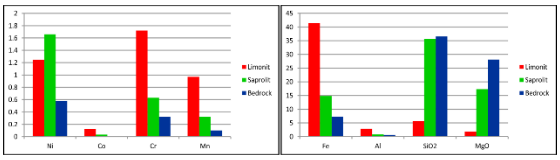


Figure 15. Histogram of total elements content values in each zone of incision A – B

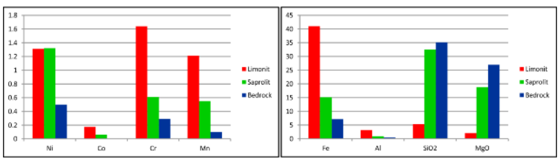


Figure 16. Histogram of total elements content values in each zone of incision C – D

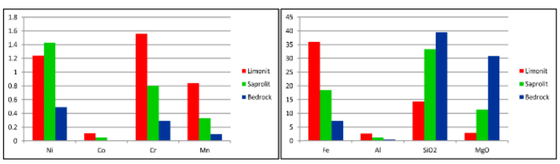


Figure 17. Histogram of total elements content values in each zone of incision E – F

3.5 Distribution and Value of Ni Content

The distribution map of Ni content in the limonite and also the saprolite zone is made using the Inverse Distance Weighting (IDW) method. The Ni element distribution map can be seen in Figure 18.

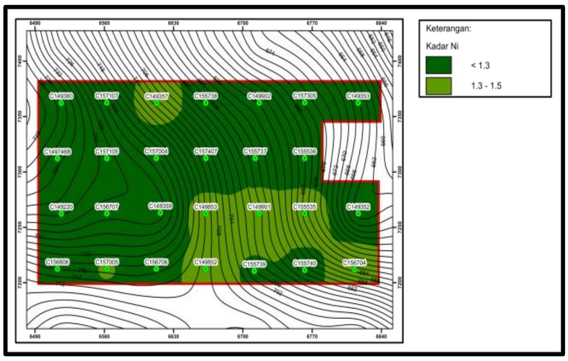


Figure 18. Ni content distribution map in the limonite zone

Based on Figure 18, there are two distribution classes found in the limonite zone as the results of IDW method based on the geochemistry. The class classification is based on the company's standard operating procedures. Ni content distribution in limonite zone is mostly dominated by Ni content with a value < 1.3% with a distribution of 74.07% that is distributed from the West Northwest - Southeast side of the research area and Ni content with a value of 1.3 - 1.5% with a distribution of 25.93% that is distributed from the Southeast and occupies a small part in the North side of the research area.

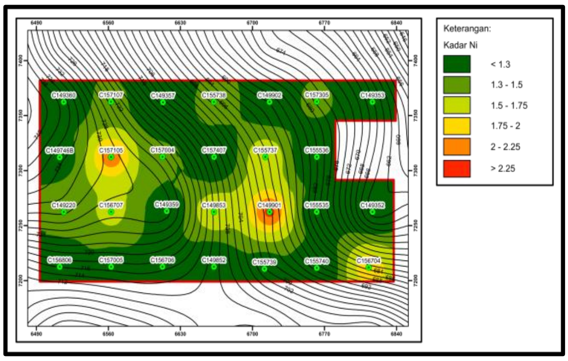


Figure 19. Ni content distribution map in the saprolite zone

Based on the Figure 19, there are six distribution classes found in the saprolite zone as the results of the inverse distance weighting method based on the geochemistry. The class classification is based on the company's standard operating procedures. It can be seen that the saprolite zone is dominated by Ni content with values < 1.3% with a distribution of 59.26%, 1.3% - 1.5% with a distribution of distribution of 18.52%, 1.5% - 1.75% with a distribution of 11.11%, 1.75% - 2% with a distribution of 3.70% distribution, 2% - 2.25% with 3.70% distribution and > 2.25% with 3.70% distribution.

3.6 Discussion

The laterite profile found in the study area consists of three zones, which are limonite zone, saprolite zone and bedrock zone. The limonite zone is a zone that has undergone complete weathering, so it no longer shows the rest of the host rock. The limonite zone was found in a brownish yellow color with fine grain size material with a very high level of weathering, the minerals found are goethite and hematite minerals. The saprolite zone is a zone that has experienced weathering but is not yet complete, so it still shows the remains of the host rock which is commonly called boulder. The saprolite zone was found in a brownish yellow, gray to greenish color with the material size of coarse grain with moderate weathering. The minerals found are goethite and garnierite while the boulders found are dunite rocks. Then the bedrock is a zone that has not undergone the weathering process, so this zone is found still in a fresh state. The bedrock zone found has a greenish gray color with a very coarse grain material size with a low level of weathering. The mineral content is olivine and pyroxine. The rock name is dunite.

Geochemical results from XRF analysis are made in the form of vertical diagrams showing the behavior of each element. The elements Cr, Fe and Al have non-mobile properties, where these elements are insoluble in groundwater so that these elements accumulate in the limonite zone. The elements Ni, Co and Mn have semi-mobile mobility properties or are soluble in acidic groundwater conditions, and no longer dissolve when the pH of the groundwater has become neutral. These elements accumulate in the lower limonite zone to the upper saprolite zone. Then the elements MgO and SiO2 have the nature of elements that are easily dissolved during the weathering process, so they will continue to dissolve and accumulate in the bedrock zone.

The value of Ni content based on geochemistry from XRF analysis results was calculated and then processed using ArcMap 10.7.1 application with the Inverse Distance Weighting method to determine the distribution pattern of Ni elements in each limonite and saprolite zone and the results is quite different. This is due to geochemical elements with their mobility properties, where the Ni element is an element with non-mobile characteristics, so that the Ni element will accumulate more in the saprolite zone as a result of the enrichment process. The results of the XRF analysis will produce a lower Ni element value in the limonite zone, so that the IDW method used will also produce a lower distribution of Ni content values compared to the saprolite zone, in line with the concept of the IDW method itself where the IDW method is estimating the weight value based on surrounding data.

4. CONCLUSIONS

The results of the distribution pattern in the limonite and saprolite zones shows that the limonite zone consists of two distribution classes, which are dominated by Ni elemental values < 1.3% and followed by Ni elemental values of 1.3% - 1.5% which occupy the Southeast and a small part in the North side of the research area. While in the saprolite zone six distribution classes were found, dominated by Ni content with values < 1.3% with a distribution of 59.26%, 1.3% - 1.5% with a distribution of distribution of 18.52%, 1.5% - 1.75% with a distribution of 11.11%, 1.75% - 2% with a distribution of 3.70% distribution, 2% - 2.25% with 3.70% distribution and > 2.25% with 3.70% distribution.

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