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# The Correlation Between Topographic Characteristics and the Thickness, Elemental Accumulation of Ni, Fe, and MgO, as well as the Distribution Pattern of Laterite Deposits Using the 2D Inverse Distance Weighting (IDW) Method in Wolo District, Kolaka Regency, Southeast Sulawesi Province

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**Abstract**: The research area is administratively located within the PIT Z area of PT. Ceria Nugraha Indotama's mining permit (IUP) in Wolo District, Kolaka Regency, Southeast Sulawesi Province. This study examines the correlation between topographic features and laterite deposit characteristics in the study region. The research methodology incorporated fieldwork, data processing using ArcMap 10.8 and Surpac 6.3 software, and laboratory analyses including petrographic and geochemical examinations. Analysis revealed two primary topographic features in the research area: steep hills and undulating hills. Steep hill topography exhibited high concentrations of MgO compounds and relatively thin laterite deposits. Conversely, undulating hill topography demonstrated optimal laterite deposits characterized by thicker laterite horizons and elevated Fe and Ni content. The distribution pattern of laterite deposits throughout the study area indicates that slope gradient significantly influences water drainage, which serves as the principal medium for the lateritization process, thereby establishing a direct relationship between topographic features and laterite deposit profiles.

**Keywords**: Geomorphology; Lateritization; Laterite Deposits; Distribution Pattern.

## 1. Introduction

Ultramafic rocks represent a distinctive category of igneous formations characterized by mineral compositions exceeding 45% ferromagnesian content while containing less than 0.3% nickel. The primary ferromagnesian minerals found in these formations include olivine ($Mg_2SiO_4$; $Fe_2SiO_4$), pyroxene ($CaSiO_3$; $MgSiO_3$; $FeSiO_3$), hornblende, mica, and biotite. Research has established that ultramafic rocks in the Sorowako region of South Sulawesi form residual nickel laterite deposits with remarkable geological significance [3][2][5]. Geological surveys indicate that ultramafic formations in Sorowako exhibit chemical composition patterns analogous to those documented across various Asia-Pacific locations, including the Philippines, Papua Province, Kalimantan Province, Southeast Sulawesi Province, and New Caledonia.

The genesis of laterite nickel deposits occurs through prolonged weathering processes in tropical climatic zones, specifically affecting nickel-bearing rock formations such as dunite (predominantly olivine), peridotite (olivine combined with pyroxene), and serpentinite. During the weathering sequence, referred to as lateritization, nickel undergoes dissolution into solution before being absorbed by iron oxide minerals, ultimately forming garnierite within the saprolite layer [3]. The development and quality of laterite nickel deposits depend on multiple interacting factors: the mineralogical and chemical composition of parent rock material, prevailing climatic conditions, structural geology characteristics, temporal duration of weathering processes, chemical dissolution mechanisms, vegetative cover, topographical features, and evolutionary timespan.

Topographical characteristics play a particularly crucial role in laterite formation as they directly influence water movement patterns across landscapes. Slope gradients determine runoff velocity, infiltration rates, and residence time of water within soil profiles—all factors that affect weathering intensity and mineral redistribution. Steeper slopes typically experience accelerated water runoff, reducing contact time between water and rock material, which may result in thinner laterite profiles. Conversely, gentler slopes allow greater water infiltration and longer rock-water interaction periods, potentially yielding thicker laterite horizons with distinctive elemental concentration patterns. The spatial distribution of laterite deposits across landscapes reflects the complex interplay between geological, topographical, and hydrological factors. Analyzing these distribution patterns requires sophisticated geostatistical approaches capable of interpolating data across unsampled locations. The Inverse Distance Weighting (IDW) methodology represents a particularly valuable geostatistical interpolation technique for examining laterite deposit distributions. This approach operates on the fundamental geographical principle that proximate locations exhibit greater similarity than distant ones—a concept known as Tobler's First Law of Geography.

When applying IDW methodology to laterite deposit analysis, researchers utilize measured values from surrounding sample points to estimate values at unsampled locations. The mathematical framework underlying IDW assumes that correlation strength and similarity between prediction points and sample data diminish proportionally with increasing distance [8]. This relationship is expressed through a power function that weights the influence of each sample point based on its distance from the prediction location. The weighting factor diminishes as distance increases, creating a distance-decay effect that prioritizes nearby observations.

The application of the IDW methodology to laterite deposit mapping offers several advantages for geological research. First, it allows the creation of a continuous surface representation from discrete sampling points, allowing researchers to visualize deposit distribution patterns across the study area. Second, the technique accommodates varying degrees of spatial influence through adjustable power parameters, allowing researchers to calibrate the model based on the known geological behavior of specific elements such as nickel, iron, and magnesium. Third, IDW provides an efficient computational solution for the large data sets commonly encountered in regional geological surveys. Understanding the relationship between topographic features and laterite deposit characteristics requires the integration of multiple analytical approaches. Field observations must be complemented by laboratory analyses to determine elemental composition and mineralogical structure. Geographic Information Systems (GIS) facilitate the spatial analysis of these data, allowing researchers to identify correlations between topographic variables and laterite profile characteristics. Three-dimensional modeling software further enhances visualization capabilities, allowing researchers to examine subsurface deposit structures in relation to surface topography. This research focuses on laterite deposits in Southeast Sulawesi Province, specifically investigating how variations in topographic conditions influence laterite formation processes and the resulting deposit characteristics. By analyzing drill core samples across various topographies and applying advanced geostatistical methods, this study aims to establish quantitative relationships between slope gradient, laterite thickness, and elemental concentration patterns.

## 2. Related Work

Nickel is a naturally occurring metallic element characterized by its shiny (lustrous) and silvery-white appearance. Nickel is one of the five most common metallic elements found on Earth, widely distributed, especially in the Earth's crust, and is a good conductor of electricity and heat. The metallic mineral known as laterite nickel is produced when ultramafic rocks weather chemically, leaving behind residual and secondary enrichment of Ni, Fe, Mn, and Co elements. The presence of reddish-brown metal oxides comprising Ni and Fe is what defines this [7]. The most recent advancements in the programming process have an impact on these conditions since this geocomputational approach is at the forefront of GIS research and geospatial analysis. The Inverse Distance Weight (IDW) approach can be used as a metric to estimate quantifiable nickel laterite resources and is typically utilized as modeling to accomplish proper distribution. Based on the value of the closest sampled place, the IDW method is a spatial interpolation approach that can be applied in geostatistics to estimate the unknown value of an unsampled location. Basically, geospatial analysis is the main application for this approach [6]. Recent advancements in programming, processing, and user interface design have a significant impact on geocomputing, which is a fundamental component of GIS research and geospatial analysis. In essence, nickel laterite exploration and resource estimation are complicated processes that involve a number of methods and variables, such as geocomputing, inverse distance weighting, structural elements, and predictive mineral modeling. It is the most crucial element for mining firms to successfully assess new areas and organize subsequent nickel laterite reserve exploration campaigns [4][9].

## 3. Research Method

The method involved collecting field data from core drilling samples, followed by laboratory analyses through petrographic thin-section analysis and geochemical analysis using X-Ray Fluorescence (XRF). The creation of laterite deposit profile cross-sections was carried out using Surpac 6.3, while the laterite deposit distribution maps were created using ArcGIS 10.8 with the 2D Inverse Distance Weighting method.

## 4. Result and Discussion

### 4.1 Results

4.1.1 Morphology

Peridotite ultrabasic rocks make up the majority of the topography in the study area's morphology. The research area's geography is hilly, with an average elevation of 350-450 meters above sea level [1]. Dominated by slope inclinations of 8°-16° with undulating hill characteristics and 16°-35° with steep hill characteristics.


Figure 1. The relief conditions at the research location show "X" as undulating hills and "Y" as steep hills.

#### 4.1.2 Lithology

Peridotite lithology makes up the unit, according to field data. Megascopic features display bodily attributes such as a fresh greenish-black color, weathered reddish-brown color, holocrystalline crystallinity, phaneritic granularity, euhedral-anhedral mineral shapes, equigranular texture, and a mineral composition of pyroxene, olivine, plagioclase, with alteration minerals such as serpentine and garnierite. The rock's structure has a massive groundmass. The microscopic appearance based on petrographic thin-section analysis of peridotite rock samples from the research area with hole ID XAB0069 shows a grayish-black color under parallel nicols and a grayish-black color under crossed nicols. It has hypocrystalline crystallinity, porphyritic granularity, inequigranular texture, euhedral to subhedral mineral shapes, and a vesicular structure having grain sizes between 0.05 and 0.8 mm. The mineral composition consists of Olivine (20%), Serpentine (15%), Orthopyroxene (25%), and Clinopyroxene (40%). There is also serpentine alteration in the form of veins derived from mafic minerals (Olivine and Pyroxene). Based on these characteristics, this rock is identified as Olivine Websterite (Streckeisen, 1976).

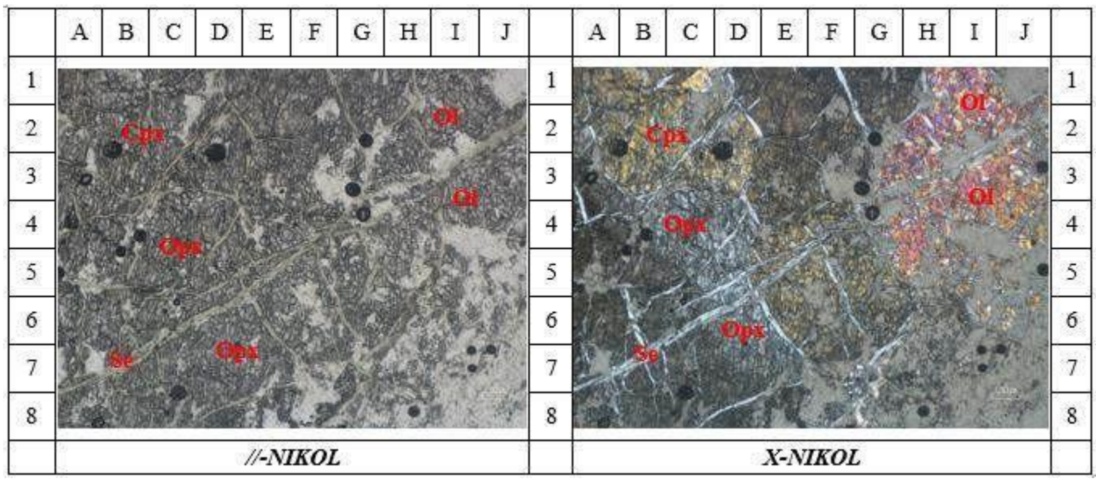


Figure 2. The microscopic appearance of the bedrock in the research area

#### 4.1.3 Laterite Deposit Profile Cross-Section

In general to create a 2D model in the form of a vertical cross-section of a laterite deposit profile, drilling data is required to provide detailed information about the subsurface geological conditions of an area. Therefore, drilling data is essential for further geological data interpretation. The analysis of drilling data in this study aims to determine the laterite profile (limonite and saprolite) and the bedrock of the study area. This observation is conducted by comparing the laterite profile of the study area with its topographic characteristics using Surpac 6.3 to obtain a relief condition that can be correlated with the laterite layers in the drilling data.

Table 1. The distribution of element accumulation and thickness of drilling data along cross-section A-B.

| XAB0054 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ELEMENT | LIM | | | SAP | | | BRK | | |
| | MEAN | MIN | MAX | MEAN | MIN | MAX | MEAN | MIN | MAX |
| Ni (%) | 0.96 | 1.07 | 1.19 | 0.34 | 0.28 | 0.40 | 0.59 | 0.41 | 0.90 |
| Fe (%) | 26.15 | 32.61 | 39.07 | 5.75 | 3.88 | 7.62 | 7.05 | 3.99 | 9.40 |
| MgO (%) | 2.76 | 2.86 | 2.95 | 12.56 | 8.89 | 16.23 | 32.26 | 12.30 | 42.17 |
| Thickness (m) | 2 | | | 2 | | | 10 | | |
| XAB0055 | | | | | | | | | |
| ELEMENT | LIM | | | SAP | | | BRK | | |
| | MEAN | MIN | MAX | MEAN | MIN | MAX | MEAN | MIN | MAX |
| Ni (%) | 0.80 | 0.83 | 0.86 | 0.94 | 0.62 | 1.27 | 0.37 | 0.22 | 0.58 |
| Fe (%) | 44.06 | 44.46 | 44.89 | 12.76 | 7.06 | 18.33 | 6.49 | 6.04 | 7.66 |
| MgO (%) | 1.60 | 1.67 | 1.78 | 26.96 | 18.76 | 37.69 | 38.12 | 36.31 | 40.53 |
| Thickness (m) | 3 | | | 7 | | | 7 | | |

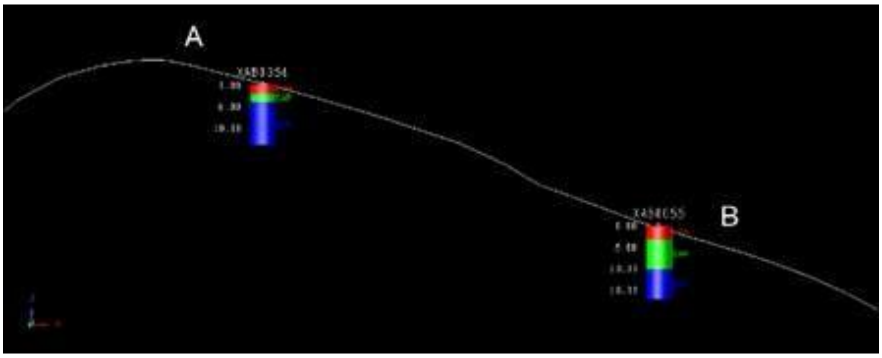

Figure 3. Drilling Data Cross-Section A-B

In the table above, it can be seen that at the drilling point XAB0054, which has a slope gradient of 8°-16° the thickness of the laterite deposit (limonite and saprolite) is quite thin with less significant element enrichment, and the bedrock zone has a relatively thick layer. This is caused by the steep slope gradient at this drilling point, which prevents water from penetrating effectively, thus hindering the lateritization process. At the drilling point XAB0055, which is also located at a slope gradient of 8°-16° a thin laterite deposit with less significant Ni enrichment was found. However, in the saprolite zone, this drilling point has a relatively high thickness compared to point XAB0054 due to the better lateritization process in this area. The formation is located on a relatively gentle slope, allowing for maximum water penetration and a high degree of weathering because the runoff or water drainage is low, providing sufficient time for the enrichment process.

Table 2. The distribution of element accumulation and thickness of drilling data along cross-section C-D

| XAB0058 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ELEMENT | LIM | | | SAP | | | BRK | | |
| | MEAN | MIN | MAX | MEAN | MIN | MAX | MEAN | MIN | MAX |
| Ni (%) | 1.02 | 0.95 | 1.13 | 0.74 | 0.22 | 1.82 | 0.45 | 0.27 | 0.60 |
| Fe (%) | 38.12 | 29.06 | 43.26 | 8.26 | 3.84 | 21.95 | 6.29 | 3.45 | 10.34 |
| MgO (%) | 1.59 | 1.26 | 2.14 | 10.27 | 0.86 | 37.73 | 24.01 | 3.12 | 43.73 |
| Tebal (m) | 3 | | | 11 | | | 8 | | |
| XAB0059 | | | | | | | | | |
| ELEMENT | LIM | | | SAP | | | BRK | | |
| | MEAN | MIN | MAX | MEAN | MIN | MAX | MEAN | MIN | MAX |
| Ni (%) | 0.88 | 0.87 | 0.89 | 0.77 | 0.25 | 1.37 | 0.37 | 0.29 | 0.45 |
| Fe (%) | 47.55 | 47.29 | 47.81 | 15.70 | 6.17 | 32.02 | 6.73 | 6.51 | 7.04 |
| MgO (%) | 0.71 | 0.60 | 0.82 | 24.92 | 6.56 | 42.38 | 40.51 | 39.64 | 42.13 |
| Tebal (m) | 2 | | | 5 | | | 5 | | |
| XAB0060 | | | | | | | | | |
| ELEMENT | LIM | | | SAP | | | BRK | | |
| | MEAN | MIN | MAX | MEAN | MIN | MAX | MEAN | MIN | MAX |
| Ni (%) | 0.82 | 0.83 | 0.88 | 0.59 | 0.25 | 0.99 | 0.37 | 0.24 | 0.73 |
| Fe (%) | 32.76 | 36.11 | 39.47 | 8.65 | 3.47 | 18.20 | 6.67 | 5.95 | 8.88 |
| MgO (%) | 2.11 | 2.58 | 3.05 | 27.11 | 5.65 | 5.65 | 34.84 | 17.07 | 42.72 |
| Tebal (m) | 2 | | | 14.25 | | | 5.75 | | |

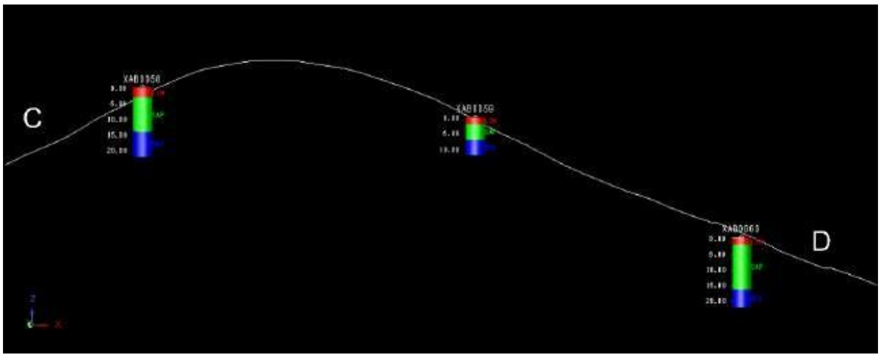

Figure 4. Drilling Data Cross-Section C-D

In the table above, it can be seen that at drilling points XAB0058 and XAB0060, which have a slope gradient of 16°-35° the laterite deposits are relatively thick. However, the distribution of element concentrations at these drilling points also indicates that the lateritization process is not optimal, as the percentage of Ni concentration is more enriched in the limonite zone compared to the saprolite zone. This suggests that the infiltration of water containing Ni into the rock is incomplete, causing Ni to be predominantly deposited in the transition zone between limonite and saprolite. At drilling point XAB0059, which is located at a slope gradient of 8°-16°, the laterite deposits are relatively thin. This indicates that the lateritization process in this area is functioning well, as the formation position is near a ridge, allowing for maximum water penetration and a high degree of weathering. The minimal runoff provides sufficient time for the enrichment process, resulting in a relatively normal distribution of elements at this drilling point.

4.1.4 Laterite Deposit Distribution Pattern

In general to determine the distribution of Ni, Fe, MgO concentrations, and the thickness of the research area's laterite deposits, exploration drilling data that has been validated and processed using ArcGIS 10.8 software with the IDW interpolation method is used. Laterite thickness and the chemical element content of Ni, Fe, and MgO are used to establish the distribution pattern of laterite deposits in the studied area. At each drilling location, X-Ray Fluorescence (XRF) is used in laboratory studies to determine the distribution pattern in the research region. After that, the concentrations in the limonite and saprolite strata are averaged and compared to the research area's slope gradient.

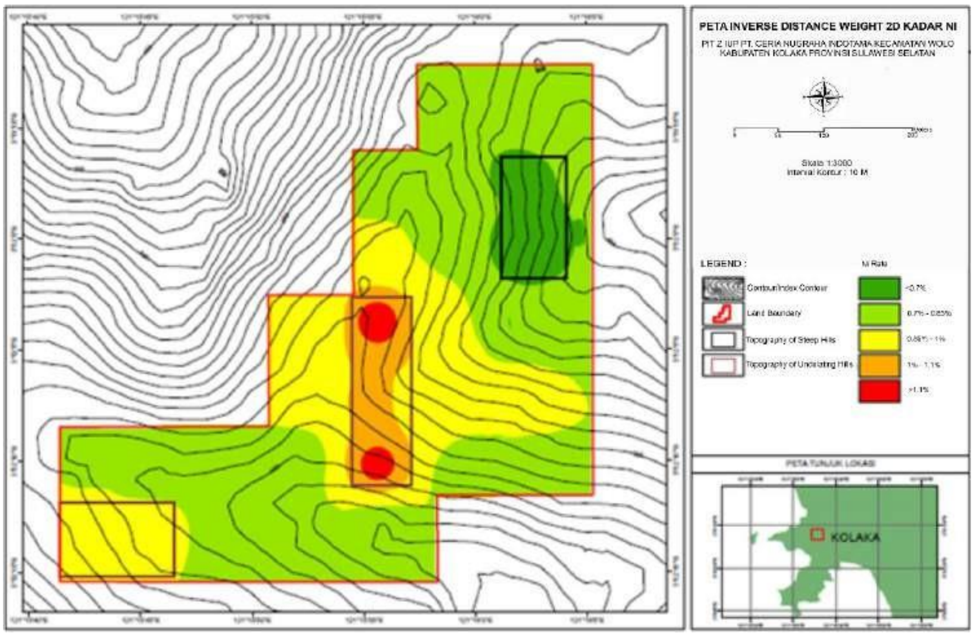


Figure 5. Ni Concentration Distribution Map

The study area's Ni distribution pattern is derived from laboratory tests using X-Ray Fluorescence (XRF) at every drilling location. Next, the limonite and saprolite layers' Ni concentrations are averaged and connected with the study area's slope gradient, where the rolling hill zone has a Ni concentration of 0.6 – 1.3%, and the steep hill zone has a Ni concentration of 0.5 – 1.2%. The results are then input into ArcGIS 10.8 to create a Ni concentration distribution map using the Inverse Distance Weighting method. This shows that the dominant Ni distribution is found in the southwest and central parts of the study area, which correspond to the rolling hill zone. This indicates that the mobility of Ni is semi-mobile, with Ni tending to react in acidic groundwater conditions. When the pH of the groundwater increases to neutral, combined with the slope conditions that are not too steep, these elements are less likely to dissolve into the underlying laterization zone. This explains the accumulation of Ni in the Ni concentration distribution map in the rolling hill zone of the study area.

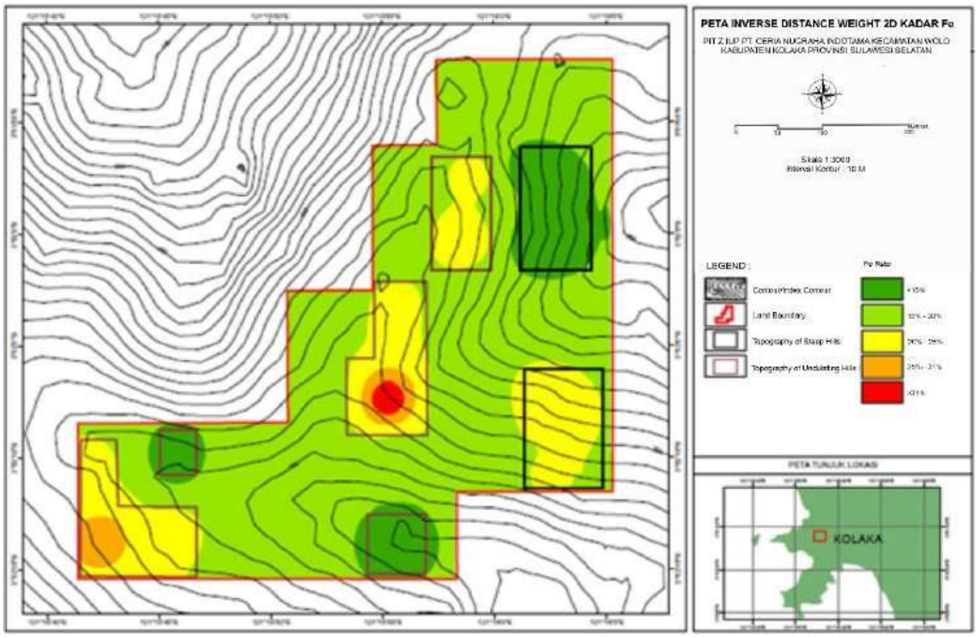


Figure 6. Fe Concentration Distribution Map

The Fe laboratory tests are used to determine the distribution pattern in the studied area using X-Ray Fluorescence (XRF) at each drilling point. Next, the average of the Fe concentrations in the limonite and saprolite layers is calculated and correlated with the slope gradient of the study area, where the rolling hill zone has an Fe concentration of 11.3 – 36.1%, and the steep hill zone has an Fe concentration of 10.3 – 24%. The results are then input into ArcGIS 10.8 to create an Fe concentration distribution map applying the method of Inverse Distance Weighting. It reveals that Fe distribution is dominant in the center of the research space, which corresponds to the rolling hill zone, but it does not accumulate maximally. Fe binds with oxygen to achieve equilibrium in nature ($Fe_2O_3$), a chemical reaction process known as oxidation. Additionally, Fe is an element with low mobility in laterite deposits. This leads to the accumulation of Fe in the limonite zone. Consequently, Fe concentrations tend to decrease in the saprolite zone down to the bedrock, regardless of the slope conditions.

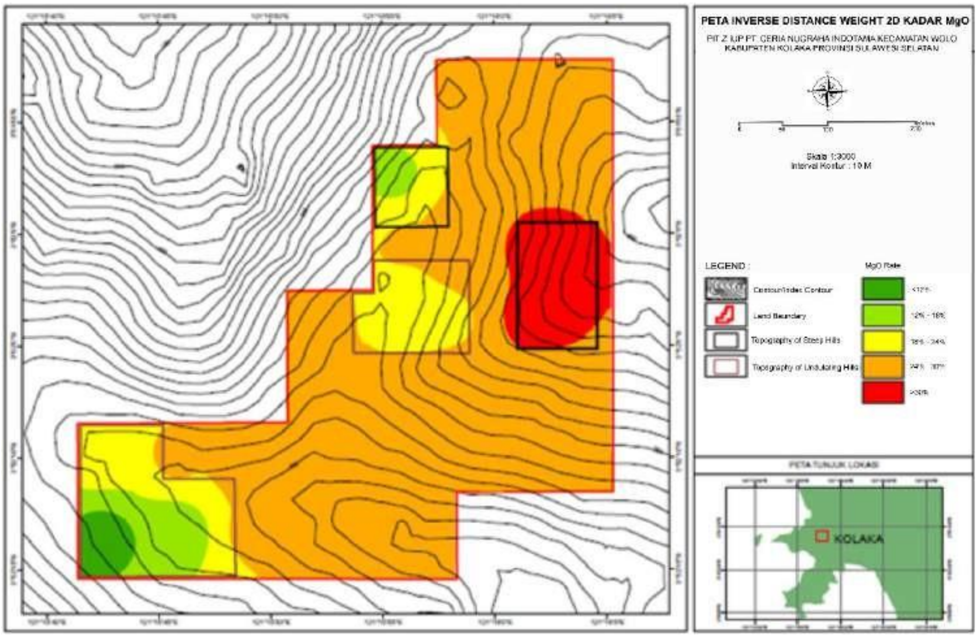


Figure 7. MgO Concentration Distribution Map

X-Ray Fluorescence (XRF) at each drilling location is used in laboratory studies to determine the MgO distribution pattern in the research area. The MgO concentrations within the limonite, saprolite, and the average of the bedrock layers and correlated with the slope gradient of the study area. In the rolling hill zone, MgO concentrations range from 7.09% to 32.20%, while in the steep hill zone, they range from 14.17% to 26.55%. The results are then input into ArcGIS 10.8 to create an MgO concentration distribution map using the Inverse Distance Weighting method. This reveals that MgO distribution is dominant in the research area's eastern section, matching the area of steep hills. This indicates that the lateritization process is less effective due to high erosion zones, causing water to run off and preventing optimal rock weathering.

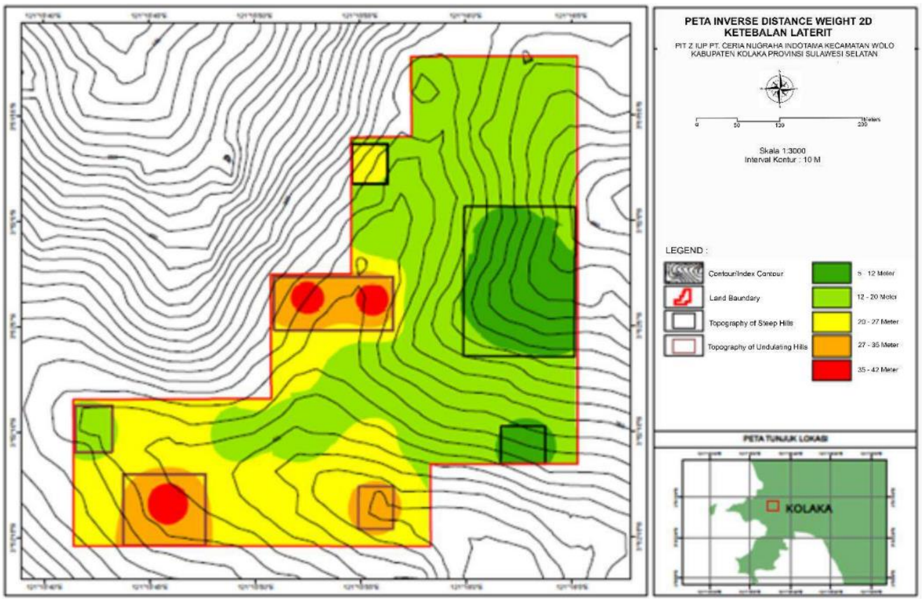


Figure 8. Thickness Laterite Distribution Map

The studied area's laterite thickness distribution pattern is primarily impacted by the intensity of ultramafic rock weathering, which is quite high, affecting the thickness of the overlying soil, with varying thickness at each drilling point. The thickness data is then correlated with the slope gradient of the study area, where the rolling hill zone has an average thickness of 16.9 meters with a range of 6 to 43 meters, and the steep hill zone has an average thickness of 12.5 meters with a range of 5 to 39 meters. The results are then input into ArcGIS 10.8 to create a laterite thickness distribution map using the Inverse Distance Weighting method. This shows that the dominant laterite thickness distribution is in the southwest and central parts of the study area, which are part of the rolling hill zone. In the steep hill zone, acidic rainwater starts to have difficulty penetrating deeper into the rock or soil, making the laterization process more difficult, with a more residual nature. This is because rainwater that falls on steep slopes generally causes erosion of the rock at such slope gradients. As a result, the weathered rock tends to be mechanically weathered through abrasion and is often transported to flatter areas. This is why laterite thickening is more difficult to occur on steep slopes.

## 4.2 Discussion

Drilling data was analyzed, and a model of the laterite deposit profile cross-section was produced using the data, accounting for slope gradients and various relief circumstances. The average values of all drilling point data—thickness, Ni, Fe, and MgO percentage in each laterite zone were calculated and classified based on the slope gradient traversed by the section. Later, a distribution map of the laterite deposits was created. This approach was employed to obtain a general overview of the relationship between the research area's laterite deposits' profile features and topographic features. The average results of the laterite deposits for each slope gradient in the study area are presented in the table below:

Table 3. The Average Thickness and Percentage Grades in the Laterite Zones

| Slope Gradient 8-16% | | | |
|---|---|---|---|
| Element | LIM | SAP | BRK |
| Ni (%) | 0.87 | 0.82 | 0.40 |
| Fe (%) | 40.34 | 13.72 | 6.77 |
| MgO (%) | 3.33 | 22.91 | 37.36 |
| Thickness (m) | 5.46 | 11.50 | 4.90 |
| Slope Gradient 16-35% | | | |
| Element | LIM | SAP | BRK |
| Ni (%) | 1.02 | 0.74 | 0.43 |
| Fe (%) | 38.12 | 13.96 | 6.81 |
| MgO (%) | 3.23 | 24.42 | 35.82 |
| Thickness (m) | 3.35 | 9.25 | 5.88 |

From the table above, it can be observed that the thickest laterite deposits are found on slopes with an inclination of 8°–16°, characteristic of rolling hill topography, with an average thickness of 5.46 meters for the limonite zone and 11.5 meters for the saprolite zone. This suggests that this topographic characteristic provides the most optimal conditions for lateritization compared to other topographic characteristics in the study area. Slopes with an inclination of 16°–35°, indicative of steep hill topography, have the thinnest laterite deposits, with a thickness of 3.35 meters for the limonite zone and 9.25 meters for the saprolite zone. This indicates a less optimal lateritization process due to high erosion zones, leading to significant runoff and insufficient rock weathering. For the bedrock zone thickness in the table, the actual thickness cannot be determined accurately because PT. CNI's drilling standard operating procedure recommends halting drilling once fresh rock is encountered at a depth of 3 meters, preventing the measurement of the true thickness of the bedrock zone. The correlation between laterite deposit thickness and slope inclination in the study area can be seen in the graph below:

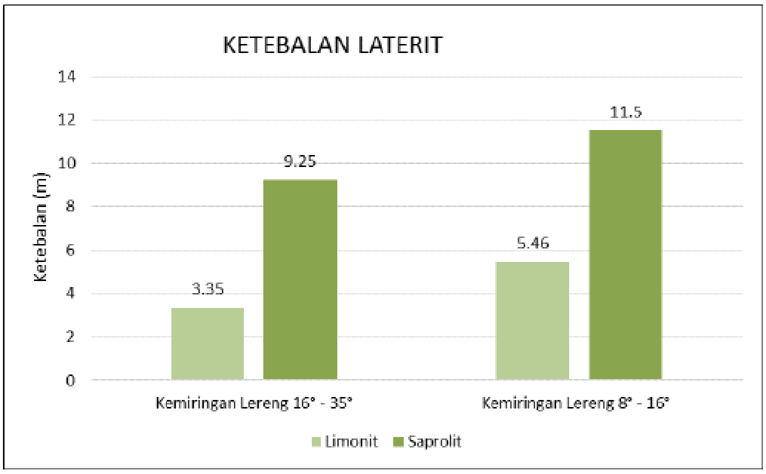


Figure 9. The Correlation Between Slope Inclination and Laterite Thickness

Based on the percentage of elemental composition, the slope inclination of 16°–35°, representing steep hill topography, has a limonite zone with the highest average Fe content (38.12%) and Ni content (1.02%) in the study area. Meanwhile, the average MgO content is the lowest (3.23%) in the study area. In the saprolite zone, the Ni content is the lowest, with a percentage of 0.74%. The Fe accumulation in the saprolite zone is 13.96%, while the MgO content is the highest at 24.42%. This indicates that the lateritization process was less optimal, as evidenced by the limited Fe distribution in the limonite zone. This suggests that Fe, undergoing weathering, was eroded and not adequately deposited in the limonite zone. Ni enrichment is considered relatively optimal since it exhibits the highest accumulation in the study area, although some drilling points in this relief lack a limonite zone. It is also observed that Ni is more concentrated in the transition zone between limonite and saprolite. In the undulating hill topography with slope inclinations of 8°–16°, the limonite zone has the highest Fe accumulation (40.34%) in the study area, along with Ni accumulation of 0.87% and MgO accumulation of 3.33%. In the saprolite zone, there is a similar pattern with the lowest Fe accumulation (13.72%), Ni accumulation of 0.82%, and MgO content of 24.42%. Observing the distribution of elemental accumulation, the lateritization process in this area is well-developed, characterized by intense weathering due to minimal runoff, providing sufficient time for supergene enrichment. The correlation of the laterite deposit composition with each topographic characteristic can be seen in the graph below:

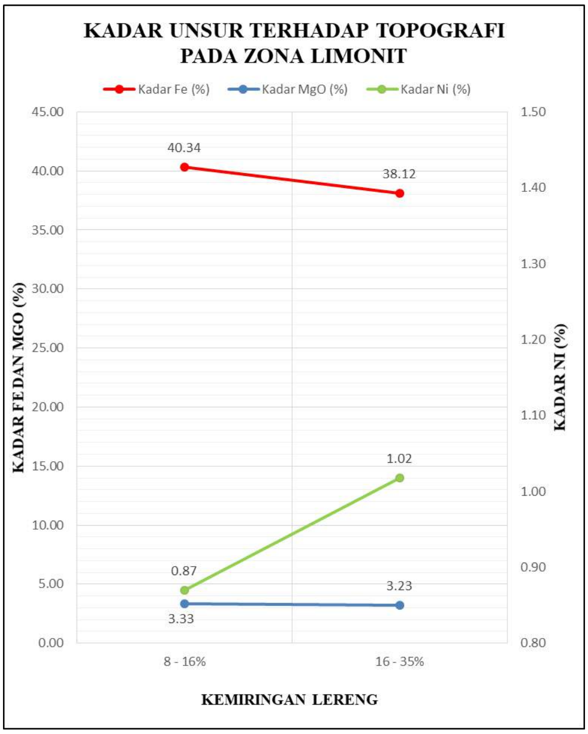


Figure 10. Correlation of Laterite Deposit Composition with Slope Inclination in the Limonite Zone

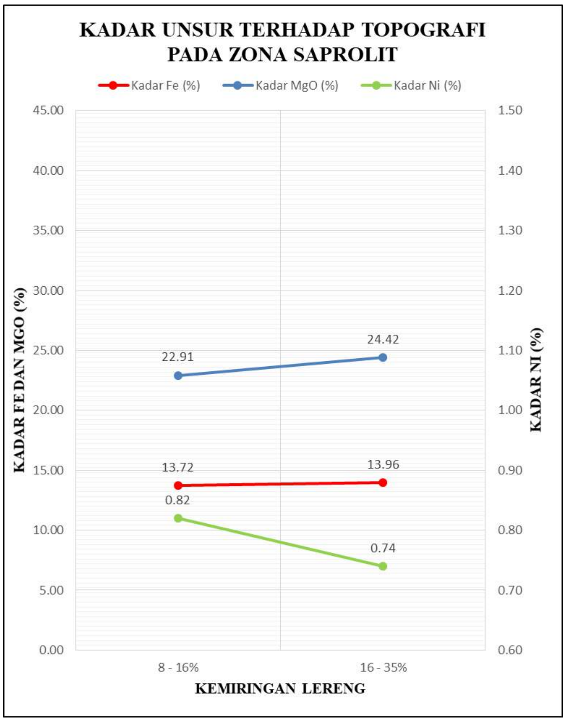


Figure 11. Correlation of Laterite Deposit Composition with Slope Inclination in the Saprolite Zone.

## 5. Conclusion

The topographic characteristics of the research area are steep hills with a slope of 16°-35° and wavy hills with a slope of 8°-16°. The steep hill topography has a limonite zone thickness of 3.35 meters and an accumulation percentage of Ni elements of 1.02%, Fe elements of 38.12%, and MgO elements of 3.23%. The saprolite zone has a thickness of 9.25 meters and an accumulation percentage of Ni element at 0.74%, Fe element at 13.96%, and MgO at 24.42%. Meanwhile, the wavy hill topography has a limonite zone thickness of 5.46 meters and the accumulated percentage of the Ni element was 0.87%, the Fe element was 40.34%, and the MgO element was 3.33%. The saprolite zone has a thickness of 11.5 meters and an accumulation percentage of Ni elements of 0.82%, Fe was 13.72%, while MgO was 22.91%. This could suggest that topographic characteristics affect how water drains as the main medium for the lateritization process.

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