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Estimation of Nickel Laterite Resources and Reserves Using Ordinary Kriging and Inverse Distance Weighting (IDW) Methods: A Case Study from the Kolaka Block, PT Indrabakti Mustika, North Konawe Regency, Southeast Sulawesi

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Abstract

This study aims to assess the geological domains and estimate the nickel laterite resources and reserves within the Kolaka Block exploration area at PT. Indrabakti Mustika, utilizing the Ordinary Kriging and Inverse Distance Weight (IDW) methods. The research employs quantitative and qualitative approaches to evaluate the geological framework and estimate the nickel laterite resources and reserves. Geological domain classification—limonite, saprolite, and bedrock layers—was achieved through detailed core section analysis, which informed the delineation of the nickel laterite zones. Based on the IDW method, the resource estimation results indicate 3,180,350 m³ (4,611,509 metric tons) of nickel laterite resources. This is subdivided into limonite zone resources (1,547,475 m³ or 2,243,840 metric tons) and saprolite zone resources (1,632,875 m³ or 2,367,669 metric tons). Using the Ordinary Kriging method, the total nickel laterite resource is estimated at 3,212,275 m³ (4,657,801 metric tons), with the limonite zone contributing 1,562,500 m³ (2,265,627 metric tons) and the saprolite zone contributing 1,649,775 m³ (2,392,174 metric tons). For the reserve estimation, the IDW method suggests a total of 1,205,875 m³ (1,748,520 metric tons) of nickel laterite reserves. These reserves are divided into limonite zone reserves (456,275 m³ or 661,600 metric tons) and saprolite zone reserves (749,600 m³ or 1,086,920 metric tons). In contrast, the Ordinary Kriging method estimates a total of 1,142,225 m³ (1,656,227 metric tons) of reserves, with limonite zone reserves of 516,700 m³ (749,216 metric tons) and saprolite zone reserves of 625,525 m³ (907,011 metric tons). These findings provide a comprehensive understanding of nickel laterite's geological and resource distribution in the Kolaka Block, offering crucial data for further exploration and development activities at PT. Indrabakti Mustika.

1. Introduction

Endowed with rich natural resources, Indonesia is one of the world's largest producers of minerals, with the mining sector playing a crucial role in its economic growth. Nickel, in particular, has emerged as a key commodity with high demand globally, and Indonesia is a major supplier. PT. Indrabakti Mustika, an active player in the nickel mining industry, has been conducting operations since 2014 following its Mining Business License for Production Operations (IUP OP) issuance. The company operates in Lameruru Village, Langgikima District, North Konawe Regency, Southeast Sulawesi, Indonesia, across 576 hectares. The region is known for its significant nickel laterite deposits, which have become a central resource for the national and international markets.

Accurate resource estimation is essential for the development and management of mining projects. Core drilling, one of the primary exploration methods, enables detailed analysis of geological domains and mineral content. Nickel laterite ores, however, exhibit significant variability in grade and distribution, necessitating precise estimation methods to assess the potential of deposits.

This study introduces a novel approach by applying and comparing two geostatistical methods—**Ordinary Kriging (OK)** and **Inverse Distance Weighting (IDW)**—to estimate the nickel laterite resources and reserves in the Kolaka Block area, with a focus on Lameruru Village. These methods represent two distinct approaches to spatially estimating mineral resources and are widely used in mineral exploration and resource modeling.

Ordinary Kriging (OK) is a geostatistical method that utilizes spatial statistics to provide predictions based on the spatial correlation between data points. OK is preferred in complex geological environments due to its ability to account for spatial relationships, resulting in lower estimation errors than other methods [2],[5]. It has been widely applied in nickel laterite deposits, as it offers more reliable and precise resource estimates [7].

Inverse Distance Weighting (IDW), on the other hand, is an interpolation method that estimates values based on the inverse distance between the estimation point and nearby data points. Although IDW tends to yield higher estimation errors than OK, it remains a valuable method, particularly when data points are densely spaced, and more straightforward modeling is advantageous [4],[6]. IDW is often used when geostatistical software or data complexity does not justify using more advanced techniques like Kriging.

The significance of this study lies in its direct comparison of these two methods, which have traditionally been used separately in resource estimation but have not been extensively compared in the context of laterite nickel deposits in Southeast Sulawesi. A key contribution of this research is its comparative analysis of the OK and IDW methods applied to the Kolaka Block exploration site, offering a deeper understanding of their relative strengths and weaknesses in estimating nickel laterite resources and reserves. Compared to previous studies, such as the work by Aldy Elriq Syahputra (2022) [1], which applied the Ordinary Kriging method for resource and reserve estimation at PT. Cinta Jaya in the Cahaya Prima Kuasa exploration block, this study adds value by integrating two geostatistical methods for resource estimation. Syahputra's research focused solely on Ordinary Kriging, using the GS+ software for geostatistical analysis and Surpac software for resource and reserve calculations. In contrast, his work was instrumental in refining resource estimates for nickel deposits at PT. Cinta Jaya, this study offers a new perspective by introducing IDW as a complementary method, allowing for a more comprehensive comparison of the two approaches in the same geographical and geological context.

By comparing the results of both OK and IDW, this study aims to provide more reliable and accurate resource estimates and improve the classification of nickel laterite resources into measured, indicated, and inferred categories. This classification process is critical for assessing the economic feasibility of mining projects and planning extraction strategies [2], [3]. For example, in previous studies using OK, resources were successfully classified based on a cut-off grade of 1.4% Ni, identifying large tonnages of economically viable nickel laterite [2]. The method chosen for estimation and classification and the selection of appropriate cut-off grades directly impact the accuracy of resource estimates and the overall economic outcomes of mining operations [3], [4]. This study not only compares the effectiveness of Ordinary Kriging and Inverse Distance Weighting in the context of nickel laterite estimation but also builds on previous work, such as that of Aldy Elriq Syahputra, by offering a more comprehensive approach to resource modeling. The results from both methods will provide valuable insights for the future development of mining operations in the Kolaka Block and contribute to the broader field of nickel laterite resource estimation.

2. Results and discussions

2.1. Results

Exploration Activities

Geologists conduct exploration activities to study an area that can produce specific resources. The research location is the Kolaka Block, an advanced exploration block in Lameruru Village. This exploration block is part of a series of extensions from the mining plan. The exploration activities at the Kolaka Block constitute detailed exploration phases. During this phase, core drilling is performed using a machine to obtain core samples. This drilling helps to understand the lithology and distribution of grades at every 1-meter depth[8].

Figure 1. The sample of the drill core box

The core drilling results are then stored in core boxes with dimensions of 104 x 40 x 7 cm (see Figure 1). These core boxes describe the minerals and analyze the quality of the grades contained within the core samples. The drilling results yielded 1,075 samples, with an average sample length of 1 meter. The data from these samples, which have been analyzed for grade quality, will be used for data processing and analysis.

Cut-off Grade

Cut-off grade data are values approved by the company with varying ranges to align with the geological domains of the laterite layers at PT. Indrabakti Mustika has established a cut-off grade of 1.25 for both the limonite and saprolite layers.

2.2. Discussions

A series of steps are carried out to estimate resources and reserves based on the obtained borehole sample data. The first step involves creating the topography of the research area by linking X, Y, and Z coordinate data to generate appropriate contour lines. The next step is to analyze the frequency distribution of the various existing geological domains, which involves determining the variogram type. The third step consists in calculating the estimation of laterite nickel resources and reserves using the Ordinary Kriging and Inverse Distance Weighting (IDW) methods. The final step is to compare the results from both methods and determine the resource and reserve quantities based on the estimation results.

Borehole Data Correlation

Correlation is used to determine the grade quantities in descriptive statistical terms. Due to their differing characteristics, this descriptive statistical analysis is conducted for the limonite and saprolite zones. In the exploration activities at the Kolaka Block, there are 43 boreholes with grade readings taken every meter. The research area features thick geological domains, allowing drilling depths of up to 40 meters. The total number of samples tested in the limonite zone is 483, while in the saprolite zone, it is 382, and in the bedrock zone, it is 210, resulting in a total of 1,075 samples tested (see Table 1).

Descriptive statistical calculations are used to provide an overview of the variables in the study. This data will be used to create histograms to analyze grades across geological domains. The X-axis on the histogram represents the grade distribution, while the Y-axis represents the number of data points. Below are the descriptive statistics and histograms illustrating the characteristics of the research samples (see table 2).

Table 1. Kolaka Block Borehole Sample Database

HOLE_ID	Y	X	Z (m)	FROM	TO	NI (%)	LITOLOGI
DE0102	9641199.38	420665.39	195.18	0	1	1.16	*Limonite*
DE0102	9641199.38	420665.39	195.18	1	2	1.27	*Limonite*
DE0102	9641199.38	420665.39	195.18	2	3	1.1	*Limonite*
DE0102	9641199.38	420665.39	195.18	3	4	1.39	*Limonite*
DE0102	9641199.38	420665.39	195.18	4	5	1.14	*Limonite*
DE0102	9641199.38	420665.39	195.18	5	6	1.12	*Limonite*
DE0102	9641199.38	420665.39	195.18	6	7	1.03	*Limonite*
DE0102	9641199.38	420665.39	195.18	7	8	1.21	*Limonite*
DE0102	9641199.38	420665.39	195.18	8	9	1.45	*Limonite*
DE0102	9641199.38	420665.39	195.18	9	10	1.29	*Saprolite*
DE0102	9641199.38	420665.39	195.18	10	10.3	1.56	*Saprolite*
DE0102	9641199.38	420665.39	195.18	10.3	10.7	0.5	*Saprolite*
DE0102	9641199.38	420665.39	195.18	10.7	11	1.87	*Limonite*
DE0102	9641199.38	420665.39	195.18	11	12	1.87	*Saprolite*
DE0102	9641199.38	420665.39	195.18	12	13	1.6	*Saprolite*
DE0102	9641199.38	420665.39	195.18	13	14	1.62	*Saprolite*
DE0102	9641199.38	420665.39	195.18	14	14.3	1.38	*Saprolite*
DE0102	9641199.38	420665.39	195.18	14.3	15	0.35	*Bedrock*
DE0102	9641199.38	420665.39	195.18	15	16	0.39	*Bedrock*
DE0102	9641199.38	420665.39	195.18	16	17	1.38	*Saprolite*
DE0102	9641199.38	420665.39	195.18	17	18	1.33	*Saprolite*
DE0102	9641199.38	420665.39	195.18	18	19	0.86	*Bedrock*
DE0102	9641199.38	420665.39	195.18	19	19.4	0.37	*Bedrock*
DE0102	9641199.38	420665.39	195.18	19.4	20	1.12	*Saprolite*
DE0102	9641199.38	420665.39	195.18	20	20.7	0.8	*Bedrock*
DE0102	9641199.38	420665.39	195.18	20.7	21	2.13	*Saprolite*
DE0102	9641199.38	420665.39	195.18	21	21.6	1.84	*Saprolite*
DE0102	9641199.38	420665.39	195.18	21.6	22	1.53	*Saprolite*

Table 2. Descriptive Statistics Results

Description	Limonite (Figure 2)	Saprolite (Figure 3)
Mean	1.138709016	1.077531486
Standard Error	0.020061537	0.03473849
Median	1.05	1.11
Mode	1.03	0.17
Standard Deviation	0.44317384	0.692159519
Sample Variance	0.196403053	0.4790848
Kurtosis	3.823013787	-0.790385669
Skewness	1.277883577	0.295425429
Range	3.44	3.09
Minimum	0	0
Maximum	3.44	3.09
Sum	555.69	427.78
Count	488	397

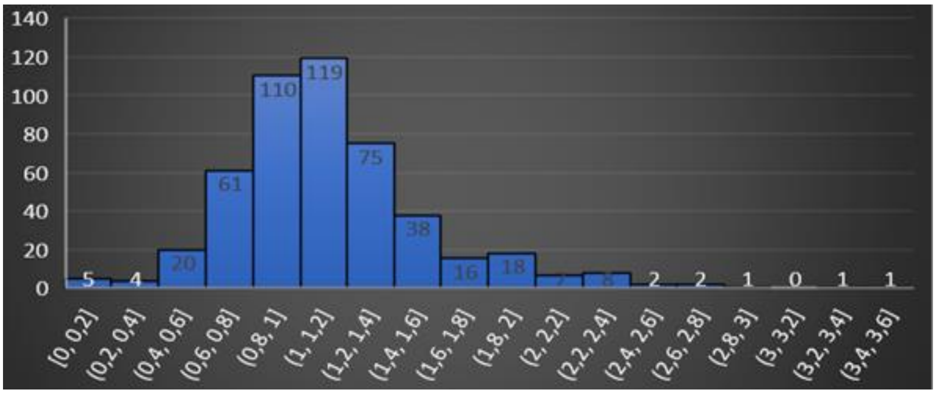

Figure 2. Histogram Limonite where the horizontal axis is Nickel content in percent, while the vertical axis is the number of samples

Based on data from the limonite zone (Figure 2), which consists of 488 samples, the mean value is 1.13, with a small measurement error of 0.02. The median value is 1.05, with a minimum value of 0 and a maximum value of 3.44. The standard deviation of the data is 0.44. A standard deviation smaller than the mean indicates that the data has low variability. The data has a skewness of 1.27, indicating a rightward skew. In the saprolite zone (Figure 3), consisting of 397 data samples, the mean value is 1.07, with a small measurement error of 0.03. The median value is 1.11, with a minimum value of 0 and a maximum value of 3.09. The standard deviation of the data is 0.69. Similar to the limonite zone, this data shows low variability, as the standard deviation is smaller than the mean value. The data skewness of 0.29 indicates a slight rightward skew.

Geological Domain

In lateritic nickel, the geological domain refers to the layers within the laterite nickel deposits. The research area has three geological domains representing each drilling location (Figure 4 – 8). The formation of these geological domains involves creating lithological sections within each borehole. The topography and the lower limonite section define the boundaries for the geological domain in the limonite zone [9]. For the saprolite zone, the boundaries include the upper limit of the lower limonite section and the lower limit of the saprolite section. In the bedrock zone, the boundaries consist of the lower saprolite section and the lower bedrock section. These sections will be processed and combined into a unified, solid layer [10].

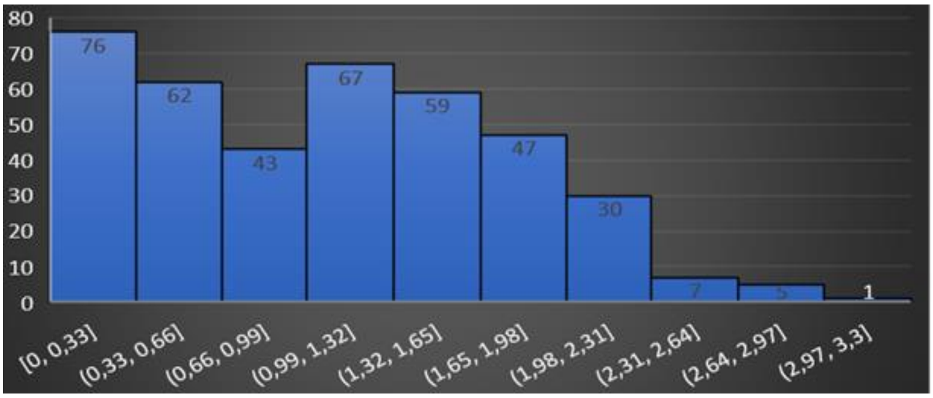

Figure 3. Histogram Saprolite where the horizontal axis is Nickel content in percent, while the vertical axis is the number of samples

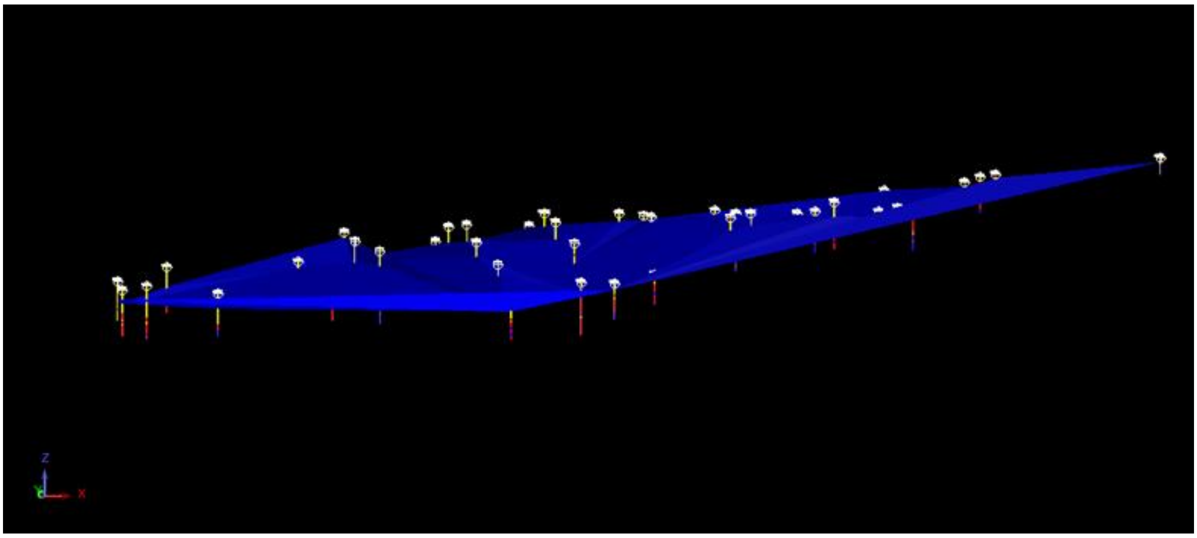

Figure 4. Limonite Zone Geological Domain

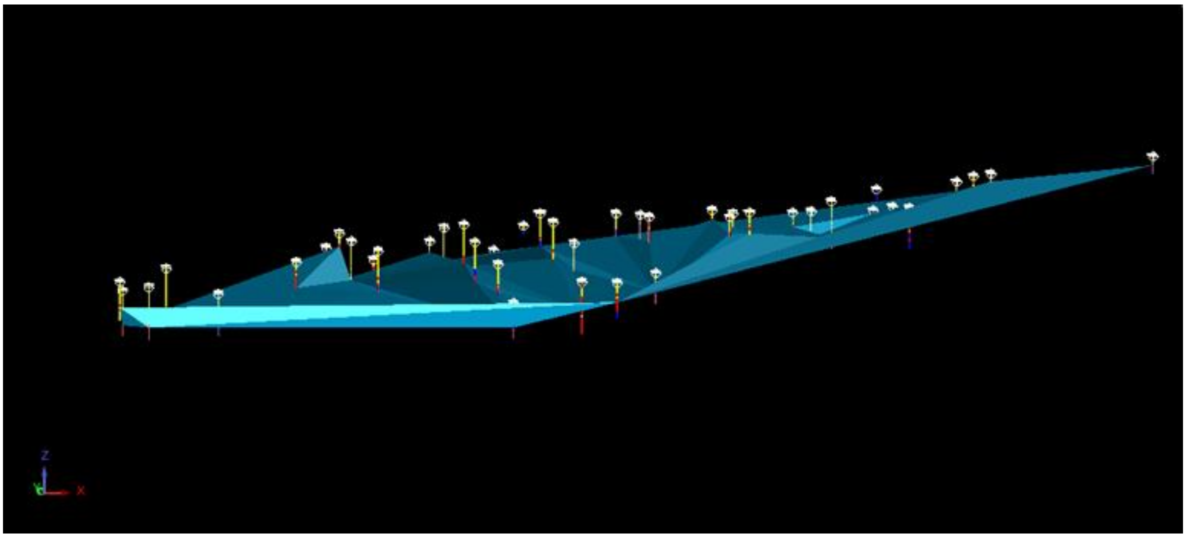

Figure 5. Saprolite Zone Geological Domain

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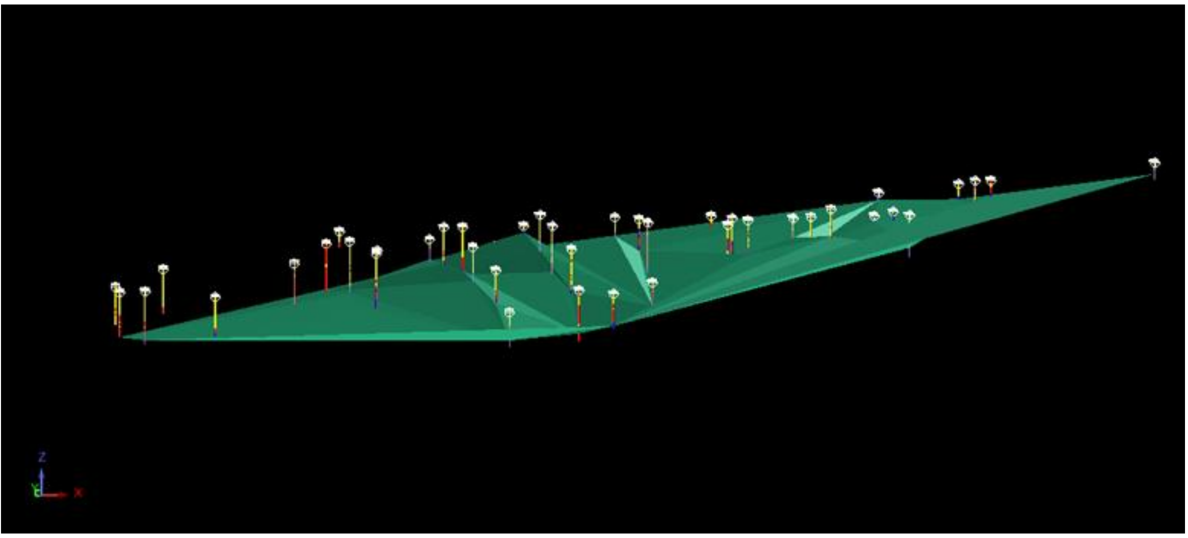


Figure 6. Bedrock Zone Geological Domain

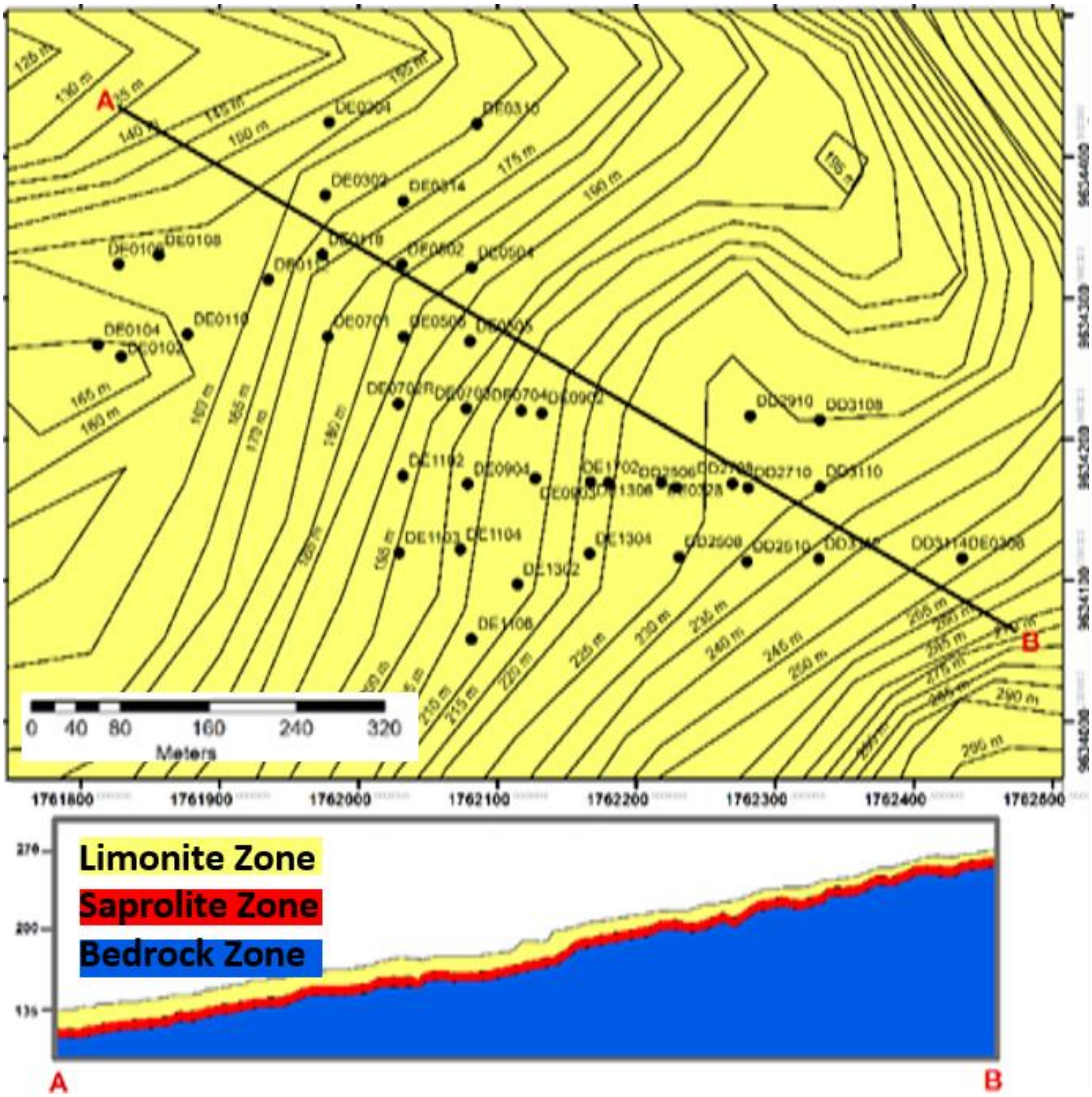


Figure 7. Geological Domain of the Laterite Nickel Layer

Figure 8. Actual Geological Domain

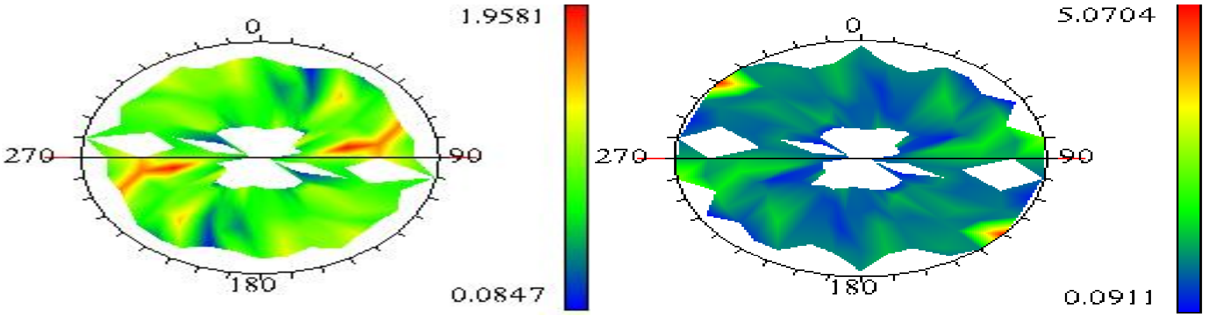


Figure 9. Variogram Map XY Direction Limonite (left) and Saprolite (right)

Once the upper and lower layers of the geological domain have been established, a block model will be created. This block model is designed to form blocks with specific grades, which will be used for estimation.

Variogram Analysis

This variogram analysis is calculated based on the laterite nickel values for each geological domain and each area. Variogram maps in the limonite and saprolite zones are created before determining the grade variogram to examine the rotation toward the main anisotropy direction. The variogram is modeled using the spherical mode (see Figure 9).

Variogram Parameters

The experimental variogram mode measures These variogram parameters in the limonite and saprolite zones (Table 3). The limonite zone is measured with a 1-meter lag for the Z lag and a 44.8-meter lag for the XY direction. The saprolite zone is measured with a 1-meter lag for the Z lag and a 47-meter lag for the XY direction. Based on the variogram map for all directions, the rotation is determined at 10° intervals laterally and in one direction vertically.

Variogram Model Fitting

The variogram model fitting aims to determine the direction of the lateritic nickel grade distribution. The results obtained from this process include the nugget effect, sill, and range in the XY direction and Z direction. The nugget effect indicates the minimum value of sample variation, the sill represents the standard deviation of the samples, and the range shows the maximum searching radius for the lateritic nickel grade. The spherical model for nickel in the limonite zone shows variability in the XY direction at 90°, and the Ni variogram for the limonite zone uses one spherical structure. The total sill for the limonite zone is 0.9844, the nugget is 0.05090, and the range is 57.542 (Figure 10).

Table 3. Variogram Parameters

Parameter	**Limonite**		**Saprolite**	
	Z Direction	**XY Direction**	**Z Direction**	**XY Direction**
Lag Distance	1	44.8	1	47
Number of Lag	44.8	31.4	47	24.6
Horizontal Search Angel	-	90	-	90
Vertical Search Angel	180	-	180	-
Cylinder Radius	0	0	0	0

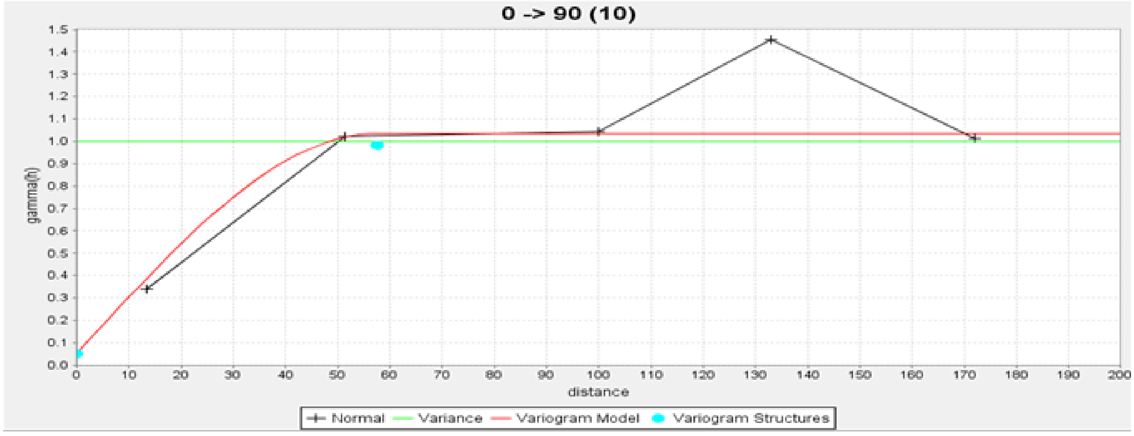


Figure 10. Orientation of the Limonite Variogram Model Direction at 90°

The spherical model for nickel in the limonite zone shows variability in the XY direction at 180°, and the Ni variogram for the limonite zone uses one spherical structure. The total sill for the limonite zone is 0.68841, the nugget is 0.05091, and the range is 56.920 (Figure 11).

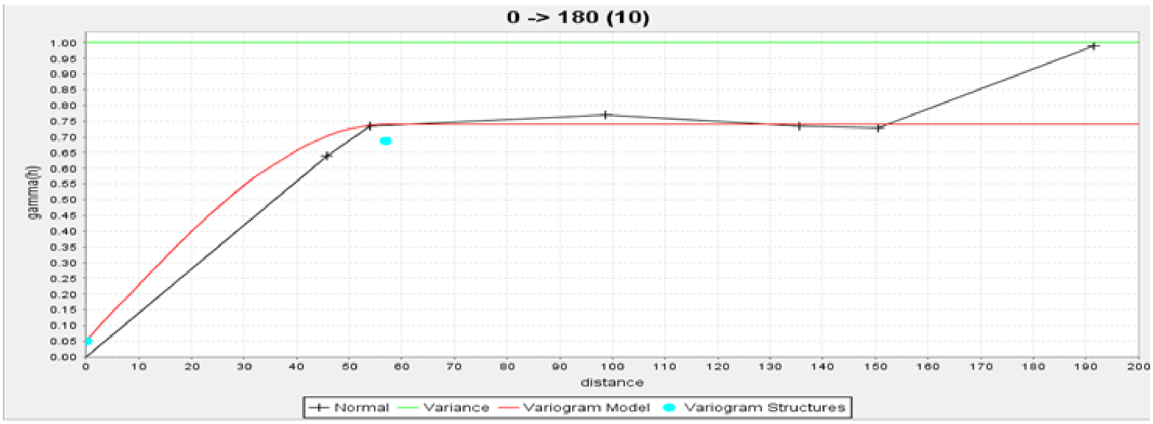


Figure 11. Orientation of the Limonite Variogram Model Direction at 180°

Meanwhile, in the saprolite zone, the spherical model for nickel shows variability in the XY direction at 90°, and the Ni variogram for the saprolite zone uses one spherical structure. The total sill for the saprolite zone is 0.49623, the nugget is 0.49622, and the range is 91.332 (Figure 12).

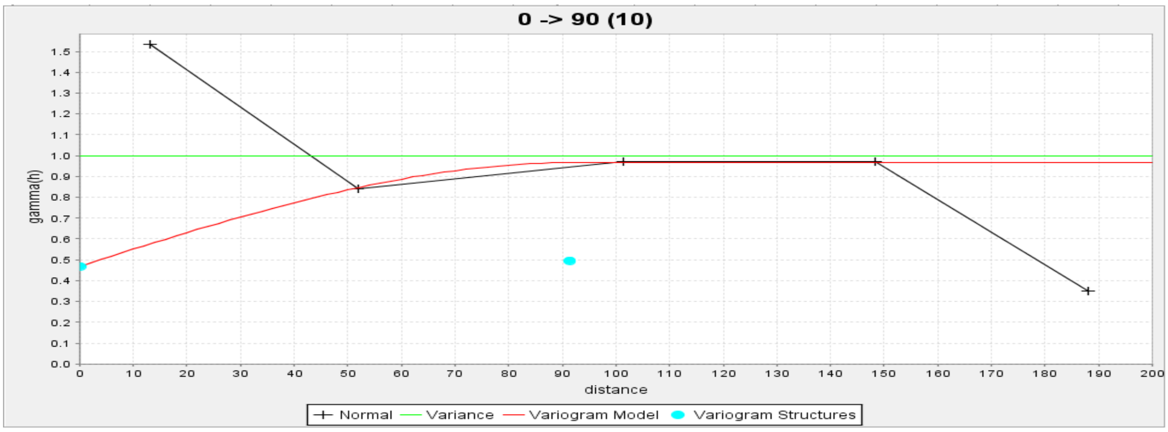


Figure 12. Orientation of the Saprolite Variogram Model Direction at 90°

The spherical model for nickel in the saprolite zone shows variability in the XY direction at 180°, and the Ni variogram for the saprolite zone uses one spherical structure. The total sill for the saprolite zone is 0.6560, the nugget is 0.1972, and the range is 61.198 (Figure 13).

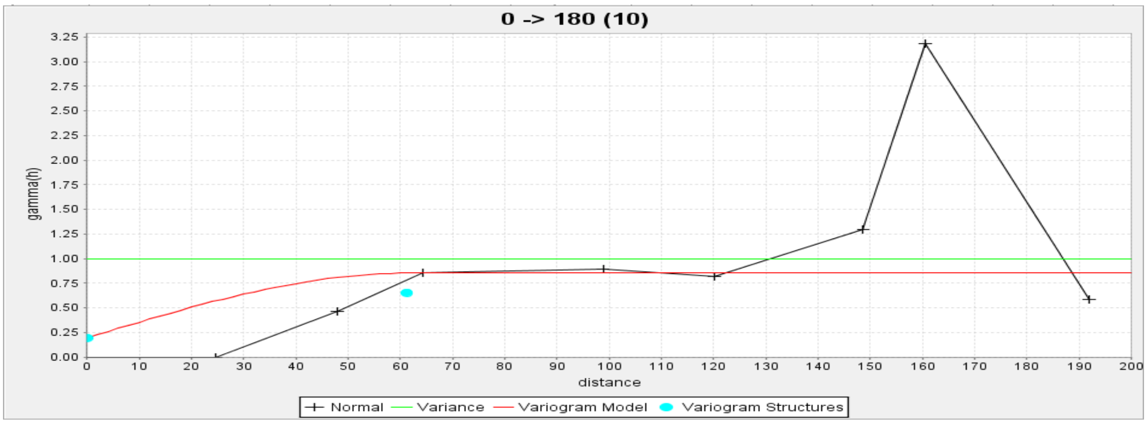


Figure 13. Orientation of the Saprolite Variogram Model Direction at 180°

Table 4. Total Structure of the Limonite and Saprolite Variogram Models

Nested Search ellipsoid	Limonite (Ni)	Saprolite (Ni)
Nugget effect	0.050917	0.469228
Range	57.5420	91.3320
Sill	1.0354	0.9655

Direction of Distribution Type

The distribution direction type indicates the values of grade distribution in specific directions. The distribution direction is isotropic if the grade values are the same in different directions. Conversely, if the grade values differ in each direction, it is considered anisotropic. Based on the model fitting above, the grade distribution direction in the limonite and saprolite layers is anisotropic. The limonite zone has an orientation with a bearing of 90°, plunge of 0°, and dip of -90°, with a maximum searching radius of 57.5. This results in an anisotropy ratio of:

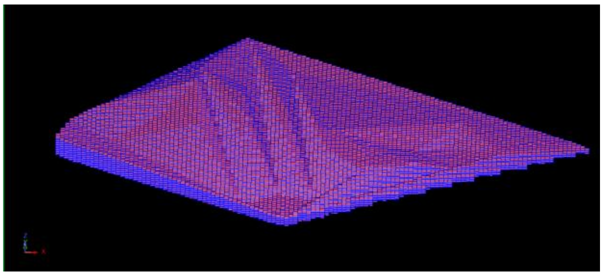
- Major/ semi major : 1,000
- Major/minor : 1,000

The saprolite zone has an orientation with a bearing of 90°, plunge of 0°, and dip of -90°, with a maximum searching radius of 91.332. This results in an anisotropy ratio of:

- Major/ semi major : 1,000
- Major/minor : 1,000

Block Model

Once the upper and lower layers of the geological domain have been established, a block model is created (Figure 14 – 15). This block model is designed to form blocks with specific grades, which will then be estimated. The modeling and resource estimation is based on a block model framework with dimensions of Length x Width x Height, which are 5x5x1 meters.



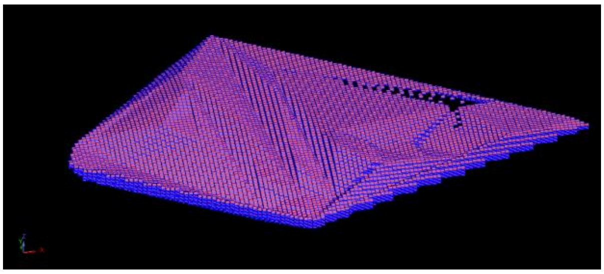


Figure 14. Block Model Shape of the Limonite Zone (left), **Figure 15.** Block Model Shape of the Saprolite Zone (right)

Resource Estimation

Limonite Zone

1. *Inverse Distance Weight* (IDW)

   The estimation of laterite nickel resources using the Inverse Distance Weight (IDW) method in the limonite layer resulted in 61,899 blocks formed (Figure 16), each estimated with varying grades. The estimation for limonite yielded a volume of 1,547,475 m³, equivalent to 2,243,840 metric tons (Table 5).

2. *Ordinary Kriging* (OK)

   Based on the nickel variogram analysis, the estimation of laterite nickel resources using the Ordinary Kriging method in the limonite zone resulted in 62,500 blocks (Figure 17). The variogram calculation yielded a resource volume of 1,562,500 m³, equivalent to 2,265,627 metric tons (Table 5).

Table 5. Limonite Resource Estimation

Ni Grade (%)	IDW		Color Code	Kriging	
	Volume (m^3)	Tonnes (m/t)		Volume (m^3)	Tonnes (m/t)
0 - 0,25	-	-	Grey	-	-
0,25 - 0,5	-	-	Brown	475	689
0,5 - 0,75	230.225	333.826	Orange	120.625	174.906
0,75 1	334.325	484.771	Yellow	450.850	653.733
1 - 1,25	526.650	763.643	Cyan	473.850	687.083
1,25 - 1,5	343.075	497.459	Green	314.600	456.170
1,5 - 1,75	106.650	154.643	Purple	159.300	230.985
1,75 - 2	250	363	Blue	36.250	52.563
2 - 3,44	6.300	9.135	Red	6.550	9.498
TOTAL	1.547.475	2.243.840		1.562.500	2.265.627

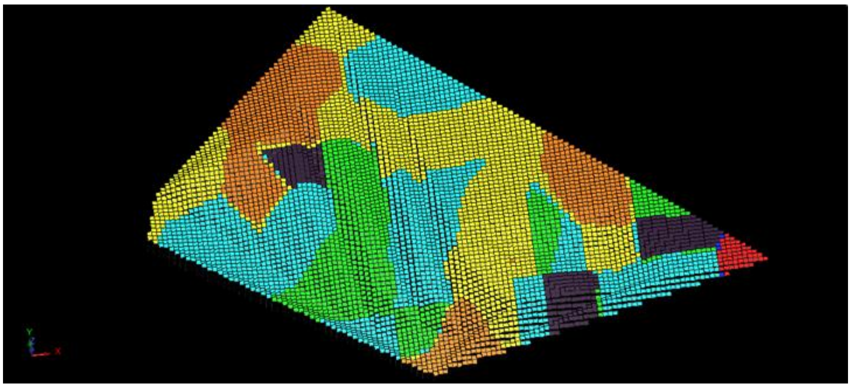


Figure 16. Resource Estimation for Limonite Zone Using IDW Method

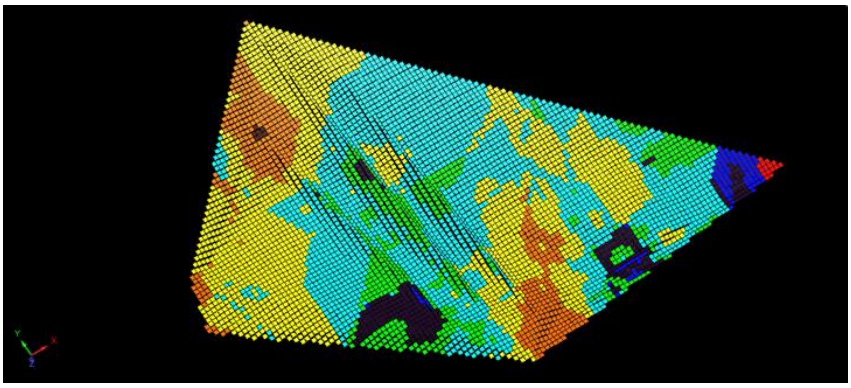


Figure 17. Resource Estimation for Limonite Zone Using Kriging Method

Saprolite Zone

1. *Inverse Distance Weight* (IDW)

   The resource estimation in the saprolite zone using the Inverse Distance Weight (IDW) method resulted in a total of 65,315 blocks (Figure 18). The estimation calculation yielded a volume of 1,632,875 m³, equivalent to 2,367,669 metric tons (Table 6).
2. *Ordinary Kriging* (OK)

   The resource estimation in the saprolite zone using the Ordinary Kriging method resulted in a total of 65,991 blocks (Figure 19). The estimation calculation yielded a volume of 1,649,775 m³, equivalent to 2,392,174 metric tons (Table 6)

   .

Table 6. Saprolite Resource Estimation

Ni Grade (%)	IDW		Color Code	Kriging	
	Volume (m^3)	Tonnes (m/t)		Volume (m^3)	Tonnes (m/t)
0 - 0,25	113.875	165.119	Grey	106.175	153.954
0,25 - 0,5	130.500	189.225	Brown	132.425	192.016
0,5 - 0,75	218.950	317.478	Orange	237.950	345.028
0,75 1	155.125	224.931	Yellow	276.525	400.961
1 - 1,25	264.825	383.996	Cyan	271.175	393.204
1,25 - 1,5	353.650	512.793	Green	276.000	400.200
1,5 - 1,75	227.525	329.911	Purple	214.975	311.714
1,75 - 2	127.700	185.165	Blue	123.525	179.111
2 - 3,09	40.725	59.051	Red	11.025	15.986
TOTAL	1.632.875	2.367.669		1.649.775	2.392.174

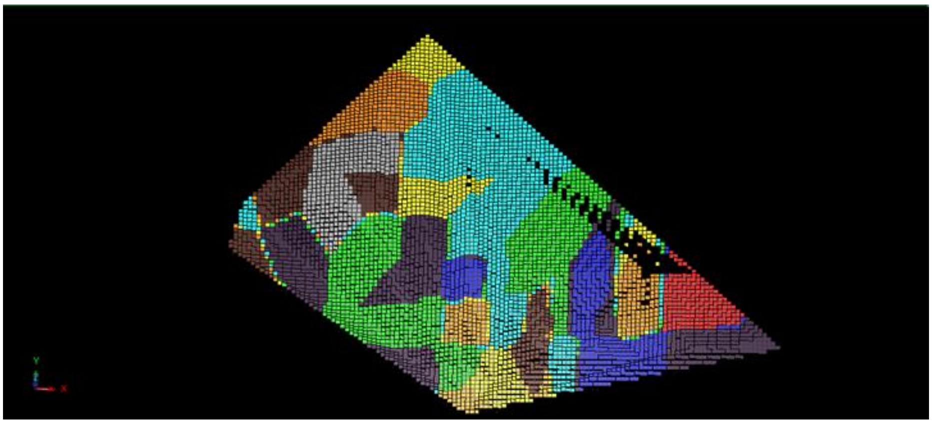


Figure 18. Resource Estimation for Saprolite Zone Using IDW Method

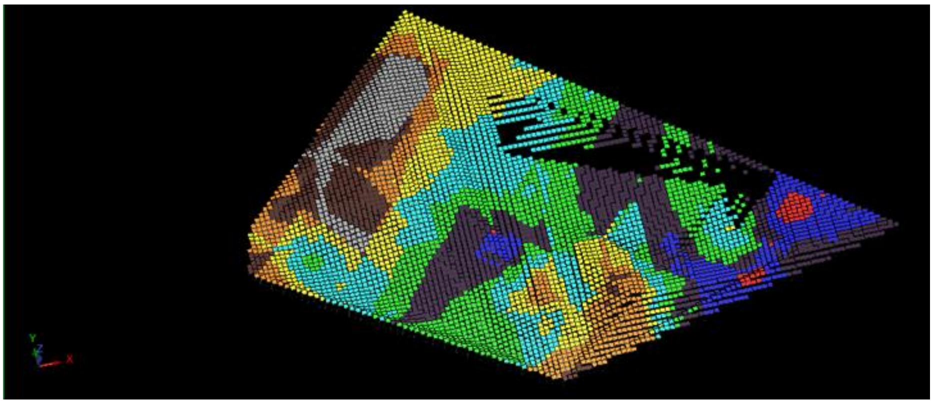


Figure 19. Resource Estimation for Saprolite Zone Using Kriging Method

Reserve Estimation

Reserve calculations are based on the total resources, considering several parameters outlined by the Komite Cadangan Mineral Indonesia (KCMI) and Standar Nasional Indonesia (SNI). These parameters include mining, metallurgical, marketing, legal, environmental, social, and economic factors. However, in this study, the reserve calculation is solely based on the financial factor, or the Cut-off Grade (CoG) set by the company at 1.25, without considering the other factors.

Limonite Zone

1. Inverse Distance Weight (IDW)
   Based on the research, estimating laterite nickel reserves using the Inverse Distance Weight (IDW) method on the limonite layer resulted in 18,251 blocks (Figure 20), each estimated with varying grades. The reserve estimation for limonite yielded a volume of 456,275 m³, equivalent to 661,600 metric tons (Table 7).
2. Ordinary Kriging (OK)
   Based on the research, estimating laterite nickel reserves using the Ordinary Kriging method on the limonite layer resulted in 20,668 blocks (Figure 21), each estimated with varying grades. The reserve estimation for limonite yielded a volume of 516,700 m³, equivalent to 749,216 metric tons (Table 7).

Table 7. Limonite Reserve Estimation

Ni Grade (%)			IDW		Color Code	Kriging	
			Volume (m^3)	Tonnes (m/t)		Volume (m^3)	Tonnes (m/t)
1,25	-	1,5	343.075	497.459	Green	314.600	456.170
1,5	-	1,75	106.650	154.643	Purple	159.300	230.985
1,75	-	2	250	363	Blue	36.250	52.563
2	-	3,44	6.300	9.135	Red	6.550	9.498
TOTAL			456.275	661.600		516.700	749.216

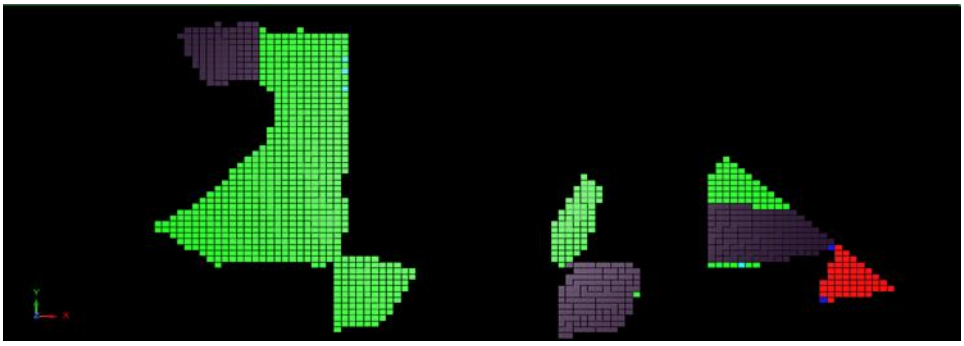


Figure 20. Reserve Estimation for Limonite Zone Using IDW Method

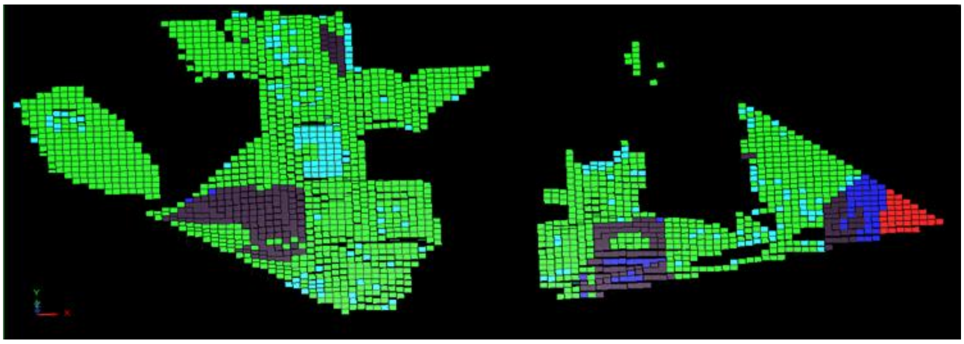


Figure 21. Reserve Estimation for Limonite Zone Using Kriging Method

Saprolite Zone

1. Inverse Distance Weight (IDW)
   Estimating reserves in the saprolite zone using the Inverse Distance Weight (IDW) method resulted in 29,984 blocks (Figure 22). The reserve estimation for saprolite yielded a volume of 749,600 m³, equivalent to 1,086,920 metric tons (Table 8).
2. Ordinary Kriging (OK)
   Estimating reserves in the saprolite zone using the Ordinary Kriging method resulted in 25,021 blocks (Figure 23). The reserve estimation for saprolite yielded a volume of 625,525 m³, equivalent to 907,011 metric tons (Table 8).

Table 8. Saprolite Reserve Estimation

Ni Grade (%)	IDW		Color Code	Kriging	
	Volume (m^3)	Tonnes (m/t)		Volume (m^3)	Tonnes (m/t)
1,25 - 1,5	353.650	512.793	Green	276.000	400.200
1,5 - 1,75	227.525	329.911	Purple	214.975	311.714
1,75 - 2	127.700	185.165	Blue	123.525	179.111
2 - 3,09	40.725	59.051	Red	11.025	15.986
TOTAL	749.600	1.086.920		625.525	907.011

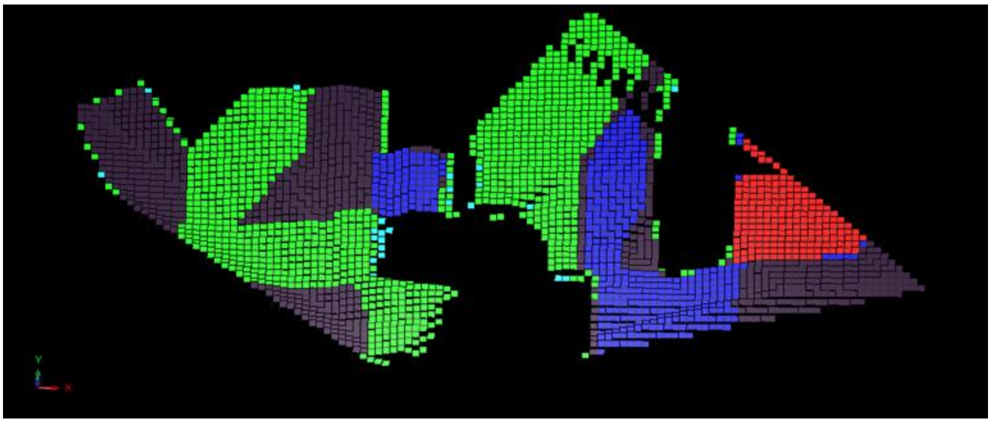


Figure 22. Reserve Estimation for Saprolite Zone Using IDW Method

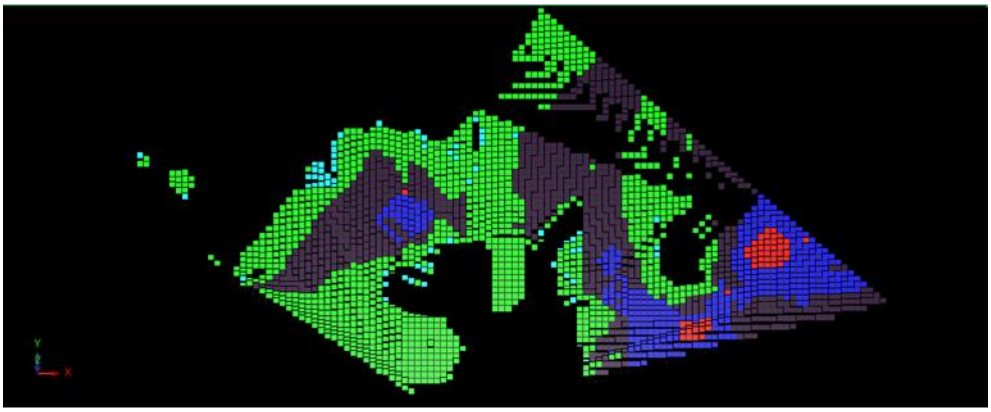


Figure 23. Reserve Estimation for Saprolite Zone Using Kriging Method

Estimating nickel laterite resources and reserves is a crucial aspect of mineral exploration, particularly in regions like Southeast Sulawesi, where laterite nickel deposits are abundant. This study applies the Ordinary Kriging (OK) and Inverse Distance Weighting (IDW) methods to estimate the nickel laterite resources and reserves within the Kolaka Block at PT Indrabakti Mustika. The results obtained through both methods highlight the significance of selecting appropriate geostatistical techniques to achieve accurate resource estimation. The findings from this study are consistent with similar research conducted in other nickel mining regions, demonstrating the effectiveness of these methods in complex geological environments.

Previous studies have applied the OK method successfully to estimate the resources and reserves in various nickel laterite deposits across Southeast Sulawesi. For instance, Husain et al. [2] utilized OK for resource estimation at PT Vale Indonesia, where similar geological conditions were found in the East Luwu District. Their approach highlighted the efficiency of OK in providing precise resource estimates for laterite nickel deposits. Additionally, Shahbeik et al. [7] compared OK with IDW and other geostatistical methods in their study on Dardevey iron ore deposits, finding that OK consistently offered lower estimation errors than IDW in mineral resource applications. These findings reinforce the reliability of OK as a robust tool for resource estimation in nickel laterite deposits.

The results of the IDW method in this study suggest a significant correlation with the OK estimates, although the IDW method produced slightly different total resource and reserve volumes. The IDW method, with its simplicity and ease of implementation, has been widely used for similar resource estimations. For instance, Amzah et al. [6] used IDW to calculate laterite nickel resources in the Morowali Regency, highlighting its efficiency in preliminary assessments. However, unlike OK, which models spatial correlation, IDW does not consider the underlying geological structure, which might explain the discrepancies observed in the estimation of reserves. This is supported by the study of Langkoke [4], who showed that geocomputing methods, including IDW, can be effective but may not fully capture the spatial nuances of mineral distributions.

The classification of geological domains (limonite, saprolite, and bedrock) in this study was based on detailed core section analysis, which is a common practice in nickel laterite exploration (Fanani et al. [16]). This approach helps in delineating zones with different ore grades, which is crucial for accurate resource estimation. In the Kolaka Block, the limonite zone contributed slightly less to the overall resource volume, consistent with findings from other nickel deposits, such as those in the Marombo Block of South Sulawesi [3]. The partitioning of resources and reserves into these domains facilitates a more targeted mining strategy and ensures that the mining activities align with each zone's geological characteristics.

This study's overall resource and reserve estimates align with other resource assessments in similar deposits. For example, the laterite nickel resources in the PT Mahkota Semesta Nikelindo District were estimated using the OK method, with results comparable to those from PT Indrabakti Mustika [5]. Similarly, resource estimates at PT Vale Indonesia and the Tinanggea District in South Konawe [11] demonstrated the applicability of both OK and IDW in capturing the complexities of laterite nickel resources. These findings underscore the significance of accurate estimation techniques in optimizing mineral exploration and subsequent extraction processes.

Moreover, the study by Zhang et al. [12] on nickel ore grade inversion using geospatial data suggests that incorporating remote sensing and spatial location data can enhance resource estimation by providing additional layers of information. This approach could be handy for future exploration activities in the Kolaka Block, where remote sensing technologies could offer valuable insights into the distribution of ore grades across the exploration area.

Finally, comparing the OK and IDW methods in this study adds to the growing body of literature that evaluates geostatistical methods for mineral resource estimation. For instance, Bargawa et al. [9] demonstrated the strengths of using geostatistical models for ore grade estimation in laterite nickel deposits. While both methods have their advantages, the choice between OK and IDW ultimately depends on the project's specific requirements, such as the level of geological understanding and the desired accuracy of the estimates.

3. Conclusion

Based on the research conducted at PT. Indrabakti Mustika, along with the information provided by the researcher and the data supplied by the company, supports the findings and discussions in the previous chapters. The geological domains, including the limonite, saprolite, and bedrock layers, were determined by creating sections from the detailed exploration results. In this exploration process, geological data that reflects the geological domains within each layer of the laterite nickel deposit was obtained.

The estimation indicates a total laterite nickel resource of 3,180,350 m^3 or approximately 4,611,509 metric tons based on the Inverse Distance Weighting (IDW) method. This total resource is divided into limonite zone resources of 1,547,475 m^3 or approximately 2,243,840 metric tons, and saprolite zone resources of 1,632,875 m^3 or approximately 2,367,669 metric tons. In contrast, the Ordinary Kriging method estimates a total nickel resource of 3,212,275 m^3 or approximately 4,657,801 metric tons. This total is divided into limonite zone resources of 1,562,500 m^3 or approximately 2,265,627 metric tons, and saprolite zone resources of 1,649,775 m^3 or approximately 2,392,174 metric tons.

The reserve estimation indicates a total nickel reserve of 1,205,875 m^3 or approximately 1,748,520 metric tons based on the Inverse Distance Weighting (IDW) method. This total reserve is divided into limonite zone reserves of 456,275 m^3 or approximately 661,600 metric tons, and saprolite zone reserves of 749,600 m^3 or approximately 1,086,920 metric tons. In contrast, the Ordinary Kriging method estimates a total nickel reserve of 1,142,225 m^3 or approximately 1,656,227 metric tons. This total reserve is divided into limonite zone reserves of 516,700 m^3 or approximately 749,216 metric tons, and saprolite zone reserves of 625,525 m^3 or approximately 907,011 metric tons.

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