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Priviet Social Sciences Journal

Volume 6
Issue 2 February, 2026

Article 13

06-02-2026

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To cite this article: Stephen, S. & Haifan, M. (2026). Estimation of lateritic nickel resources using the Inverse Distance Weighting (IDW) method at PT Five Star Indonesia, Petasia District, Central Sulawesi Province. *Privient Social Sciences Journal, 6*(1), 136-145.
https://doi.org/10.55942/pssj.v6i2.1594

To link to this article: https://doi.org/10.55942/pssj.v6i2.1594

Private Social Sciences Journal
E-ISSN 2798-866X
P-ISSN 2798-6314
https://doi.org/10.55942/pssj.v6i2.1594

Volume 6
Issue 2
February Edition 2026

Estimation of lateritic nickel resources using the Inverse Distance Weighting (IDW) method at PT Five Star Indonesia, Petasia District, Central Sulawesi Province

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Received 02 January 2026
Revised 05 February 2026
Accepted 06 February 2026

ABSTRACT

This study aims to estimate lateritic nickel resources in the Western Block of PT Five Star Indonesia and to map the spatial distribution of Ni and Fe grades to support technical decision-making. The analysis uses drillhole data with an approximate 25 m spacing. Laterite intervals are grouped into low-grade (LGO), medium-grade (MGO), and high-grade (HGO) zones based on Ni content, and a 3D block model is constructed with a 2×2×2 m block size. Grade estimation is performed using the Inverse Distance Weighting (IDW) method to generate grade and volume models. Tonnage is calculated using a bulk density of 1.6 t/m³. The resource estimation results indicate a total of 3,334,400 tonnes with average grades of 1.41% Ni and 33.59% Fe, classified as Measured Resources. Spatially, the HGO zone tends to extend toward the southeast, whereas LGO and MGO are more widely distributed in other parts of the block, highlighting grade variability across zones that is visible in cross-sections and interpolation outputs. These findings confirm laterite heterogeneity, which should be managed through grade control and more selective mining boundary definition. In addition to quantitative estimates, this study provides contour maps and sections illustrating grade changes across the block, enabling the identification of priority areas. Model outputs are evaluated by checking consistency between estimated grades and nearby drillhole data and by reviewing the continuity of grade zones along strike and dip directions. This approach helps flag uncertainty early for field verification and model updates during the initial mine planning and feasibility stages. The results provide an initial input for pit design, production scheduling, and selective-mining strategies. Further work is recommended to conduct infill drilling and compare IDW with geostatistical kriging to improve estimation robustness.

Keywords: resources; estimation; Inverse Distance Weighting (IDW); level; nickel laterite

1. INTRODUCTION

Indonesia is widely recognized as a country endowed with abundant mineral resources distributed across almost the entire archipelago. This wealth of mineral resources constitutes vital capital for supporting national development, particularly through the mining sector, which has long played a strategic role in the national economy. Mining activities contribute significantly to state revenue through taxes, royalties, and other forms of non-tax income. In addition, the mining sector generates indirect economic impacts, including employment creation, increased income for communities surrounding mining areas, and the stimulation of supporting sectors such as transportation, construction, and mineral processing (Altin, 2011). The abundance of mineral resources in Indonesia is closely related to its complex geological and tectonic settings. Indonesia is located in an active tectonic region influenced by long-term geological processes. These processes include magmatic activity, tectonism, metamorphism, and intensive weathering, which have resulted in the formation of various economically valuable mineral deposits. Such geological conditions place Indonesia among countries with significant potential for metallic mineral resources, including gold, copper, bauxite, iron, and nickel (Ardi & Jafar, 2024).

Nickel is a metallic mineral commodity with high economic value and a strategic role in industrial development. Nickel possesses excellent resistance to corrosion and oxidation, making it highly suitable as an alloying element in metal production (Golightly,1979). In its pure form, nickel is relatively soft and ductile; however, when alloyed with other metals, such as iron and chromium, it forms alloys with high mechanical strength, good chemical stability, and strong resistance to corrosive environments.

Stainless steel is one of the most important products derived from nickel utilization. Stainless steel is extensively used in daily life and industrial applications. Its uses include kitchen utensils such as spoons, forks, knives, and cooking equipment, as well as building ornaments, household appliances, and various industrial machine components (Langkoke et al, 2024). On an industrial scale, stainless steel plays a crucial role in construction, manufacturing, chemical, and other processing industries. According to Sukandarrumidi (2007), the corrosion resistance and durability of nickel make it an essential raw material for modern industrial development. In Indonesia, nickel deposits are predominantly found in the form of lateritic nickel deposits. Lateritic nickel deposits are formed through the intensive weathering of ultramafic rocks over long geological periods. This weathering process is strongly influenced by tropical climatic conditions, including high rainfall, high humidity, and relatively stable temperature throughout the year. Intensive chemical weathering leads to the leaching of certain elements and the enrichment of Ni in specific horizons within the laterite profile. Lateritic nickel deposits are characterized by lateral and vertical variations in thickness and grade (Putra et al., 2024).

Generally, a lateritic nickel profile consists of several distinct layers, each with different physical and chemical characteristics (Rachman, 2016). These layers exhibit variations in the nickel grade, mineral composition, and geotechnical properties. Such characteristics make lateritic nickel deposits a unique type of mineral deposit that requires specific approaches for exploration and mining. A thorough understanding of lateritic nickel deposit characteristics is therefore essential for designing appropriate exploration strategies, conducting accurate resource estimations, and developing effective mine planning. Along with the increasing demand for Ni to support industrial activities, particularly in manufacturing and metal processing, the need for systematic exploration of Ni resources has become increasingly important (Zandi, 2013). Exploration activities aim to identify the presence, distribution, and potential of nickel resources. The information obtained from exploration forms the basis for decision-making in subsequent stages, including feasibility studies, mine planning, and mining operations. Consequently, exploration programs must produce reliable and accountable data (Salekin et al., 2018).

In the context of lateritic nickel mining, resource estimation represents one of the most critical stages prior to the commencement of mining activities (Wakila et al., 2018). Resource estimation aims to quantify the amount of nickel-bearing material and to determine the quality or grade of nickel contained within the deposit. The results of resource estimation significantly influence technical mine planning, including the selection of mining methods, mine design, production scheduling, and determination of mine life. Resource estimation serves as the primary basis for evaluating the economic feasibility of mining projects. A reliable resource estimation must accurately represent the actual geological conditions of a deposit. Inaccurate estimations may lead to errors in mine planning and potentially result in substantial financial losses. Therefore, selecting an estimation method that is appropriate to the characteristics of the deposit and the availability of exploration data is crucial. The chosen estimation method should be capable of optimally utilizing the available data and producing results that closely approximate real field conditions.

One of the commonly used methods for mineral resource estimation is the IDW method. IDW is a spatial interpolation technique based on the principle that the value at an unsampled location is influenced by the values of surrounding data points, with the degree of influence inversely proportional to distance. Data points located closer to the estimation location exert a greater influence, while those farther away contribute less. This principle is founded on the assumption that spatially closer points tend to have more similar characteristics than points located farther apart. The IDW method is relatively simple to apply and does not require complex statistical assumptions. For this reason, it is frequently used during the early stages of exploration or in situations where drilling data are limited. In lateritic nickel resource estimation, IDW can be applied to model the spatial distribution of nickel grades and deposit volumes based on exploration drilling data. The resulting estimation provides an initial representation of the resource potential within a mining area.

Based on the above considerations, this study was conducted to evaluate the potential of lateritic nickel resources through a systematic resource estimation process. The study focuses on the application of the IDW method for estimating lateritic nickel resources. The data used in this study were obtained from exploration drilling activities conducted in the western block of PT Five Star Indonesia. The drilling data include information on drill hole coordinates, drilling depth, laterite layer thickness, and nickel grades for each drilling interval. The selection of the western block of PT Five Star Indonesia as the study area was based on indications of prospective lateritic nickel mineralization as well as the availability of adequate exploration data. The available drilling data were processed and analyzed using the IDW method to generate a resource estimation model that illustrates the spatial distribution of nickel grades and the volume of the lateritic deposit. This model is expected to represent the actual deposit conditions with reasonable accuracy.

The results of the resource estimation obtained from this study are expected to provide valuable information for mine planning purposes. Information regarding the quantity and quality of lateritic nickel resources can serve as a basis for developing production plans, determining mining strategies, and evaluating the economic viability of the project. Moreover, the findings of this study are expected to support further exploration activities and contribute to more effective and sustainable management of mineral resources. In summary, this study is expected to provide both practical and scientific contributions to lateritic nickel exploration and mine planning. A systematic and data-driven resource estimation approach is essential for optimizing the utilization of nickel resources. Through the application of an appropriate estimation method, the management of lateritic nickel resources can be improved to achieve maximum economic benefits while maintaining principles of responsible and sustainable resource development.

2. LITERATURE REVIEW

2.1. Lateritic Nickel Deposits

Lateritic nickel deposits are a type of nickel accumulation formed through the intensive chemical weathering of ultramafic rocks, such as peridotite and dunite, over long geological periods. This process commonly occurs in tropical to subtropical regions characterized by high rainfall, warm temperatures, and good drainage conditions. Under these climatic settings, chemical weathering reactions are accelerated, causing primary minerals within ultramafic rocks to decompose and undergo significant mineralogical transformation. During the lateritization process, chemical elements are redistributed according to their degree of mobility. Highly mobile elements are leached and transported away by percolating water, whereas relatively immobile elements, such as nickel and iron, remain and become progressively enriched within specific horizons of the weathering profile. This enrichment process results in the formation of lateritic nickel deposits with distinctive vertical zoning and variable nickel grades.

In general, a lateritic nickel profile is divided into three main zones: the limonite zone, the saprolite zone, and the underlying bedrock. The limonite zone is the uppermost layer and is dominated by iron oxides and hydroxides, typically containing low to moderate nickel grades. Beneath the limonite zone lies the saprolite zone, which consists of partially weathered ultramafic rocks and generally exhibits higher nickel grades. The saprolite zone is often the primary target for mining activities due to its more favorable nickel content and physical characteristics. Below the saprolite zone is the bedrock, representing the least weathered ultramafic parent rock that serves as the source material for the overlying lateritic profile. The clear vertical zoning and relatively continuous lateral distribution of lateritic nickel deposits have important implications for exploration and resource evaluation. Variations in thickness and grade between zones require detailed drilling and careful geological interpretation to accurately define nickel distribution. Therefore, a thorough understanding of lateritic nickel formation processes and profile characteristics is essential for reliable resource estimation and effective mine planning.

2.2. Mineral Resources and Resource Estimation

Mineral resources can be defined as naturally occurring concentrations or accumulations of solid material that possess economic value and reasonable prospects for extraction. In mineral exploration, the concept of mineral resources emphasizes not only the presence of mineralization but also the level of geological confidence derived from exploration data. Consequently, mineral resource assessment requires systematic and data-driven approaches. Resource estimation is a critical stage in mining exploration, as it forms the foundation for mine planning, economic evaluation, and investment decision-making. Through resource estimation, the quantity of mineralized material and the quality or grade of the contained mineral can be determined. These parameters are essential for assessing the technical feasibility and economic viability of a mining project.

Accurate resource estimation must represent actual subsurface geological conditions as closely as possible. Inaccurate estimates may lead to improper mine design, inefficient production planning, and unreliable economic projections. Therefore, resource estimation should be conducted using appropriate methods that account for deposit characteristics and the quality of available exploration data. In lateritic nickel deposits, resource estimation presents specific challenges due to pronounced vertical variations in grade and thickness across different zones, despite relatively uniform lateral continuity. This condition requires careful treatment of drilling data and the application of estimation methods capable of capturing vertical variability. A reliable estimation approach must adequately reflect these characteristics to produce a realistic resource model.

2.3. Inverse Distance Weighting Method

The IDW method is a deterministic interpolation technique commonly used in mineral resource estimation. The method is based on the assumption that the value at an unsampled location is influenced by surrounding data points, with the magnitude of influence inversely proportional to distance. Points located closer to the estimation location have a greater influence, while those farther away contribute less. In practice, the IDW method estimates values by calculating a weighted average of nearby sample data, where the weights are determined by the distance between sample points and the estimation location. This approach is relatively simple and does not require complex statistical assumptions, making it easy to apply and interpret.

For lateritic nickel deposits, the IDW method is widely used to estimate the spatial distribution of nickel grades and layer thickness based on drilling data. The relatively homogeneous lateral nature of lateritic deposits, combined with clear vertical zoning, makes IDW particularly suitable for areas with moderate drill spacing. When applied using appropriate parameters and supported by sound geological interpretation, the IDW method can provide a practical and representative estimation of lateritic nickel resources (Sun et al., 2020).

3. METHOD

The method applied in this study is the estimation of lateritic nickel resources using the IDW method. The data used consist of primary and secondary data obtained from the research area and related exploration documents, which were subsequently processed and analyzed in a systematic manner. The dataset includes lithological data representing lateritic nickel profiles from drill holes, assay data containing nickel grade analysis results, collar data comprising drill hole coordinates and elevations, and survey data indicating total drill hole depth. All data were initially processed using Microsoft Excel to construct a structured database, after which the data were imported into Surpac version 6.5.1 for modeling and resource estimation. The IDW method was applied based on the assumption that the estimated grade at a given location is influenced by surrounding data points, where the degree of influence is inversely proportional to distance, such that closer data points exert a greater influence than those located farther away.

The estimation of nickel grade using the Inverse Distance Weighting (IDW) method is expressed by the following equation:

$$Z^* = \frac{\sum_{i=1}^{n} \frac{1}{d_i^k} \times Z_i}{\sum_{i=1}^{n} \frac{1}{d_i^k}}$$

Where:
Z^*= estimated grade value
Z_i= grade value at the i-th data point
d_i= distance between the estimation point and the i-th data point (meters)
k= weighting power
n= number of data points used in the estimation
Z= original measured grade value

4. RESULT AND DISCUSSION

4.1. Drill Hole and Grade Data

The data used in the lateritic nickel resource estimation were obtained from exploration activities conducted within the mining concession area of PT Five Star Indonesia. The dataset consists of drill hole data derived from exploration drilling carried out in the western block of PT Five Star Indonesia. A total of 112 drill holes were used in this study, with 3,200 assay records. The drilling data include hole ID, lithological information, nickel (Ni) grades, casing data, and survey data comprising coordinates, elevation, depth, and drill hole orientation. Nickel grade data were obtained after the drill core samples were analyzed in the laboratory. All drilling data were compiled and processed into a single database in spreadsheet format using Microsoft Excel. This preliminary processing stage was conducted to ensure data consistency, completeness, and accuracy prior to further analysis. The validated database was then imported into Surpac version 6.5.1 for subsequent modeling and lateritic nickel resource estimation Surono (2013).

4.2. Lateritic Nickel Resource Estimation

The estimation of lateritic nickel resources was carried out through several systematic data-processing stages. The initial stage involved the construction of a comprehensive database, which functions to correct data grouping and verify the accuracy of exploration data. Database construction is a critical step in resource estimation, as the reliability of the estimation results is highly dependent on the quality of the input data. A well-structured database provides a clearer understanding of the mineral potential within the study area. The design of the resource estimation system was developed by considering predefined parameters used as controls in calculation and data standardization. The drilling database was structured based on several key variables, including hole ID, drill hole coordinates consisting of easting, northing, and elevation (x, y, and z), lateritic nickel lithology comprising limonite (LIM), saprolite (SAP), and bedrock, drill hole depth (end of hole), thickness of each nickel-bearing layer (depth from–depth to), and nickel grade data. These variables served as the primary inputs for the resource estimation process (Sukandarrumidi, 2017)

The integrated database was subsequently modeled using Surpac version 6.5.1. Modeling was conducted in the form of a three-dimensional block model to represent the spatial distribution of nickel grades and ore volumes within the lateritic deposit. This three-dimensional model allows for a clearer analysis of ore distribution both vertically and laterally. The spatial distribution of drill holes resulting from exploration activities is illustrated in Figure 1, showing the arrangement of drill holes forming the mining area. This visualization facilitates the identification of ore boundaries within each lateritic layer. Color differentiation was applied to assist in the estimation process by distinguishing ore zones based on lithology, where red represents the limonite layer, green represents the saprolite layer, and blue represents the bedrock.

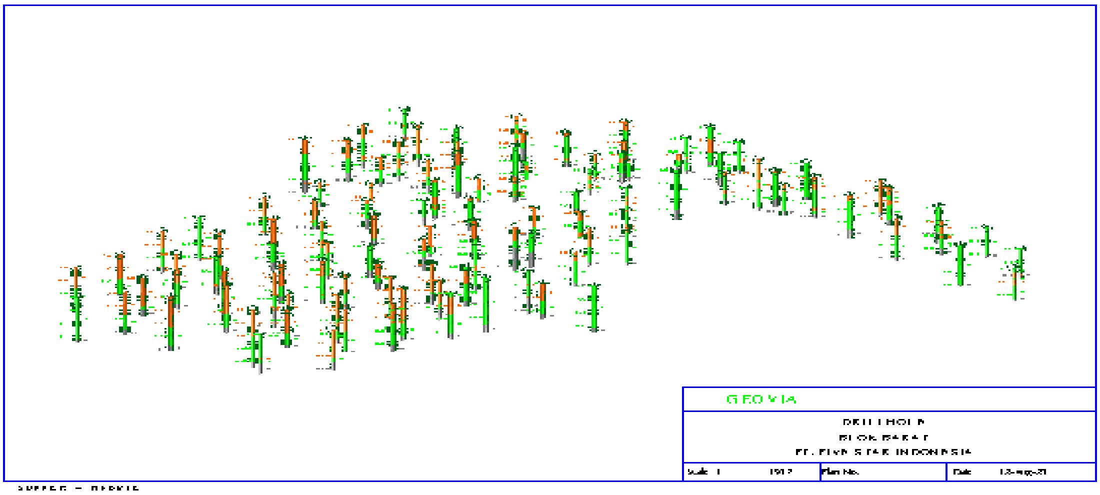

Figure 1. Drill Hole

The block model serves as a medium for displaying processed data derived from the geological database. Through this model, resource estimation is performed by classifying nickel grades from the lowest to the highest values within the deposit. The estimation method applied is based on the distance between drill holes, where distance is the primary factor controlling the weighting of sample influence rather than block size. However, this method does not fully account for data clustering effects; consequently, data points with equal distances but different spatial distribution patterns may produce similar estimation results. Based on the modeling results shown in Figure 2, the block model employed a block size of 2 × 2 × 2 meters, resulting in a total of 55,252 blocks. This three-dimensional block model provides a comprehensive representation of the spatial distribution of lateritic nickel ore, which can be used as a basis for evaluating resource potential and supporting subsequent mine planning activities.

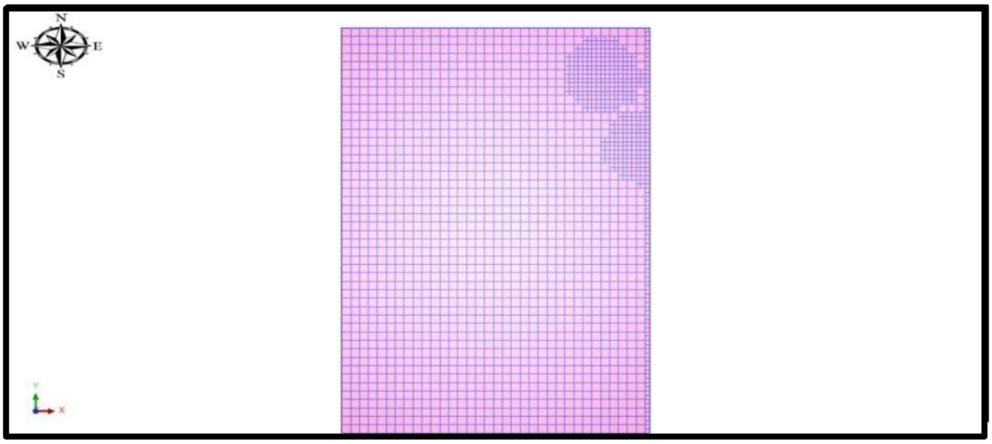

Figure 2. Western Block Model

4.3. Direction of Nickel Distribution in the Western Block

The distribution of nickel ore in the Western Block is classified into three categories based on nickel grade, namely *Low Grade Ore*, *Medium Grade Ore*, and *High Grade Ore*. *Low Grade Ore* (LGO) has a nickel grade range of 0.01–0.8%, *Medium Grade Ore* (MGO) ranges from 0.8–1.6%, while *High Grade Ore* (HGO) represents the highest grade category with nickel contents ranging from 1.6–2.5%, based on assay data. The analysis of nickel distribution indicates that zones with the highest nickel grades tend to extend toward the southeastern part of the study area. In contrast, medium-grade nickel zones are more evenly distributed toward the northern and southern directions, occurring at varying depths. This distribution pattern reflects the spatial variability of lateritic nickel mineralization in the Western Block and provides insight into the directional development of ore zones, as illustrated in Figure 3.

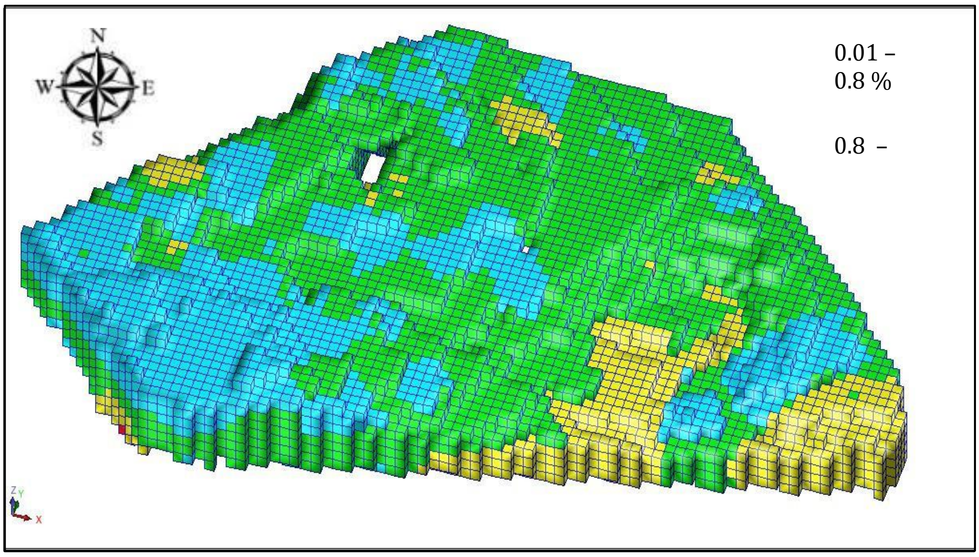

Figure 3. Direction of Nickel Distribution in the Western Block

4.4. Resource Estimation Using the IDW Method

Lateritic nickel resource estimation was conducted using the IDW) method. The volume calculation was performed by determining the thickness of each block within the saprolite layer based on the block model results. The calculated volume was then multiplied by the material density to obtain the tonnage of the deposit. The resulting tonnage represents the estimated lateritic nickel resource. The results of the lateritic nickel resource estimation using the IDW method are presented in Table 1, which summarizes the distribution of volume, tonnage, and average nickel (Ni) and iron (Fe) grades for each grade classification.

Table 1. Results of Lateritic Nickel Resource Estimation Using the IDW Method

Ni Grade (%)	Volume (m^3)	Tonnage (tons)	Average Ni (%)	Average Fe (%)
0.1 – 0.8	1,731,375	2,770,200	1.06	36.74
0.8 – 1.6	351,375	562,200	1.16	25.51
1.6 – 2.5	1,250	2,000	2.03	18.47
Total	**2,084,000**	**3,334,400**	**1.41**	**33.59**

Based on the resource estimation results obtained using the IDW method, the total lateritic nickel resource tonnage is 3,334,400 tons, with an average nickel grade of 1.41% and an average iron grade of 33.59%.

4.5. Resource Classification in the Western Block

Mineral resource classification is a critical component of exploration activities, particularly in mineral resource estimation. In this study, resource classification was carried out for the lateritic nickel deposit in the Western Block through geometric modeling of the lateritic nickel ore body, followed by resource classification based on the results of the IDW estimation. The resource classification refers to the mineral resource classification standards established by KCMI (2011). Based on the estimation results and applied classification criteria, the entire lateritic nickel resource in the Western Block is classified as a Measured Resource. The total measured resource amounts to 3,334,400 tons, with average grades of Ni 1.41% and Fe 33.59%, and a material density of 1.6 tons/m^3. This measured resource classification is supported by the drilling pattern applied in the study area, which follows a systematic grid drilling pattern with uniform drill hole spacing of 25 m × 25 m. Furthermore, the lateritic nickel deposit is hosted within ultramafic rocks characterized by the presence of garnierite and serpentine minerals, which contributes to a high level of geological confidence in the estimated resource (Tonggiroh et al., 2017).

5. CONCLUSION

Based on the results of this study on the lateritic nickel deposit in the Western Block, it can be concluded that the distribution of lateritic nickel grades indicates that the highest grade zones, classified as *High Grade Ore* (Ni 1.6%–2.5%), tend to extend toward the southeastern direction, while *Medium Grade Ore* zones (Ni 0.8%–1.6%) are distributed toward the northern and southern directions at varying depths. The resource classification results show that the entire lateritic nickel resource in the Western Block is categorized as a measured resource, with a total tonnage of 3,334,400 tons, average grades of Ni 1.41% and Fe 33.59%, and a material density of 1.6 tons/m^3, supported by a systematic grid drilling pattern with uniform drill hole spacing of 25 m × 25 m, which provides a high level of geological confidence. Furthermore, resource estimation using Surpac version 6.5.1 and the Inverse Distance Weighting (IDW) method indicates that the total area of the Western Block is 7.79 ha, with a total deposit volume of 2,084,000 m^3 and a total tonnage of 3,334,400 tons at a density of 1.6 tons/m^3, with nickel grades ranging from a minimum of Ni 0.01% to a maximum of Ni 2.5%.

Ethical Approval

This study did not require formal ethical approval as it constitutes normative legal research and does not involve medical experimentation or vulnerable populations. The research was conducted in accordance with generally accepted ethical standards in social science and legal research. Data collection relied on document analysis of legislation, legal doctrines, and regulations of international sports organizations, as well as publicly accessible institutional documents.

Informed Consent Statement

Not applicable.

Confidentiality Statement

Not applicable.

Authors' Contributions

S contributed to the conceptualization of the study, research design, lateritic nickel resource estimation, data analysis using the IDW method, and preparation of the original draft of the manuscript. MH contributed to data collection, geological interpretation, block modeling and resource classification, as well as the review and editing of the manuscript. All authors have read and approved the final version of the manuscript.

Disclosure Statement

The author declares no conflict of interest related to this research.

Data Availability Statement

All data supporting the findings of this study are derived from publicly available legal materials, including legislation, academic publications, and official regulations of international and national sports organizations. No additional datasets were generated or analyzed.

Funding

This research received no external funding.

Notes on Contributors

Stephen
Stephen is a researcher in the field of mining engineering with a focus on lateritic nickel resource estimation and geological modeling. His research interests include mineral resource evaluation, spatial analysis, and the application of geostatistical and deterministic methods in mining exploration.

Mohammad Haifan
Mohamad Haifan is a researcher specializing in mineral exploration and mining data analysis. His work concentrates on lateritic nickel deposits, drilling data interpretation, and the use of mining software for resource estimation and mine planning.

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