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Analysis of Geostatistical Methods for Mineral Resource Estimation: A Literature Review

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ABSTRACT

Mineral resource estimation is the process of determining the volume and grade of mineral deposits based on exploration data (SNI 4726:2011). Its objective is to provide a quantitative assessment of the economic potential of mineral deposits. This process involves geological, statistical, and geostatistical principles, while considering data quality, distribution, and deposit characteristics. Geostatistical methods, such as Ordinary Kriging (OK), Indicator Kriging (IK), and Inverse Distance Weighting (IDW), are widely used in resource estimation due to their ability to integrate spatial relationships between data, making them superior to conventional methods. Each method has specific characteristics that make it suitable for certain conditions. OK is well-suited for data with homogeneous distribution, such as nickel, as it can produce accurate estimates with low RMSE. IK is often applied to gold deposits with fluctuating grades and complex spatial relationships. IDW, though simpler, is effective for minerals with homogeneous distributions, such as nickel and iron ore. Previous studies emphasize that the choice of method should consider parameters such as data distribution, type of mineralization, and regional geology. By analyzing the characteristics of these methods, this study evaluates the suitability of OK, IK, and IDW based on the type of mineral and data distribution. This approach aims to support more optimal exploration and management of mineral resources.

INTRODUCTION

Mineral resource estimation is the process of determining the volume and grade of a mineral deposit based on acquired exploration data (SNI 4726:2011). This estimation aims to provide a quantitative overview of the economic potential of a mineral deposit. The process is conducted by adhering to geological, statistical, and geostatistical principles while considering data quality, distribution, and deposit characteristics. The primary classifications emphasized are measured, indicated, and inferred resources, as

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outlined in the SNI 4726:2011 standard. Resource estimation using geostatistical methods plays a critical role in determining resource quantities. Geostatistical estimation methods are considered superior to conventional approaches because they incorporate spatial relationships between data points. This spatial analysis enhances the accuracy and reliability of resource estimation, making it an essential tool in mineral resource evaluation.

Geostatistics is a field of study that examines spatial distributions, which is highly beneficial for mining engineers and geologists. It is particularly useful in analyzing mineral grades, thickness, accumulation, and practical applications related to challenges in ore deposit evaluation (Matheron 1963). Various methods can be employed to predict the distribution and volume of minerals, such as Ordinary Kriging (OK), Indicator Kriging (IK), and Inverse Distance Weighting (IDW). Each method has unique characteristics that make it more suitable for specific situations, depending on the data characteristics, estimation objectives, and the mineral distribution being evaluated. Although these three methods are widely used, this research focuses on determining which geostatistical method is most appropriate for specific minerals. The objective is to evaluate the suitability of OK, IK, and IDW methods for particular mineral types based on existing literature and to analyze their applicability in various geological scenarios and data distributions. This study aims to contribute to the development of more optimal resource estimation approaches, particularly in supporting the exploration and management of mineral resources.

METHODOLOGY

The steps undertaken by the author are illustrated in the flowchart shown in Figure 1. This research is based on a literature review encompassing both national and international journals. The study aims to identify the most suitable method for resource estimation using geostatistical approaches, as outlined in the stages depicted in Figure 1.

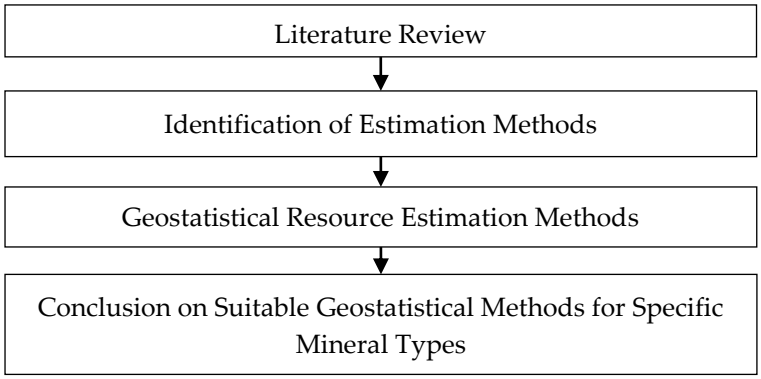

Figure 1. Research Flowchart

The initial stage of this research begins with data collection related to geostatistical estimation studies and various estimation methods used. The next stage involves identifying the characteristics of estimation methods in relation to the minerals being estimated. This analysis includes several parameters such as the type of mineralization, spatial variability of data, geology of the minerals (mineralization), and data distribution. The final stage draws conclusions through an analysis of which methods are suitable or closely aligned with the requirements for specific types of minerals, as not all methods are applicable to every mineral. The results of this analysis can serve as recommendations for selecting and determining the appropriate geostatistical method to be used. Previous studies on the use of geostatistical methods are presented in Table 1.

Table 1. Previous Studies on the Use of Geostatistical Methods for Resource Estimation in Minerals

Researcher	Year	Research Findings
Amadua, et. al.	2022	Inverse Distance Weighting is more suitable than Ordinary Kriging in all ore zones.
Bargawa & Amri	2021	IDW performs better than OK overall; however, in the limonite zone, the Ordinary Kriging (OK) method demonstrates better performance compared to IDW for both Ni variables and thickness.
Carvalho, D., et. al.	2017	The Indicator Kriging method can be used for complex mineralization, such as gold deposits.
Conoras, et. al.	2021	Based on the correlation coefficient (R) values, the Ordinary Kriging (OK) method is more recommended than Inverse Distance Weighting (IDW) for resource estimation.
Kurniawan, A, R., dan Amri	2019	Based on the analysis of values *r* and RMSE, the Indicator Kriging method is more accurate than Ordinary Kriging for estimating epithermal gold deposits.
Arief Pambudi Nugraha, et. al.	2020	Isotropic orientation performs better than anisotropic orientation, as observed from the lower error (RMSE). Furthermore, the results of the Co-Kriging method (IK) are superior compared to those of Kriging.
Hendro Purnomo	2021	The estimation of iron (Fe) content using the Ordinary Kriging method is **underestimated**, while the Indicator Kriging method tends to **overestimate**. The Ordinary Kriging method is considered more suitable for this analysis.
Hassan Riyadi	2023	The results of the Ordinary Kriging estimation are considered sufficiently accurate and satisfactory.
M Rizky	2022	The analysis results indicate that the IDW method provides estimates that are closer to the composite values compared to the Ordinary Kriging (OK) method.
Alan Budiman Thamsi, et. al.	2023	The IDW method is suitable for use in nickel resource estimation.
Zhexenbayeva, A., et. al.	2024	Multi-point geostatistics (IK) demonstrates superior results in geological modeling of vein-type gold deposits.
Bargawa, W. S	2009	The Indicator Kriging (IK) method is suitable for application in precious metal deposits, such as gold ore, which exhibit asymmetric grade distributions.
Safrudin, R., & Conoras, W. A.	2021	The Ordinary Kriging method provides better results, as indicated by the correlation coefficient (R) value approaching 1.

The IDW method assigns higher weights to data that is closer, resulting in more variable estimates. In contrast, the OK method tends to produce more homogeneous values because it emphasizes spatial uniformity through variogram structures. The conclusion of this study indicates that although the OK method offers stability and smoothness in its results, the IDW method can provide insights into the choice of estimation methods depending on the specific data conditions. The choice of method depends on the objectives of the estimation and the nature of the analyzed data. The interpretation of IDW is commonly used in resource estimation, particularly in mining. The magnitude of an estimate is significantly influenced by distance and weights, which change based on the distance between the estimation point and

the target point (Rafsanjani et al., 2016). This method is based on the principle that closer values have a greater influence compared to those farther away. It is suitable for data with homogeneous distribution and areas with limited spatial information. However, it is less effective for complex or heterogeneous data. Ordinary Kriging is a method that assumes the mean of an unknown population, and the spatial data does not contain any trend. In addition to the absence of trends, the data used must also be free of outliers. Ordinary Kriging is one of the methods included under the Kriging methods commonly used in geostatistics. This method has an assumption for its practical application, which is the intrinsic stationarity of the spatial field and the availability of sufficient observations for estimation (Puspita, 2013). Indicator Kriging (IK) is a non-parametric geostatistical method used to estimate probability values based on specific threshold values (Antunes and Albuquerque, 2013; Goovaerts, 1997). The Indicator Kriging (IK) technique was first introduced by Journel (1983). This technique is used when the spatial correlation of variance parameters is very difficult to model or when ordinary kriging does not provide accurate estimates for areas with high-grade concentrations mixed with waste (Sullivan, 1984). Indicator Kriging can be used in cases where ordinary kriging fails to provide precise estimations, particularly in situations involving high-grade mineral concentrations mixed with waste materials.

RESULT

From previous studies, all methods can be used for mineral resource estimation; however, several parameters must be considered, such as data distribution, type of mineralization, regional geology, and the characteristics of the mineral. According to research by Hendro and Purnomo (2021), the Ordinary Kriging (OK) method can be applied to nickel estimation because its data distribution tends to be uniform and has a good RMSE value. Indicator Kriging (IK) and Ordinary Kriging (OK) are suitable for gold deposits because they exhibit asymmetric grade distributions (Bargawa, 2009). These methods are effective in handling complex spatial relationships within data. On the other hand, the Inverse Distance Weighting (IDW) method is more suitable for estimating nickel and iron ore types.

Table 2. Comparison of Methods in Estimating Mineral Resources

Research	Type of Mineral				
	Gold	**Nickel**	**Iron Ore**	**Galena**	**placer**
Amadua, et. al.					IDW
Bargawa et. al.		IDW			
Carvalho, D., et. al.	IK				
Conoras, et. al.	OK				
Kurniawan, A, R., et. al.	IK				
Arief Pambudi Nugraha, et. al.					
Hendro Purnomo		OK			
Hassan Riyadi				OK	
M Rizky			IDW		
Alan Budiman Thamsi, et. al.		IDW			
Zhexenbayeva, A., et. al.	IK				
Bargawa, W. S	IK				
Safrudin, R.,		OK			

CONCLUSION

Based on the analysis, it can be concluded that the geostatistical methods OK (Ordinary Kriging) and IK (Indicator Kriging) are suitable for use with gold minerals due to their advantages in handling data with fluctuating grade distributions and complex spatial relationships. Meanwhile, the IDW (Inverse Distance Weighting) method is suitable for nickel minerals because it is sufficient for minerals with homogeneous and stable grade distributions.

REFERENCES

1. Amadua, C. C., Owusub, S., Folic, G., Brakoc, B. A., & Abanyied, S. K. (2022). Comparison of ordinary kriging (OK) and inverse distance weighting (IDW) methods for the estimation of a modified palaeoplacer gold deposit: a case study of the Teberebie gold deposit, SW Ghana. Group, 250, 700. Doi: http://doi.org/10.26480/mjg.01.2022.19.28
2. Antunes, I. M. H. R., & Albuquerque, M. T. D. (2013). Using indicator kriging for the evaluation of arsenic potential contamination in an abandoned mining area (Portugal). *Science of the Total Environment*, *442*, 545-552. https://doi.org/10.1016/j.scitotenv.2012.10.010
3. Bargawa, W. S. (2009). Application of Non-Linear Kriging in Estimating Gold Ore Grade. JIK TEKMIN, 22(2), 101-114. http://eprints.upnyk.ac.id/id/eprint/13222
4. Bargawa, W. S., & Amri, N. A. (2016, February). Mineral resources estimation based on block modeling. In AIP Conference Proceedings (Vol. 1705, No. 1, p. 020001). AIP Publishing LLC. http://doi/10.1063/1.4940249.
5. Bargawa, W. S., & Amri, N. A. (2021). Perbandingan Metode Geostatistik dari Hasil Estimasi Sumberdaya Nikel Laterit. http://journal.itny.ac.id/index.php/ReTII
6. Carvalho, D., & Deutsch, C. V. (2017). An overview of multiple indicator kriging. Geostatistics Lessons, 7. http://geostatisticslessons.com/lessons/mikoverview
7. Conoras, W. A., & Djin, A. (2021). Pemodelan Estimasi Sumberdaya Endapan Emas (Au) Daerah Loloda Menggunakan Metode Inverse Distance Cube (ID3) Dan Ordinary Kriging (OK). DINTEK, 14(2), 82-95. https://jurnal.ummu.ac.id/index.php/dintek/article/view/950
8. Deutsch, C. V., & Journel, A. G. (1998). GSLIB: Geostatistical software library and user's guide (p. 369). Oxford University Press.
9. Indonesia, S. N. (2011). Guidelines for Reporting Mineral Resources and Reserves. SNI, 4726, 2011. https://perhapi.or.id/doc/sni-4726.pdf
10. Isaaks, E.H. and R.M. Srivastava., (1989), Applied geostatistics, Oxford University Press, New York.
11. Journel, A. G. (2003). Multiple-point geostatistics: a state of the art. *Unpublished Stanford Center for Reservoir Forecasting paper*. https://pangea.stanford.edu/departments/ere/dropbox/scrf/documents/reports/16/SCRF2003_Report16/SCRF2003_Andre_Journel.pdf
12. KCMI, (2011), Indonesian Code for Reporting Exploration Results, Mineral Resources, and Mineral Reserves, Indonesian Mineral Reserves Committee (KCMI). https://perhapi.or.id/doc/sni-4726.pdf
13. Kurniawan, A. R., & Amri, N. A. (2019). Estimation of Gold Resources Using Ordinary Kriging and Indicator Kriging Methods at Pit X, PT Indo Muro Kencana, Tanah Siang District, Murung Raya Regency, Central Kalimantan. http://journalsttnas.ac.id/online/index.php/ReTII
14. Matheron, G., (1963). Principles of geostatistics. Econ Geol 58: 1246-1266.
15. Nugraha, A. P. (2020). Comparison of Geostatistical Methods Kriging and Co-Kriging Using Point Kriging Estimation. ReTII, 177-181. https://journal.itny.ac.id/index.php/ReTII/article/view/2013/1071
16. Purnomo, H. (2021). Mapping the Distribution of Iron Grades in Nickel Laterite Deposits Using Indicator Kriging and Ordinary Kriging Interpolation Methods. PROMINE, 9(1), 29-36. https://doi.org/10.33019/promine.v9i1
17. Puspita, W. (2013). Geostatistical Data Analysis Using the Ordinary Kriging Method (Doctoral Dissertation, Universitas Pendidikan Indonesia. http://repository.upi.edu/id/eprint/4122

18. Riyadi, H., Warmada, I. W., Titisari, A. D., & Idrus, A. (2023). Estimation of Base Metal Skarn Resources Using the Ordinary Kriging Geostatistical Method in Block A Ruwai, Lamandau Regency, Central Kalimantan Province. ReTII, 18(1), 802-810. https://journal.itny.ac.id/index.php/ReTII/article/view/4593
19. Rizky, M., & Yulhendra, D. (2022). Estimation of Iron Ore Resources Using Inverse Distance Weighted and Ordinary Kriging Methods at PT. KUATASSI, Solok Regency, West Sumatra. Journals Mining Engineering: Bina Tambang, 7(1), 96-106. https://ejournal.unp.ac.id/index.php/mining/article/view/117752/106678
20. Rafsanjani, M. R. (2016). Estimation of Lateritic Nickel Ore Resources Using the IDW Method in Southeast Sulawesi Province. *Jurnal Geomine*, *4*(1). DOI: 10.33536/jg.v4i1.39
21. Safrudin, R., & Conoras, W. A. (2021). Estimation of Lateritic Nickel Resources Using Ordinary Kriging Geostatistical Method at PT Dharma Rosadi Internasional, Central Halmahera Regency, North Maluku Province. Jurnal GEOMining, 2(1), 38-48. https://doi.org/10.33387/geomining.v2i1.3921
22. Thamsi, A. B., Ainunnur, I., Anwar, H., & Aswadi, M. (2023). Estimation of Nickel Resources Using the Inverse Distance Weight Method at PT Ang and Fang Brothers. JGE (Journal of Geophysical Exploration), 9(1), 5-17. https://doi.org/10.23960/jge.v9i1.235
23. Zhexenbayeva, A., Madani, N., Renard, P., & Straubhaar, J. (2024). Using multiple-point geostatistics for geomodeling of a vein-type gold deposit. Applied Computing and Geosciences, 23, 100177. https://doi.org/10.1016/j.acags.2024.100177