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Performance Evaluation of Ordinary Kriging and Inverse Distance Weighting Methods for Nickel Laterite Resources Estimation

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Abstract *The choice of an accurate interpolation technique for predicting nickel grade and other elements in unsampled location is an important issue in mineral resources estimations. The use of kriging variance on geostatistics method for measuring of confidence level is difficult to apply directly. This study introduces the use of RMSE (root mean square error) in the selection of the best variogram model related to the accuracy of the estimation performance. In this case study, use OK (ordinary kriging) and IDW (inverse distance weighting) techniques for nickel laterite resource estimation. Result indicates at low CV values, OK model is relatively more accurate than IDW that is shown by a low RMSE value. Correlation between skewness and IDW techniques indicates that data with low skewness (<1) IDW with a power of 1 is better than other power value and data with high skewness (>2.5) a power of 2 yielded the most accurate.*

Keywords: geostatistics, nickel laterite, RMSE.

Abstrak *Pemilihan teknik interpolasi yang akurat untuk memprediksi kadar nikel dan unsur lain di lokasi yang tidak memiliki data merupakan masalah penting dalam penaksiran sumberdaya mineral. Penaksiran sering mengabaikan nilai parameter statistik dasar yaitu CV (koefisien variansi) dan skewness yang berhubungan dengan teknik interpolasi yang dipilih. Penggunaan variansi kriging pada metode geostatistik ternyata sulit dipakai secara langsung untuk mengukur tingkat keyakinan taksiran kadar. Penelitian ini mengenalkan penggunaan RMSE (root mean square error) dalam pemilihan model variogram yang berkaitan dengan akurasi kinerja teknik penaksiran. Teknik penaksir OK (ordinary kriging) dan IDW (inverse distance weighting) dipakai untuk studi kasus estimasi sumberdaya nikel. Pada nilai CV rendah, model OK relatif lebih akurat dibandingkan dengan model IDW yang ditunjukkan dengan nilai RMSE yang rendah. Data dengan nilai skewness rendah, model IDW pangkat 1 lebih akurat dibandingkan dengan nilai pangkat yang lain, sedangkan pada nilai skewness yang besar, model IDW pangkat 2 menghasilkan penaksiran lebih akurat.*

Kata kunci *: geostatistik, laterit nikel, RMSE.*

1. Introduction

There are several interpolation method was developed by using computer tool can be used to estimate the potential resources and reserves, among other are IDW and OK method. IDW process is simpler and quicker unlike kriging that requires preliminary modeling step of the relationship between a variance and distance [1]. The IDW method has been applied mainly because of simple and quick while kriging has been used due to provides best linear unbiased estimates [2]. As a comparison the IDW and OK procedure were applied to evaluate laterite nickel resources in this research. Nickel laterite is product of intensive deep weathering of olivine rich ultramafic rocks and their serpentinized equivalents. In general profile of the nickel laterite can be divided into limonite zone, saprolite zone and bed rock [3, 4].

The research area is located in East Halmahera regency, North Maluku Province of Indonesia which is a region nickel laterite deposit well developed (Figure 1). Geologically the area (see Figure 2) is located in east arm of Halmahera that is widely occupied by ultrabasic rocks complex, as a resource potential of nickel laterite, with predominant north - east and north – northeast trending structure [5].

Objective of the research was to evaluate the relative performance of the IDW and OK in predicting amount of nickel, based on root mean square error (RMSE) value, and to analyze the relationship between statistic parameters and performance of the methods.

2. Methods and Material

Kriging is spatial prediction technique for linear optimum unbiased interpolation with a minimum mean interpolation error [6]. This method work with the parameter obtained from the result of fitting between experimental semivariogram and theoretical model as main base [7]. The most widely used models are spherical, exponential and Gaussian

[8]. In this study to select a semivariogram theoretical model is based on the root mean square error (RMSE) value whereas the smallest value was chosen as the best model [9].

A semivariogram experimental defined by equation below [8].

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(x_1) - Z(x_{i+h})]^2 \quad (1)$$

where:
$Z(x_i)$: Sample value of the variable at point x_i
$Z(x_i + h)$: Sample value of the variable at a point distance h from pointx_i.
$\gamma(h)$: The experimental semivariogram value at the distance interval *h*.
$n(h)$: Number of sample pairs within the distance interval *h*.

Ordinary kriging (OK) is one of the basic on kriging methods that provides an estimate at unobserved location, based on weighted average of around observed sites within an area [1]. Some points that it should be noted in OK prediction are [10]:
OK prediction at an unsampled location $\hat{Z}$ is defined by an equation:

$$\hat{Z} = \sum_{=1}^{n} \lambda_i . Z_i \quad (2)$$

The weight λ_i calculated by a formula:

$$\sum_{i}^{n} \lambda_i . C(i,j) + \mu = C(i,0), \text{ with } \sum_{i=1}^{n} \lambda_i = 1 \quad (3)$$

Kriging variance can be expressed with the following equation:

$$\sigma_R^2 = C(0) - ((\sum_{i=1}^{n} \lambda_i C_{i0}) + \mu) \quad (4)$$

where:
Z_i : A sample value at point *i*.
$C(i,j)$: Covariance between sample *i* and sample *j*.
μ : Lagrange multiplier.
$C(i,0)$: Covariance between sample and block 0.

To identify a sample weight, IDW assumed that degree of correlations and similarities between neighbors is proportional to the distance between them [1]. The IDW equation that is used in weighting is written below [8]

$$w_i = \frac{\frac{1}{di^k}}{\sum_{i=1}^{n} \frac{1}{di^k}} \quad (5)$$

To estimate a predicted point is used equation below:

$$\hat{Z}_0 = \sum_{i=1}^{n} w_i . Z_i \quad (6)$$

where:
$\hat{Z}_0$: Target points where the value should be estimated.
w_i: A sample weight in point *i*.
d_i: A distance between point *i* and a prediction point.
k: A power parameter.
Z_i: A sample value in point *i*.

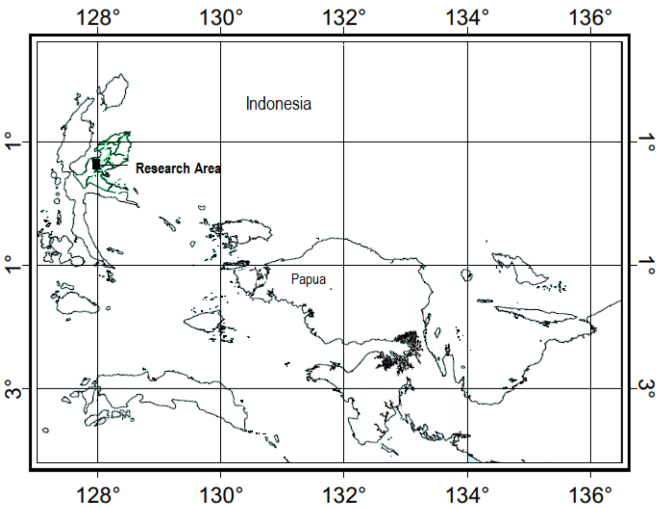

Figure 1: Location of The Research Area in Halmahera Indonesia

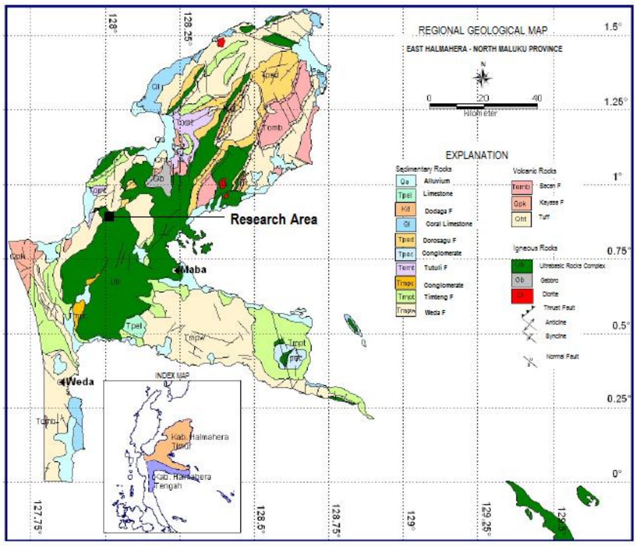

Figure 2. Regional Geological Map of East Halmahera Indonesia

To compare the accuracy of interpolation method was used parameter of root mean square error (RMSE). The RMSE indicated deviate from the measured value and it is calculated with equation [1]:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\hat{Z}(x_i) - Z(x_i)\right)^2} \qquad (7)$$

where:

$\hat{Z}(x_i)$: The estimation value.
$Z(x_i)$: The observed value.
n : Total number of the estimation.

The prediction is not much deviate if a root mean square error value is low.

3. Result and Discussion

Geochemical assay data, consisted of Ni, Fe, Co, MgO, and thickness used in this research were obtained from 266 holes of core drilling. The assay data then discriminated and composited into two zone namely: limonite and saprolite base on the Fe content, where Fe >25% implied in limonite zone and Fe ≤25% included in saprolite zone. Summary statistic for all variables obtained from 266 composite data in saprolite zone and 256 data in limonite zone are given in Table 1.

Table 1. Descriptive Statistics for Saprolite and Limonite Zone

Zone	Variable	CV	Mean	Minimum	Maximum	Standard deviation	Skewness	Kurtosis
Saprolite	Ni	0.25	1.44	0.57	2.47	0.36	0.16	2.71
	Fe	0.29	13.10	6.32	23.58	3.92	0.66	2.76
	Co	0.41	0.05	0.01	0.12	0.02	0.17	2.16
	MgO	0.55	19.65	0.02	83.50	10.90	2.67	17.62
	Thickness	0.53	11.94	1.70	31.00	6.13	0.74	2.92
Limonite	Ni	0.11	1.27	0.91	1.61	0.14	-0.19	2.56
	Fe	0.14	34.34	19.95	46.08	4.66	-0.41	3.25
	Co	0.19	0.10	0.01	0.19	0.019	0.14	7.71
	MgO	0.87	4.94	0.01	42.03	4.34	6.00	48.43
	Thickness	0.49	14.33	3.00	32.00	7.09	0.28	2.23

To identify the possible spatial structure of different variables, semivariogram experimental were calculated according to anisotropy model. Assigning the best semivariogram model for each variable was based on root mean square error (RMSE) value, whereas the lowest RMSE value was chosen as the best model [9].

Table 2 present the RMSE value and different theoretical semivariogram models as a result of matching with experimental semivariogram for each variable. Among different theoretical model were tested, the gaussian model were identified as the best fit in most variable and the spherical model as the most second. In case of Fe in saprolite zone, the best spatial variation was described by the exponential model. Parameters from the best of the theoretical semivariogram model were then used in estimation process by method of ordinary kriging (OK). In this study estimation process by IDW utilizes semivariogram and anisotropic ellipsoid parameter as well. IDW predictions were also exercised by varying number of power, from 1 to 3, and used a number of the closest neighboring points range from 3 to 20 equal with were used in the kriging process. Result of the RMSE according to OK and IDW power of 1, 2 and 3 were given in Table 3 and Table 4.

Table 2. The Fitted Semivariogram Models, Their Parameters and The RMSE Result

Zone	Variable	Model	Nugget	Sill	Spatial ratio (Nugget/ sill) (%)	RMSE
Saprolite	Ni	Spherical	0.12	0.134	90	0.3631822
		Exponential	0.11	0.129	85	0.3628729
		Gaussian	0.12	0.133	90	0.3612104
	Fe	Spherical	13.34	15.84	84	4.0456964
		Exponential	14.13	15.82	89	3.9520821
		Gaussian	14.30	15.81	90	4.0529959
	Co	Spherical	0.00027	0.00048	56	0.0185057
		Exponential	0.00022	0.00049	45	0.0187511
		Gaussian	0.00031	0.0005	62	0.0184628
	MgO	Spherical	100.50	118.76	85	9.6123543
		Exponential	118.32	118.32	100	10.512994
		Gaussian	112.58	118.56	95	9.7275199
	Thickness	Spherical	31.52	38.04	87	6.1221147
		Exponential	29.66	37.49	79	6.1197187
		Gaussian	31.52	37.35	84	6.1148616
Limonite	Ni	Spherical	0.014	0.0215	65	0.1377566
		Exponential	0.012	0.0216	56	0.1380914
		Gaussian	0.016	0.0219	73	0.1378577
	Fe	Spherical	10.93	21.96	50	4.0066196
		Exponential	7.77	21.92	35	4.0192654
		Gaussian	12.79	22.42	57	4.0498155
	Co	Spherical	0.00036	0.000397	91	0.0203200
		Exponential	0.00035	0.000398	88	0.0203326
		Gaussian	0.00037	0.000401	92	0.0203006
	MgO	Spherical	4.52	17.29	26	4.3917197
		Exponential	11.7	17.19	68	4.4719982
		Gaussian	6.15	18.50	33	4.3632099
	Thickness	Spherical	27.66	54.51	51	6.2105023
		Exponential	20.16	54.87	37	6.3267003
		Gaussian	32.79	55.27	59	6.1660768

Table 3. Result of The RMSE According to OK and IDW Powers Of 1-3 for Saprolite Zone

Zone	Variable	Skewness	Spatial ratio (Nugget/ sill) (%)	Interpolation model	RMSE
Saprolite	Ni	0.16	90	OK-Gaussian	0.361210
				IDW 1	0.389315
				IDW 2	0.389915
				IDW 3	0.392149
	Fe	0.66	89	OK-Exponential	3.952082
				IDW 1	4.017983
				IDW 2	4.073498
				IDW 3	4.228154
	Co	0.17	56	OK-Gaussian	0.018463
				IDW 1	0.018515
				IDW 2	0.018815
				IDW 3	0.019268
	MgO	2.67	85	OK-Spherical	9.612354
				IDW 1	9.638006
				IDW 2	9.606666
				IDW 3	9.781412
	Thickness	0.74	84	OK-Gaussian	6.114862
				IDW 1	6.076767
				IDW 2	6.159322
				IDW 3	6.319711

Table 4. Result of The RMSE According to OK and IDW Powers of 1-3 for Limonite Zone

Zone	Variable	Skewness	Spatial ratio (Nugget/ sill) (%)	Interpolation method	RMSE
Limonite	Ni	-0.19	65	OK-Spherical	0.137757
				IDW 1	0.149785
				IDW 2	0.151100
				IDW 3	0.152736
	Fe	-0.41	50	OK-Spherical	4.006620
				IDW 1	4.143441
				IDW 2	4.192333
				IDW 3	4.271817
	Co	-0.14	92	OK-Gaussian	0.020301
				IDW 1	0.021336
				IDW 2	0.022697
				IDW 3	0.024200
	MgO	6.00	33	OK-Gaussian	4.363210
				IDW 1	4.380377
				IDW 2	4.356661
				IDW 3	4.375914
	Thickness	0.28	59	OK-Gaussian	6.166077
				IDW 1	6.570200
				IDW 2	6.720203
				IDW 3	6.911015

Different classes of spatial dependence for both saprolite and limonite variables were evaluated by the ratio between the nugget variance and sill value [11]. Based on Table 3 and Table 4, the best fitted semivariogram analysis for all variables indicated nugget/sill equal to 33-92% which was classified as medium to weak spatial dependence. Result of the IDW prediction with using different power value, indicated that IDW with power of 2 provided the most accurate prediction if the data had skewness >2.5, whereas data with skewness value <1 the best estimation was yielded by IDW with power of 1. Table 3 and Table 4 shows parameters of skewness and result of RMSE. Table 5 suggested that there was a relationship between value of CV and RMSE, while the data set had CV value <0.5 then result of the OK prediction was better than IDW and if value of CV > 0.5, so the IDW prediction more accurate than OK

Table 5. Parameters of Coefficient of Variation (CV), Skewness and Result of RMSE

Variable	Zone	CV	Skewness	Interpolation model	RMSE
Ni	Saprolite	0.252	0.16	OK-Gaussian	0.361210
				IDW 1	0.389315
	Limonite	0.113	-0.19	OK-Spherical	0.137757
				IDW 1	0.149785
Fe	Saprolite	0.29	0.66	OK-Exponential	3.952082
				IDW 1	4.017983
	Limonite	0.136	-0.41	OK-Spherical	4.006620
				IDW 1	4.143441
Co	Saprolite	0.41	0.17	OK-Gaussian	0.018463
				IDW 1	0.018515
	Limonite	0.188	-0.14	OK-Gaussian	0.020301
				IDW 1	0.021336
MgO	Saprolite	0.55	2.67	OK-Spherical	9.612354
				IDW 2	9.606666
	Limonite	0.87	6	OK-Gaussian	4.363210
				IDW 2	4.356661
Thickness	Saprolite	0.53	0.74	OK-Gaussian	6.114862
				IDW 1	6.076767
	Limonite	0.49	0.28	OK-Gaussian	6.166077
				IDW 1	6.570200

Estimation of nickel deposit was based on the two dimensional model with the result was stated by tonnage. The tonnage was obtained from the result of between volume times density of each zone, while the volume was obtained from the result of between thickness of each zone by square of the drill hole grid (50 x 50 m). In this research was assumed the density of the limonite was 1.6 ton/m³ and the saprolite was 1.5 ton/m³ with cutoff grade value were 1.5% and 1 % for the saprolite and limonite ore respectively. Base on the best performance interpolation method was chosen, the amount of the nickel resources in the saprolite zone was calculated with using OK-Gaussian procedure for Ni variable and IDW power of 1 technique for variable of thickness, while nickel in the limonite zone was calculated according to OK-Spherical and Gaussian procedures for both Ni and thickness variables respectively. Result of the nickel resources estimation was presented in Table 6.

Table 6. Tonnage of Ni Resources

Zone	Ore tonnage	Average (% Ni)	Ni tonnage
Saprolite	3,719,899.6	1.58	58,815.96
Limonite	14,678,485.3	1.27	186,618.12

5. Conclusion

Based on the discussion above, some conclusions can be noted:

a) In the saprolite zone, performance of the OK procedure was relatively better than IDW for the Ni variable otherwise for the thickness variable performance of the IDW power of 1 was better than OK. In the limonite zone, the OK technique has better performances than IDW for both variable of Ni and thickness.

b) The Ok procedure has better performance than IDW when the data set has coefficient of variation <0.5 whereas the IDW procedure produce better performance than OK when the data set has CV >0.5.

c) The IDW power of 2 has better prediction than IDW with other power value for if the data set has high skewness value (>2.5) otherwise IDW with power of 1 resulted in better estimation if the data with low skewness (<1).

d) Based on the best performance of the interpolation method the nickel resources estimation in the study area was estimated by using OK procedure for Ni variable and IDW power of 1 for thickness variable in the saprolite zone, while in the limonite zone was used OK procedure for both Ni and thickness variables.

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