

Competitiveness of Inverse Distance Weighting Method for the Evaluation of Gold Resources in Fluvial Sedimentary Deposits: A Case Study

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Abstract Gold mineralisation at Pepe occurs in a sedimentary sequence known as the Banket Series formation. Due to cut-back, further exploration has been done to obtain credible resource estimates for pragmatic mine planning and design. There is therefore, the need for the application of an appropriate, accurate and cost effective estimation method. The selection of the method used for any particular deposit depends on several factors including ease-of-use, robustness, accuracy and precision. Although the mine employs Ordinary Kriging (OK), which has gained much recognition and proven to be a very good estimator, it is complex and time consuming. This calls for effective alternatives. Inverse Distance Weighting (IDW) is another reliable method of estimation as it is simple, accurate and fast, and has proven to be effective for some deposits. This study seeks to verify the propriety and applicability of IDW to the estimation of the orebody by comparing the estimates obtained from Inverse Distance Weighting (IDW) and Ordinary Kriging methods. Correlation analysis performed on ID²W and OK model grades indicated a near perfect correlation coefficient of 0.93; an indication that ID²W can be used as a good alternative to OK at Pepe.

Keywords: *sedimentary, Ordinary Kriging, correlation, orebody, resource, regression*

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1. Introduction

Gold mineralisation in the Pepe deposit occurs in a sedimentary sequence known as the Banket Series /formation. It is composed of stacked fluvial sedimentary rocks developed within a braided river system. Essentially, the deposit can be described as fossil placer, in which the gold was deposited simultaneously with the sediments. Thus, the gold mineralisation is associated with the conglomerates and is found within the matrix that binds the pebbles together. The deposit has been mined for several years and the pit is being cut back in order to expand the pit. Hence, credible resource estimates of the deposit are essential to make the right decisions with regard to proper mine planning and design. There is therefore, the need for application of an appropriate, accurate and cost effective method for estimation.

The selection of the estimation method used for any particular deposit depends on several factors including ease of implementation and operation, robustness, accuracy and precision. Though the company employs Ordinary Kriging (OK), which has gained much recognition and has proven to be a very good estimator, OK is complex and time consuming. This calls for effective alternatives. Inverse Distance Weighting (IDW) is another reliable method of estimation [1] which is

simple, accurate and fast and has proven to be effective for some deposits. The study is aimed at evaluating the propriety and applicability of IDW as an alternative resource estimation method for the Pepe deposit.

A total of 8 928 1-m drill hole samples (comprising 118 Diamond Drill samples and 8 810 Reverse Circulation samples, were used for resource modelling using ID²W and ordinary kriging. The descriptive statistics of the ID²W and OK model grade estimates imply that ID²W model compares well with the OK model.

The study indicates that ID²W method could be used as an alternative resource estimation method for the mine when there is too much pressure within limited time to produce comparable resource estimate quickly.

1.1. Local Geology

Gold mineralisation occurs in a sedimentary sequence known as the Banket Series /formation [2]. It is composed of stacked fluvial sedimentary rocks developed within a braided river system about two billion years ago. Essentially, the deposit can be described as fossil placer, in which gold was deposited simultaneously with the sediments. The Banket Reef Zone comprises a sequence of individual beds of quartz conglomerates (Banket beds), breccia conglomerates, meta-sandstones (also called quartzites) and grits. All known gold mineralisation is associated with the conglomerates and is also found within the matrix that binds the pebbles together.

Gold content is a function of the size and the amount (packing) of quartz pebbles present within the conglomerate unit - the bigger and or more pebbles present, the higher the grade concentration [3,4]. Gold is generally found native with only minor electrum and with only 3-7% silver. Accessory oxides present in the ore include magnetite, goethite, ilmenite and rutile [5].

2. Materials and Methods

2.1. Data Used

Data used for this study was made up of field data that included attitude measurements, descriptions of geological exposures encountered during field mapping, collar coordinates; down hole survey data; and geology (logging) data for the reverse circulation and diamond drill holes. A total of 8 928 drill hole samples which consist of 118 Diamond Drill inclined hole (DD) samples and 8 810 Reverse Circulation (RC) vertical hole samples, covering a strike length of 1 km were obtained. Both the reverse circulation (RC) and the diamond drill (DD) holes were sampled at 1 m interval. The data was validated to correct any errors or inconsistencies. All the data files were prepared and saved in comma-separated formats and imported individually into Surpac software. Figure 1 shows the collars of drillhole layout in the study area.

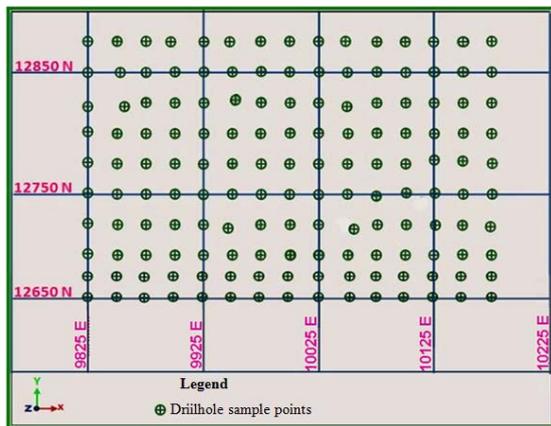


Figure 1. Drillhole Layout in the Project Area

2.2. Delineation of the Ore Zones

The interpretation of the ore zones were based on geological control on the mineralisation. Vertical section plots were generated in Y-Z plane at intervals of 25 m, in addition to structural mapping of the area.

The drilling intersects various layers of sedimentary rocks which are occasionally intercepted by intrusives. Zoning was done from the bottom of the hole to the top and established by using the reefs characteristics, including thickness, lithology, pebble assemblage and the grade distribution. Cross-sections of drillholes were plotted and the reef zones encountered at the project area are A, C and E.

In delineating the ore zones, drill holes were brought to Surpac screen. They were annotated and coloured to display the geological zones and assay (Au) values. Using both the geology and the assay values, strings of different colours were used to digitise and delineate the various ore zones as shown in Figure 2. Ore zones and geology were

delineated for all sections 25 m apart. Strings used for digitising were saved to a file. Figure 2 is a typical digitised section at 12 700 N.

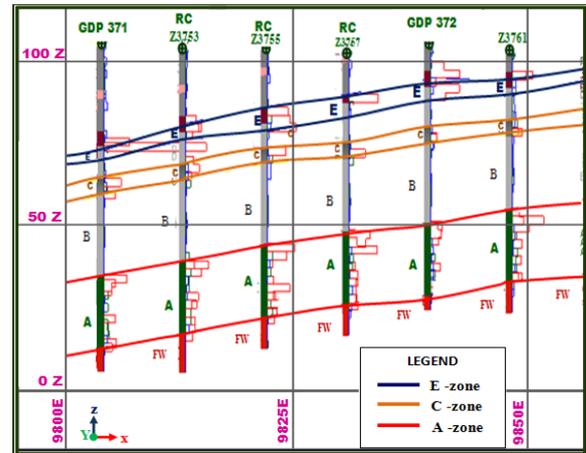


Figure 2. Section along 12700 N of the Project Area

The strings used for digitising the ore zones for each section were linked together to generate a triangulated 3-dimensional wireframe model covering the entire strike length of the project area. Figure 3 shows the 3-dimensional wireframe solid generated. It shows the distinct parallel reefs. The output file obtained at the end of the digitising became the ore zone string file and was saved. The assay data bounded by the ore zone string files were selected and used for further work.

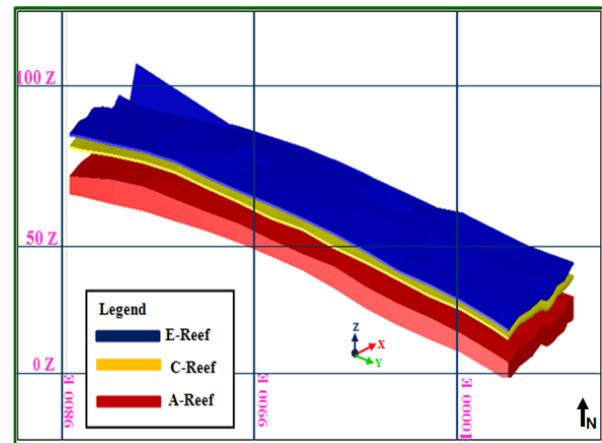


Figure 3. Three Dimensional Wireframe Solids Generated for the Project Area

2.3. Statistical Analysis of Data

For groups of samples to be combined for statistical analysis, they should belong to statistically similar distributions [6]. F and t-tests were therefore carried out to test the commonality of population for DD and RC data [7]. The F and t-tests at 5% level of significance indicated that the difference between the populations of the RC and DD grade was not significant; hence they were combined. Statistical analysis was carried out on the selected Au 1-m composite data within the wireframe. Figure 4 and Figure 5 show the raw data histogram and log probability plot respectively.

Figure 4 indicates that the data is positively skewed and that there might be some difficulty in resource estimation with this data [8]. The tight inflexion at high grades in

Figure 5 indicated the presence of outliers in the data. Top-cutting technique was therefore used to mitigate the impact of such outliers.

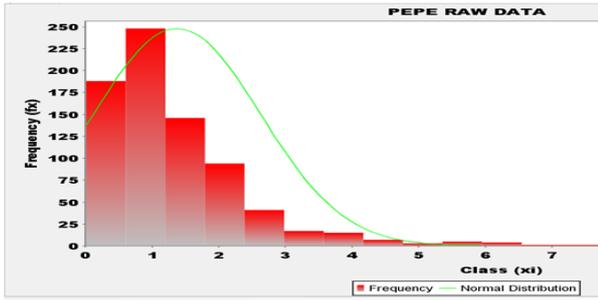


Figure 4. Histogram of Pepe Orebody Data

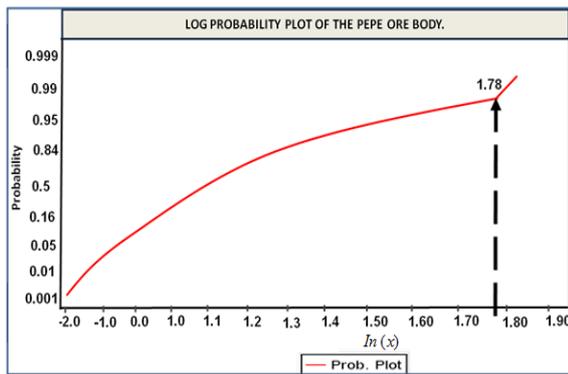


Figure 5. Pepe Ore Deposit Log Probability Plot

In this study, for A-Reef, top-cut value of 5.93 g/ t was deduced from the log-probability plot shown in Figure 5 at the point of inflexion by taking an antilog of 1.78. This conforms with the formula proposed by Bluman [6] that "an outlier" treated at 95 % confidence interval is equal to mean + (1.96 x standard deviation). The summary statistic for the distribution of 1 m composites of the other reefs after the top-cutting is shown in Table 1. Although these statistics still indicate some positive skewness, it is mild and without significant outliers.

Table 1. Summary Statistics of Top Cut 1-m Samples

	A-Reef zone	C-Reef zone	E-Reef zone
No. of samples	7510	2981	3301
Min.	0.01	0.01	0.01
Max.	5.93	2.85	3.94
Mean	1.1	0.99	0.89
Median	1.06	0.96	0.84
Mode	1.01	0.91	0.80
Variance	2.08	0.37	0.32
Std	1.44	0.61	0.56
Skewness	1.13	0.58	0.72
Kurtosis	2.17	2.41	2.85

2.4. Variogram Modelling

The composited drillhole data captured within the various wireframes were used for the variography analysis for all the reef zones.

Downhole variography was performed basically to obtain the nugget variance for the various ore zones since

it has the shortest lag spacing of 1 m. The downhole variograms were modelled with a single structure spherical model since that was found to fit the experimental points well. The variograms are shown in Figure 6 - Figure 8 and their parameters are shown in Table 2.

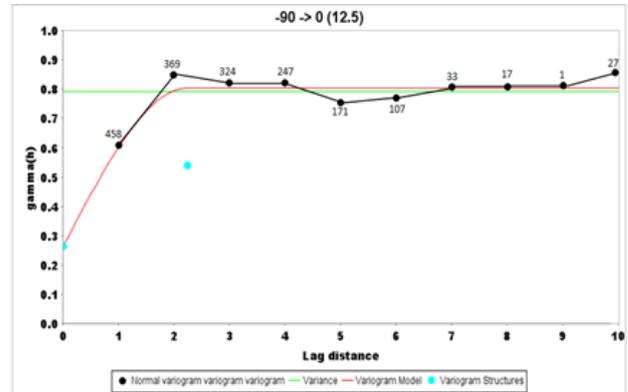


Figure 6. A-Reef Downhole Spherical Semi-Variogram

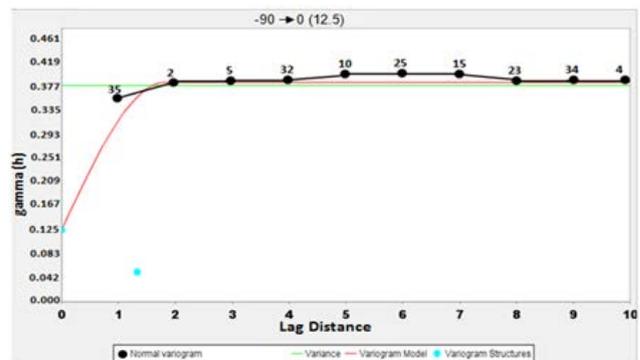


Figure 7. C-Reef Downhole Spherical Semi-Variogram

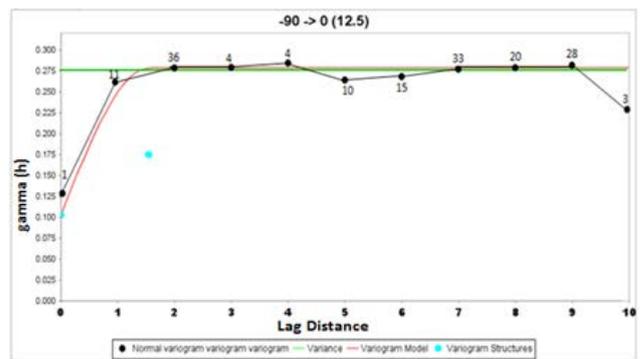


Figure 8. E-Reef Downhole Spherical Semi-Variogram

Table 2. Downhole Semi-Variogram Model Parameters of Various Zones

Ore zone	Lag spacing	Azimuth	Plunge/Dip	Co	C	a
A	1.0	0	-90	0.264	0.531	2.24
C	1.0	0	-90	0.125	0.254	1.82
E	1.0	0	-90	0.100	0.210	1.54

Co is the nugget variance

C is the spatial variance

a is the range.

Horizontal experimental directional semi-variograms were calculated, modelled and analysed in 13 different directions for all grade values within the study area to verify anisotropy. A lag spacing of 25 m, that is

equivalent to drillhole spacing, was used for directional variograms for the reef zones. Some of the experimental semi-variograms and their appropriate models that show nested structures, of A-Reef zone are shown in Figure 9 and Figure 10. Table 3 shows the parameters of 13 Horizontal directional semi-variograms of A-Reef zone.

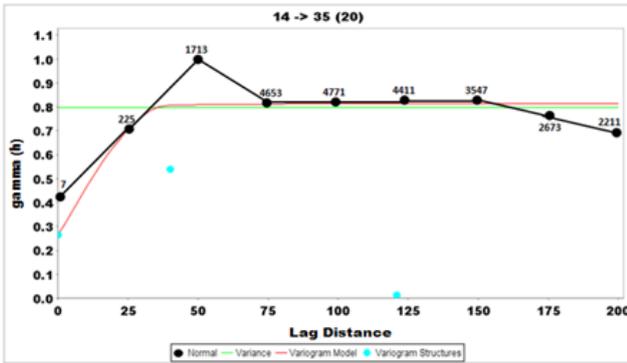


Figure 9. A-Reef Experimental and Model Semi-Variogram along Strike

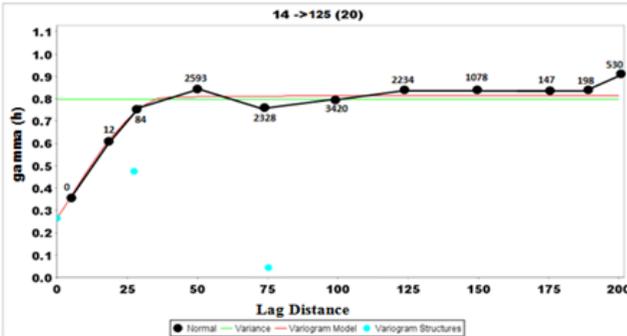


Figure 10. A-Reef Experimental and Model Semi-Variogram across Strike

Table 3. A-Reef Horizontal Directional Semi-Variogram Parameters.

Azimuth	Directions	C ₀	C ₁	C ₂	a ₁	a ₂
0		0.264	0.531	0.007	26.50	50.35
30		0.264	0.26	0.003	11.33	46.64
35	Major	0.264	0.514	0.031	39.52	120.20
60		0.264	0.352	0.025	33.28	55.21
90		0.264	0.362	0.041	26.73	37.67
120		0.264	0.341	0.025	23.81	43.25
125	semi-major	0.264	0.519	0.031	29.29	72.28
180		0.264	0.338	0.042	10.20	12.86
210		0.264	0.339	0.036	9.55	48.53
240		0.264	0.362	0.013	25.05	30.58
270		0.264	0.158	0.193	17.22	29.38
300		0.264	0.193	0.182	35.57	42.15
330		0.264	0.241	0.130	8.35	33.98

From the variogram models (Figure 9 and Figure 10), it was observed that the continuity of mineralisation was not the same in all directions. The mineralisation was therefore assumed anisotropic. Similar analyses were done for Reefs C and E.

Direction of maximum continuity in the A, C and E reef zones was along strike (NE-SW) while the semi-major continuity is across strike (NW-SE). Table 3 contains the parameters of the models. In all cases, the variogram models were cross-validated. A Scatter plot of the

predicted versus actual gold grade values of A-Reef zone are also presented in Figure 11.

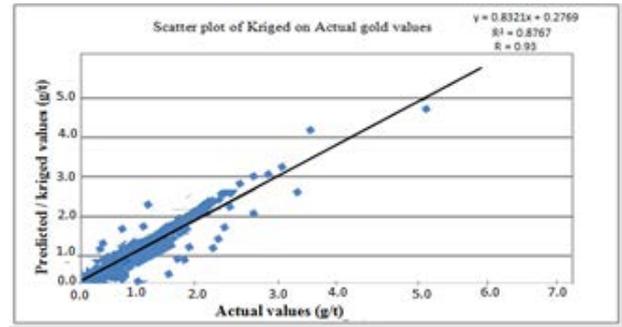


Figure 11. Scatter Plot of Predicted (Kriged) on Actual Values (A-Reef)

Figure 11 shows a very good positive relationship with nearly 45° curve. The correlation coefficient is approximately one (1) indicating a good model according to Dowd [8] and Sinclair & Blackwell [9].

2.5. Block Modelling

An unconstrained block model was generated in Surpac and constrained by using the mineralised zone wireframes. The model composed of 3-dimensional cells or blocks each of which has attributes such as grades, rock type, density and oxidation codes. Block size was based on at least 50 % of the distance between drill hole spacing and mining bench height of 3 m. Therefore, a block size of 10 m x 10 m x 3 m in the northern, eastern and elevation directions respectively was used for the block model.

2.6. Grade Interpolation

Grade interpolation of the Pepe resource was modelled using Inverse Distance Weighting (IDW) and Ordinary Kriging methods to evaluate the deposit. Composites within the resource wireframes were used for the estimation.

For the IDW, various weighting powers of 1, 2, 3, and 4 were considered. These were validated graphically by comparing the model grades with assay composite grades. Trend analysis technique was used to compare the downhole composite grades against the IDW model block centroid for a range of northings. Figure 12 shows a Swath plot along the northings on 9925 Eastings of the project area.

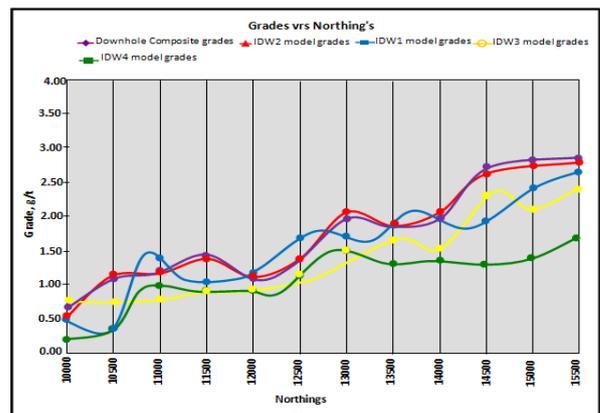


Figure 12. Swath Plot of IDW Model Grades against Downhole Composite Grades on 9925 E

3. Results and Discussions

3.1. Swath Plot Inference

It can be seen from the swath plot in Figure 12 that ID²W model grades compared better with the downhole model grades than the other power indices; hence, its grade and tonnage values were chosen, compared and analysed with OK values. OK was used to estimate grade into the block model using "Surpac block model menu". Table 4 also shows the summary of average grades and total tonnages produced by OK method for all the reefs.

Table 4. Summary of OK Estimates

Reef zones	Tonnage (t)	Average grade (g/t)
A-Reef	157 852 2	1.740
C-Reef	255100	0.829
E-Reef	271000	1.260

3.2. Analysis of Results

Bench by bench ID²W estimates of grades and tonnages for all the reef zones were compared with those of OK. ID²W and OK model values were checked to determine if the data values were evenly dispersed or not.

Table 5. Descriptive Statistics of ID²W and OK Method

Ore Zones	Estimation Method	Mean Grade (g/t)	Variance (g/t) ²
A	ID ² W	1.710	0.047
	OK	1.740	0.044
C	ID ² W	0.801	0.013
	OK	0.929	0.008
E	ID ² W	1.210	0.091
	OK	1.260	0.096

The descriptive statistics of the ID²W and OK grade estimates (shown in Table 5) imply that ID²W estimates compare well with the OK grade estimates.

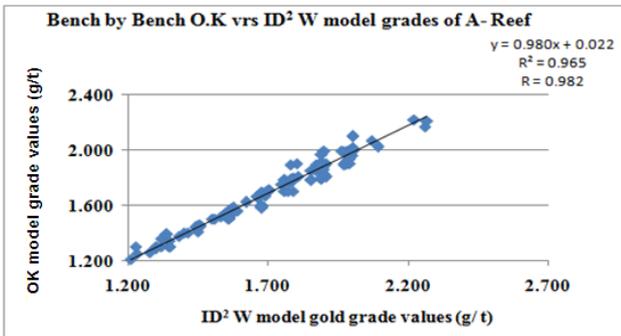


Figure 13. Scatter Plot of Bench by Bench O.K on ID²W Model Grades of A-Reef Zone

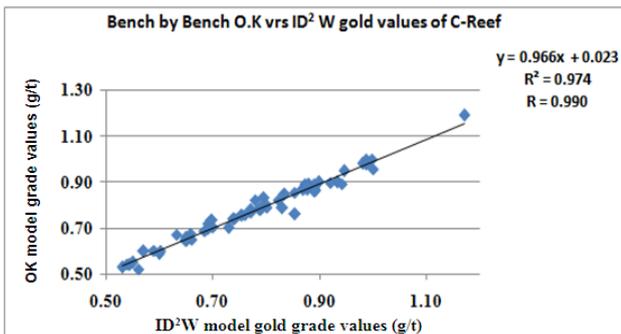


Figure 14. Scatter Plot of Bench by Bench O.K on ID²W Model Grades of C-Reef Zone

Also, regression and correlation analysis were done to assess further relationships between ID²W and OK model grades. Some of the scatter plots of the regression of ID²W on OK are shown in Figure 13 – Figure 15 for all the reefs. All show very good positive relationship with nearly 45 ° curves with slopes of about 0.93. They all show very high correlation coefficients of at least 0.9.

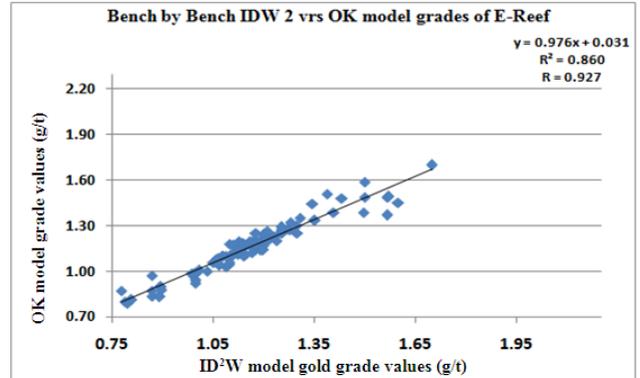


Figure 15. Scatter Plot of Bench by Bench O.K on ID²W Model Grades of E-Reef Zone

Grade-tonnage curves for all reefs were plotted for both OK and ID²W models. These are shown in Figure 16. There is no significant difference in the reserves at any cut-off between them for this sedimentary deposit.

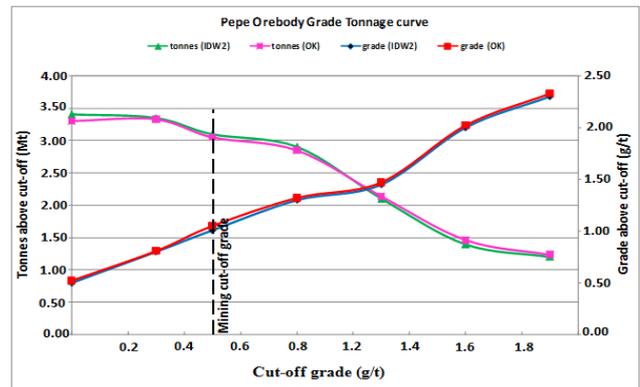


Figure 16. Grade -Tonnage Curve of Pepe Orebody

4. Conclusion

Cross validation of inverse distance weighting models indicate that the ID²W option is the most appropriate one for this fluvial sedimentary deposit. Regression and correlation analysis, as well as comparison of the grade-tonnage curves, of OK and ID²W estimates indicate that there is no significant difference between them. Thus, the ID²W method could be used as a feasible alternative resource estimation method for the Pepe deposit when there is too much pressure and time constraint to produce comparable resource estimates quickly.

Acknowledgement

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Statement of Competing Interest

The authors have no competing interest.

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