

Semivariogram Modelling of Porosity and Permeability of Ikphesi Dolomitic Marble, Akoko Edo L.G.A, Edo State Using Microsoft Excel Package

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Abstract

This paper demonstrates Semivariogram modelling of physical properties (porosity and Permeability) and its procedure for Ikphesi dolomitic marble deposit Akoko Edo L.G.A, Edo State, Nigeria. Forty two (42) dolomite samples were collected at pre-determined distance (6m interval depending on the pit size and horizontal level). Porosity and permeability values for the test samples were determined from the laboratory using ASTM Standard Test Method C97-83, and ASTM Standard Test Method D 4525-90. Semivariogram values for different distances covered and number of pairs were determined using Microsoft Excel package. Experimental semivariogram plots for both permeability and porosity values were done in East-West and North-South directions to determine the semivariogram properties (sill, nugget effect, and range). Final modelling for porosity and permeability of the data set (values) were performed. Semivariograms were constructed for each of the properties and the distribution patterns of the samples were identified from the plot. The spherical model for permeability from the plots for the models in W-E and N-S directions, the patterns of distribution-n are not similar, which suggest that permeability within the deposit are anisotropic in nature, while in the spherical model for porosity, the pattern of distribution both in the W-E and N-S direction are similar, that is isotropic in nature. Semivariogram model should be performed in all directions to determine the nature of mineral properties whether anisotropic or isotropic.

Keywords: Semivariogram, Permeability, Porosity, Models, Spherical, Exponential and Patterns

1. Introduction

Semivariogram in a simplify form, can be defined as the sum of the square of the difference between a physical property at different locations in a specified direction divided by 2 multiply by the number of pairs of samples under consideration. It is a measured of spatial variability [1]. The degree of difference of a parameter as a function of their relative distance and direction is referred to as semi-variogram (or a variogram) $\gamma(h) = 1/2 \text{Var}[Z(s) - Z(s + h)]$, term it the variogram because it “tends to become established for its simplicity” and acknowledge that $\gamma(h)$ is also called the semivariogram [2].

Sampling for points close to each other produces typically similar outcomes compared to sampling for points separated by larger distances. The variogram distance measures the degree of

dissimilarity $\gamma(h)$ between data separated by a vector or class of vectors h . If $z(xi)$ and $z(xi + h)$ are pairs of samples lying within a given class of distance and direction, given $N(h)$ is the number of data pairs within this class, the experimental semivariogram can be defined as average squared difference between the components of data pairs [3].as in the following equation:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [(z(x) - z(i + h))]^2$$

This spatial variability measure is called a semivariogram, but it is commonly referred to as a variogram [4]. For any interpolation between the sample variogram estimations a variogram model can be used. The variance of the entire data set is referred to as the sill and the distance at which the model semivariogram meets the data set variance is defined as the range (Figure. 1).

The experimental semivariogram is a descriptive statistic of data that can be used for checking geological assumptions and determine the nature of mineral deposits whether isotropic or anisotropic. It is a basic tools for geostatistic estimation.

1.1 Component of a Semivariogram

Components of semivariogram are referred to as elements or parameters of semivariogram. They include (figure 1);

i. The sill; ii. The Nugget Effect iii. Spherical Component iv. The range or zone of influence. The sill, C is the semivariogram value

along semivariogram axis where the curve begins to level out (flatten off), It is measured measured in percentage square, $(\%)^2$.

The nugget effect, C_0 , is the value corresponding to the semivariogram axis where the curve cross the semivariogram axis, measured in $(\%)^2$.

Spherical component, C_1 , is the value of the semivariogram that correspond with the different between the sill and the nugget effect, measured in $(\%)^2$.

And the range, a, is the horizontal distance from the origin to the point where the curve started flatten off, measured in meters.

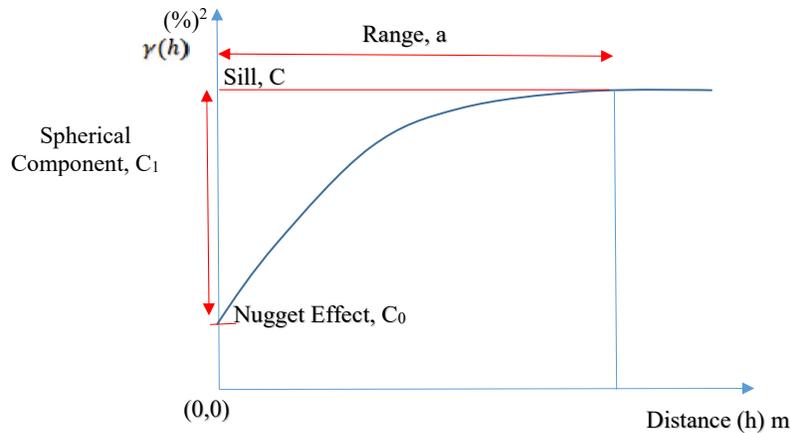


Figure 1: Semi-Variogram Components

Note: semivariogram can be with sill or without skills.

The study area is located at Akoko- Edo local Government Area of Edo state. It covers the north-Eastern part of Ikpeshi town (it runs between longitude 6o 10' 30"and 6 o 20' 64" East; and between latitude runs 7o 15' and 7o 20' North). The Precambrian basement complex in Igarra is made up of a metasupracrustl suite comprising of quartzite, quartz-chists, metaconglomerates, marble and calc-silicate rocks. Within this area is the Igarra schist belt. Ikpeshi is a nature endowed village in Akoko – Edo Local Government of Edo State. The village is located along Auchu – Ibillo road, at

latitude 7.33784°N and longitude 6.1397°E. Ikpeshi is among the communities that makes up ward 8 in Akoko – Edo L.G.A and the postal/zip code is 312123. The topography is undulating, rough but well drained by dendritic drainage pattern. Recently, there has been influx of quarrying companies processing marble [5]. Ikpeshi area has diverse rocks, massive carbonate deposits and mineral type's particularly industrial minerals at different localities (Figure 2, showed study area).

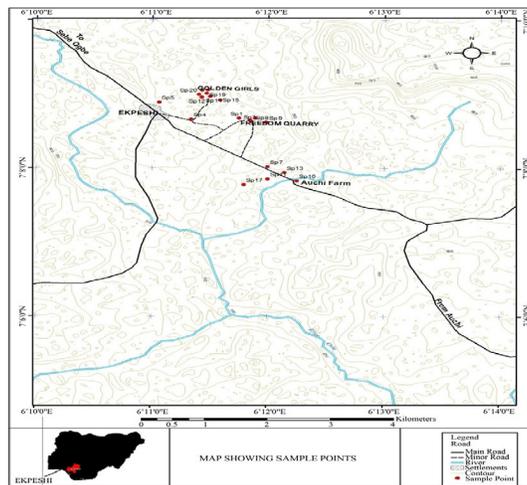


Figure 2: Map of the Study Area

2. Methodology

Forty two samples of dolomite intact samples were collected at Ikphesi open pit at Akoko Edo L.G.A, Edo State, Nigeria. The materials used in samples collection include; Chiesel, Hammer, Polythene bags, Hand towel, Measuring tape, paper tape and line, Global Positioning System (GPS).

Standard used for the intact samples were, ASTM Standard Test Method C97-83 (for porosity) and, ASTM Standard Test Method D 4525-90 (for permeability). Microsoft excel software version 2010 was used for semivariogram determination and models plotting in North South and West East directions.

2.1 Limitation of the Study

Large data sets are required for modelling of such properties and cost of data collection and laboratory tests are expensive.

2.2 Model Semivariogram

Semivariogram modeling is used in the prediction of unknown measure value at a known location. Such a method is called kriging (Cressie 1993). By using information such as the nugget, sill, and range, the variogram function can be used to estimate (interpolate) the value at a known location. Generally semivariogram models are of two categories, namely those with sills and those without any sill.

Models without a sill include the linear, the generalised linear and the De Wijsian models, while models with a sill include the Spherical, the Exponential and the Guassian models and other several ones. The following are examples of positive definite models [6].

Spherical Model: $\gamma(h) = C_0 + C \left\langle \frac{3h}{2a} - \frac{h^3}{a^3} \right\rangle$ when $0 < h < a$

$$\gamma(h) = C_0 + C \text{ when } h > a \quad (2)$$

Exponential Model: $\gamma(h) = C_0 + C(1 - \exp(-\frac{h}{a}))$ when $h > 0$ (3)

Gaussian Model: $\gamma(h) = C_0 + C(1 - \exp(-\frac{h^2}{a^2}))$ when $h > 0$ (4)

Where $\gamma(h)$ is the semivariogram, C_0 is the nugget effect; C is the sill, h is the distance between the pair of samples under consideration, "a" is the range of influence.

Fitting semi-variogram model required some steps which include;

- i. Select a distance in a specified direction, whether E-W or N-S
- ii. determine the pairs of samples with the distance between them
- iii. calculate the difference between them (properties under consideration)
- iv. square the difference, and sum the squared of the differences then divide by 2N, where N is the number of pair, this gives rise to semivariogram values at specified distance
- v. plot the data on the graph and determine a goodness of fit for each point.

3. Results

The result from porosity and permeability tests on forty two intact samples were plotted and the experimental semivariogram from the plot were modelled using spherical and exponential model with the aid of microsoft excel version 2010 in North-South and East – West directions. The results were hereby presented below.

Experimental Semivariogram Plot for Porosity Data Set of Ikphesi dolomitic formation In West-East Direction at 18m above level (Figure 2).

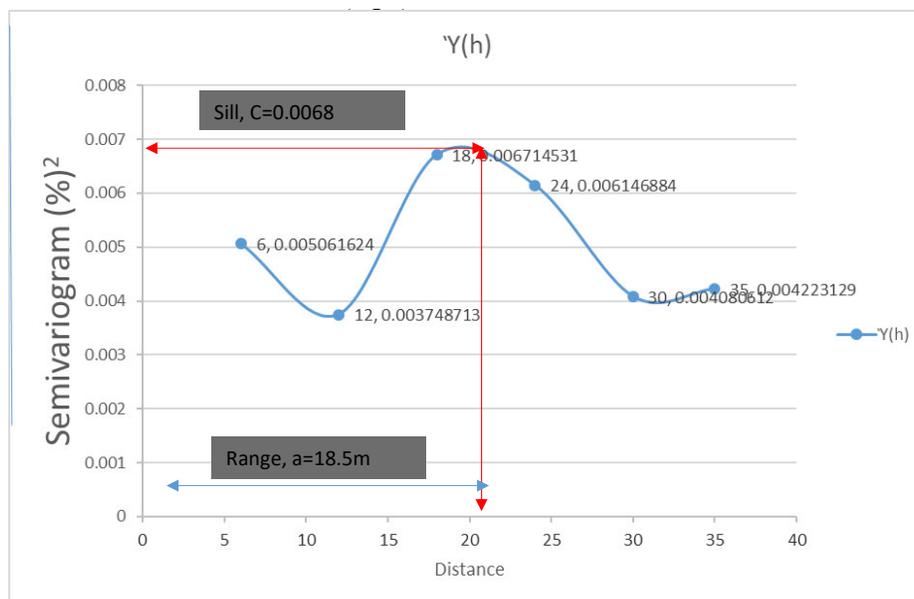


Figure 2: Semivariogram Plot for Porosity West-East Direction

Figure 2 show that the plot has no nugget effect, C_0 , i.e. $C_0 = 0$, while the sill effect, $C=0.00685$, and range of influence, $a=18.5m$. The plot of the semivariogram for porosity did not cross the semivariogram axis, hence no Nugget effect, and with the sill value of 0.00685 and a range of influence of 18.5m. The dotted

line is extrapolated when assume that it has nugget effect, but in reality it has none.

Experimental Semivariogram Plot for Permeability Data Set of Ikpeshi Formation in West-East Direction At 18m Level (Figure 3)

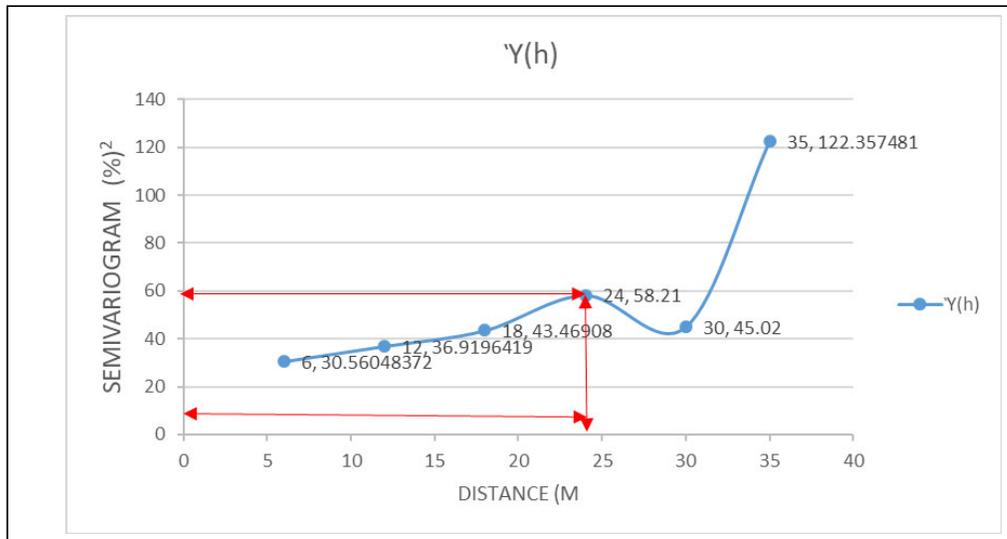


Figure 3: Semivariogram Plot for Permeability in West-East Direction (Measured in Millidarcy)

Figure 2 showed that the plot has no nugget effect, C_0 , i.e. $C_0 = 0$, while the sill effect, $C = 59$, and range of influence, $a = 24m$. The plot of the permeability data set did not start from the origin, hence no nugget effect.

Model for the Permeability Data Set of Ikpeshi dolomitic samples
Spherical Model:

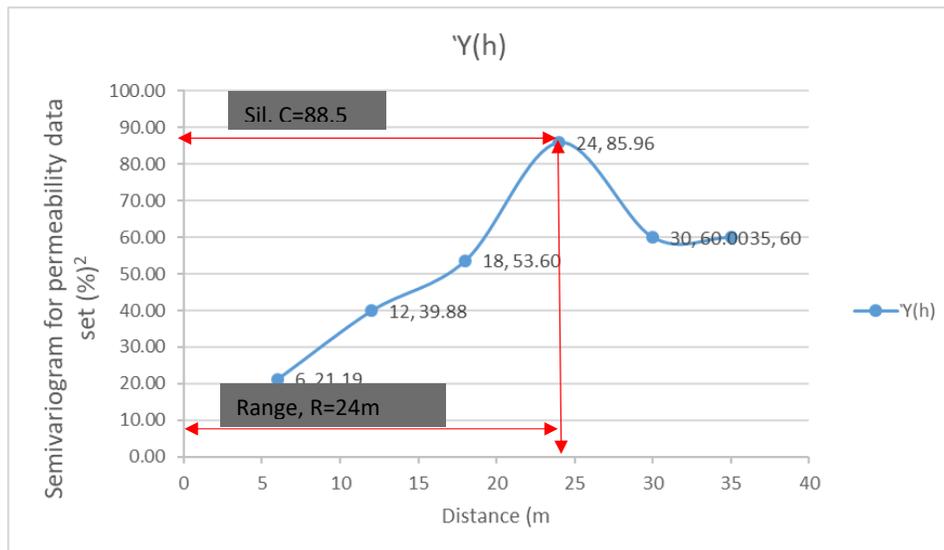


Figure 4: Spherical Model for permeability Data Set in West-East Direction for Ikpeshi Dolomite Deposit

Exponential Model:

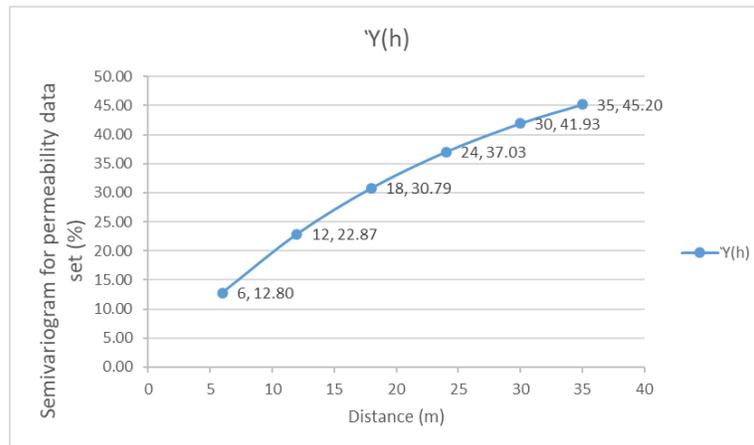


Figure 5: Exponential Model for Permeability Data Set in West-East Direction for Ikphesi Dolomite Deposit.

Model for the Porosity Data Set of Ikphesi Dolomite Deposit (Figure 6):

Spherical Model:

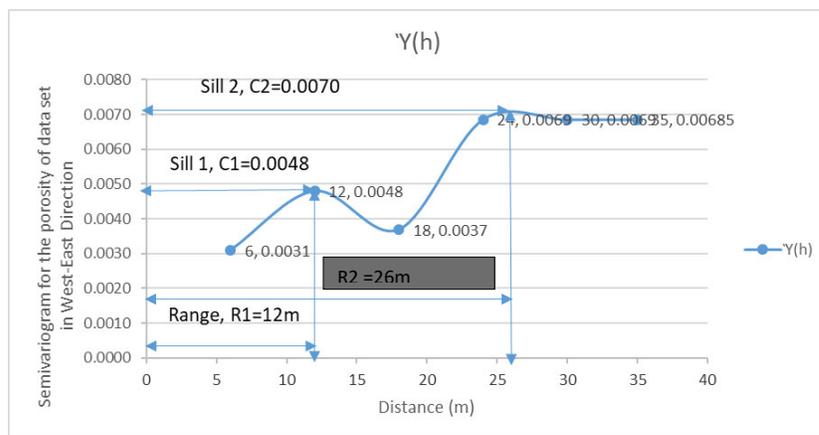


Figure 6: Spherical Model for Porosity Data Set in West-East Direction for Ikphesi Dolomite Deposit.

Exponential Model:

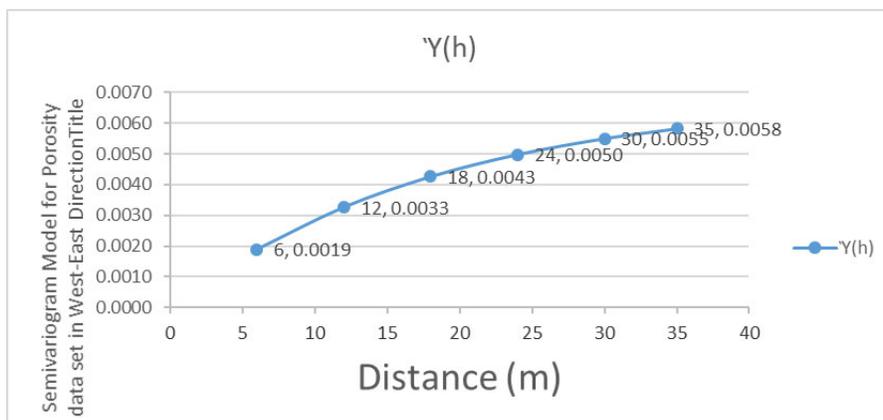


Figure 7: Exponential Model for Porosity Data Set in West-East Direction for Ikphesi Dolomite Deposit.

Spherical model for permeability in the North – South direction (Figure 8)

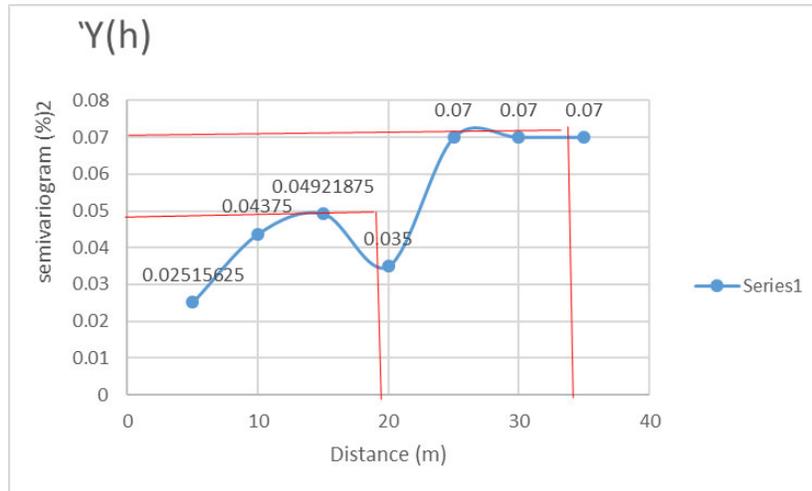


Figure 8: Spherical Model for Permeability Data Set in North South Direction for Ikphesi Dolomite Deposit

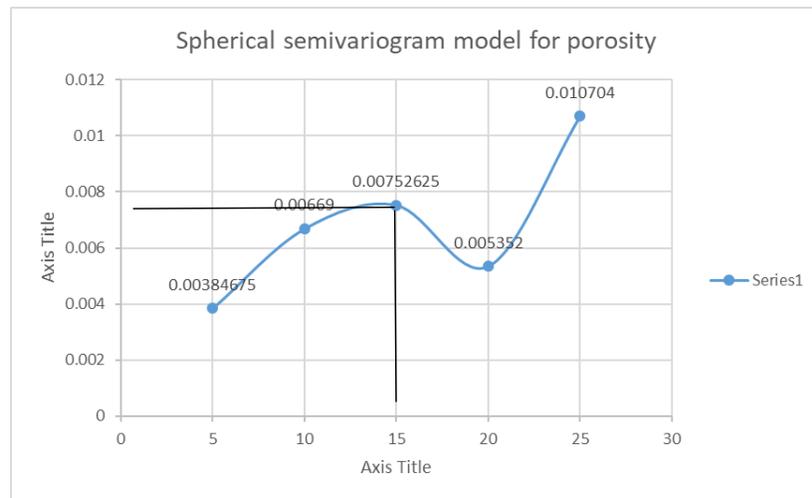


Figure 9: Spherical Model for Porosity Data Set in North – South Direction for Ikphesi Dolomite Deposit

Note: permeability measurement is in millidarcy (mD) not in percentage (%)

4. Discussion

4.1 Discussion on Experimental Semivariogram Construction for Porosity Set of Data

There is variation within the data set of samples used for semi-variogram plot for porosity as indicated by the shape of the semi-variogram until it reaches the sill ($C = 0.685\%$) where there is no relation between the sample. To the left, decrease in semi-variogram for porosity with increase in distance. To the right, increase in semi-variogram of porosity data set give rise with increase in distance between pairs of samples (Figure 2).

4.2 Discussion on Experimental Semivariogram Construction for Permeability Set of data

There is no nugget effect for all the plots. Increase in semi-variogram value of permeability gives rise to increase in distance between them. This shows that there is variation between pairs of data set for permeability as the distance between pair's increases.

The sill effect in fig 4.2 was extrapolated because of the limit pairs of samples used in the construction of the semi-variogram. The sill effect, $C = 59$. With the range of influence of 24m (Figure 3).

4.3 Semi-Variogram Model for Permeability Data Set

Both the spherical model and exponential model were performed for the same permeability data sets. The pattern differs from the two models. For the spherical model, the sill effect is $88.5 (\%)^2$ and range of influence is 24m in the West East direction (figure 4), while in the North South direction the sill effects are $(49.92\% \text{ and } 75.0 (\%)^2)$ with the corresponding range of influence, a (16m and 27m) (figure 8). No Nugget effect for the two patterns. In exponential model, the semivariogram has not reach the sill (limit data set) unless if extrapolated (figure 5). And if extrapolated, the range of influence could be three times that of the range for exponential model. From the plot for the models in W-E direction and North South direction, the distribution patterns are not the

same in the two directions (Figure 4 and Figure 8) which suggest that permeability within the deposit are anisotropic, that is not the same throughout the deposit.

4.4 Semivariogram Model for Porosity Data Set

For spherical model, the descriptive pattern show that it has two sill ($C_1 = 0.0048$ and $C_2 = 0.0070$) with two ranges of value of $a_1 = 12\text{m}$ and $a_2 = 26\text{m}$ in the west east direction. While the model plot in North South direction has one sill value, $C = 0.0075$ at range of influence of 15m , but have similar pattern but the plot in North South direction is yet to reach the sill (limited data). While the exponential models in W-E direction (porosity and permeability) were similar in pattern of distribution (Figure 5 and 7). From literature, porosity and permeability thus follow spherical model in its distribution. Hence, the construction and modelling of porosity and permeability data set in all directions should be performed. The pattern of distribution of the porosity data set with in the deposit suggest that it is isotropic, that is exhibit similar pattern and that porosity is similar both in North South and West East direction (based on the 2 directions). Since the exponential model do not reveal any intrinsic feature within the deposit, that was why it was not plotted.

5. Conclusion and Recommendations

Semivariogram modelling of mineral properties like permeability and porosity was performed and demonstrated in this paper. Porosity distribution patterns were similar in North South and West East direction for spherical model (Figure 6 and 9), hence it is isotropic in nature, while permeability distribution patterns differ in the North South and West East direction, hence anisotropic in nature. Hence, it should be extended to grade value distribution and other properties. But note that it is when the pattern are similar in all directions, then it becomes isotropic.

I hereby recommends the following;

- i. More data set should be collected for variogram plotting; further plottings should be done in all direction.
- ii. From (ii) establish the distribution pattern for the porosity of the deposit based is isotropic (same pattern in North South and West East directions) while the distribution pattern for the permeability of the deposit are anisotropic (different pattern in North South and West East directions [7-16]).

References

1. Kigobe, M., & Kizza, M. (2006, January). Dealing with

spatial variability under limited hydrogeological data. Case study: Hydrological parameter estimation in Mpigi-Wakiso. In *Proceedings from the international conference on advances in engineering and technology* (pp. 211-220). Elsevier Science Ltd.

2. Schabenberger, O., & Gotway, C. A. (2017). *Statistical methods for spatial data analysis*. Chapman and Hall/CRC.
3. Goovaerts, P. (1999). Geostatistics in soil science: state-of-the-art and perspectives. *Geoderma*, 89(1-2), 1-45.
4. Bagheripour, P., Asoodeh, M., & Nazarpour, A. (2013). Vertical resolution enhancement of petrophysical Nuclear Magnetic Resonance (NMR) log using ordinary kriging. *Central European Journal of Geosciences*, 5, 450-456.
5. Anifowose A.Y.B., Odeyemi I.B. and Bamisaye C.A. (2008): Establishing a solid mineral database for a part of South-western Nigeria Geospatial World. www.gisdevelopment.net accessed 22nd September, 2020.
6. Aziz, M. K. B. M., Yusof, F., Daud, Z. M., Yusop, Z., & Kasno, M. A. (2019). Comparison of semivariogram models in rain gauge network design. *Matematika*, 157-170.
7. ASTM Standard Test Method C97-83. ASTM C97: Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone. ASTM International website. ASTM C97
8. ASTM Standard Test Method D 4525-90. ASTM International website.
9. GEOSTATISTICAL SOFTWARE LIBRARY. (2022) <http://www.gslib.com>. (Accessed 13th Nov. 2022).
10. Deutsch, C. V., & Journel, A. G. (1992). Geostatistical software library and user's guide. *New York*, 119(147), 578.
11. Idris, G. N., Asuen, G. O., & Ogundele, O. J. (2014). Environmental impact on surface and ground water pollution from mining activities in Ikpeshe, Edo State, Nigeria. *International Journal of Geosciences*, 5(7), 749-755.
12. Journel, A.G. and Huijbregts, C.J. (1992). Mining Geostatistics. Academic Press, New York, P. 600 .
13. Kitanidis, P. K. (1997). *Introduction to geostatistics: applications in hydrogeology*. Cambridge university press.
14. MATEMATIKA, MJIAM, Volume 35, Number 2, 157-170 © Penerbit UTM Press.
15. Nqangi M. (2013). Geostatistical Modelling and Simulation of uncertainty of Kimberlite Pipe.
16. M.Sc. Mining Engineering Project. Faculty of Engineering and Built Environment, University of the Witwatersand, Johannesburg. On-line access. Pp. 45. Accessed:18th July, 2023.9

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