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Gostatistical Analysis for Manganese Element in Ghorabi Iron Ore Mine Area, Bahariya Oasis, Egypt

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Abstract— Manganese represents a problem in iron ore of Ghorabi area and it is considered undesirable ingredient when the ore charging to blast furnace. This paper aims to study the variation of manganese founded in Ghorabi iron ore using geostatistical modelling. The ore is divided geologically into four separated zones. Experimental variograms were constructed to show the spatial variability of manganese element within the deposit. Spherical and gaussian variogram models were fitted to the experimental variograms. After fitting the variogram of each zone to suitable model, the models were used to construct a distribution maps using the ordinary kriging and indicator kriging in different cut-off for the four different zones.

Index Terms— Geostatistics, GS+, Variogram, Ordinary kriging, Indicator Kriging, Ghorabi Mine Area, Manganese Element, Iron Ore.

1 Introduction

Performance of a blast furnace greatly depends on the quality of input raw materials, specifically the iron ore and its undesired elements associated with the raw material. Mineralogical characterization helps in identifying mineral phases and associated gangue materials since these materials greatly influence the bulk chemistry of the process and the quality of hot metal. A clear mineralogical analysis of iron ore samples of any particular deposit helps in selecting suitable blast furnace grade ore through the usual practice of blending, beneficiation etc.

Chemical characterization involves the analysis of iron ore and agglomerates, analysis of coke and lime stone. The major constituents of iron burden are Fe_2O_3, FeO, SiO_2, $A1_2O_3$, and the traces elements like Cu, Ni, Co, Pb, Zn and ,Mn. The detrimental elements in iron raw material for iron making and subsequent steel making that may be present in quality ore are listed below along with their allowable limits.

- Na_20 + K_20: should not exceed 0.8%
- Zinc: maximum allowable limit is 0.02%
- Phosphorous: should not exceed 0.04%
- Sulfur (adversely affect the environment): should be kept below 0.01%
- Mn_2O maximum allowable 3.2 %
- SiO_2 should not exceed 8%

The variogram can be described as the variation in values among samples some distance apart as a measure of their spatial correlation [1]. Constructing of an experimental variogram is the first step in any geostatistical analysis. It can be computed from a set of randomly spaced data through finding pairs of data that are oriented in the required direction, determining the distance between the samples, then summing the squared differences of the grades and dividing by the number of pairs [2]. Kriging provides the best estimate of the mean value of a regionalized variable. It provides the Best Linear Unbiased Estimator (BLUE) of the grade. During kriging, each sample is assigned a sample weight. The weighted samples are then linearly combined to give the best estimate. It is the 'best' estimate because the procedure minimizes the expected error between the estimated grade and the true grade. Sample weights are calculated such that the variance of the estimate is a minimum [3]. In this paper geostatistical technique is used for modeling the manganese element in Ghorabi iron ore.

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2 Geology of study area

The Bahariya Oasis Depression is one of the seven major depression of the western desert of Egypt .It lies between latitudes 27◦ 48' and 28◦ 30' N., and between longitudes 28◦ 30' and 29◦ 10' E., at about 160 Km west of the Nile valley and 320 Km SW of Cairo. The depression is oval-shaped, extending in a NE-SW trend. It has a maximum length of 100 Km along its NE-SW axis, and a maximum width of 45 Km. The depression is surrounded by plateaus which rise 250-300 m above sea level. It is closed from all directions by steep scarps. These scarps are dissected by wadies which end internally at the depression floor. Gentle slopes except for the relatively steep slopes of the isolated hills and hillocks characterize the floor of the depression. Structural setting of the northeastern plateau of El-Bahariya Depression and the included iron ore occurrences i.e., Ghorabi, and Nasser. Figure 1 illustrates the locations Ghorabi, and Nasser area. Ghorabi area structurally divided into four zones [4,5].

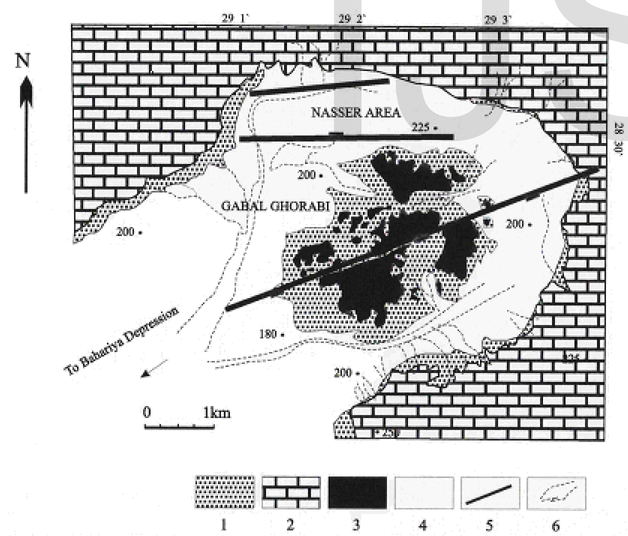

Fig.1. Simplified geological map of Ghorabi – Nasser area [6] 1=Clastic rocks of the Cenomanian Bahariya Fm.; 2=Karstified limestone of the middle Eocene Naqb Fm.; 3=Iron ore deposits; 4=Quaternary sediments; 5=Faults; and 6=Drainage lines.

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3. Methodology

The most important aim of the geostatistical application is to understand the behavior of the natural phenomena. Because of this advantage this methodology has been used in different areas such as mining, hydraulic, petroleum, and meteorology, etc. This procedure can be applied in two different steps. The first step of the geostatistical approach is to set up mathematical function related with the regional dependence [7]. It is called semivariogram function (SV).

Subsequently, a theoretical SV function is fitted to determine an SV function in order to use the kriging technique. If a theoretical SV function is determined, then it is possible to run kriging technique in order to model the regional distribution of the Regionalized Variable. The most important step of the geostatistical method is to determine a highly correlated SV function. Hence, it is possible to make a valid interpretation about the distribution. By using kriging technique, it is possible to understand the regional behavior of the natural phenomena for every point in the study area.

3.1 Variogram

The variogram is the basic geostatistical tool for visualizing, modeling, and exploiting the spatial autocorrelation of a regionalized variable [8]. As the name implies, a variogram is a measure of variance. Although procedures exist for modeling the variogram through iterative or least-squares methods, practitioners recommend actual inspection of the observed variogram and the fitted model. A properly fitted model then allows the computer program to calculate estimates that reflect the spatial extent and orientation of autocorrelation in the variable to be mapped [9].

The purpose of the variogram is to define the distance over which values in the data set are interdependent, i.e., it is used as a method for determining the range of influence, and thus weights to be used in interpolation among measurements. It also allows explicit calculation of what is termed variance [10].

A straightforward way of measuring how a variable z changes in value between site x and a site h units distant, say x + h, is to compute the difference z(x) - z(x + h). If the surface represented by the two points is continuous and h is a small distance, one expects that the difference is small as well. If h were very large relative to the spatial degree of change in the variable, then the difference might be expected to increase. Translating this intuitive notion into a formula (1) which is:

$$\gamma(h) = [1/2N] \sum [z(x) - z(x+h)]^2 \qquad (1)$$

Where N is the number of paires

3.1.1 Commonly used variogram models

Most geostatistical estimation or simulation algorithms require an analytical variogram model, which they will reproduce with statistical fluctuation [11]. The following are some commonly used variogram models shown in figure 2 [12]:

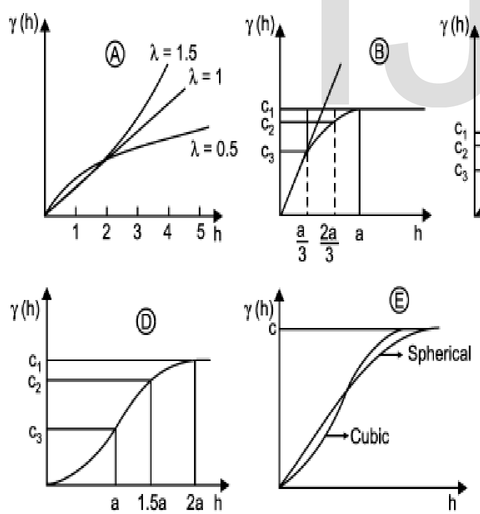

Fig.2. Some of Commonly Used Variogram Models:

(A) Power Functions, (B) Spherical Model, (C) Exponential Model, (D) Gaussian Model and (E) Cubic Model.

3.2 Kriging

The general technique of prediction is known as kriging. It requires a mathematical model to describe the spatial covariance, usually expressed as a variogram, which its parameterized form has become the central tool of geostatistics. Successful kriging and estimation of the variogram depend on sampling adequately without bias and with suitable spatial configurations and supports. These differ somewhat from design-based estimation with its emphasis on random sampling [13].

Kriging is a spatial prediction method of nice statistical properties. Kriging shares the same weighted linear combination estimator according to the formula (2)

$$\hat{z} = \sum_{i=1}^{n} w_i z_i \qquad (2)$$

Where Zi is the sample value at location i, Wi is a weight, n is the number of samples. As we will show next that estimators of the above form are unbiased if the sum of the weights is 1. The distinguishing feature of kriging, therefore, is its aim of minimizing the error variance [14].

3.2.1 Ordinary kriging (OK)

In practice, kriging is usually implemented using variogram rather than covariogram because it has better statistical properties (unbiased and consistent). From equation (3):

$$\gamma(h) = C(0) - C(h), \text{ we have } C(h) = C(0) - \gamma(h) \qquad (3)$$

Substituting this covariogram into the unconstrained mean squared error (MSE) leads to the formula (4):

$$\begin{aligned} MSE &= \sum_i \sum_j w_i w_j (\sigma^2 - \gamma_{ij}) + \sigma^2 - 2\sum w_i (\sigma^2 - \gamma_{i0}) + 2\lambda\left(\sum w_i - 1\right) \\ &= -\sum_i \sum_j w_i w_j \gamma_{ij} + 2\sum w_i \gamma_{i0} + 2\lambda\left(\sum w_i - 1\right). \end{aligned} \qquad (4)$$

Similar to the covariogram, the weights can be solved by setting the equations of the 1st derivatives w.r.t. wi's to zero [15].

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3.2.2 Indicator kriging (IK)

Kriging of indicator variables, which represent membership in a set of categories, used with naturally categorical variables like facies or continuous variables that have been threshold into categories (e.g., quartiles, deciles), especially useful for preserving connectedness of high and low permeability regions. Direct application of kriging to perm will almost always wash out extreme values.

Indicator Kriging uses thresholds to create binary data (0 or 1 values), and then uses ordinary kriging to make spatial predictions based on the indicator data. Predictions using indicator kriging are interpreted as the probability of exceeding the specified threshold [16].

Indicator Kriging assumes the model:

$$I(s) = \mu + \varepsilon(s) \quad (5)$$

Where μ is an unknown constant and I(s) is a binary variable.

The creation of binary data may be through the use of a threshold for continuous data, or it may also be the case that the observed data is 0 or 1.

4. Experimental Work

Manganese is too brittle to be of much use as a pure metal. It is mainly used in alloys, such as steel. Therefore the present study was carried out on manganese element which founded in Ghorabi iron ore, using chemical analysis composition of 183 bore holes data to trace the distribution of manganese element in Ghorabi mine area, Bahariya Oasis, Western desert, Egypt. Gs+ software was used to construct the variograms and kriging. According to the data arrangement, the required parameters for constructing variograms and kriging were introduced to the program. The boreholes location and some major faults were shown in figure 3.

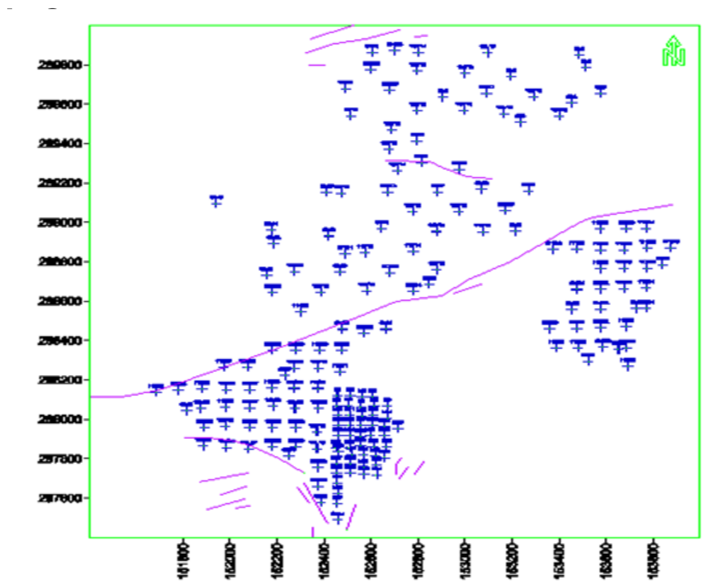

Fig.3. Boreholes location and all attributes of iron ore deposite of Ghorabi, Bahariya Oasis, Western Desert, Egypt.

5. Results and discussions

5.1. Statistical analysis

Traditional statistical methods are based on the assumption that all sample values are equally representative of the deposit under study, and the physical positions of the samples with respect to each other are not taken into account. Statistical analysis in the present study, gives the distribution of manganese content and standard parameters; mean, standard deviation, coefficient of variation, variance, coefficient of skewness and coefficient of kurtosis. Table (1) show that the all zones have normal distribution and as previously mentioned the allowable manganese percent for the blast furnace must not exceed 3.2% but as seen in table (1) the mean values for all zones except central zone exceed that percent. The south west and south east zones records a high variance and standard deviation values while the high value of coefficient of variation recorded in central zone and approximately the same in south east and south west. On the other hand the low value of coefficient of variation founded in the north zone.

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TABLE 1
Statistical parameters

Parameters	Ghorabi (N)	Ghorabi (c)	Ghorabi (SE)	Ghorabi (SW)
Number	33	28	32	90
Minimum	0.58	0.26	0.51	0.55
Maximum	5.01	3.73	7.03	8.06
Mean	3.25	1.62	3.56	3.72
Standard Deviation	1.21	1.06	1.88	2.18
Variance	1.47	1.12	3.52	4.76
Skewness	-0.16	0.31	0.1	0.21
Kurtosis	2.03	1.74	1.8	1.66
Coefficient of Variation	0.37	0.65	0.53	0.56

5.2. Geostatistical analysis

5.2.1 Variogram

Depending on the available data for each area isotropic variogram were constructed and fitted to a suitable model as shown in figure 4. The variogram parameters for Mn % in studied areas were summarized in table.2.

TABLE 2
Geostatistical parameters

Parameters	Central zone	North zone	South east zone	South west zone
Model type	Spherical	Gaussian	Spherical	Gaussian
Co (%)2	0.343	0.459	0.01	0.43
Co+ C (%)2	1.082	2.928	4.115	4.493
Range, m	421	969	310.9	289

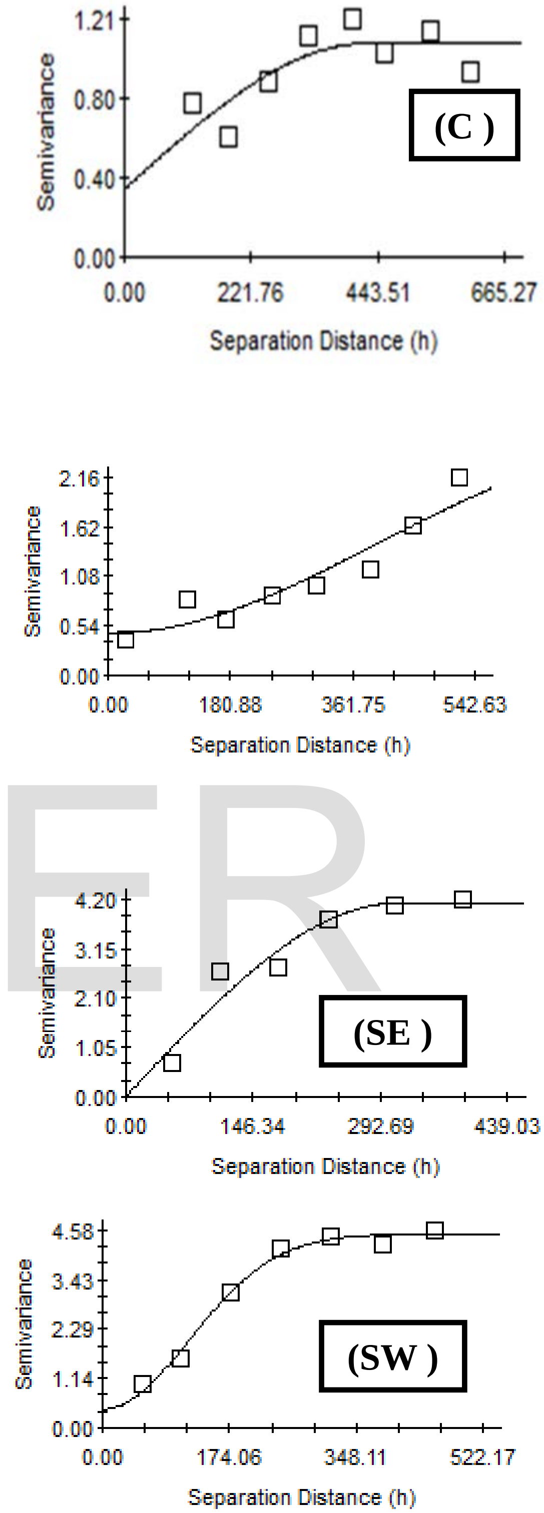

Fig.4. Variogram models for Mn % in studied areas where, (C) central zone, (N) north zone, (SE) south east zone, and (SW) south west zone.

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The variogram models for every zone as shown in figure 4 indicate that every zone has it's specific characterization in manganese distribution and that obviously from the different models fitted for every zone since spherical model appears in the central and south east zones where the gaussian model recorded in both north and south west zones. As shown from geostatistical parameter in table (2) zone (SE) recorded the lowest nugget effect and that is mean in the short range there is high continuity on the other hand it has the high sill and that is mean there is a high continuity between samples and at the same times there is high variation between sample values. The central zone recorded the smallest sill but in the same time recorded a high nugget effect and that is mean in the short range there is a high variation between the sample values verses the long range. The highest nugget effect and range were recorded in the north zone. The highest sill and lowest range were recorded in south west zone. From all these observes can concluded that the manganese distribution has a specific distribution for every zone separately.

5.2.2 Ordinary kriging

Ordinary Kriging is used to interpolate the unknown locations by creating map analysis that showing the distribution of Mn % in studied areas as shown in fig.5. It is clear that the distribution vary greatly from one zone to another. The maximum variation in distribution founded in the SW zone and the low variation recorded in C zone while the N and SE zones recorded a moderate variation. Low percent of manganese founded in the north zone where the maximum value is 0.58%. The highest percent of all is 8.06% is founded in south west zone. There are some areas have a high percent of manganese far away from the desired percent founded in the south east and south west zones and the optimum solution for this problem is blinding process or isolation of these areas by selective mining. As shown from figure 5 it is strongly suggested that the production must be from all zones at the same time to keep the percent of manganese at the allowable percent to blast furnace. These distribution maps are very useful in mine planning, they may takes as a strong guide where selecting the production faces, blinding process and the best direction for production.

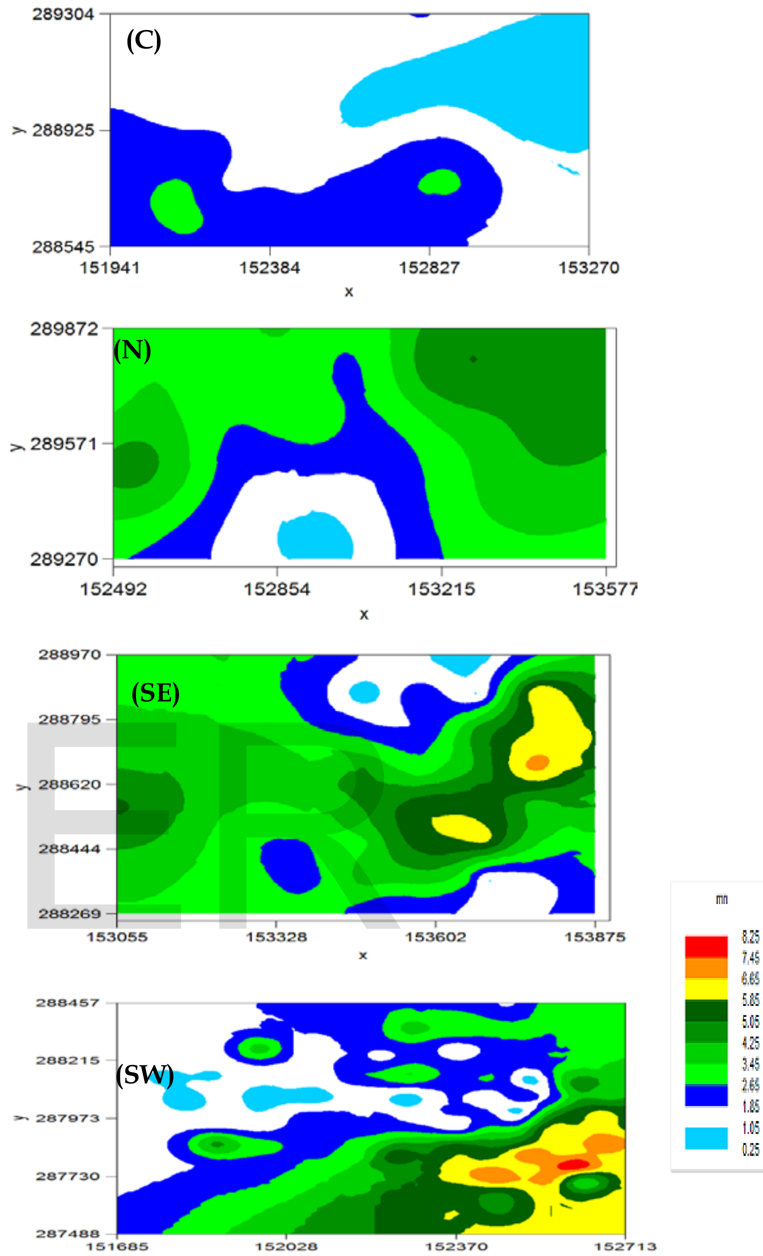

Fig.5. Ordinary Kriged models shows Manganese % distribution in studied areas where, (C) central zone, (N) north zone, (SE) south east zone, and (SW) south west zone.

5.2.3 Indicator kriging

Indicator kriging used to represent membership in a set of categories, used with naturally categorical variables like facies or continuous variables that have been threshold into categories, especially useful for preserving connectedness of high and low permeability regions. Indicator kriging models for the studied zones

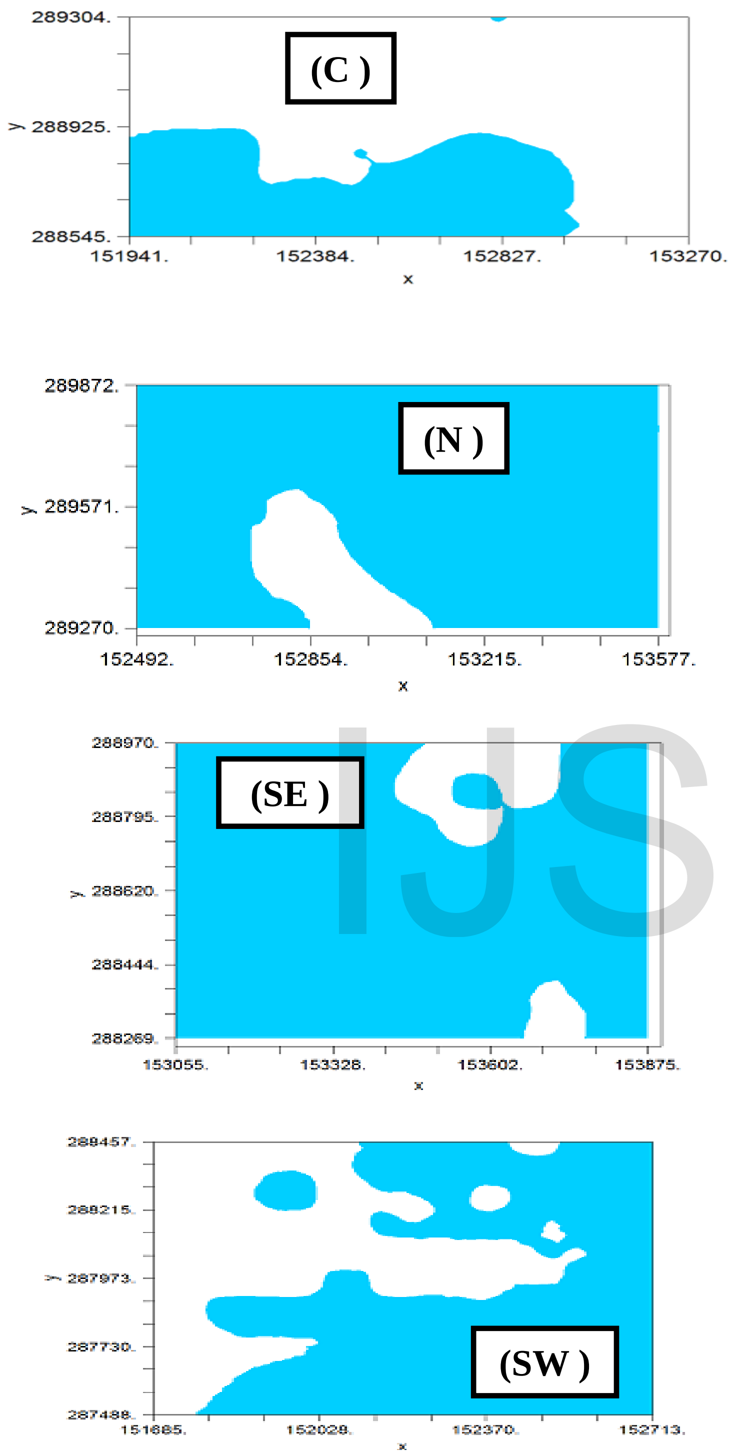

Fig.6. Indicator Kriged models shows Manganese % distribution at 2 % cut-off grade in studied areas where, (C) central zone, (N) north zone, (SE) south east zone, and (SW) south west zone.

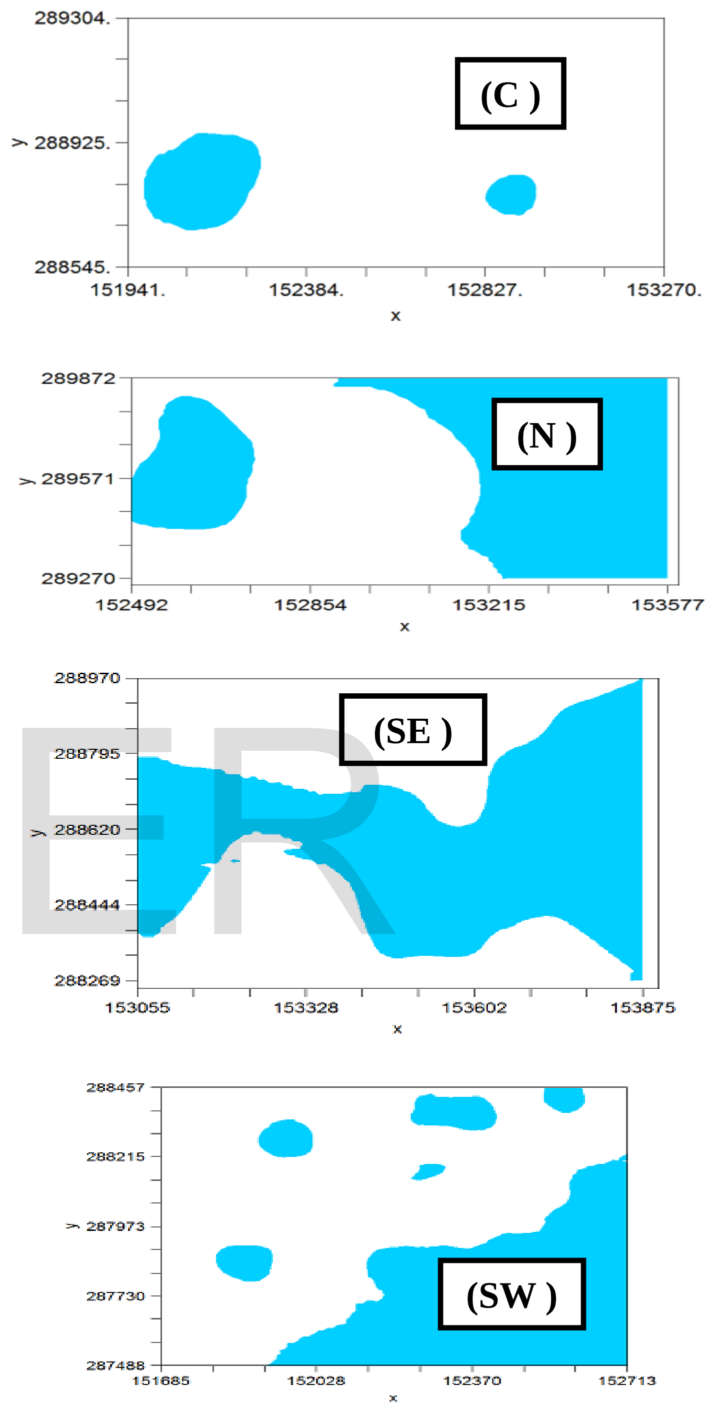

Fig.7. Indicator Kriged models shows Manganese % distribution at 3 % cut-off grade in studied areas where, (C) central zone, (N) north zone, (SE) south east zone, and (SW) south west zone.

were constructed at two different cut-off grade 2% and 3% to show and identify the areas which above and dawn the indicated cut-off. Figure 6 and 7 shows clearly the areas above and dawn the selected cut-off.

The white color area is the area dawn the cut-off where the colored area indicate the area above the cut-off and consequently easy choose the faces for production. In the central area there is no problem with the manganese percent because the major area founded under the cut-off.

But on the other hand in the south east and south west zones represented the most areas of very high manganese percent and that's clearly shown from the colored areas in these two zones.

6. Conclusions

1- Applying geostatistical techniques revealed the behavior of manganese mineralization within the deposit as reflected by the variograms.

2-Geostatistical analysis allows predicting the manganese percent for the unsampled locations along the studied area. This information can facilitate the optimization and maintenance suitable percent required for blast furnace.

3- Geostatistical analysis can be used successfully in constructing a distribution map for manganese that strongly useful in mining planning and production.

4- Ordinary and indicator kriging models clearly indicated the high and low areas in manganese percent and consequently help in choosing the production faces and directions.

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