International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 12 ǁ December 2025 ǁ PP. 60-68

Ore Modeling and Geostatstic for Grade Estimation of Gosu Gold Deposit in Qeissan Area, Blue Nile State, Sudan

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Abstract

Gold grade estimation in structurally controlled mesothermal deposits requires precise geological interpretation and robust geostatistical techniques. This study focuses on the northern Gosu auriferous quartz veins deposit, where a 3D ore model was constructed by integrating geological maps, borehole data; lithology and assay. Data processing, variogram analysis and Ordinary Kriging were employed to ensure accurate and reliable resource estimation. The results demonstrate that combining ore modeling with geostatistic significantly enhances the accuracy and visualization of subsurface gold distribution, providing vigorous gold grade estimation.

Keywords: *Grade estimation; Ore modeling; Ordinary Kriging; Gosu North*

Date of Submission: 07-12-2025 Date of acceptance: 19-12-2025

I. Introduction

Qeissan area locates in Blue Nile State, southeast of Sudan. The Qeissan District forms part of the Pan-African Shield and is recognized for its substantial mineral potential. Volcano-sedimentary rocks, which constitute over 75% of the study area, are thrust over the older quartzo-feldspathic gneisses. Gold-bearing quartz veins are hosted within both the volcano-sedimentary sequence, comprised of greenschists, and the underlying gneissic basement.

Geological features are essentially three-dimensional, it also called geomodelling and 3D geological modeling, which is a key method for estimating resources. GM is the process of creating a three-dimensional representation of the geology, structures and mineralization within a specific area, it uses various data; maps, drill logs, assays, geophysical and geochemical surveys to build 3D representations of geology, structures, and mineralization (Pan et al.,2012, Adeli et al.,2017, Chanderman et al.,2017, Lelliott et al.,2009, Wellmann et al,.2019). This helps visualize orebody geometry and extend geological maps into full dimensions. Geomodelling integrates data management, spatial analysis, interpretation, 3D visualization, statistics, and predictions (Pan et al.,2012). It's essential for solving geological problems and offers a platform for research, design, and decision-making (Chen et al.,2021). To ensure accuracy, model uncertainties must be identified and quantified using techniques like kernel density smoothing and borehole resampling, factoring in data quality, density, and geological knowledge (Lelliott et al.,2009).

In geological modeling and geostatistic plays a crucial role in estimating the grade and spatial distribution of mineral resources. Geostatistic Techniques like kriging are used to interpolate and extrapolate data by accounting for spatial correlations among observations. When geostatistical methods (models) are combined with geological modeling, the result is more realistic and dependable models that capture geological complexity, spatial grade variation, and offer more precise resource estimations.

Gosu auriferous quartz veins are located some 9km NE Qeissan town (Fig.1). It consists quartz veins surrounded by great number of quartz veinlets and stringer. It is hydrothermal gold deposit controlled by shear zone types. The Northern part of Gosu quartz strike is NW, dipping 50-60 degrees to West in general. It hosted in metavolcanic; chlorite schists. In this study 3D ore modeling and geostatistic method; ordinary kriging applied to estimate gold grade to Northern part of Gosu auriferous quartz veins.

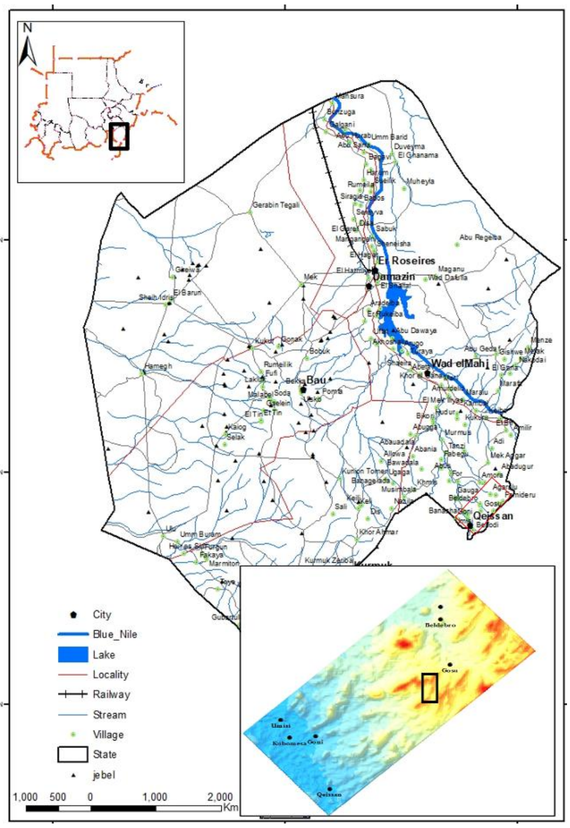

Fig. (1): location of Gosu area

Geological Background

The Gosu area lies within the Qeissan region m(Fig.2A), Qeissan is a part of the Southern Blue Nile's ophiolite-greenstone belt. It's mainly composed of Upper Proterozoic rocks; gneisses, schists, and amphibolites, which overlain by steeply dipping meta-sediments, occasionally disrupted by basic meta-volcanics. Several phases of granite and granodiorite intrusions, including biotite granite in the west and syenite-gabbro complexes intruded the units in the eastern part of the area. The intrusions may have provided the necessary heat for metamorphism and mobilization of mineralizing fluids. The area undergone low to high grade regional metamorphism and several deformation phases. Plastic deformation of the meta-sediments is visible in the northeast with open folds, while open to tight folds are observed in the quartz veins. Severe brittle deformation led to shearing in the quartzo-feldspathic rocks, basic meta-volcanics, and quartz veins, forming a NE-SW dilation zone rich in gold-bearing veins. Faults trend NW-SE, NE-SW, and E-W, strongly influencing gold mineralization.

The Gosu auriferous quartz veins coinciding with these trends, indicating a significant structural control of gold mineralization. The auriferous quartz veins in Gosu area are discontinuous, showing pinch and swell characters. The veins are less than meter to 7 meters wide and about 1.3 km long. The quartz bodies are folded and fractured. The hosted chlorite schist is talc- bearing. Visible gold is observed in altered vugs and rusty stained cracks in the sheared quartz vein.

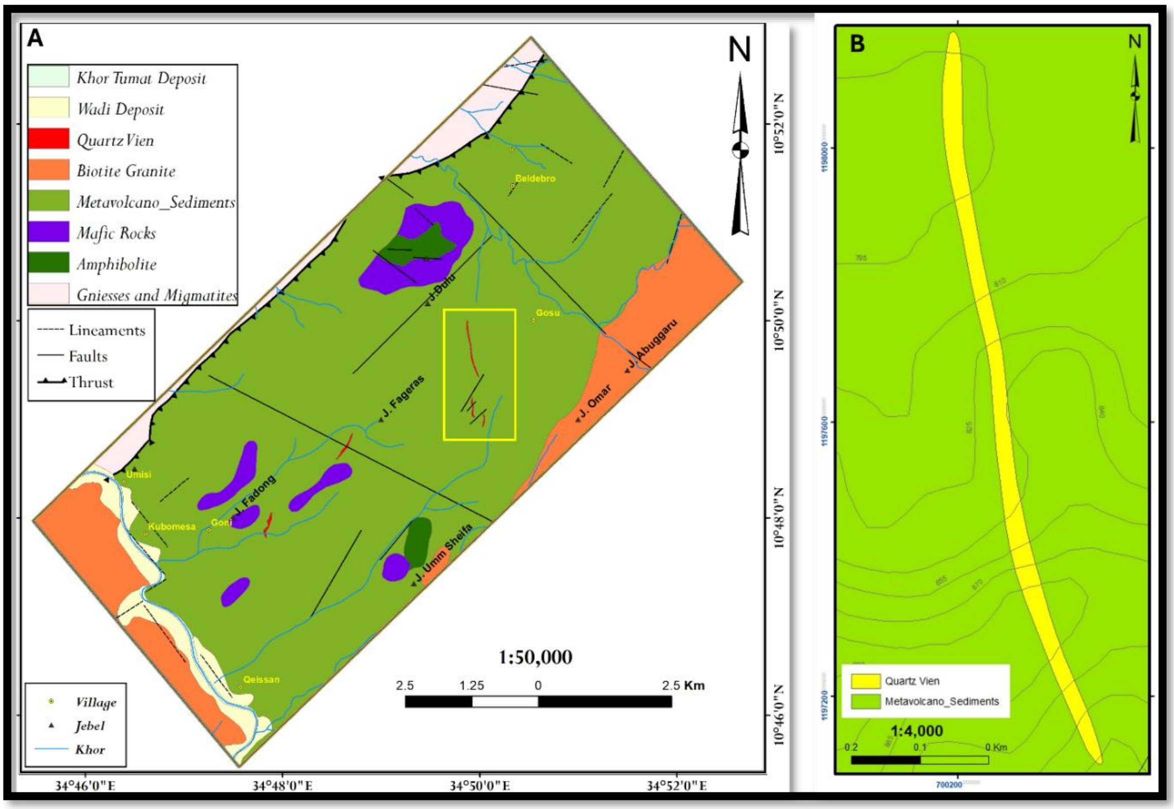

Fig. (2): (A) Geology of Qeissan Area. (B) Auriferous quartz vein of Gosu North.

II. Material and Methodology

Fifteen diamond boreholes, totaling 764.60 meters depth were drilled. The borehole collars were marked on irregular profiles along the quartz vein body. Boreholes were drilled with drilling angles 60 and 90 degrees with 90 degrees as azimuth in order to intersect the down depth extensions of the auriferous quartz veins at 30 to 70 meters below surface. 430 core rock samples were collected, crushed, pulverized and assayed for gold at Rida Laboratory; duplicate samples were sent to a United Arab Emirate Industrial and OMAC Laboratories for cross check. Well documented data is used to establish resource database.

Geological modeling

Based on core drilling data, the subsurface geology of the Gosu gold-bearing quartz veins includes four main lithologies as below.

- High-grade gneisses and amphibolites.
- Island arc volcaniclastic assemblages.
- Syn-tectonic gabbroic intrusions.
- Late-tectonic andesite dykes and quartz veins.

Gold-bearing quartz veins are mostly hosted in gneisses and volcaniclastic metasediments (Fig.2B). The quartzo-feldspathic grey gneisses are metamorphosed to amphibolite facies and hydrothermally altered into kaolinized, sericitized, and often silicified. The gneisses interbedded with migmatite and amphibolite schist. Structural fractures from shearing and faulting make the quartzo-feldspathic grey gneiss a key host for mineralization, though it's poorly exposed at the surface. These gneisses are sharply overlain by island-arc assemblage of volcanics; andesitic tuffs and pyroclastics—showing schistosity or weak foliation as chlorite schist. Pyroclastic rocks are strongly sheared and mylonitized, especially along contact zones (Abdel Magid, 1983; Abel Rahman ,1983; Abdel Rahman ,2000).

Meta-Volcanic rocks overlie gneisses along sharp tectonic contacts. Andesitic tuffs and pyroclastics are highly sheared and mylonitized near contacts (Toum, 1985).

Syn-tectonic gabbro is foliated, fractured, and weathered near the surface, intruding into gneiss, amphibolite, and andesite layers. Additionally, massive porphyritic andesitic dykes cut through the grey gneiss (Vail et al., 1986).

3D ore modeling

Orebody modelling is a reflection of geological and geometrical reality of an ore deposit (Roy and Sarkar, 2014). To create a 3D orebody model using Surpac software version 6.6.2 from GEOVIA, several steps have been followed as below

Create geological database

The database is created based on the raw data, which obtained from the boreholes. four tables are import in the database, containing different data. The imported tables are collar, survey, geology and assay in csv format.

Ore Sectioning and Solid Model Generation

Borehole assay data over 0.25 ppm are selected and digitized to create ore outlines in string format. These outlines are cleaned by removing overlaps, duplicates, spikes, and triangulated within and between section segments to build a 3D ore model(Fig.3). The model is then validated and used for visualization, volume estimation, and geological database integration. Calculated volumes of solid objects (e.g., Trisolation1, True Solid) are compiled and verified(Table1).

Table (1): Solid Modelling Orebodies Report

Minimum			**Maximum**			**Area**	**Volume**
X	Y	Z	X	Y	Z	(m^2)	(m^3)
700140.2	1197863.6	740.8	700183.6	1198084.8	777.8	16786.6	58461.9

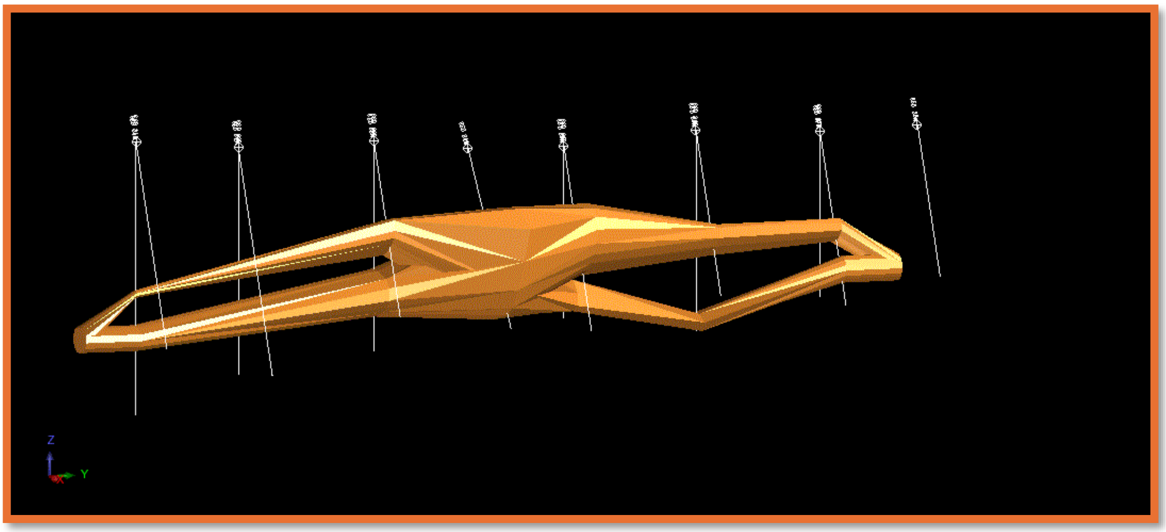

Fig. (3): Shows solid model of Gosu North with boreholes.

Topographic Surface (DTM)

XYZ data from a 10m DEM are converted to string format and used to generate a digital terrain model (DTM). This surface is applied to truncate the ore model, aligning it with actual topography.

Block modelling

Block modelling divides solid ore into customized block units for better resource evaluation. It determines ore deposit volume, compares with solid model, and estimates block grade using compositing techniques. The factors that determine the size of the block are mainly to reflect the changing characteristics of the ore body. If the block size is too large or too small, the sample evaluation result will be average, and it cannot accurately reflect the characteristics of grade changes. The size of these blocks is selected based on several factors, such as the drill hole spacing, mining method (bench height), and ore deposit geological settings. The optimal block size for estimation is mainly a function of drillhole spacing, is one half of the drillhole spacing or larger. If the deposit has consistent mineralization and a low nugget, a quarter of the drillhole spacing may be acceptable. 3D coordinates spatially define the model extents. Block modelling has been done with block size of 5 m x5 m x 5 m. Then the block model is constrained according to the extent of the ore deposit and the volume of the block model is calculated (Fig.4).

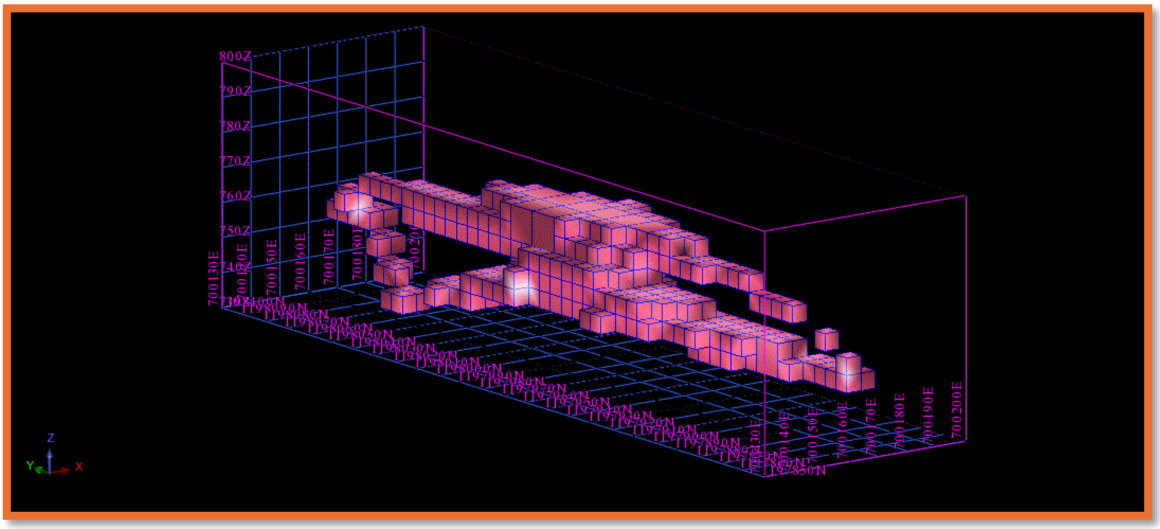

Fig. (4): Constrained 3D modeling of orebody, Gosu North.

The block model validated visually by checking the volume model (edges of the domain) and by comparing volume model with solid model volume. When the block model is created, built and validated, the three-dimensional modeling of orebody is constructed. So, the volume of estimated domain is defined, but with no grade information.

III. Database and Data analysis

The data is cleaned up from errors and used in statistical, geo-statistical analysis and reserve estimation. Univariate Statistic and EDA used to describe, analyze, examine patterns of distribution and summarize the assay data. Basic statistic, histogram are most common methods in univariate data analysis and density distributions. Univariate Statistical analysis (Table 2), histograms provide that the data set of Gosu is asymmetric, positively skewed distribution (Fig. 5), have outliers or extreme low and high values and coefficient of variation is generally greater than one. The presence of low extreme values may due to the existence of many values close to zero or under detection limit. slightly high coefficient of variation indicates the presence of some erratic high sample values. The determined outliers; lower and high are removed by applied cutoff (0.25 ppm) and top cut (2.8 ppm) may help to reshape the skewed distribution to normal distribution data.

Table (2): Univariate Statistical summary

Statistic parameter	**Gosu**	
N	1333	
Mean	0.37	Measures of Location
Median	0.04	
Mode	0.01	
Minimum	0.00	
Maximum	39.20	
Range	39.20	
Variance	5.50	M. Spread
Std. Deviation	2.35	
Interquartile Range	0.12	
Skewness	11.47	M. Shape
coef. of variance	6.26	

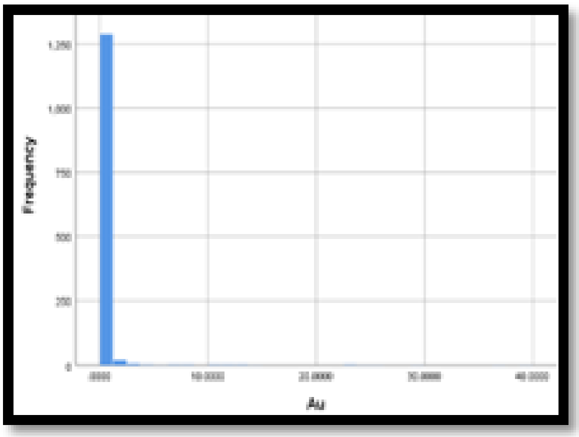

Fig. (5): Histograms demonstrate Au distribution of Gosu

Composite is an even representation of sample grades based on sample length to eliminate the bias. From simple statistic of data length; mode and the frequency of the sample lengths is 2m (Fig.6) shows the dominant sample interval, is selected as the composite length. Fig. (7) showed plots of the sample grades against the sample lengths, there are remarkable patterns in length 1m. Snowden (2009) reported the data can be composited to longer lengths than the sample interval, due to that variance become lower and variogram smooth and also reduce the amount of data available to work with.

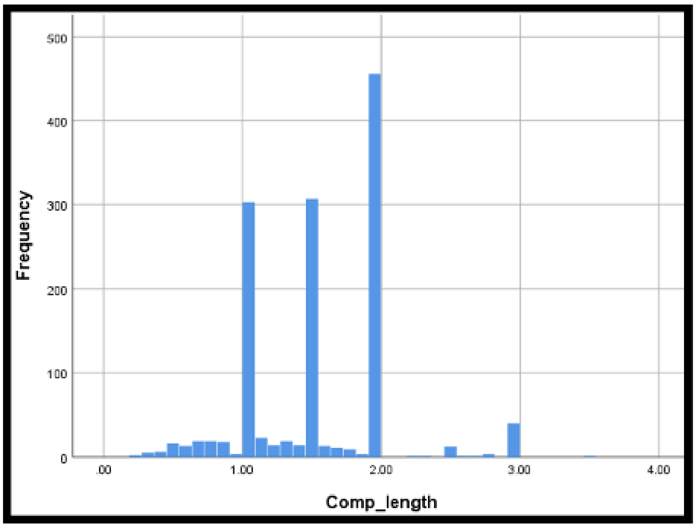

Fig. (6): Composite length selection

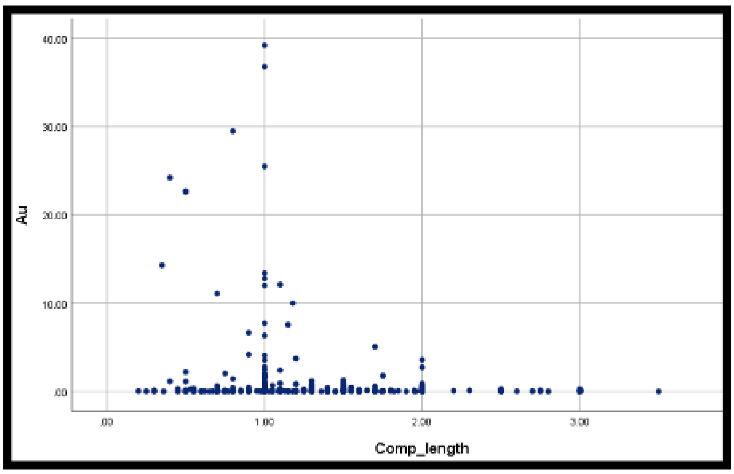

Fig. (7): shows plot the grades (Au) against the sample lengths

Semi-variogram

Semi-variogram provide useful parameters for estimating and understanding spatial variability, including maximum search distance, anisotropy ratios, nugget value, sill value, and range. An omni-directional and directional variograms were used to obtain variogram model parameters; sill, nugget effect, and range (Table 3).

Table (3): Variogram model parameters of Gosu North

Model Type	Nugget	Sill	Range	Structure
Spherical	0	1.30262	8.572	1

Directional variograms are calculated along a specific direction, with the best variogram having the longest range. Variogram maps define anisotropy ellipsoid, with primary maps; major and secondary; semi major providing the third candidate perpendicular to one another; minor, allowing for the calculation of anisotropy ellipsoid parameters (Table 4) and (Fig.8). The resulted anisotropy Ellipsoid parameters summarized in Tables (5).

Table (4): Elements used in variogram map

Plane dip	-75
Dip direction	90
N. of variogram	36
Spread angle	40
Spread limit	15
lag	27
Max. distance	195
N. of samples	71
N. of boreholes	6

Table (5): Results of anisotropy parameters

Plunge	-75
Bearing	90
Dip	-0.0
Major: semi-major	1
Major: minor	1

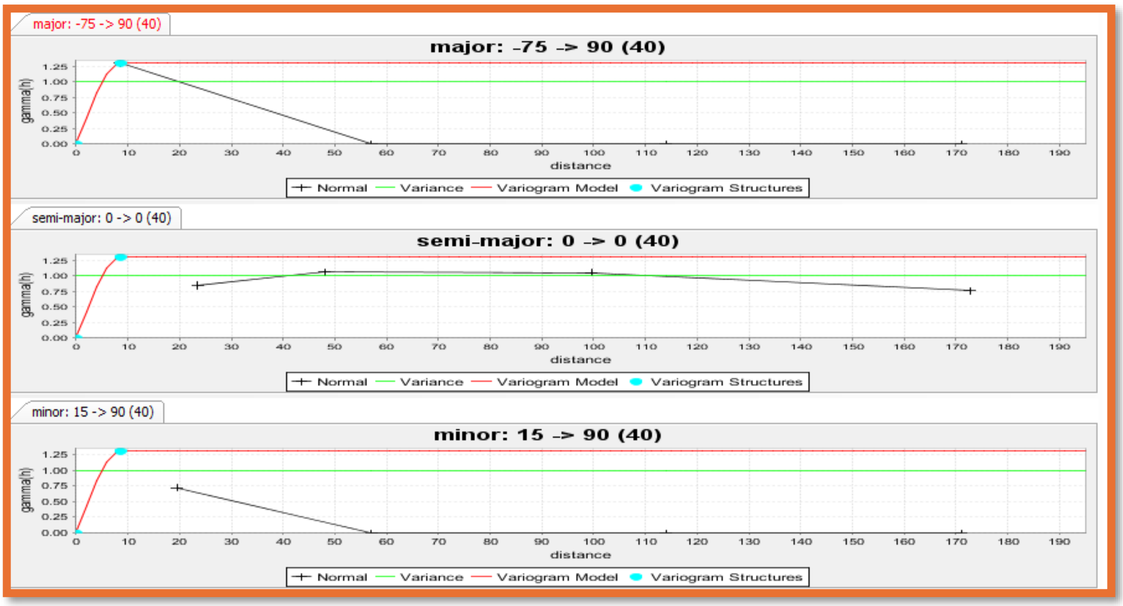

Fig. (8): Gosu North variogram.

Exploration database has been cleaned, treated from extreme values, analyzed and spatial variability or continuity well understood. This database became resource database and ready for estimation and grade modeling.

Estimation

Understanding geostatistical theory, data processing, ore body modeling, variogram and ordinary kriging have been done for proper resource estimation. Ordinary Kriging (OK) is a linear geostatistical method which provides local estimation by interpolation, used to reduce the volume variance effect (Azmi et al., 2020). Resource estimation of Au for Gosu North is completed with many search parameters such as composited drillhole file coded with estimation domains and top cut, three-dimensional block model constrained with estimation domain, Search neighborhood parameters including search ellipse and minimum and maximum number of informing samples for estimation, Sample weighting information from variogram models for each domain and Number of discretisation points for estimation (Tables 4 and 5). Discretisation of 3x3x 3 is used to correct the estimate for the volume variance effect. Results obtained from gold resource estimation summarized in Table (6). After conducting the resource estimation through the OK method, the 3D models of the deposit were drawn (Fig.9).

Table (8.2): OK estimates of Gosu North

Volume(m³)	Tones	Au(g/t)	Gold (g)	Gold(kg)
53708.65	139642.5	0.71	99146.18	99.1

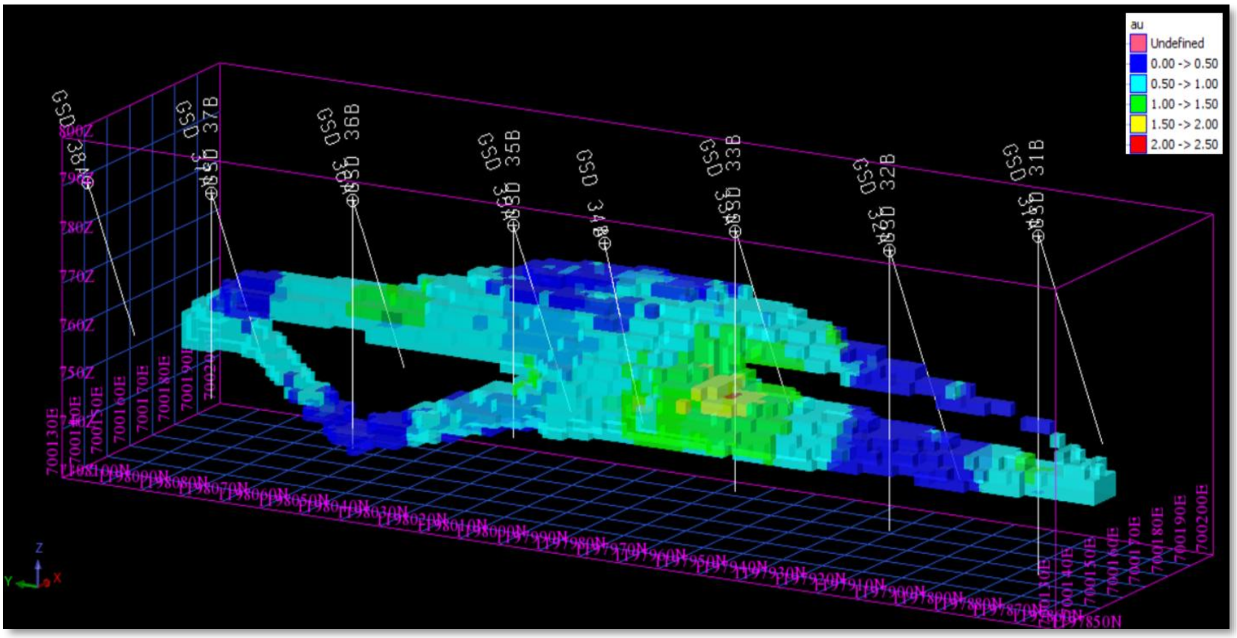

Fig. (9): 3D model of the Gosu North gold deposit with OK estimator.

IV. Conclusion

A three-dimensional orebody model of Gosu North area was constructed from cleaned borehole assay data, triangulated, and validated against topography using a digital terrain model. A corresponding block model was generated and confined within the defined mineralized shell.

Geostatistical analysis of the composited assay data revealed a positively skewed distribution, necessitating the application of a top-cut grade for normalization. Sem-variogram analysis successfully established the spatial continuity and anisotropy of the gold mineralization.

Ordinary Kriging was subsequently applied for resource estimation, utilizing the refined data and geological constraints. This process estimated a total resource of 139,642.5 tones at an average grade of 0.71 g/t Au. The resulting contained metal is approximately 99.1 kilograms of gold.

This model provides a robust foundation for initial resource evaluation and future grade modeling

Reference:

[1]. **Abdel Raman**, A. A. (2000): Lithochemical investigation of Proterozoic rocks in the Kadalo area, eastern Blue Nile state, Southeastern Sudan. MSc thesis. Un. Of Juba. Pp 1-92.

[2]. **Abdel Raman**, E.M. (1983): The geology of the mafic-ultramafic masses and adjacent rocks south of the Ingessana Igneous complex, Blue Nile Province, E. Sudan. Unpubl. M.Phil. thesis, Portsmouth Polytechnic, England. Pp 1-222.

[3]. **Abdel Magid**, A. M. (1983): The Geology of the metamorphic Terrain South-West of the Ingessana Mafic-Ultramafic Complex, E. Sudan. MSc. Thesis. Portsmouth Poltechnic. Pp 1-203.

[4]. **Adeli**, A., Emery, X., Dowd, P. (2017): Geological Modelling and Validation of Geological Interpretations via Simulation and Classification of Quantitative Covariates. Minerals 2018, 8, 7, pp 1-18.

[5]. **Azmi**, H., Moarefvand, P., Maghsoudi, A (2020): Resource estimation of the Damanghor gold deposit (Brdaskan, Northeast Iran) based on geological and grade continuity. Geopersia 10(2), pp 381-394.

[6]. **Chanderman**, L., Dohm, C.E., Minnitt, R. C. A. (2017):3D geological modelling and resource estimation for a gold deposit in Mali. The Southern African Institute of Mining and Metallurgy 117(2): pp 189-197.

[7]. **Chen**, Q., Liu, G., Ma, X., Zhang, J. (2021): Three-Dimensional Geologic Modeling. Encyclopedia of Earth Sciences Series (EESS). Springer, Cham. pp 1-6

[8]. **Lelliot**t, M.R., Cave; M.R., Wealthall, G.P. (2009): A structured approach to the measurement of uncertainty in 3D geological models. Quarterly Journal of Engineering Geology and Hydrogeology. 42(1): pp 95-105.

[9]. **Roy**, I and Sarkar, B. (2014): Orebody Modelling: An Integrated Geological Geostatistical Approach. ResearchGate. https://www.researchgate.net/publication/215718731

[10]. **Snowden**, V. (2009): Resource Estimation. Snowden Publishers. pp 1-185

[11]. **Pan**, M., Li, Z., Gao, Z., Yang, Y., Wu, G. (2012): 3-D geological modeling-concept, methods and key techniques. Acta Geol. Sin. (Engl. Ed.). V (86)4. pp 1031-1036.

[12]. **Toum**, I.M. (1985): The geology of the Qeissan Area, Blue Nile Province, S.E. Sudan. M.Phil.thesis, Portsmouth Polytechnic,England. Pp 1-198.

[13]. **Wellmann**, F., Schaaf, A., Varga, M., Hagke, C. (2019): Problems and Solutions in Structural Geology and Tectonics. Developments in Structural Geology and Tectonics. V (5). pp 189-204.

[14]. Vail, J. R., Hughes, D. J., Abdel Magid, A. E. M., Abdel Rahman, E. M., Toum, (1986): Geology of southern Blue Nile Province, Sudan. Bull.No.37. GRAS. pp 1-38