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Research Paper

Identifying the Promising Areas of Zailik Gold Mineralization in the Northwest of Iran Using Fuzzy Overlay of Information Method

Mohammadzadeh M.J.[1*], Rajaei M.M.[2]

1- Associate Professor, Faculty of Mining Engineering, Sahand University of Technology, Tabriz, Iran
2- Ph.D student, Faculty of Mining Engineering, Sahand University of Technology, Tabriz, Iran

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Abstract: This research aims to simultaneously use geochemical modeling and geological parameters for gold grade estimation to identify promising zones of epithermal gold mineralization in the Zailik region, northwest of Iran. For this purpose, the employed geological evidence includes lithology and alterations like silicification, iron oxides, phyllic, and propylitic. For geochemical modeling two methods were utulized: 1) artificial neural network (ANN), 2) integrating ANN with the Firefly algorithm. Geological evidence after quantification, along with the estimated amounts of gold in artificial intelligence methods, was entered into the hierarchical system in Expert Choice software for weighting. In this method, the weighting and determination of the degree of relative importance of geological parameters were attempted after consulting geological and exploration experts. Subsequently, artificial intelligence methods were also compared with each other using quantitative criteria such as the coefficient of determination and the root mean square error function. The results showed that the combined method of artificial neural networks with the Firefly algorithm provides better results due to the higher coefficient of determination (R2=0.643) and lower error function (RMSE=0.754). Therefore, it has a higher degree of importance to identify promising areas for mineralization. Finally, all the above parameters were combined with each other in the Arc GIS software using the fuzzy overlay method, and the optimal exploration targets were detected in the north and northeast of the region, enabling to continue the exploration targets along the root of gold mineralization in the neighboring areas according to the introduced model.

Keywords: Artificial neural network, Firefly algorithm, AHP, Fuzzy overlay, Zailik gold.

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*Corresponding Author Email: *mohammadzadeh@sut.ac.ir*

INTRODUCTION

The set of processes, including the investigation of exploration data, the extraction of mineralization predictive witness patterns, and finally the combination and integration of these evidences, in order to identify promising mineralization areas, is called mineral resource modeling. In new methods, it will not be possible to achieve optimal modeling without the simultaneous use of geological sciences, mathematics (statistics and probabilities), and computer engineering (artificial intelligence). Today, with the advancement of technology and the use of computer programs developed in the past and in the form of artificial intelligence methods (machine learning algorithms and meta-heuristic optimization algorithms), modeling of mineral resources is done with minimal errors. Among the most important machine learning algorithms is the artificial neural network method [1]. The common feature of meta-innovative optimization algorithms is to draw inspiration from biological systems to solve optimization problems, and today these methods are very attractive for mining exploration engineering [2]. One of the most important of these algorithms is the firefly algorithm, which is applied to solve optimization problems and is able to discover better solutions than other algorithms in solving the most difficult optimization problems [3]. In this research, the combination of artificial neural network method (machine learning algorithm) and Firefly algorithm method (meta-heuristic optimization algorithm) was used [4]. The main purpose of this research is to generate a robust two-dimensional surface modeling using the above integrated techniques and the fuzzy overlay method, in order to identify promising zones for gold mineralization and to detect reliable surface anomalies in the Zailik region in the northwest of Iran. Notably, this type of modeling is being used in the early stages of exploration as one of the tools for determining the location of drilling boreholes. For this purpose, two types of data were used, one data-base and the other knowledge-base data. In the data-base method, first, all known quantitative indices and the relationships between these indices are compared with geological evidence and patterns; Then, points that are similar to these indices, present in those areas, are searched. In this case, areas with similar characteristics are considered as promising and suitable areas for exploration targets. This type of modeling is strongly influenced by several factors such as the sufficiency of the input training data, the frequency of predictor variables, as well as the precise determination of the parameters involved in machine learning algorithms and meta-heuristic optimizer algorithms for model training. On the other hand, the experiences of carrying out exploration operations and investigations of the relationship between known mineral deposits and geological patterns are considered as the basis of the knowledge-base method in preparing mineral resource modeling. The general process of conducting this research is as follows:

1- Analyzing lithogeochemical data and performing necessary pre-processing on gold elements and related paragenes,
2- Predicting and estimating gold using ANN and ANN-FFA methods,
3- Comparing quantitative evaluation criteria such as coefficient of determination (R^2) and root mean square error (RMSE) function,
4- Quantifying geological evidence such as lithology and types of alteration such as argillic, propylitic, siliceous, and iron oxide,
5- Determining relative and comparative importance coefficients in artificial intelligence methods and geological parameters in Expert Choise software, and
6- Determining the promising areas of gold mineralization using the fuzzy overlay method in Arc GIS software.

METHODS

One of the most important artificial intelligence methods is the artificial neural network (ANN) method, which usually uses the multilayer perceptron (MLP) structure and its most important application is the prediction and estimation of functions. To improve the results obtained from ANN training, the accuracy of ANN can be increased by changing the initial initialization, repeating the training of the network, changing the number of neurons and changing the training, transfer and training functions. But one of the best solutions to obtain appropriate results is to optimize ANN parameters (weights and bias) using meta-heuristic algorithms such as Firefly alghorithm (FFA). FFA has many similarities to other swarm intelligence algorithms such as particle swarm optimization, bee colony, and ant colony; But, FFA is much simpler and more precise in both concept and implementation [5]. Also, in this research, the AHP, a subset of the MCDM [6], is used to weigh the evidence based on comparison and expert judgment. In general, this process is a theory based on relative measurement. In this type of measurement, the focus is not on the exact measurement of values, but the ratios between them are checked. This process, by quantifying the weight of the decision-making criteria, then making pairwise comparisons (pair by pair) between these criteria, ranks them and provides the possibility of making a correct decision with the presence of qualitative, quantitative or combined criteria. The implementation of this method is carried out in four phases: building a hierarchical tree, performing pairwise comparisons, calculating weights, and determining the compatibility rate of the system. There are various methods such as the Boolean method, the index superposition method, the statistical weight of evidence method, and the fuzzy logic method to combine information layers. In fuzzy systems, uncertain phenomena are better described by obtaining expert opinions and information from two important sources, one is from experts who describe their knowledge and information about the system in a descriptive manner, and the other is obtained from measurements and mathematical models. The important issue is the combination of these two types of information in the design of fuzzy systems. The main language of these systems is fuzzy type mathematics (instead of using classical mathematics). In this type of mathematics, in order to combine layers of information, various types of "fuzzy and" operators, "fuzzy or" operators, fuzzy algebraic product, fuzzy addition, and gamma operator are used [7]. In this paper, the fuzzy overlay method with the "and" operator was used to combine information layers, to determine promising areas, and to model Zailik mineralization.

DISCUSSION AND RESULTS

In order to determine the geochemical layers, modeling with ANN and ANN-FFA methods was used in which the input parameters to the modeling structure, the grade of Au paragenes (Ag, As, Mo, Sb, Pb), and the Au output parameter were defined. In ANN-FFA method, after initialization, FFA was used to optimize ANN weights and bias. According to Table 1,the comparison of error values, and coefficient of determination in the modeling, it was found that the ANN-FFA method has the highest coefficient of determination and the lowest error function compared to the ANN method, so it has the highest correlation with the real data and the modeling has higher accuracy. In order to create the final modeling of vein mineralization in the Zailik range, the fuzzy map of all geochemical and geological layers with the AND fuzzy operator (taking into account that several witnesses are needed simultaneously to prove the hypothesis) was combined with each other by the fuzzy overlay method in Arc GIS software, and the predictive map of the promising areas of mineralization was obtained in order to continue the exploration operations (proposal of drilling points) in the form of Figure 1.

Table 1. Comparison of correlation values and error functions

Model	Train data		Test data	
	R2	RMSE	R2	RMSE
ANN	0.572	0.782	0.533	0.835
ANN-FFA	0.602	0.763	0.643	0.754

CONCLUSIONS

In this paper, in order to identify promising areas for Au mineralization and to detect surface anomalies in Zailik region of northwest Iran, two-dimensional surface modeling was attempted using the fuzzy overlay method. This type of modeling was used as a tool to determine the location of earlier drilling boreholes. The data used were geological parameters such as lithology, argillic, propylitic, siliceous and iron oxide changes, as well as the results of geochemical modeling using ANN and ANN-FFA artificial intelligence methods. In order to validate geochemical modeling using artificial intelligence, by quantitatively comparing the accuracy evaluation criteria, it was shown that the ANN-FFA method had the highest coefficient of determination (R^2=0.643) and the lowest error function (RMSE=0.754) compared to the ANN method. Also, the location of the estimated values were in good agreement with each other and the lithology and alterations related to Au mineralization. The geological evidences used are lithology, argillic, propylitic, siliceous, and iron oxide alterations, which after converting these parameters into mathematical numbers, along with the estimated values in artificial intelligence methods, were entered into the hierarchical system in Expert Choise software for weighting. According to the expert judgments in the geological evidence, the lithological parameter was more important in the final decision to determine the promising mineralization areas. All the estimated values in artificial intelligence methods as well as geological parameters as witness layers were integrated using the fuzzy overlay method in ArcGIS software. As a result of the two-dimensional surface modeling, the Au promising zones were specifically determined and suggested as reliable points for exploratory drilling. In order to check the accuracy of the final modeling map, the results of 3 suggested boreholes based on this model were analysed. These exploratory boreholes were drilled in the proposed Au mineralization areas in the north and eastern parts of the S01 vein, which showed high Au grade values, indicating the prosperity of the introduced model by confirming the accuracy of the proposed gold mineralization areas.

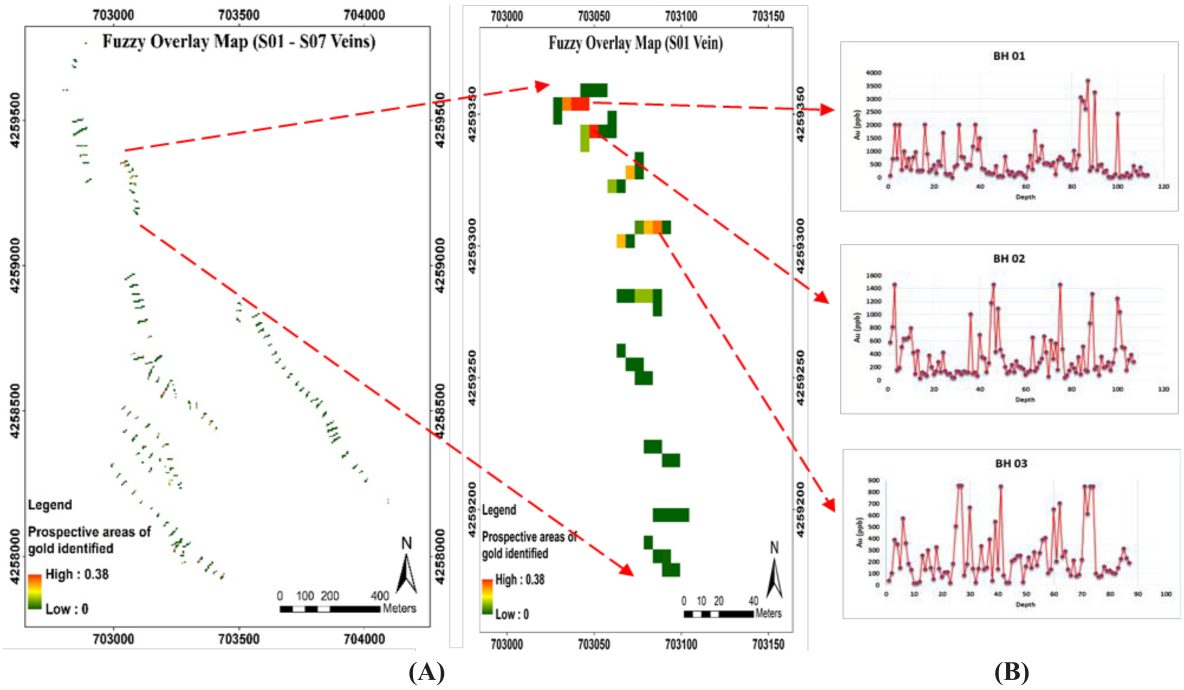

Figure 1. A: Combined map using the fuzzy overlay method for determining the final promising zones of S01-S07 veins, **B:** Drilling points

REFERENCES

[1] Mahmoudabadi, H., Izadi, M., and Menhaj, M. B. (2009). *"A hybrid method for grade estimation using genetic algorithm and neural networks".* Computational Geosciences, 13: 91-101.

[2] Soltani-Mohammadi, S., Hoseinian, F. S., Abbaszadeh, M., and Khodadadzadeh, M. (2022). *"Grade estimation using a hybrid method of back-propagation artificial neural network and particle swarm optimization with integrated samples coordinate and local variability"*. Computers & Geosciences, 159: 104981.

[3] Ghezelbash, R., Daviran, M., Maghsoudi, A., Ghaeminejad, H., and Niknezhad, M. (2023). *"Incorporating the genetic and firefly optimization algorithms into K-means clustering method for detection of porphyry and skarn Cu-related geochemical footprints in Baft district, Kerman, Iran"*. Applied Geochemistry, 148: 105538.

[4] Nayak, J., Naik, B., Pelusi, D., and Krishna, A. V. (2020) *"A Comprehensive Review and Performance Analysis of Firefly Algorithm for Artificial Neural Networks"*. In: Yang, X. S., He, X. S. (Eds.), Nature-Inspired Computation in Data Mining and Machine Learning. Studies in Computational Intelligence, Vol. 855, Springer, Cham, 137-159. DOI: https://doi.org/10.1007/978-3-030-28553-1_7.

[5] Yousefi, A., and Amirshahi, B. (2015). *"A hybrid meta-heuristic algorithm based on ABC and Firefly algorithms"*. Journal of Advances in Computer Engineering and Technology, 1(4): 53-58.

[6] Ghezelbash, R., and Maghsoudi, A. (2018) *“Comparison of U-spatial statistics and C–A fractal models for delineating anomaly patterns of porphyry-type Cu geochemical signatures in the Varzaghan district, NW Iran”*. Comptes Rendus Geoscience, 350(4): 180-191.

[7] Boadi, B., Sunder Raju, P. V., and Wemegah, D. D. (2022). *“Analysing multi-index overlay and fuzzy logic models for lode-gold prospectivity mapping in the Ahafo gold district – Southwestern Ghana”*. Ore Geology Reviews, 148: 105059.