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Mitigating uncertainties in mineral exploration targeting: Majority voting and confidence index approaches in the context of an exploration information system (EIS)

Mahyar Yousefi [a,*], Mark D. Lindsay [b,c,d], Oliver Kreuzer [e,f]

[a] Faculty of Engineering, Malayer University, Malayer, Iran
[b] CSIRO Mineral Resources, Kensington, WA 6151, Australia
[c] ARC Centre for Data Analytics for Resources and Environments (DARE), Perth and Sydney, Australia
[d] School of Earth Sciences, The University of Western Australia, Crawley, WA 6009, Australia
[e] Corporate Geoscience Group, PO Box 5128, Rockingham Beach, WA 6969, Australia
[f] Economic Geology Research Centre (EGRU), College of Science and Engineering, James Cook University, Townsville, QLD 4811, Australia

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ABSTRACT

Various mineral prospectivity modelling (MPM) approaches are available for targeting mineral deposits, each method capable of predicting areas of high prospectivity. Given the diversity of MPM approaches, the modelled areas of high prospectivity can differ across different MPMs. However, rather than a negative, different MPM outputs can benefit mineral exploration targeting because each method has its advantages. Rather, the problem lies in the lack of consensus over how to best select and delimit mineral exploration targets from different MPM results. Here we aim to address the challenges outlined above whilst quantifying and mitigating the effects of inherent uncertainties. We first generate eleven different prospectivity models utilising deep learning, machine learning, fuzzy logic, and geometric average integration methods. Then, we adopt a majority voting ensemble technique to incorporate and combine the predictions of each prospectivity model. Next, we propose a confidence index designed to mitigate uncertainty associated with our multi-technique approach to MPM. The confidence index quantifies variation in prospectivity values for each cell of the MPM target area. The conjunction of a confidence index and majority voting model facilitates consistent and robust algorithm-driven extraction of exploration targets based on an ensemble of prospectivity models.

1. Introduction

Over the past few decades, various mineral prospectivity modelling (MPM) methods have been developed, each capable of identifying areas that are highly prospective for a chosen mineral deposit type and, thus, aiding mineral exploration targeting (e.g., Yousefi et al., 2021). The diversity in weighting methods and integration approaches can result in a variety of MPM outputs that not only make the selection of exploration targets a more challenging task but also serve to propagate uncertainty into target selection (e.g., Burkin et al., 2019; Yousefi et al., 2021). To mitigate this issue, generating sound targeting models, validating them against the locations of the known targeted mineral deposits, and selecting targets from the 'best performing' model is common practice (e.g., Bonham-Carter, 1994; Kreuzer et al., 2020; Yousefi et al., 2021). Whilst the various approaches to MPM are being continuously improved (Nykänen, 2008; Nykänen et al., 2008; McCuaig et al., 2010; Hagemann et al., 2016a, 2016b; Yousefi et al., 2019, 2021; Yousefi and Hronsky, 2023; Yousefi et al., 2023a; Mostafaei et al., 2024), significant uncertainty remains concerning how to best select mineral exploration targets from the models generated. For instance, exploration data can be weighted using statistics, expert knowledge, user-defined functions, and logistic functions (e.g., Bonham-Carter, 1994; Pan and Harris, 2000; Harris et al., 2015; Yousefi et al., 2021). Weighted predictor maps can be integrated using a variety of methods such as statistical functions, fuzzy operators, supervised machine learning, supervised deep learning, unsupervised deep learning, and geometric average function (e.g., Bonham-Carter, 1994; Carranza, 2008; Yousefi and Carranza, 2015b; Zuo and Wang, 2020; Rahimi et al., 2021; Yousefi et al., 2021, 2023a, b; Bahri et al., 2023; Ghasemzadeh et al., 2023). However, choosing the most appropriate method(s) remains challenging. The holistic nature of

* Corresponding author at: Malayer University, Malayer, Postal Code: 65719-95863, Iran.
E-mail address: M.Yousefi.Eng@gmail.com (M. Yousefi).

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