Machine learning-based normalization of Thorium in airborne gamma-ray spectrometry for improved anomaly detection

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ABSTRACT

Airborne gamma-ray spectrometry (AGRS) is a widely used geophysical method for geological mapping and mineral exploration, through the measurement of potassium (K), uranium (eU), and thorium (eTh) in rocks and weathered materials (Dickson & Scott, 1997; Minty, 1997). However, radioelement anomaly detection is often hindered by environmental factors such as soil moisture, precipitation, and radiation attenuation (IAEA, 2003). Traditional processing techniques, such as ratio-based normalization, provide partial corrections but may not fully capture geochemical variability. In this study, we introduce a machine learning (ML)-based approach to normalize thorium concentrations using a Random Forest regression model. By treating thorium as a geochemically stable reference element, we implement feature transformations, as thorium (eTh), squared thorium (eTh^2) and thorium ratios (eTh^2/eU, eTh/(eU + eTh)) (Fig. 1) to enhance prediction accuracy and improve anomaly detection.

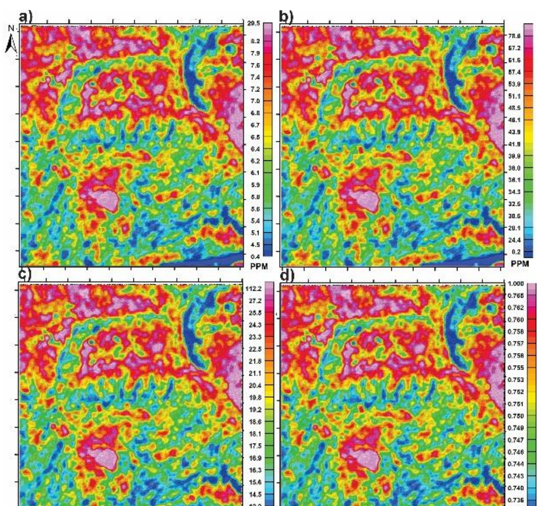

Figure 1: AGRS maps used as input to perform the thorium normalization. a) eTh b) eTh^2, c) eTh^2/eU, and d) eTh/(eU+eTh).

The methodology for thorium normalization follows a machine learning-based approach inspired by Saunders et al. (1993) and utilizes Random Forest regression to refine the estimation of ideal thorium values. First, AGRS data are processed to ensure all grids share the same resolution and coordinate system. The dataset includes thorium (eTh) and derived variables, as shown in Figure 1, which serve as input features for training the Random Forest model. The model predicts ideal thorium values (eThi), replacing the traditional mean-based normalization approach with a data-driven estimation. Thorium normalization is then computed as eTh_normalized = (eTh - eThi)/eTh enabling a refined detection of thorium anomalies. A logarithmic transformation is applied to enhance data interpretability and mitigate the effects of extreme values. The methodology integrates GIS-based interpolation techniques to generate classified thorium maps, categorizing thorium concentrations into distinct ranges based on statistical thresholds or geological significance. This approach enhances anomaly detection and geospatial analysis, producing higher-resolution maps with more detailed geochemical features, as illustrated in Figure 2.

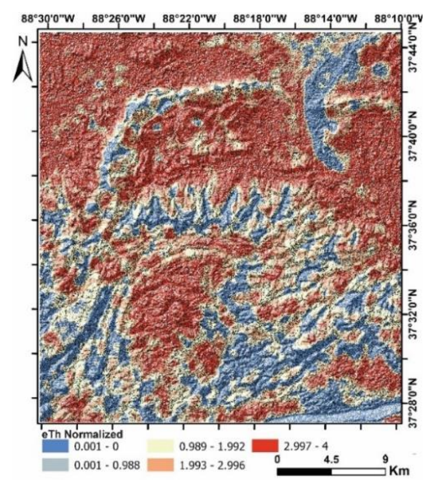

Figure 2: Normalized Thorium map.

The thorium normalization distribution (in Figure 2) represents the spatial variability more clearly and coherently after implementing ML normalization, facilitating the identification of geochemically significant anomalies for subsequent interpretation. This study highlights the potential of machine learning for optimizing AGRS data analysis and enhancing geophysical exploration.

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