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# A comparison of fractal methods and probability plots in identifying and mapping soil metal contamination near an active mining area, Iran

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## HIGHLIGHTS

- As, Pb and Zn are studied along major elements in soil samples near Pb–Zn mine site
- Probability plot and two fractal methods are used to determine thresholds
- Fractal methods provide more distinct separation between populations
- Samples affected from geogenic/anthropogenic processes are delineated graphically

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## ABSTRACT

Mining activities may contribute significant amounts of metals to surrounding soils. Assessing the potential effects and extent of metal contamination requires the differentiation between geogenic and additional anthropogenic sources. This study compares the use of conventional probability plots with two forms of fractal analysis (number–size and concentration–area) to separate geochemical populations of ore-related elements in agricultural area soils adjacent to Pb–Zn mining operations in the Irankuh Mountains, central Iran. The two general approaches deliver similar spatial groupings of univariate geochemical populations, but the fractal methods provide more distinct separation between populations and require less data manipulation and modeling than the probability plots. The concentration–area fractal approach was more effective than the number–size fractal and probability plotting methods at separating sub-populations within the samples affected by contamination from the mining operations. There is a general lack of association between major elements and ore-related metals in the soils. The background populations display higher relative variation in the major elements than the ore-related metals whereas near the mining operations there is far greater relative variation in the ore-related metals. The extent of the transport of contaminants away from the mine site is partly a function of the greater dispersion of Zn compared with Pb and As, however, the patterns indicate dispersion of contaminants from the mine site is via dust and not surface/groundwater. A combination of geochemical and graphical assessment, with different methods of threshold determination, is shown to be effective in separating geogenic and anthropogenic geochemical patterns.



## 1. Introduction

Approximately 250,000 km$^2$ of the Earth surface is directly affected by mining activities (Dollhopf, 2006). Indirect effects extend over much larger areas, generating a variety of negative impacts on public health and the environment (Meza-Figueroa et al., 2009). Much of this impact relates to the dispersion of metal contamination into soils, sediments, ground and surface waters, and subsequent uptake by biota. Relating effects of contamination on the environment commonly requires separation of background population(s) and patterns related to natural or geogenic processes from populations or outlying values relating to the effects of mineralisation or anthropogenic environmental contamination. This is particularly important in agricultural areas (Tlili-Zrelli et al., 2012).

Methods for separating geochemical populations may be broadly classified into non-structural and structural approaches. Non-structural statistical approaches emphasise the characteristics of frequency distributions or probabilities, based on various parametric and non-parametric methods applied to univariate or multivariate data (Kürzl, 1988; Sinclair, 1991; Hoaglin, 2001; Bounessah and Atkin, 2003; Filzmoser,

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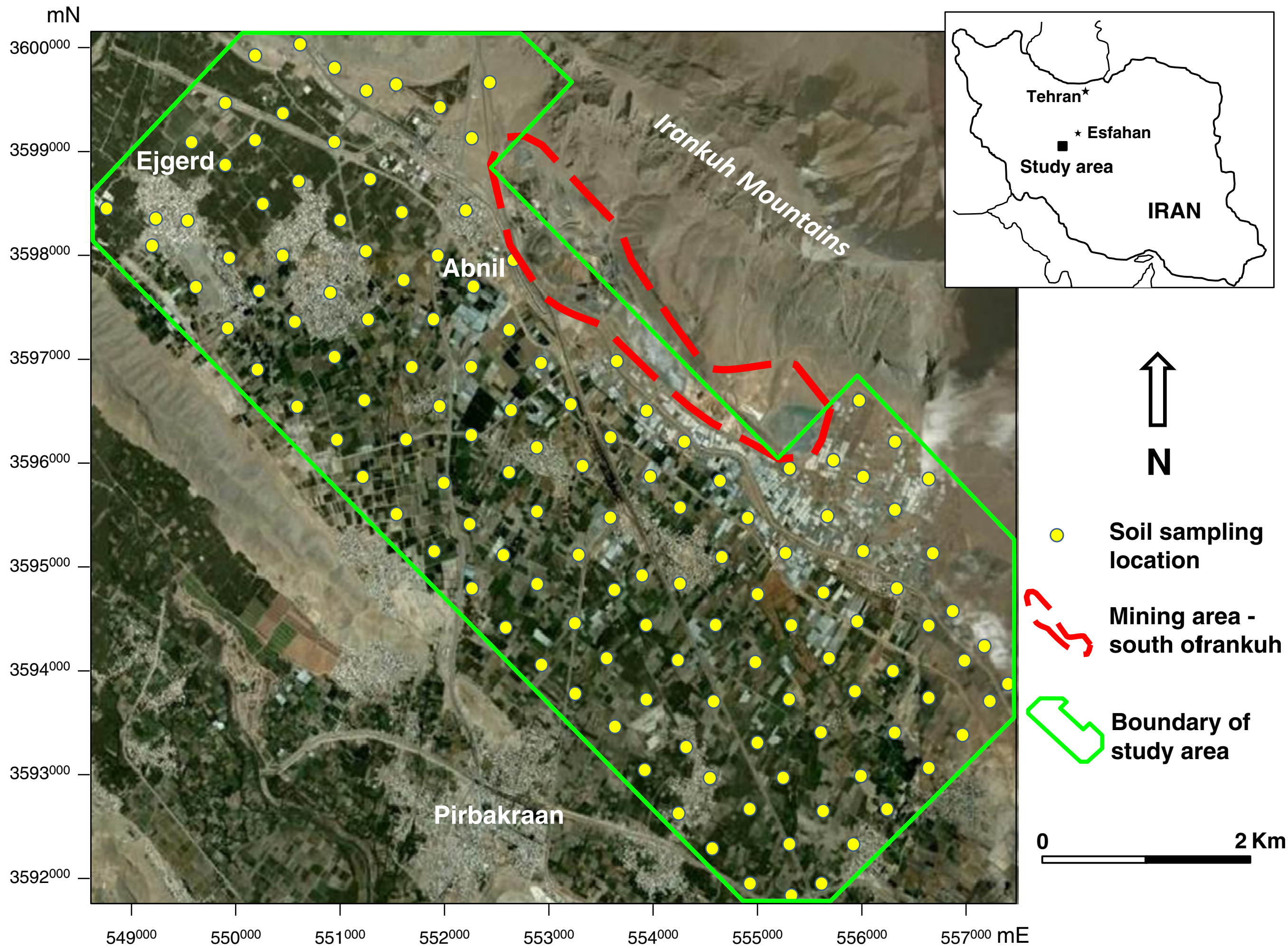


**Fig. 1.** Image of the study area (from Google Earth) with sampling locations.

2005; Zhang and O'Connor, 2005; Chipres et al., 2009). Probability and related plots (e.g. Q–Q) are commonly used to determine the nature of data distributions and identify different populations (Kafadar and Spiegelman, 1986; Clare and Cohen, 2001; Papastergios et al., 2011; Boylan and Cho, 2011) and offer a more objective approach than histogram analysis and related methods (Vermeesch, 2005). Hence, probability plots of various types have been widely used in geochemical studies in exploration and environmental contexts (Fleischhauer and Korbe, 1990; Tobías et al., 1997). Such methods, however, have a number of limitations including the capacity to separate overlapping populations of mixed or potentially non-parametric distribution types, relating to the effects of different processes operating at various spatial scales (Reimann et al., 2005, 2008; Cohen et al., 2010, 2012).

Structural methods involve frequency distributions and also spatial variability and correlation, and include various forms of spatial statistics and filtering. Within this there is increasing use of fractal methods (Salvadori et al., 1997; Lima et al., 2003; Albanese et al., 2007). There are a variety of fractal methods aimed at establishing power-law functions within geochemical data and allowing separation of statistical populations of data. These include number–size (Shen and Cohen, 2005; Deng et al., 2010), singularity indices (Sun et al., 2010), and those that incorporate spatial characteristics such as radial–density (Lattuada et al., 2004), concentration–distance (Li et al., 2003), concentration–area (Cheng et al., 1994), perimeter–area (Cheng, 1995), concentration–volume (Afzal et al., 2011), power spectrum–area fractal models (Zuo, 2011) and multifractal methods (Gonçalves, 2001).

In this paper we compare the use of probability plots and fractal analysis, along with bivariate element relationships, to separate geogenic and anthropogenic metal distribution patterns in soils from agricultural areas near Esfahan, Iran, adjacent to long-running base metal mining and processing operations.

## 2. Threshold determination

The application of probability plots has been well-documented by Stanley (1988), Sinclair (1991) and others. If, for a chosen statistical distribution type (e.g. normal, log-normal, $\chi^2$), cumulative data plot as a straight line, then the data can be assumed to conform to that

**Table 1**
Statistical parameters of As, Pb and Zn in soils of the study area (concentrations in mg/kg).

| Parameters | As | Pb | Zn |
|---|---|---|---|
| **N** | 137 | 137 | 137 |
| **Mean** | 10.1 | 46.5 | 233.5 |
| **Median** | 7.6 | 24.9 | 122.4 |
| **MAD*** | 2.1 | 8.2 | 35.6 |
| **Std. Deviation** | 7.5 | 56.6 | 314.3 |
| **Skewness** | 2.6 | 3.9 | 4.2 |
| **Kurtosis** | 7.9 | 18.3 | 21.9 |
| **Minimum** | 3.5 | 11.7 | 67.0 |
| **Maximum** | 47.1 | 392.0 | 2435 |

* Median Absolute Deviation.