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Geochemistry and spatial variability of metal(loid) concentrations in soils of the state of Minas Gerais, Brazil

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ABSTRACT

Since 2009 a policy has been implemented in Brazil to establish the natural concentrations of potentially toxic substances in soil for each state. Historically a 'mining state', Minas Gerais established a Quality Reference Value for metal(loid)s for all of the soils in the state. To successfully establish these values it is important to study the spatial geochemical diversity for the state. In this context, the objectives of this work are: (1) to evaluate the natural concentrations of metal(loid)s in pristine Minas Gerais soils and (2) to interpret the spatial variability in concentration of these elements. The 0–20 cm layer of soils was sampled for 697 georeferenced sites including the main geological materials and soil groups. Soil properties were analyzed according to methodologies suitable for Brazilian soils. The concentration of metal(loid)s was determined by acid extraction according to EPA 3051A. Descriptive statistics, Pearson correlation and spatial variability analyses were performed. The dominance of acidic pH and low CEC values reflects the pervasive deep acid weathering. The variability of metal(loid) concentrations for soils of the state may be attributed to geological diversity and different pedogenesis. Correlation and spatial analysis indicated that the Fe concentration is strongly associated with metal(loid) concentrations in topsoil. According to the spatial geochemical diversity of the state, a k-means cluster analysis was performed which identified four clusters. A significant difference in the mean values of metal(loid) concentrations between the clusters confirmed that the single Quality Reference Value established does not represent the geochemical diversity of soils in Minas Gerais.

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1. Introduction

Historically Minas Gerais has been known as the most mineral rich state in Brazil. Reserves of precious stones and gold discovered in the 17th century made this region the economic center of the Portuguese province. Currently, large reserves of Al, Au, $CaCO_3$, Fe, Cr, Cu, Mn, Nb, Ni, Pb, P, Sn and Zn have been identified. Minas Gerais is one of the largest producers of metal and non-metal minerals in Brazil (Dardenne and Schobbenhaus, 2001).

Minas Gerais hosts all thirteen soil groups of the Brazilian Soil Classification System and twelve of the FAO Soil Classification System. The geological materials are also highly diverse. In the northern part of the State, Proterozoic and Paleogene sedimentary rocks partially cover igneous rocks. Proterozoic metamorphic rocks with common plutons occur in the east and south. In the west, Mesozoic pyroclastic rocks and sedimentary rocks interbanded with mafic igneous rocks occur, conferring a high degree of geological diversity to the state (Moreira and Camelier, 1977; COMIG, 2003).

The Quality Reference Values (QRVs) for metal(loid)s in Minas Gerais soils were established in 2011 (COPAM, 2011). The QRV represents the natural concentration of potentially toxic elements in the soils of the state. These values were obtained by EPA 3051A acid digestion (USEPA, 2007) of topsoil samples for the main rocks of the state. In spite of the geological variability, just one QRV was allocated for As (8 mg kg^{-1}), B (11.5), Ba (93), Cd (0.4), Co (6), Cr (75), Cu (49), Hg (0.05), Mo (0.9), Ni (21.5), Pb (19.5), V (129), and Zn (46.5) for the entire state. A single QRV is of little value and studies of pedogeochemical variance are necessary in Minas Gerais to quantify natural variations in metal(loid) concentrations and improve the monitoring of soil contamination in the state, considering its large area, mining, industrial activities and geo-pedological diversity.

The objective of this study was to assess the concentration and spatial distribution patterns of Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sr, V and Zn in non-contaminated soils of Minas Gerais.

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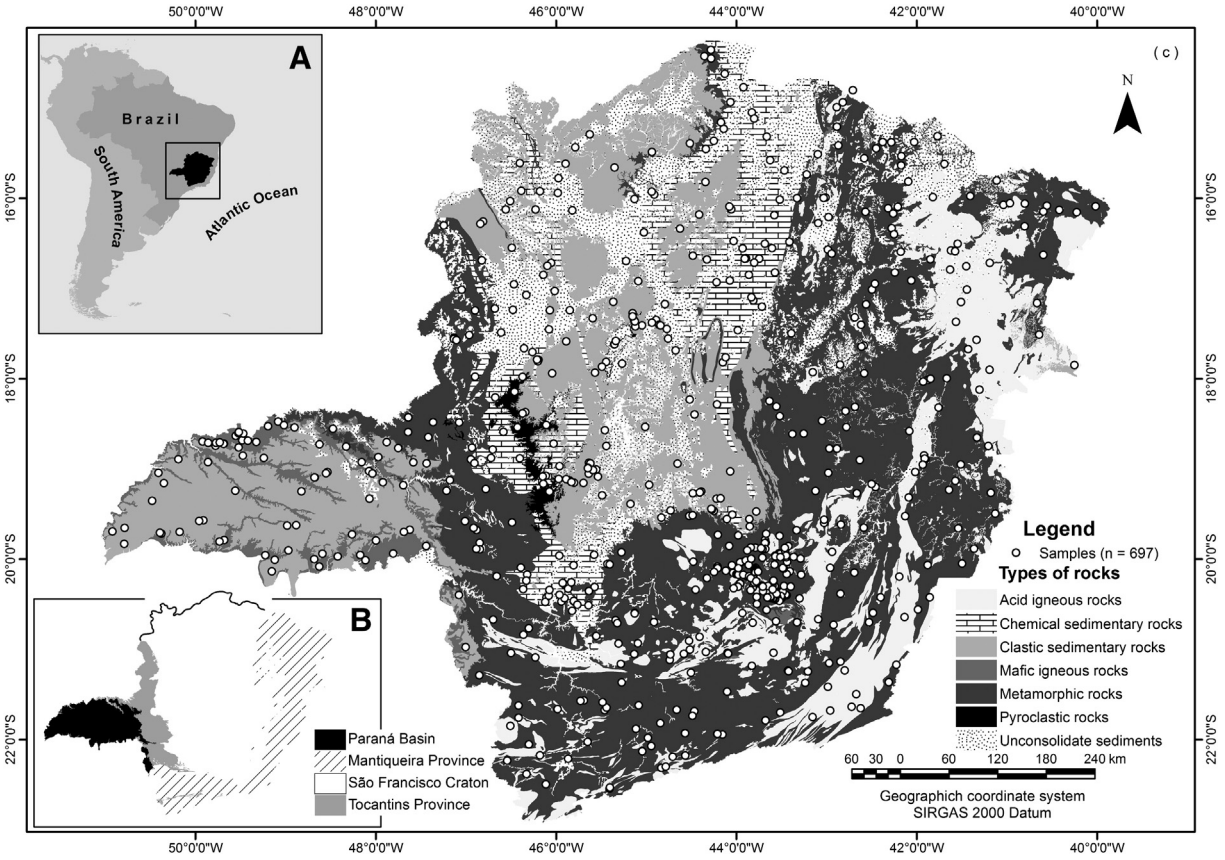

Fig. 1. (a) Location of Minas Gerais state, (b) geological provinces of Minas Gerais, (c) samples collected in study area according to type of rocks.

2. Study area

Minas Gerais in southeast Brazil has a total area of approximately 589,000 km^2 and particular landscape diversity. Altitudes vary between 250 m, in the São Francisco valley, and 1500 m, in highlands associated with resistant rocks and horst–graben systems. Minas Gerais can be divided into three climatic regions: i) areas at lower altitudes (in the São Francisco valley), with an average temperature of 23 °C and precipitation below 1200 mm per year; ii) areas at higher altitudes (on and around the highlands), with an average temperature of 20 °C and precipitation above 1800 mm per year; and iii) the rest of state, with a transitional climate between the other two (Nunes and Vicente, 2009).

Table 1
Soil occurrence in the study area.

Soil group[a]	Area (%)[b]	Parent material[c]
'Yellow' Haplic Acrisols Clayic (ha AC ce 'a')	<0.01	Neoproterozoic metapelites
'Red' Haplic Acrisol Clayic (ha AC ce 'b')	3.96	Neoproterozoic gneiss, granitoid, marble and biotite-schist
'Red-Yellow' Haplic Acrisol Clayic (ha AC ce 'c')	7.62	Archean gneiss, granite and metapelites, Paleoproterozoic gneiss and Cretaceous sandstone
Haplic Arenosol Dystric (ha AR dy)	2.77	Neoproterozoic and Cretaceous sandstones
Fluvic Cambisol (fv CM)	0.06	Holocenic alluvial beds
Haplic Cambisol (ha CM)	17.09	Neoproterozoic BIF, quartzite, schist, arcosian sandstone, siltstone, claystone, granitoid, Paleoproterozoic granite
Haplic Cambisol Humic (ha CM hu)	0.37	Neoproterozoic migmatite, granite, granitoid and quartzite, Cretaceous alkaline rocks
'Yellow' Haplic Ferrasol Clayic (ha FR ce 'a')	1.44	Paleoproterozoic gneiss and granite, Paleogene sediments, Cretaceous alkaline rocks
'Red' Haplic Ferrasol Clayic (ha FR ce 'b')	29.05	Cretaceous sandstone, mafic, pyroclastic and alkaline rocks, Neoproterozoic limestone and Paleoproterozoic BIF
'Red-Yellow' Haplic Ferrasol Clayic (ha FR ce 'c')	22.93	Paleoproterozoic gneiss and granite, paleogene sediments, Cretaceous alkaline rocks
Haplic Fluvisol (ha FL)	1.83	Holocenic alluvial beds
Haplic Gleysol Dystric (ha GL dy)	0.1	Holocenic alluvial beds
Haplic Gleysol Humic (ha GL hu)	0.28	Holocenic alluvial beds and Cretaceous mafic rocks and sandstones
Haplic Chernozem Clayic (ha CH ce)	<0.01	Neoproterozoic limestone
Voronic Chernozem (vo CH)	<0.01	Neoproterozoic limestone
Haplic Leptosol (ha LP)	9.19	Neoproterozoic claystones, siltstones, BIF, quartzite and schist and Mesoproterozoic phyllite, metasandstone
Haplic Luvisol Chromic (ha LV cr)	0.05	Archean gneiss, Neoproterozoic gneiss and marble
Haplic Nitisol Clayic (ha NT ce 'a')	0.49	Neoproterozoic limestone
'Red' Haplic Nitisol Clayic (ha NT ce 'b')	0.35	Archean gneiss and Neoproterozoic granitoid
Haplic Planosol Dystric (ha PL dy)	0.01	Neoproterozoic limestone
Petric Plinthosol Dystric (pt PT dy)	0.1	Mesoproterozoic and Neoproterozoic schist
Haplic Regosol (ha RG)	<0.01	Archean quartzite, Paleoproterozoic BIF and schist
Rock outcrop	2.31	-

[a] FAO (2006).
[b] UFV et al. (2010).
[c] COMIG (2003).

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