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Exposure of aluminum in the Araçuaí-Itinga Lithium Pegmatite District, Minas Gerais, Brazil: Contamination and toxicological effects on populations established nearby mining activities

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Abstract

This study aims to assess the geological, geochemical, and toxicological aspects of aluminum in the Araçuaí-Itinga lithium district, located in the Jequitinhonha River basin, Minas Gerais, with an emphasis on potential health risks for various population groups. Geological investigation revealed a predominance of aluminum-rich granites and metasediments, which serve as source and hosts for lithium--mineralized pegmatites. The study found that lithium levels pose no risk to human health, with maximum concentrations of the order of approximately 0.015 mg/L in water, 78 mg/kg in soil, and 33.7 mg/kg in stream sediments. However, elevated aluminum levels, where found in over 80% of the studied area, with concentrations exceeding the recommended maximum of 0.1 mg/L. Water samples exhibited aluminum levels ranging from 0.200 and 0.928 mg/L, while concentrations reached 3.1% in soil, and 0.96% in stream sediments. These values highlight the need for for further investigations into potential environmental and human health impacts. Additionally, aluminum concentrations of 1,059 mg/kg were detected in 12 vegetable samples. Plasma analyses of individuals living in the Igrejinha and Fazenda Velha communities revealed aluminum values above the normal limit of 3 µg/L in 68% of the examined individuals, and in 94% of dialysis patients, indicating significant health risks for those undergoing dialysis. The primary route of aluminum for the sampled individuals was water, facilitated by itstransition from rock-to soil-to water-to food. It is estimated that approximately 3,200 people near tributaries of the Jequitinhonha River, particularly in the Valley of Córrego do Piauí, are at risk of aluminum exposure. These findings underscore the urgent need for further research and interventions to mitigate the health risks associated with aluminum exposure in these communities.

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1. Introduction

The integration of medical geology into the analysis of mining operations provides a crucial framework for understanding the complex environmental and health impacts associated with these activities, as extensively documented in academic literature (Licht 2001; Selinus et al. 2005; Singh 2004, Skinner and Berger 2003, Cortecci 2002, Finkelman et al. 2007, Dissanayake and Chandrajith 2009, Selinus et al. 2010). This interdisciplinary field bridges the gap between geoscience and public health, offering a robust foundation for the scientific investigation of how geological materials may adversely affect human health.

Instances of human contamination from both natural and anthropogenic sources are well-documented across different countries, including Argentina, Bangladesh, and Chile (arsenic), China (selenium), and the United States (iodine) (Selinus 2006). in South America, the work of Figueiredo et al.

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(2010) investigates the presence of As, F, Hg, Pb, Se, U-Th, underscoring the global relevance of medical geology.

Research in Brazil has highlighted the environmental impact and health risks associated with mining operations, particularly in regions that already exhibit high concentrations of elements harmful to human health. Investigations have ranged from Santo Amaro da Purificação in Bahia (Carvalho et al. 1984), andthe Iron Quadrangle of Minas Gerais (Matschullat et al. 2000), to the Ribeira Valley, spanning São Paulo and Paraná, and extending to Itambaracá and São Francisco (Paoliello, 2002; Cunha 2003; Figueiredo 2005). Collectively, these studies underscore the critical issue of pollution caused by hazardous elements.

The environmental contamination and health impacts resulting from mining activities are well documented in the literature (Licht 2001, Selinus et al. (2005), Skinner and Berger 2003, Cortecci 2002, Finkelman et al. 2007, Dissanayake and Chandrajith 2009, Selinus et al. 2010). Adopting a medical geology perspective provides deeper insights into both the direct and indirect effects of mining on human health. Furthermore, this approach facilitates the development of comprehensive strategies for environmental monitoring and public health, with the primary goal of mitigating the adverse impacts of mining activities. Through rigorous scientific research and interdisciplinary collaboration, it is possible to promote responsible mining practices that prioritize both human health and environmental integrity.

In the context of Brazil's vast territory and rich diversity of mineral resources, conducting studies to protect communities from the adverse impacts of mining is of paramount importance. Special focus is given to the Araçuaí-Itinga region in the Jequitinhonha basin, Minas Gerais, where significant geochemical anomalies of lithium (Li) and aluminum (Al) in pegmatites define the geochemical landscape, and where decades of intense mining activity, including both open-pit and underground operations, have been documented. This study is recognized as a crucial element of the Context Analysis phase of mining projects, as outlined in the methodology of Social Impact Assessment in Mining (Esteves; Franks; Vanclay, 2012, cited by Demajorovic 2024, p. 48). Consequently, this research aims to conduct a detailed investigation of the geological environment, selected chemical its mineral deposits and potential contaminants, to establish a baseline of the natural concentrations of selected chemical elements and assess their potential toxicological effects on populations living in areas affected by mining activities.

2. Location, Characterization of the Area: Physiographic, Geological and Socio-Economic

2.1. Physiographic aspects

This study, conducted between2008-2011, in a 600 km² area within the mid-lower basin of the Piauí Stream, encompasses parts of the municipalities of Araçuaí and Itinga in Minas Gerais, Brazil, a region known for its geographical and demographic diversity. Araçuaí has a population of 36,478, with 43% living in rural areas, while Itinga has 13,981 inhabitants, 59% of whom live in the countryside. The region experiences a semi-arid climate, characterized by severe droughts in winter and rainfall in summer, resulting in a water deficit for eight months a year. The average temperatures stays around 24.4º C, ranging from 19.3º C to 31.1º C.

Water supply is a challenge in the Taquaral region of Itinga, where only this community has access to treated water; with the remaining areas rely on tributaries of the Jequitinhonha. The region features a diverse range of soils, including Acrisols derived from granite and metasedimentary rocks, as well as Cambisols, Planosols, and Neosols associated with alluvial deposits. Additionally, Latosols are formed from detritus-lateritic layers.

The examined area has a topography resembling an amphitheater, flanked by elevations ranging from 300 to 850 meters. It is drained the Piauí Stream, whitch cuts through areas with metasedimentary rocks and pegmatites. The landscape is predominantly flat, gradually rising toward the edges of the plateaus. The steep slopes contribute to erosion and sediment deposition along the margins of the watercourse. These topographical characteristics highlight the need for effective water resource management and soil conservation measures.

2.2. Geological aspects and mineral resources

The local geology is shaped by the Araçuaí Orogeny, as described by Almeida et al. (1977), Pedrosa-Soares and Wiedemann-Leonardos (2000), and Pedrosa-Soares et al. (2001) and marked by the presence of Neoproterozoic metasediments and formations belonging to the Macaúbas Group and the Salinas Formation, as outlined by Paes et al. (2009). The area is distinguished by intrusions of granitoids, both syn- and post-tectonic. Additionally, the region is locally covered by layers of Tertiary sandstones, Tertiary-Quaternary detritus-lateritic deposits, and recent alluvial sediments as illustrated in Figure 01. This stratigraphic configuration underscores the complex interplay of geological processes, including sedimentation, igneous intrusions tectonism, that have shaped the region throughout the geological time.

According to Paes et al. (2009) the lithological components associated with the Macaúbas Group, located in Northern and Southern portions of the study area, consists of quartz-mica schist and gray gneisses with fine to medium grain size. These rocks exhibit thin banding highlighted by K-feldspar, sillimanite, plagioclase, and muscovite. They also contain accessory minerals such as andalusite, black tourmaline, and cordierite, indicating metamorphism within the amphibolite facies, with localized evolution into migmatites. Additionally, layers of calc-silicate rocks and quartzites are notable. U-Pb dating of detrital zircon indicates an age of 950 Ma, interpreted as the sedimentation age during continental rifting, as detailed by Pedrosa-Soares et al. (2001).

As described by Paes et al. (2009), the Salinas Formation in the study area consists of fine-grained quartz-biotite schist containing andalusite, muscovite, tourmaline, and predominantly cordierite. The deposition of the Salinas Formation is estimated to have occurred approximately 800 million years ago, during a stage of passive continental margin evolution, as indicated by Pedrosa Soares et al. (2001).

According to Pedrosa-Soares et al. (2001, 2009), the formation of granitic rocks in the magmatic arc of the Araçuaí Orogeny is estimated to have occurred between 630 and 490 Ma, comprising five granitoid supersuites. In the study area, the intrusives bodies are represented by the G4 Supersuite, which includes biotite granites associated with pegmatites mineralization containing tourmaline, spodumene, and S-type petalite. These granites are peraluminous, with ages dated at

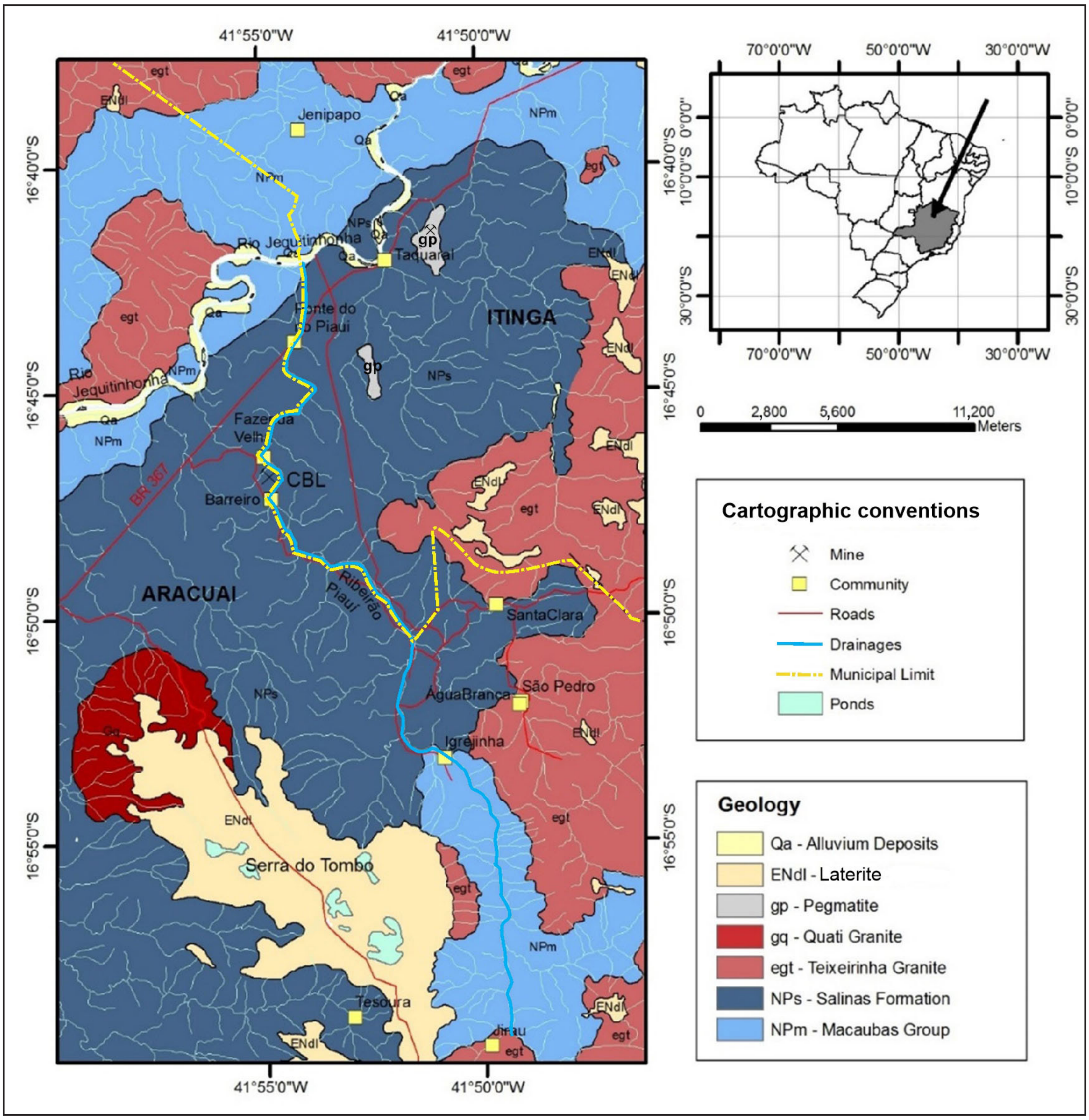

FIGURE 1. Location and Geological Map of the Araçuaí-Itinga region (Simplified from Paes et al. 2009).

approximately 535 ± 8 Ma (Pb-Pb method) and are classified post-collisionalTwo notable intrusives from this suite are identified in the study area are the Teixeirinha and Quati Granites.

In the eastern part of the study area, the Teixeirinha Granite, which is actually a monzogranite (dated at 523 ± 19 Ma, U/Pb on zircon), is characterized by its light color and medium grain size. Its is primarily composed of quartz, potassium feldspar, and biotite, with tourmaline and garnet as accessory minerals. While typically isotropic, it may exhibit fine foliation at its margins (Paes et al. 2009) and frequently is frequently intersected by pegmatite veins.

In the southwest part of the study area, the Quati Granite, described by Paes et al. (2009) is present. This granite is light gray with a a porphyritic texture, characterized by large K-feldspar crystals in a medium-grained matrix of quartz, feldspar, and biotite. A weak foliation is seen at its margins, indicating some degree of mineral alignment.

In the north-central part of the study area, two large pegmatite bodies, known as the Corrego Taquaral pegmatitesare present. They measure approximately 2 2.5 km by 0.7 km with the southern body being smaller, and extend in a north-south direction. These pegmatites are primarily composed of feldspar (including microcline and albite), spodumene, quartz, and muscovite. Onyx and black tourmaline (afrizite) are frequently found, while biotite is rare.

To the west of the Piauí River lies the Cretacic flat plateau that forms the Serra do Tombo, formed by partially laterized sandy-clayey latosols (Paes et al. 2009). This plateau appears to belocated at the margins of granite intrusions, and in its slopes, there are talus breccias and felsic pyroclastic materials, including tuffs and lapilli-tuffs.

The Araçuaí-Itinga lithium-tin district is particularly notable for its zoned pegmatites, which intrude schists of the Salinas Formation. The pegmatites are associated with post-collisional S-type granites, characterized by a distinct potassic and alkaline geochemical signature. As documented by Bizzi et al. (2003), these granites formed during the final stages of an episode of crustal melting, marking the closure of the Braziliano Cycle, approximately 555 million years ago.

Among the various pegmatites identified in the study area, the Tomazini quarry stands out as a significant site, where pegmatite is mined for use as dimension stones. Blocks measuring 4,5, and 8 m³ are transported to the port of Vitória - Espírito Santo, from where they are exported to Europe. The pegmatite at this site has a thickness of 4 meters and is exposed over a length of 60 meters. Structurally, it is aligned with the foliation of the host biotite-quartz schist, of the Salinas Complex, oriented to N20°W, and with a dip of 22° to the NE.

A notable feature of the study area is the presence of the Cachoeira lithium mine, operated by Companhia Brasileira de Lítio (CBL) In 2008, the mine operated employed 300 workers and produced 6,000 tons of pegmatite ore containing 22% spodumene, with 1.2% Li2O. A flotation process is used locally to concentrate the ore. In nearby Divisa Alegre, a chemical plant processes the concentrate, and the extracted lithium is sold for use in batteries, ceramics, glass, pharmacy and lubricants.

The orebody, designated 1C1, has been exposed by underground workings down to a depth of 100 meters below the surface. It is generally conformable but occasionally discordant with the surrounding schistose foliation, lodging in a NE cleavage fracture system with sub-horizontal to sub-vertical dip angles (Romeiro, 1998; Romeiro and Pedrosa-Soares, 2005). The pegmatite is tabular and discontinuous, primarily composed of K-feldspar, quartz, spodumene, and muscovite. The spodumene exhibits a greenish hue, is coarse-grained, and sometimes reaches metric dimensions.

A recent assessment by Paes et al. (2009) describes the region as facing significant challenges, including low social indicators and living conditions comparable to those observed in the hinterland of the northeastern Brazil. However, the area is also recognized for its natural beauty and cultural richness, including remnants of indigenous and Afro-Brazilian heritage. Agriculture and cattle farming remain essential economic activities for many municipalities, supplemented by artisanal (Figure 2) pottery as either a primary source of income or a supplemental income during extended droughts or between agricultural harvests. Currently, mining contributes to the local economy through the extraction of graphite, lithium, and granite dimension stones. Additionally, the extraction of clay for red ceramic production, plays a role in the local economy, serving both as a material for basic construction and as a medium for traditional handicrafts.

3. Materials and methods

In August 2005, the Geological Survey of Brazil (SGB-CPRM) conducted a comprehensive sampling and analysis in the study area. This effort resulted in the collection of 35 stream sediment samples, 30 soil samples, 13 drainage water samples, and 14 drinking water samples, with the findings later incorporated into this study's database by Lopes et al. (2006).

Building on of previous SGB-CPRM studies, this research involved the collection of 37 additional samples from natural water sources, primarily from the Piauí River, bringing the total to 51 samples. The sampling density correspondsone sample per 14 km², with adjustments made in the eastern region due to access limitations. Specific locations covered by the SGB-CPRM study were revisited, and additional samples were collected in surrounding areas to ensure comprehensive coverage. Consequently, for statistical analysis, we obtained data from 51 samples of natural anduntreated water consumed by communities.

The geochemical study encompassed various materials, including stream sediments, soil, natural water source and food. To collect samples of drainage water and natural water supplies for cation and anion analysis, two 50 ml glass centrifuge tubes were used. The collection process employed disposable syringes without needles, equipped with a 45 mm porosity filter to remove suspended sediments, like pollutants and clays, which were particularly prevalent during the rainy season. For cation analysis, the samples were treated with a 1:1 solution of HNO3 (nitric acid), then stored at low temperatures in an ice chest and cooler bags equipped with gel packs.

Soil samples were generally collected from road cuts and auger holes in pastures using a 25 x 25 km grid., Samples were taken from the upper part of the B horizon (at an average depth between 20 and 30 cm). Duplicates were collected every 20th sample. The analysis

of samples of soil and stream sediment were carried out by inductively coupled plasma emission spectrometry (ICP-OES/MS) in the fine fraction (< 80 # or 0.177 mm), obtained after drying at low temperature (maximum 50° C), and grinding at 150 #. For the assay, the samples were, solubilized with aqua regia (AR: 3ml HCl:1 ml HNO3), in the SGS-Geosol laboratories.

The water sample filtration method was based on the studies of Smith et al. (1996), which examined the geochemistry of aluminum in the tropical climates of Uganda and its health implications. Their research found that filtering the samples through an acidified filter with 40µm porosity before analysis with ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) provided the most accurate results. This conclusion was drawn from a comparative analysis of acidified and non-acidified samples, as well as filtered and unfiltered samples.

The methodology adopted for sample collection, storage, and analysis follows standard procedures as outlined by Silva et al. (2012), and is based on the guidelines guidelines established by the National Program for Research in Environmental Geochemistry and Medical Geology (PGAGEM), proposed by Lins (2003). These procedures comply with geochemical standards established by the International Geoscience Programme (IGCP-259) under the auspices of UNESCO-IUGS, as well as by the Working Group on Global Geochemical Baselines of the IUGS-IAGC (Darnley et al. 1995).

Each stream sediment sample collection was conducted over 30 meters stretch along accessible channels. Soil samples were preferably taken at the depth of 25 cm. These collections resulted in a total of 39 stream sediment samples, 49 soil samples, 15 drainage water samples, 44 natural water samples, and 12 food samples from local gardens.

FIGURE 2. Ceramic sculptures modeled by artisans from the villages of the Jequitinhonha Valley-MG (Azoury 2011).

The analysis of food samples aimed to detect abnormal or harmful concentrations that could pose a risk to consumers. This investigation seeks to trace the pathway of substances from rocks and soils to water, and ultimately, to the food consumed by residents.

For analytical purposes, stream sediment and soil samples wer tested for 36 chemical elements using ICP-MS with aqua regia digestion at Embrapa-Solos RJ. Drainage and supply water samples were analyzed for 28 elements via ICP-OES, and seven anions (fluoride, chloride, nitrite, bromide, nitrate, phosphate, and sulfate) were measured using ion chromatography at the Mineral Analysis Laboratory (LAMIN) of the CPRM.

During water sample collection, key parameters such as pH, temperature, conductivity, and dissolved oxygen levels were measured. Food samples, including beans, mustard, chives, cabbage, cucumber, mango, and peppers, were analyzed for 36 elements using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This analysis followed a digestion process using nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) and was carried out at Embrapa Solos in Rio de Janeiro.

The toxicological studies were conducted across the populations of Itinga and Araçuaí, including a specific group undergoing hemodialysis procedures. A total of 149 blood samples were collected. Using vacuum collection tubes without anticoagulants, approximately 5 ml of blood were drawn from each participant, targeting the analysis of trace metals. To ensure sample preservation until analysis, they were stored at -20° C during transport to the analytical laboratory.

Blood samples were centrifuged at the Araçuaí laboratory to separate the plasma from the red blood cells before analysis. Each plasma sample, about 1.5 ml, was then analyzed using ICP-MS at the Pharmaceutical Sciences Laboratory of the University of São Paulo (USP), located at the Ribeirão Preto campus.

4. Results and discussion

4.1. Water Supply and Drainage

The analyses of the water samples from the supply and drainage networks indicated pH levels ranging from 6 to 9.5, conductivity below 500 µS/cm, and an average temperature of 27.7º C. Regarding dissolved oxygen (DO), approximately 40% of the samples collected during the dry season had values below 5 ppm, failing to meet the human consumption standards established in Decree Conama 357/2005. A comparison with the data from Lopes et al. (2006) revealed a slight reduction in pH and dissolved oxygen levels. This difference is likely due to the distinct sampling periods: CPRM conducted their sampling in July, a dry period when water levels are lower and the concentration of chemical substances is higher, leading to a decrease pH and dissolved oxygen levels. On the other hand, the sampling for this study took place in April, during the transition from the rainy to the dry season.

Out of the 51water samples analyzed, only the one from the Taquaral community is treated. The remaining samples, which supply approximately 80% of the region, contain aluminum levels ranging from 0.200 mg/L to 0.928 mg/L, with an average of 0.405 mg/L. This is particularly significant because legislation — Decree 518/MS (2004) and CONAMA (2005) standards — establishes a maximum allowable aluminum concentration in drinking water of 0.200 mg/L.

The average aluminum concentration in the samples was estimated to beat 0.276 mg/L, Communities such as Malhada Preta, Lagoão, Jiraú, Igrejinha, Brooks São Pedro, Água Branca, Batista, Santa Clara, Barreiro, Fazenda Velha, Ponte do Piauí, Laranjal, and Jenipapo face the risk of aluminum exposure due to consuming completely untreated water (Figure 3). The samples taken at Fazenda Velha exhibited extreme values of 7.2 mg/L and 25.3 mg/L were considered atypical and eading to their exclusion from the analysis.

Iron and manganese levels in 59 water samples exceeded safe limits (0.300 ppm for Fe and 0.100 mg/L for Mn), with Fe ranging from 0.300 to 8.539 mg/L (average of 1.304 mg/L) and Mn from 0.100 to 1.4 mg/L (average of 0.356 mg/L). Additionally, elevated levels of arsenic, tin, boron, lead, chloride, cobalt, lithium, and nickel were detected, underscoring the urgent need to strengthen environmental monitoring.

4.2. Samples of Soil and Stream Sediments

The chemical analysis of soil samples from the study area showed that high aluminum concentrations are present in about 60% of the area, with an average concentration of 30,748 mg/kg, as shown in Figure 04. This value far exceeds the average of 17,770 mg/kg found in soils from eight different drainage basins (Rivers: das Velhas, Paracatu, Abaeté, Urucuia, Carinhanha, Jequitaí, Verde Grande, and São Francisco)

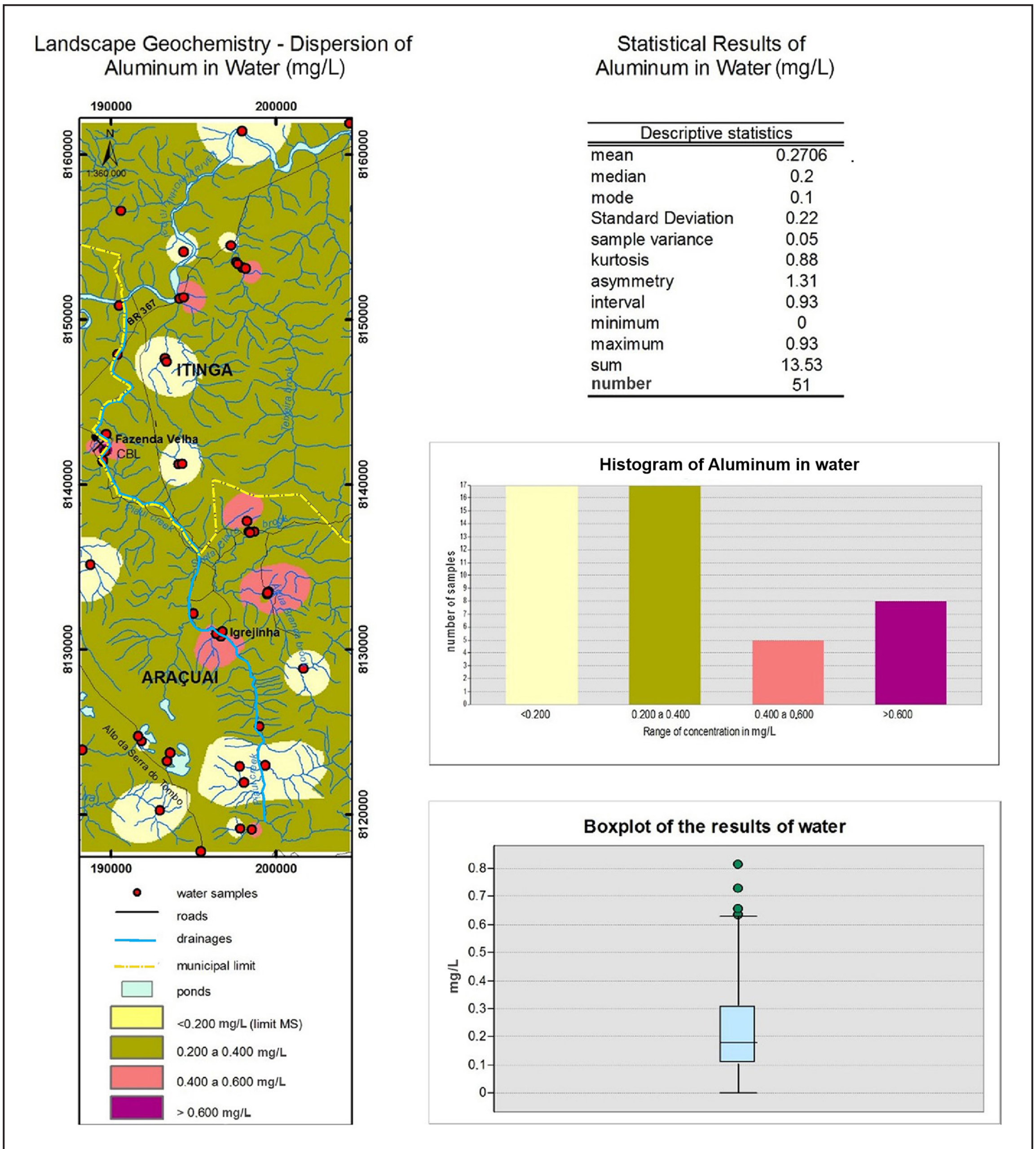

FIGURE 3. Results of natural water supply analyses, spatialized map and statistical treatments in the research area in part of the Araçuaí and Itinga-MG municipalities.

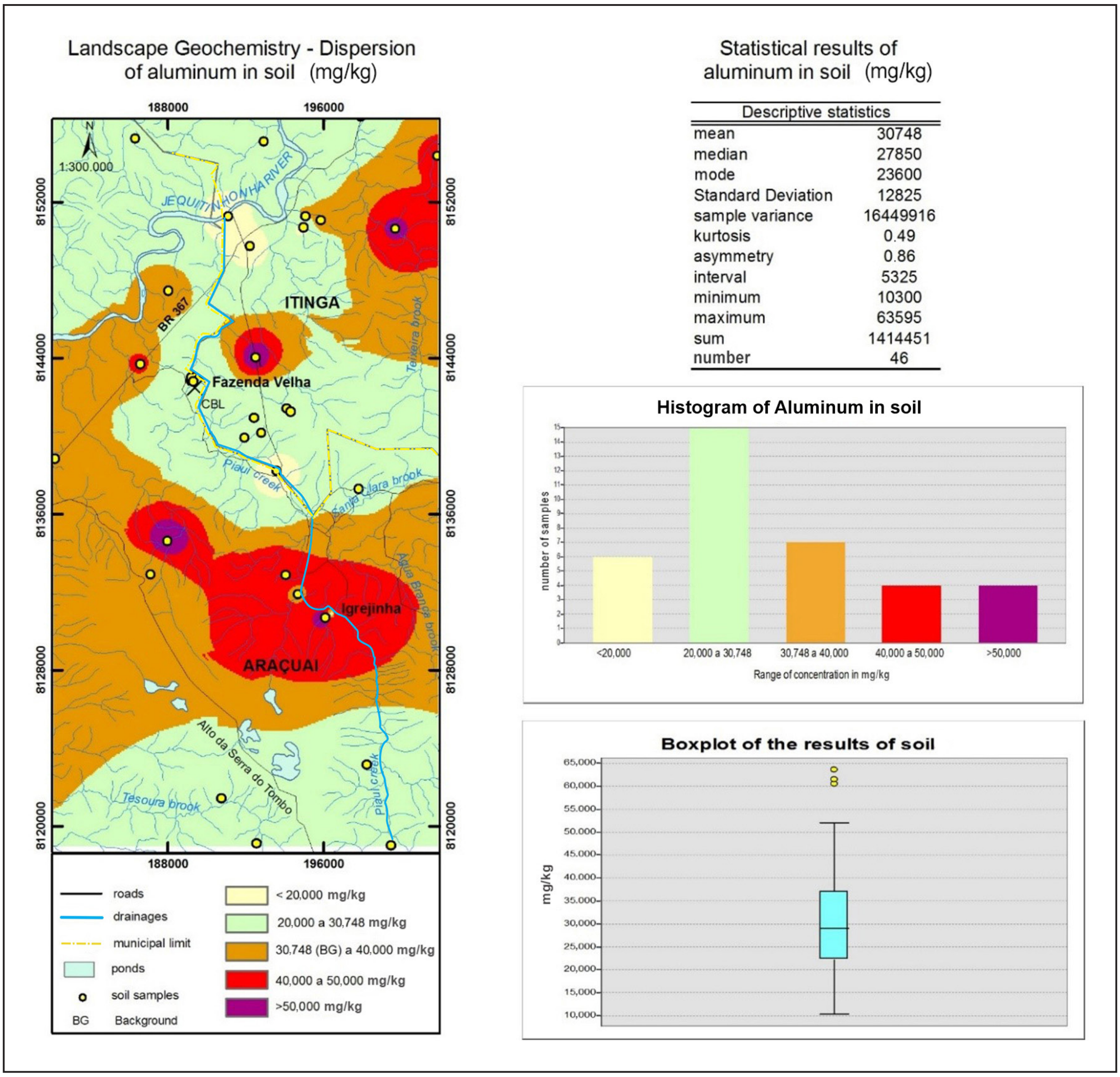

FIGURE 4. Location and aluminun content of samples of soil collected in the research area. Statistics of the data, a histogram and a boxplot of the results are included.

in Minas Gerais, according to Viglio (2010), as indicated in Table 01. It's noteworthy that two soil samples from areas with detrital lateritic covers, which exhibited an exceptionally high average Al concentration of 84,744 ppm, were excluded from the statistical analysis. Even though they were excluded, these samples emphasize the significant potential for these deposits to contribute to Al levels in the environment.

Chemical analyses of aluminum in 34 sediment samples collected in the study area indicated an average concentration of 8,600 mg/kg, with a maximum of 23,800 mg/kg, as shown in Figure 05. Among these samples, 18 locations, representing approximately 50% of the area, exhibited Al concentrations close to the average of 8,815 mg/kg found in the eight aforementioned drainage basins in Minas Gerais State (Viglio 2010), as listed in Table 01. For comparison, Ruby (2009) discussed the agricultural soils of the Jaguari river basin, in São Paulo State, where residual sediments in this region contain an average aluminum concentration of approximately 25,000 mg/kg, suggesting a considerable natural presence of this element in certain soil types. This comparison underscores the variability and widespread presence of Al in both soil and sediment across different geographical regions within Minas Gerais, emphasizing the need for further investigation into its environmental distribution and potential impacts.

4.3. Vegetation

To assess the presence of aluminum (Al) in the local diet, four vegetable samples were collected in April 2008 from the communities of Laranjal and Tesoura, located to the North-Northeast and to South of the study area, respectively. Additionally, eight additional samples of vegetables were obtained from areas with high levels of Al, including two from Fazenda Velha, three from Igrejinha, and three from Pega, in Virgem da Lapa, a municipality approximately 40 km south of the Itinga-Araçuaí region, which shares with a similar geological context. Two samples of water from the Araçuaí River (one treated and one untreated) in the same region were

TABLE 1. Average and maximum values of aluminum in 70% of the drainage basinsin Minas Gerais (Viglio 2010))

	Sediment (mg/kg)	Soil (mg/kg)
Average value	8.815	17.770
Maximum value	44.528	89.137

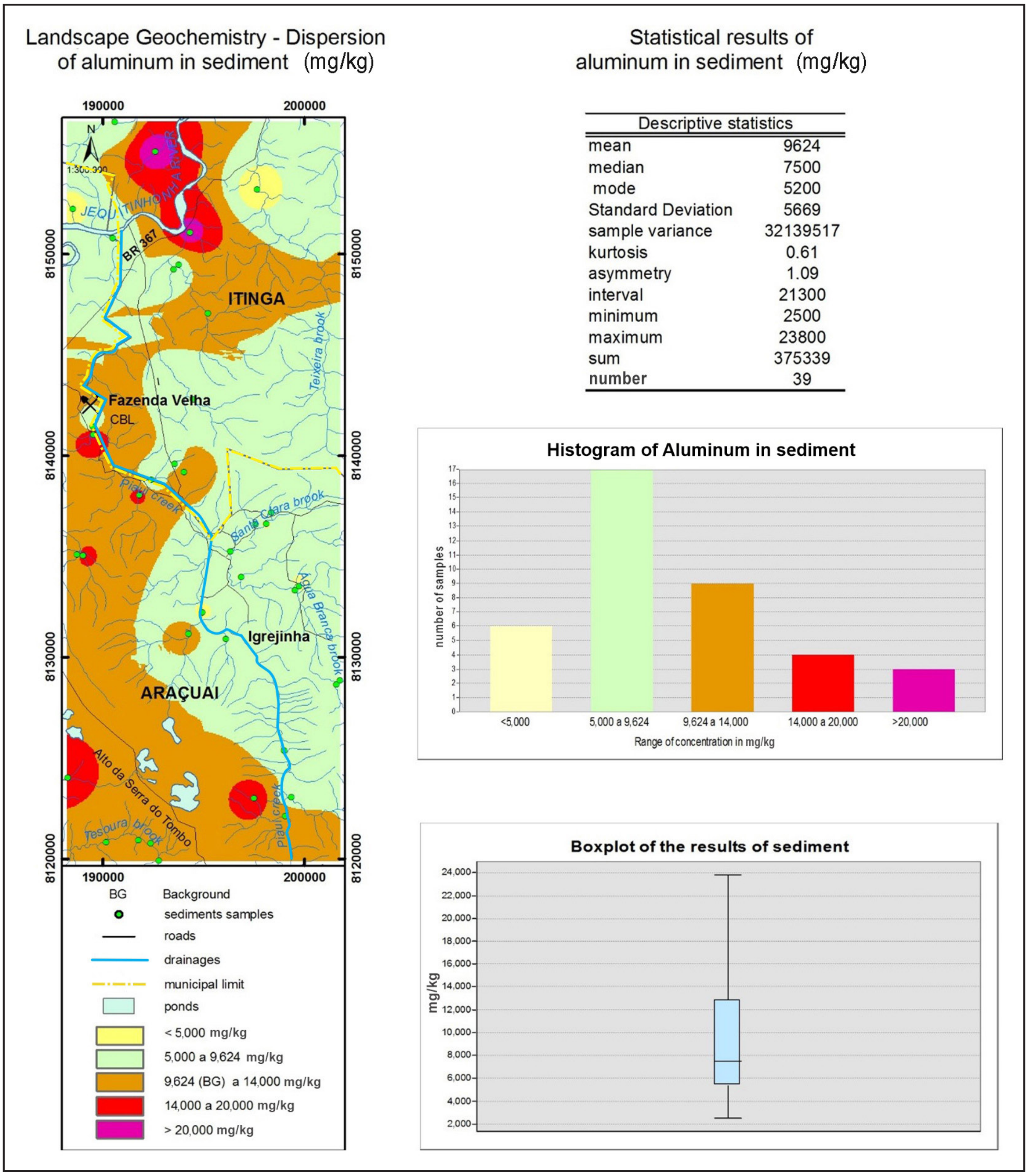

FIGURE 5. Location and aluminum content of stream sediment samples collected in the research area: statistical data, histogram, and boxplot of the results.

also collected, both with Al concentrations below 0.100 ppm. A soil sample from the site revealed Al concentrations above the reference value for the study area, measuring twice as high as the standard for the eight drainage basins of Minas Gerais. The vegetable samples had an average of 1059 ppm of aluminum, ranging from 50 to 4948 ppm. Detailed results are presented in Table 02.

The analysis of the 12 vegetable samples revealed an average concentration of aluminum 1059 mg/kg, with values ranging from 50 to 4948 mg/kg. These results, along with those from the soil samples collected in the gardens of these communities, are presented in Table 02. The findings of this study indicate the risk of aluminum bioaccumulation in the local food chain and its potential implications for the residents' diet.

For comparison, it is worth mentioning the study by Batista (2003) on the behavior of aluminum in the Neves Corvo mine, Portugal, located in the Iberian Pyrite Belt, an area rich in polymetallic sulfide deposits. While small amounts of aluminum can promote plant growth, its toxicity limits the absorption of essential nutrients such as phosphates, calcium, magnesium, potassium, and nitrogen. Stream sediments from Neves Corvo exhibited an average of 62.403 mg/kg Al, three times the reference value for Portugal, and the soil had an average of 62.418 mg/kg Al, varying with the pH. In the leaves of the cistus, a common shrub in the area, the Al level was 1.274 mg/kg. These values are comparable to those observed in Araçuaí-Itinga region, although aluminum concentrations in sediments and soils of Neves Corvo are approximately seven and two times higher, likely due to the presence of schists and greywackes associated with the polymetallic mineralization of the region.

A study conducted by the US Agency for Toxic Substances and Disease Registry (ATSDR 2008), established a daily intake limit for aluminum at 70 ppm for an individual weighing 70 kg. The study highlighted that the human body absorbsbetween 0.1% and 0.6% of aluminum from ingested food and between 0.07% and 0.39% from water consumption. Additionally, the findings indicated that the excess aluminum not absorbed is excreted through urine, a detail corroborated by earlier research from (ATSDR 2006).

Furthermore, the Center for US Food Safety (CFS 2009) conducted an evaluative study to determinethe levels of aluminum utilized as an additive in various food products, with the objective of assessing population exposure and potential health risks in Hong Kong. The study analyzed 256 food samples and identified elevated aluminum concentrations in certain products, notably in bread and steamed cakes (with an average concentration of 100-320 mg/kg), muffins (average concentration of 250 mg/kg), pancakes and waffles (average concentration of 160 mg/kg), coconut pies (average concentration of 120 mg/kg), cakes (average concentration of 91 mg/kg), and jellyfish (with a significantly higher average concentration of 1,200 mg/kg). Based on these findings, the CFS recommended that the food industry reduce the usage of aluminum in food products and ensure transparent disclosure of aluminum content to consumers, aiming to mitigate the potential health risks associated with excessive aluminum intake.

An article by the European Food Safety Authority (EFSA 2008) reviewed existing scientific data and concluded that exposure to aluminum from food does not increase the risk of developing Alzheimer's disease, according to the Center for Food Safety (CFS 2009).

In the research here presented, the average lithium values were recorded at 78.0 mg/kg in soil and 2.30 mg/kg in plants. These findings contrast with those from the River Jordan Valley study by Ammari et al. (2010), where soil derived from carbonate rocks showed lithium concentrations ranging from 1.06 to 2.68 mg/kg, while plants contained levels between 2 and 27 mg/kg. This discrepancy suggests that the lithium concentration in the soil is influenced more by factors such as topography, climate, and water availabilitythan the by bedrock

TABLE 2. Results of nine food and soil samples from the research area and three samples from the Pega community, located in the municipality of Virgem da Lapa.

Sample	Food	whater - Al (mg/kg)	Soil - Al (mg/kg)	Locality
CR-V-1001C	Maxixe	1.522	34.881	Fazenda Velha
CR-V-1001D	Mango	482	22.500	Fazenda Velha
CR-V-1010E	Chives	1.534	26.678	Escola da Igrejinha
CR-V-1010F	Mustard	1.834	45.940	Igrejinha
CR-V-1010G	Kale	249	48.790	Igrejinha
CR-V-1002	Mustard	4.948	52.096	Laranjal
CR-V-1003A	Chives	307	42.046	Laranjal
CR-V-1003B	Beans	50	42.408	Laranjal
CR-V-1008	Kale	52	27.100	Tesoura
CR-V-1029A	Kale	389		Pega (Virgem da Lapa)
CR-V-1029B	Chives	913	36.238	Pega (Virgem da Lapa)
CR-V-1029C	Peppers	437		Pega (Virgem da Lapa)

composition alone. Additionally, the study highlighted that consuming 250-300 g/day of spinach, containing 1.15 to 1.38 mg of lithium, can serve as an important dietary source in Jordan, contributing to the daily lithium intake necessary for health benefits.

The findings of this research for aluminum indicate that approximately 3,200 people living in the studied area of 600 km² in the municipalities of Araçuaí and Itinga may be consuming water with aluminum levels above the limit deemed safe by health standards (MS, CONAMA). Considering the geological characteristics of the region comprising granites and aluminous metasediments, as illustrated in Figure 06, it is estimated that a broader rural population of approximately 50,000 people in he surrounding areas may also be at risk of exposure to harmful levels of aluminum.

4.4. Toxicological Studies

A multidisciplinary team composed of medical, biological, and geological professionals developed a specific protocol for the collection and analysis of toxicological data, selecting blood plasma as the primary sampling target due to its reliably in indicating aluminum presence. For this study, the populations of two specific communities, Igrejinha and Fazenda Velha, located in the municipality of Araçuaí, were chosen for investigation after it was observed that their water sources contained aluminum concentrations exceeding the limits established by current health legislation for potable water, according to guidelines from the Ministry of Health. Additionally, the research included an assessment of individuals undergoing dialysis treatment three times a week in the city of Teófilo Otoni, 197 kilometers away from Araçuaí, with the aim of assessing the potential correlation between aluminum exposure levels with kidney health.

This group was included in the research to assess the effects of aluminum exposure from dialysis solutions (anthropogenic sources) compared to exposure from natural aluminum sources, as observed in the previously mentioned communities. Following Silva et al. (2012) the recommendations on medical geology, preliminary activities involved consultations with the Araçuaí health department to ensure support and facilitate contact with the selected communities. Interviews with health secretaries revealed the prevalence of health conditions such as renal insufficiency, hypertension, anemia, nervous system disorders, circulatory system diseases, and diarrhea. In Igrejinha, located 23 km from Araçuaí (Figure 01), blood samples were collected from 99 individuals out of approximately 380 residents. In Fazenda Velha, 11 km from Araçuaí, 34 blood samples were collected from 34 individuals out of a group of approximately 240 inhabitants. The plasma of all of these samples were separated for further analysis.

In the study conducted in Igrejinha, the plasma samples from 99 individuals revealed that 73% exceeded the aluminum

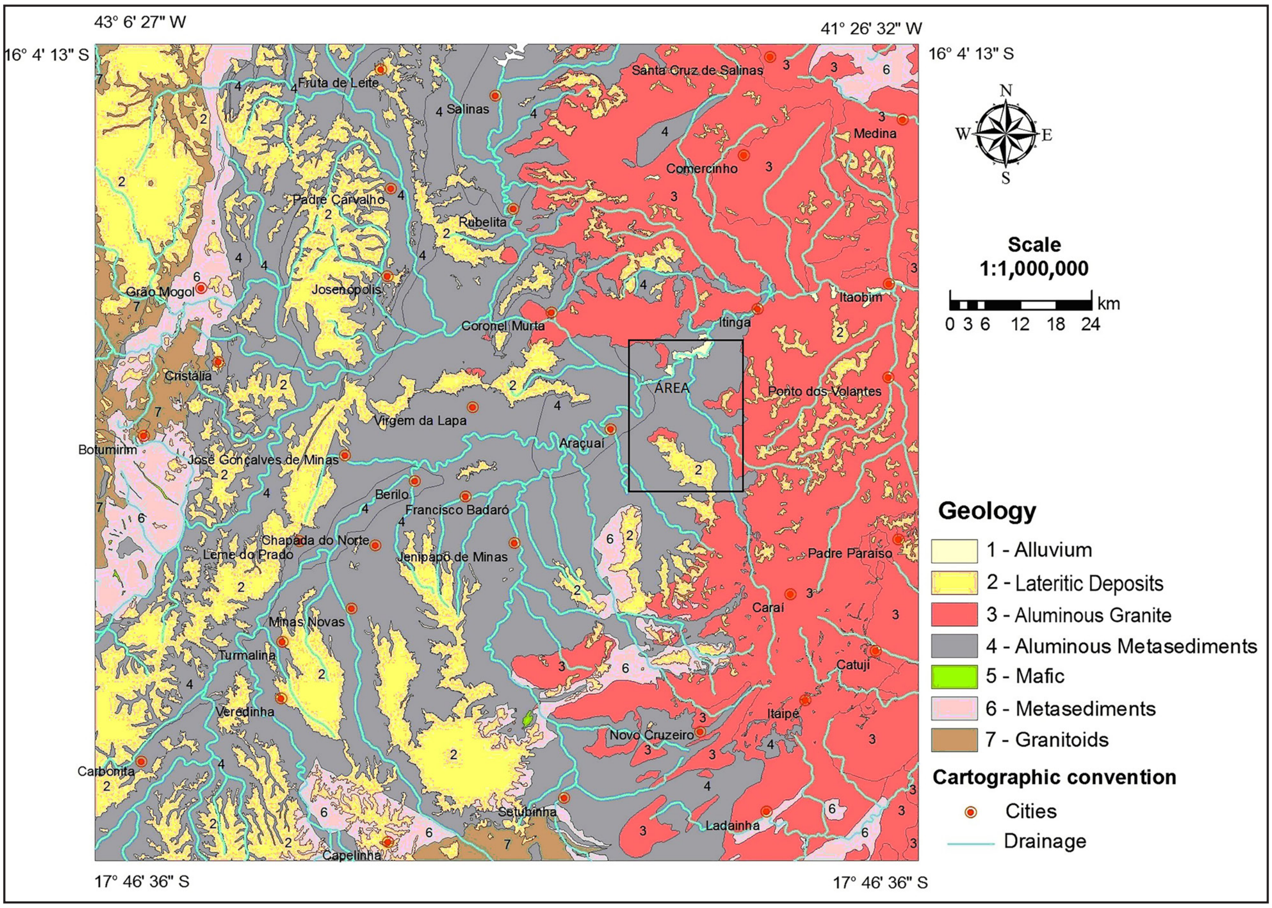

FIGURE 6. Regions with the same geological context of the research area located in Araçuaí and Itinga (taken from Machado and Silva 2010).

threshold of 3µg/L, as defined by the US (ATSDR 2008) (Table 03). Furthermore, 55% of the plasma samples exhibited aluminum concentrations above 10 µg/L, surpassing the tolerance limit for individuals without prior aluminum exposure, according to the criteria established by Jerome and Fujimura (1998) and supported by the CAH (Taylor 2006) for people without a diagnosis of renal insufficiency. Notably, 10% of the samples showed aluminum levels above 60 µg/L, 4% exceeded 100µg/L, and 2% surpassed 200 µg/L, indicating a high risk of toxicity for both the general population and especially for dialysis patients, as per the Resolution 86/C104/04 of the European Commission and the CAH guidelines.

In a subgroup of 30 children aged 0 to 10 years of Igrejinha, plasma levels aluminum ranged from less than 1 to 337.66 µg/L, with a median of 14 µg/L. This data highlights a significant exposure risk, with 73% of the children exceedingthe 3 µg/L threshold , 67% surpassing 10 µg/L (associated with toxic risk according to the CAH - Taylor 2006), 17% exceeding 60 µg/L, and 10% surpassing 100 µg/L, a level considered highly toxicity for children by the CAH. Additionally, 7% of the children presented aluminum concentrationsabove 200 µg/L.

Meanwhile, the analysis of 34 samples collected in the Fazenda Velha community revealed that 56% of the participants had aluminum levels above 3 µg/L. Additionally, 32% of the samples exceeded 10 µg/L, 9% surpassed 60 µg/L, and another 9% exceeded 100 µg/L, indicating a significant concern regarding aluminum exposure in this population.

A comparison with the study by Jeronymo and Fujimura (1998), indicates a significantly higher risk of aluminum toxicity in the Araçuaí group. . While in Jeronymo and Fujimura research 15% of participants had aluminum levels above 60 µg/L, in Araçuaí is three times higher, with 44% of individuals exhibiting elevated aluminum concentrations in plasma.

It is important to note that, aluminum levels in dialysis patients cannot be directly compared to those in the populations of Igrejinha and Fazenda Velha due to different sources in exposure (Figure 07). The Araçuaí dialysis group is exposed to aluminum through both diet and hemodialysis fluids, whereas the populations of Igrejinha and Fazenda Velha are primarily exposed through food and water.

The Agency for Toxic Substances and Disease Registry (ATSDR 2006) warns that high aluminum intakes can cause musculoskeletal effects, including joint pain and bone softening. Pregnant or lactating women exposed to aluminum face additional risks related to fetal to neurological development. Furthermore, individuals with impaired renal function are at greater risks due to aluminum accumulation in the body, which may contribute to dementia associated with aluminum exposure.

The condition known as “dialysis dementia,” first described by Alfrey et al. (1972) in patients undergoing hemodialysis, is characterized by progressive speech impairment eventually leading to complete loss of speech, coma, and often death. This syndrome underscores the severe impact of aluminum exposure in dialysis patients, highlighting the extreme risks associated with aluminum accumulation in their bodies.

Regarding aluminum’s neurotoxicity, Martyn et al. (1989) provided evidence linking aluminum exposure in drinking water to an increased risk of Alzheimer’s disease. Their study, conducted across eighty-eight districts in England and Wales, they identified a 1.5 times greater risk of Alzheimer’s in areas with average aluminum concentrations in water exceeded 0.11 mg/L compared to areas with levels below 0.01 mg/L. This study sets a precedent for further investigations intothe

TABLE 3. Concentration of aluminum in blood plasma (serum) in µg/L in individuals of Igrejinha and Fazenda Velha (Araçuai) submitted to dialysis.

Location	Age group	n	Median µg/L	Mínimum µg/L	Máximum µg/L	n (%) above 3.00*µg/L	n (%) above 10.00**µg/L	n (%) above 60.00**µg/L	n (%) above 100.00**µg/L	n (%) above 200.00**µgL
Igrejinha	0-10	30	14.14	<1	337.86	73	67	17	10	7
	11-60	61	9.12	<1	167.85	70	49	7	2	0
	Above 60	8	9.35	<1	61.57	88	50	13	0	0
Subtotal		99	10.98	<1	337.86	73	55	10	4	2
Fazenda Velha	11-60	26	3.98	<1	170.92	54	35	8	8	0
	Above 60	8	5.21	1,04	161.92	63	25	13	13	0
Subtotal		34	4.66	<1	170.92	56	32	9	9	0
total Individuals		133	9.12	<1	337.86	68	49	10	5	2

* 3.00 µg/L: up to this value, the amount of Al in blood plasma is considered normal, according to ATSDR (2008);

** according to CAH (2006);

< 10µg/L: people with no history of renal failure;

< 60 µg/L: presents low risk of toxicity in patients with renal failure;

> 60µg/L: excessive accumulation; risk of toxicity in children;

> 100µg/L: high risk of toxicity in children;

> 200µg/L: high risk of toxicity in any age group.

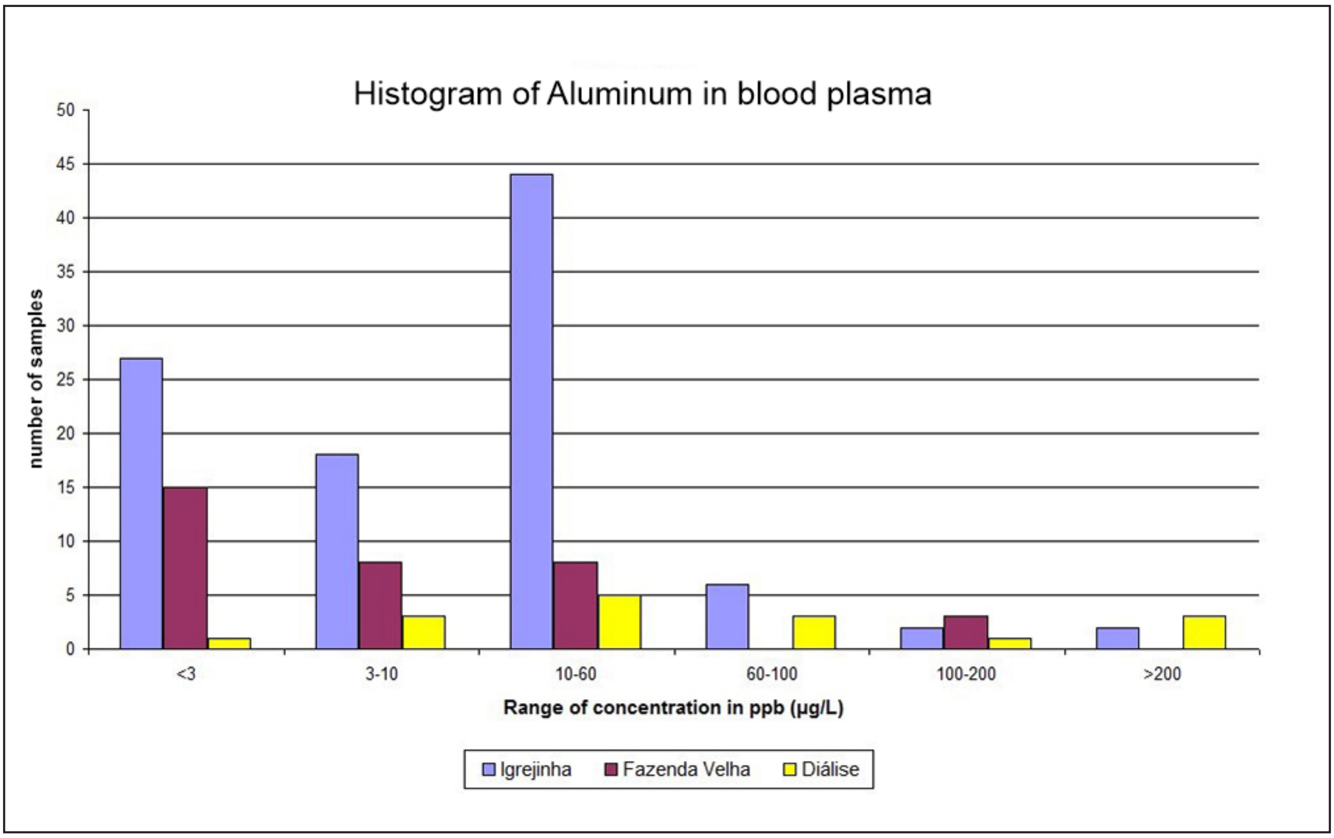

FIGURE 7. Results of the plasma analysis for aluminum versus the number of samples. The greatest concentration are lower than 60 µg/L.

relationship between aluminum and neurodegenerative diseases.

Building on earlier research, Flaten et al. (1996) expanded the scope beyond aluminum's potential role in Alzheimer's disease, examining its broader toxic effects. Their study explored aluminum's impact across various domains, from adverse effects on agriculture to clinical conditions in humans, including encephalopathy, osteomalacia, and anemia in patients with chronic renal failure. This work underscored the complexity of aluminumtoxic toxicity and the need for a deeper understanding of its mechanisms of action.

Later, Flaten (2001) reiterated aluminum's neurotoxicity, emphasizing the growing body of evidence supporting its potential role in the development and progression of Alzheimer's disease. In a reviewed thirteen epidemiological studies, Flaten found that nine reported significant positive correlations between aluminum levels in drinking water and the incidence of Alzheimer's, further strengthening the hypothesis of a link between aluminum exposure and neurodegenerative disease.

Suay and Ballester (2002), in their review of epidemiological studies on drinking water consumption, concluded that exposure to aluminum concentrations above 0.1 mg/L doubled the risk of developing Alzheimer's. They emphasized the importance of investigating additional pathways of aluminum exposure and the need for ongoing monitoring of its effects on human health.

The body of research on on aluminum's toxicity reflects growing concern about its adverse effects on human health, particularly its potential role in the development of Alzheimer's disease. From the research by Martyn et al. (1989), which linked aluminum exposure in drinking water to an increased risk of Alzheimer's, to the work of Flaten (2001) and Suay and Ballester (2002), which reinforced this association and emphasized the need for further investigation into aluminum exposure pathways, the accumulated evidence underscores the importance of thoroughly understanding aluminum's toxicity. These studies underline the necessity of multidisciplinary research to elucidate the mechanisms underlying aluminum toxicity and to develop strategies for minimizing human exposure to this metal, aiming to mitigate its harmful health effects.

Most research on human aluminum toxicity has focused on individuals with kidney issues, providing critical benchmarks for clinical diagnosis, as noted by Jeronymo and Fujimura (1998), the European Commission's Resolution 86/C104/04, (Taylor 2006), and the ATSDR (2008). Additionally, much of the research on aluminum exposure has centered on drinking water consumption among individuals without kidney problems (Martyn et al. 1989; Suay and Ballester

2002), indicating a gap in understanding exposure through other pathways and across broader populations.

Klotz et al. (2017) provided a comprehensive analysis of aluminum exposure and its potential link to Alzheimer's disease, drawing the following conclusions : a) Aluminum has the potential to induce a specific encephalopathy characterized by dementia syndrome upon exposure; b) The encephalopathy caused by aluminum is recognized as a distinct pathological condition, separate from Alzheimer's-type dementia; c) Although higher levels of aluminum have been identified in the brains of individuals with Alzheimer's disease, it remains unclear whether aluminum contributes to these changes or if it represents a separate, unrelated alteration arising from Alzheimer's pathology itself and d) The evidence from epidemiological studies regarding the relationship between aluminum exposure and Alzheimer's disease remains highly uncertain and does not strongly indicate a direct association.

The review by Igbokwe et al. (2019) provided a detailed examination of the pathological mechanisms underlying aluminum toxicity. It highlighted the association between aluminum poisoning and various pathological syndromes, as well as the toxic pathways contributing to these effects, suggesting potential avenues for targeted interventions. Recent epidemiological research has increasingly focused on exploring these pathologies in relation to specific human diseases, including Alzheimer's disease, autism, osteoporosis, diabetes mellitus, and inflammatory bowel disease, among others detailed in the review.

In the study area, aluminum exposure originates from outcropping rocks rich in aluminum-bearing minerals. Through weathering and pedogenesis, these rocks break down, resulting in soil that contains grains of weather resistant minerals, such as quartz, secondary minerals likelimonite and gibbsite, and free ions that are either temporarily retained or washed away by rainwater . Aluminum is typically found in secondary minerals, in a stable form, however, it is possible that some portion temporarily exists as free ions in the soil. These dissolved ions may be absorbable by local plants transported into groundwater and surface water systems, where they have the potential to assimilated by living organisms .

This sequence of rock-soil-food exposure pathways mirrors those previously documented for aluminum in Neves Corvo, Portugal (located in the Iberian Pyrite Belt), and for lithium in the Jordan River Valley.

Given the elevated aluminum concentrations detected in the plasma of study participants, it is plausible to outline an aluminum exposure pathway as rock-soil-water-food-individuals within the rural population of Araçuaí-Itinga, particularly affecting those in the Piaui Creek drainage basin.

The review conducted by Igbokwe et al. (2019) provided a comprehensive analysis of the pathological bases associated with aluminum toxicity, emphasizing its association with various pathological syndromes. Furthermore, it elucidated the pathogenic mechanisms underlying aluminum's toxic effects, suggesting potential paths for targeted interventions. Recent epidemiological research has increasingly focused on investigating these pathologies in relation to specific human diseases, including Alzheimer's disease, autism, osteoporosis, diabetes mellitus, and inflammatory bowel disease, among others discussed in the review.

5. Conclusions and recommendations

The results and analyses of this study lead to several key conclusions:

1. Lithium in the region: Lithium concentrations in water, soil, and stream sediments in the studied region do not pose a significant threat to human health, with averages of 0.015 mg/L, 78 mg/kg, and 33.7 mg/kg, respectively.
2. Elevated aluminum concentrations: Over 80% of the studied area exhibits aluminum concentrations in water (0,200 mg/L to 0,928 mg/L, with the average of 0,405 mg/L) exceeding the recommended limits by health and environmental agencies. Additionally, the region's soils contain high aluminum levels, contributing to its presence in local vegetation and the food chain.
3. Natural sources of metals: Geochemical assessments indicate that the metals identified as health risks in the area originate from natural environmental sources, rather than industrial emissions or mining activities.
4. Aluminum exposure pathway: The study delineates a pathway of aluminum exposure that originates in rocks, transfers to soil, untreated water, and local foods, primarily affecting rural communities near watercourses, especially those in the Piauí Creek basin.
5. Impact on the local population: Approximately 3,200 inhabitants in the studied areas estimated to consume water with aluminum levels exceeding safety standards established by regulatory agencies. In the evaluated communities, a significant proportion of individuals are exposed to aluminum concentrations representing toxicity risks, especially for those with renal dysfunctions.

These conclusions underscore the need for monitoring and control measures to mitigate health risks associated with aluminum exposure in the studied region. In the evaluated communities of

Igrejinha and Fazenda Velha, 68% of individuals have aluminum concentrations exceeding 03 µg/L, 49% surpass 10 µg/L, 10% exceed 60 µg/L, 4% surpass 100 µg/L, and 2% are above 200 µg/L. With the exception of the lowest threshold, the remaining concentrations pose a toxicity risk, particularly for individuals with renal dysfunctions. Notably, approximately 44% of dialysis patients are at risk of aluminum toxicity, with plasma levels exceeding 60 µg/L, as established by the CAH (Taylor 2006).

Individuals with renal failure, who are particularly vulnerable to aluminum exposure, may accumulate significant amounts of aluminum in various organs due to impaired renal excretion capabilities. This accumulation can lead to bone or neurological complications. Even healthy individuals who consume aluminum-containing pharmaceutical products at recommended doses may experience adverse effects with prolonged use. Specifically, cases of children with renal failure suffering from neurological and bone disorders due to to high aluminum levels in the body have been documented. Additionally, bone damage has been reported in children consuming medications containing aluminum, with the underlying mechanism being aluminum's interference with phosphate absorption in the stomach — a process essential for bone healt.

The Clinical and Analytical Handbook (Taylor 2006) explores the dynamics of aluminum (Al) within the human body, particularly focusing on its transportation through blood transferring. It emphasizes plasma aluminum measurement as a critical method for assessing the total body burden of this element. For individuals with renal failure, the Handbook defines specific plasma aluminum thresholds to evaluate toxicity risk: 1) Levels below 10 µg/L are considered safe for individuals without a history of renal failure; 2) levels below 60µg/L represent a low risk of toxicity for patients with renal failure; 3) levels above 60µg/L indicate excessive accumulation and a risk of toxicity, particularly in children; 4) concentrations exceeding 100µg/L are a cause for concern due to a high risk to children and 5) a level above 200µg/L signifies a high risk of toxicity for all patients. Furthermore, according to the ATSDR (2008), normal plasma aluminum levels range from 1-3µg/L.

In Brazil, research on aluminum toxicology remains limited. Jeronymo and Fujimura (1998) investigated aluminum quantification in plasma samples from both healthy individuals and patients with chronic renal failure, whether undergoing dialysis or not. Their findings revealed that all 26 individuals without renal issues had serum aluminum levels below 10µg/L. Among patients with renal failure who were not on dialysis, 33% exhibited serum aluminum levels between 11 and 17µg/L. In contrast, dialysis patients displayed a wider distribution of levels, with notable portions falling into higher risk categories.

According to Jeronymo and Fujimura (1998), the European Commission established specific benchmarks to protect hemodialysis patients. It recommends that drinking water contain less than 200µg/L of aluminum, and dialysis solutions less than 10µg/L. Plasma aluminum concentrations are considered safe up to 60µg/L, with values between 60 to 100µg/L indicate accumulation. However, plasma aluminum levels should not exceed 200µg/L.

The findings of this research were reported to the State Health Department of the State of Minas Gerais, the agencies responsible for the health of the municipalities of Araçuaí and Itinga and to the exposed population, as well as to monitor the mitigating measures that were adopted for the region. Following this communication, the aforementioned agencies advised the affected population to use carbon-added filters, to minimize aluminum exposure.

This scenario underscores the critical importance of monitoring and of medical intervention in susceptible populations, especially those with pre-existing conditions that increase the risk of aluminum toxicity. Early detection of elevated aluminum levels and the implementation of exposure reduction strategies are essential in preventing long-term complications. Additionally, raising awareness about the risks associated with aluminum exposure and educating both healthcare professionals and the public on ways to minimize it are imperative. Understanding aluminum sources, including water, food, and consumer products, can help protect those most vulnerable to its adverse effects, promoting a proactive approach to environmental and individual health management. Mining companies are encouraged to adopt this approach by prioritizing community health and conducting comprehensive assessments of potentially harmful natural chemicals in their surrounding environments. These assessments should include evaluations of sediments, soil, water, and plants before, during, and after mining operations, with an emphasis on annual monitoring.

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A - Study design/ Conceptualization **B** - Investigation/ Data acquisition
C - Data Interpretation/ Validation **D** - Writing
E - Review/Editing **F** - Supervision/Project administration

References

Alfrey A.C., Mishell J.M., Burks J, Contiguglia S.R., Rudolph H., Levin E., Holmes J.H. 1972. Syndrome of dyspraxia and multifocal seizures associated with chronic hemodialysis. Transactions - American Society for Artificial Internal Organs, v. 18, n 1, 257-261.

Azoury R. 2011. Ceramic sculptures modeled by artisans from the villages of the Jequitinhonha Valley-MG. Pointo dos Volantes Minas Gerais-Brasil. Pulsar Imagens. Available online at: https://www.pulsarimagens.com.br

Ammari T. G., Al-Zu'bi Y., Abu-Baker S., Dababneh B., Gnemat W., Tahboub A. 2010. The occurrence of lithium in the environment of the Jordan Valley and its transfer into the food chain. Environmental Geochemistry and Health, v. 33, 427-437. https://doi.org/10.1007/s10653-010-9343-5

Almeida F.F.M. 1977. O Cráton do São Francisco. Revista Brasileira de Geologia, (4), 349-364.

ATSDR. 2006. Toxicological profile for aluminum (draft for public comment). Atlanta, U.S. Department of Health and Human Services, Public Health Service.

ATSDR. 2008. Toxicological profile for aluminum. Atlanta, U.S. Department of Health and Human Services, Public Health Service.

Batista M.J.A.F. 2003. Comportamento de elementos químicos no sistema rocha-solo-sedimento-planta na área mineira de Neves Corvo: implicações ambientais. PhD Thesis, Universidade de Aveiro, Departamento de Geociências. Available online at: http://hdl.handle.net/10773/2745 / (acessed on 29 Nov. 2010).

Bizzi L.A., Schobbenhaus C., Vidotti R.M., Gonçalves J.H. 2003. Geologia, tectônica e recursos minerais do Brasil: texto, mapas e SIG. Brasília, CPRM, 2003. Available online at: https://rigeo.sgb.gov.br/handle/doc/5006 / (acessed on 10 April 2025).

Carvalho F.M., Barreto M.L., Silvany-Neto A.M., Waldron H.A., Tavares T.M. 1984. Multiple causes of anaemia amongst children living near a lead smelter in Brazil. Science of The Total Environment, 35(1), 71-84. https://doi.org/10.1016/0048-9697(84)90369-3

CFS. 2009. Aluminium in food. Risk Assessment Studies, Report n. 35 2009. Chemical Hazard Evaluation. Centre for Food Safety. Food and Environmental Hygiene Department. The Government of the Hong Kong Special Administrative Region. Available online at: https://www.cfs.gov.hk/english/programme/programme_rafs/files/RA35_Aluminium_in_Food_e.pdf. / (acessed on 10 April 2025).

Conama. Resolução n. 357, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes e dá outras providências. Diário Oficial da União, 142(53), 58-63. Available online at: https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Resolucao/2005/res_conama_357_2005_classificacao_corpos_agua_rtfcda_altrd_res_393_2007_397_2008_410_2009_430_2011.pdf / (acessed on 7 Feb. 2025).

Cortecci G. 2002. Geologia e salute. Università degli Studi di Bologna.
Cunha F.G. 2003. Contaminação humana e ambiental por chumbo no vale do Ribeira, nos estados de São Paulo e Paraná, Brasil. PhD Thesis, Instituto de Geociências, Universidade Estadual de Campinas, Campinas, 111 p. Available online at: https://rigeo.sgb.gov.br/handle/doc/140. (acessed on 10 April 2015).
Darnley A.G., Bjorklund A., Bølviken B., Gustavsson N., Koval P.V., Plant J.A., Steenfelt A., Tauchid M., Xuejing X., Garrett R.G., Hall G.E.M. 1995. A global geochemical database for environmental and resource management: recommendations for international geochemical mapping final report of IGCP Project 259. Canada, UNESCO, 132 p. Available online at: https://unesdoc.unesco.org/ark:/48223/pf0000101010 / acessed on: 10 April 2025.
Demajorovic, J. (org.). 2024. Licença social para operar: gestão de impactos sociais e desenvolvimento local. São Paulo, Editora Senac, 350 p.
Dissanayake C.B., Chandrajith R. 2009. Introduction to Medical Geology. Heidelberg, Springer-Verlag Berlin, 297 p. https://doi.org/10.1007/978-3-642-00485-8
EFSA. 2008. Safety of aluminium from dietary intake: scientific opinion of the Panel on Food Additives, Flavourings, Processing Aids and Food Contact Materials (AFC). EFSA Journal, 754, 1-34. https://doi.org/10.2903/j.efsa.2008.754
Figueiredo B.R. 2005. Contaminação ambiental e humana por chumbo no vale do Ribeira (SP-PR). ComCiência, 71, Available online at: https://www.comciencia.br/dossies-1-72/reportagens/2005/11/09.shtml / (acessed on 25 Feb. 2010).
Figueiredo B.R., Litter M.I., Silva C.R., Mañay N., Londono S.C., Rojas A.M., Garzón C.,
Tosiani T., Di Giulio G.M., De Capitani E. M., Dos Anjos J.Â.S.A., Angélica R.S, Morita M.C., Paoliello M.M.B., Cunha F.G., Sakuma A.M., Licht O. A. 2010. Medical geology studies in South America. In: Selinus O., Finkelman R.B., Centeno J.A. Medical Geology: a regional synthesis. New York, Dordrecht Heidelberg London. p. 79-106. https://doi.org/10.1007/978-90-481-3430-4_4
Finkelman R.B, Selinus O., Centeno A. 2007. **Medical Geology in developing countries, Part 1. Environmental Geochemistry and Health, 29(2), 81-167. Special Issue.** https://doi.org/10.1007/s10653-006-9075-8
Flaten T.P. 2001. Aluminium as a risk factor in Alzheimer's disease, with emphasis on drinking water. Brain Research Bulletin, 552(2), 187-196. https://doi.org/10.1016/S0361-9230(01)00459-2
Flaten T.P., Alfrey A.C., Birchall J.D., Savory J., Yokel R.A. 1996. Status and future concerns of clinical and environmental aluminum toxicology. Journal of Toxicology and Environmental Health,48(6), 527-542. https://doi.org/10.1080/009841096161050
Igbokwe I.O., Igwenagu E., Igbokwe N.A. 2019. Aluminium toxicosis: a review of toxic actions and effects. Interdisciplinary Toxicology, 12(2), 45-70. https://doi.org/10.2478/intox-2019-0007
Jeronymo S.A., Fujimura H. Y. 1998. Dosagem de alumínio no soro de indivíduos sadios e em pacientes com insuficiência renal crônica mantidos ou não em tratamento dialítico. Jornal Brasileiro de Nefrologia, 20(2), 144-150.
Klotz K., Weistenhöfer W., Neff F., Hartwig A., van Thriel C., Drexler H. 2017.The health effects of aluminum exposure. Deutsches Ärzteblatt, 114(39), 653-659. https://doi.org/10.3238/arztebl.2017.0653.
Licht O.A.B. 2001. A geoquímica multielementar na gestão ambiental: identificação e caracterização de províncias geoquímicas naturais, alterações antrópicas da paisagem, áreas favoráveis à prospecção mineral e regiões de risco para a saúde no estado do Paraná, Brasil. PhD Thesis, Curitiba. Available online at: https://acervodigital.ufpr.br/handle/1884/41646 / (acessed on: 20 April 2025).
Lins C.A.C. 2003. Programa Nacional de Pesquisa em Geoquimica Ambiental e Geologia Médica-PGAGEM. Recife, CPRM, 13p. Available online at: https://rigeo.sgb.gov.br/handle/doc/17282 / (acessed on 10 April 2025).
Lopes Jr, I., Silva C.R., Marques C. 2006. Contaminações naturais de elementos metálicos nas águas da bacia hidrográfica do Ribeirão Piauí, Município de Itinga-MG. In: Congresso Brasileiro de Geologia, 43, p. 68.
Machado M., Silva S.F. 2010. Mapa geodiversidade do estado de Minas Gerais. Belo Horizonte, CPRM – Serviço Geológico do Brasil. Available online at: https://rigeo.sgb.gov.br/handle/doc/14704 / (acessed on 10 April 2025).
Martyn C.N., Barker D.J. Osmond C., Harris E.C., Edwardson J.A., Lacey R.F. 1989. Geographical relation between Alzheimer's disease and aluminum in drinking water. The Lancet, 333(8629), 59-62. https://doi.org/10.1016/S0140-6736(89)91425-6
Matschullat J., Borba R.P., Deschamps E., Figueiredo B.F., Gabrio T., Schwenk M. 2000. Human and environmental contamination in the Iron Quadrangle, Brazil. Applied Geochemistry, 15(2), 181-190. https://doi.org/10.1016/S0883-2927(99)00039-6
Paes V.J.C., Raposo F.O., Pinto C.P., Oliveira F.A.R. 2009. Folha Itaobim, escala 1:100.000: mapa e relatório. In: Projeto Jequitinhonha. Programa Geologia do Brasil. Belo Horizonte, CPRM-Serviço Geológico do Brasil.
Paoliello M.M.B. 2002. Exposição humana ao chumbo e cádmio em áreas de mineração, vale do Ribeira, Brasil. 2002. PhD Thesis, Faculdade de Ciências Médicas, Universidade Estadual de Campinas, Campinas, 173 p.
Pedrosa-Soares A.C., Wiedemann-Leonardos C.M. 2000. Evolution of the Araçuaí Belt and its conection to the Araçuaí-Ribeira Belt, eastern Brazil. In: Cordani U.G., Milani E.J., Thomaz Filho A., Campos D.A. (ed.). Tectonic evolution of South America. Rio de Janeiro, 31st IGC. p. 265-285. Available online at: https://rigeo.sgb.gov.br/handle/doc/19419 / (acessed on 10 April 2025).
Pedrosa-Soares A.C., Noce C.M., Wiedemann C.M., Pinto C.P. 2001. The Araçuaí-Congo Orogen in Brazil: an overview of a confined orogen formed during Gondwanaland assembly. Precambrian Research, 110(1-4), 307-323. https://doi.org/10.1016/S0301-9268(01)00174-7
Pedrosa-Soares A.C., Chaves M., Scholz R. 2009. Eastern brazilian pegmatite province: field trip guide: PEG2009. In: International Symposium on Granitic Pegmatites, 4. 28 p.
Romeiro J.C. P. 1998. Controle da mineralização de lítio em pegmatitos da Mina da Cachoeira, Companhia Brasileira de Lítio, Araçuaí, MG. MSc Dissertation, Instituto de Geociências, Universidade Federal de Minas Gerais, 94 p.
Romeiro J.C. P., Pedrosa-Soares A.C. 2005. Controle do minério de espodumênio em pegmatitos da Mina da Cachoeira, Araçuaí, MG. Geonomos, 13 (1-2), 75-81. https://doi.org/10.18285/geonomos.v13i1e2.137
Ruby E.C. 2009. Qualidade ambiental de solos agrícolas da Bacia do Rio Jaguari. MSc Dissertation, Instituto de Pesquisas Energéticas e Nucleare. https://doi.org/10.11606/D.85.2009.tde-11032010-153933
Selinus O., Alloway B., Centeno J.A., Finkelman R.B., Fuge R., Lindh U., Smedley P. 2005. Essentials of Medical Geology. Burlington, Elsevier Academic Press, 832 p.
Selinus O. 2006. Introdução a geologia médica. In: Silva C.R et al. Geologia médica no Brasil: efeitos dos materiais e fatores geológicos na saúde humana, animal e meio ambiente. Rio de Janeiro, CPRM, 220 p. Available on line at: https://rigeo.sgb.gov.br/handle/doc/1211 / (acessed on 10 April 2025).
Selinus O., Finkelman R.B., Centeno J.A. 2010. Medical geology: a regional synthesis. New York, Springer Dordrecht Heidelberg London, 392. https://doi.org/10.1007/978-90-481-3430-4
Skinner H.C.W., Berger A.R. 2003. Geology and health: closing the gap. New York, Oxford University Press. https://doi.org/10.1093/oso/9780195162042.001.0001
Silva C.R., Mello E.F., Almeid, C.N. 2012. Proposta para avaliação de riscos geológicos à saúde ambiental em áreas de mineração. Revista Brasileira de Geociências, 42(2), 303-322. https://doi.org/10.5327/Z0375-75362012000200007
Smith B., Breward N., Crawford M.B., Galimaka D., Mushiri S.M., Reeder S. 1996. The environmental geochemistry of aluminium in tropical terrains and its implications to health. *Geological Society, London, Special Publications*, 113, 141-152. https://doi.org/10.1144/GSL.SP.1996.113.01.1
Singh H. 2004. Theoretical basis for medical geology. Sarawak, University Malaysia.
Suay L.L., Ballester D.F. 2002. Review of studies on exposure to aluminum and Alzheimer's disease. Revista Española De Salud Pública, 76(6), 645-658.
Taylor A. 2006. CAH: Clinical and analytical handbook: trace element analyse. 4th Ed. Guildford, UK, Royal Survey County Hospital.
Viglio E.P. 2010. O alumínio nas bacias dos Rios São Francisco e Doce no estado de Minas Gerais. Belo Horizonte, CPRM. Available online at: https://rigeo.sgb.gov.br/handle/doc/17285. / (acessed on 10 April 2025).