journal of Geoethics and social Geosciences

Journal of Geoethics and Social Geosciences, 01, 02, 2026; doi:10.4401/jgsg-117

Conflicts between mineral exploration and environmental conservation: an analysis of the dual role of geoscientists considering geoethics

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Article history: received May 6, 2026; accepted July 8, 2026; published July 17, 2026

Abstract

Historically, mineral exploration, prospecting, and extraction have been subjects of debate, with positions ranging from endorsement to criticism. In Brazil, these activities date back to the colonial period and intensified particularly from the 1940s onward, driven by the commercial exploitation of mineral resources and petroleum. In the early 21st century, technological advances expanded extraction and increased the demand for new port terminals in response to the intensification of international trade and changes in global logistics. This context has generated conflicts between the production and transportation of mineral resources and environmental conservation. In recent decades, geoscientists have emphasized that the impact of human activities on Earth already exceeds that of natural forces. In this scenario, the article analyses the tension between mineral extraction and conservation, highlighting the dual role of geoscientists in light of geoethics. To this end, two case studies are examined: mining in the Quadrilátero Ferrífero*, focusing on* Serra do Curral *in Minas Gerais State, and the debate over the construction of a port terminal in Ponta Negra, Rio de Janeiro State. These cases highlight*

the need for a geoethical approach, throughout the entire production chain, including legal aspects and intergenerational rights.

Keywords: Geoethics, Geosciences, Environmental conservation, Mining, Oil exploitation, Global logistics, Intergenerational justice.

1. Introduction

History shows that mineral exploitation dates back to the earliest periods, involving the search for mineral deposits from the extraction of clay for pottery production, through the development of knowledge and skills in working with metals, to the pursuit of precious stones and metals.

Exploration, prospecting, and extraction were driven by both, the challenge of discovering mineral resources and by the desire for profit. As reflected by Georgius Agricola (1494-1555), one may argue whether "the art of mining is truly profitable for those who practice it, or whether it is beneficial to the rest of humanity" (Agricola, 1556, p. 4).

It is evident that this activity has always been shaped by the relationship between the availability of mineral reserves, increasing human demand, and the pursuit of profit. The author also notes that "the profession of mining stands out in honour and dignity" being regarded as an excellent means "of acquiring wealth in an honourable way" (Agricola, 1556, p. 4).

However, mining activities require multiple areas of expertise, encompassing everything from extraction and processing to smelting, subsurface investigation, machinery manufacturing, and knowledge of legal regulations and juridical aspects, as illustrated in the following excerpt from Book I: "As a rule, one man understands only the methods of mining, another possesses knowledge of washing, another is experienced in the art of smelting, another has knowledge of measuring the hidden parts of the earth, another is skilled in the art of making machines, and finally, another is versed in mining law" (Agricola, 1556, p. 4).

This activity intensified from the 16th, 17th, and 18th centuries onward, driven by mineral exploitation during the colonial period, followed by the First Industrial Revolution, with

an emphasis on coal and iron, and the Second Industrial Revolution, marked by the prominence of oil and steel in the early 20th century. From the 1940s to the present day, there has been a growing demand for metals, metallic alloys, petroleum, and, more recently, for elements belonging to the group known as rare earth elements (Agricola, 1556; Simmons, 1968; Figueirôa, 2006; de Sousa Filho and Serra, 2014).

In contrast, mineral exploitation is marked by divergent views, ranging from appreciation to outright condemnation. As Georgius Agricola observes, "there has always been great disagreement among men regarding metals and mining, some praising them, others condemning them entirely" (Agricola, 1556, p. 4).

In this context, at the beginning of the 20th century, Vladimir Ivanovich Vernadsky (1863-1945)[1] presented early observations on the influence of human activities in transforming the natural environment, stating that "humankind, in particular, endowed with reason and capable of directing its will, has the power to reach, directly or indirectly, regions inaccessible to other living organisms," and that the idea of the "immutability of the limits of life in the biosphere must be approached with caution" (Vernadsky, 2019, p. 156).

In the 1940s, in his work The Biosphere and the Noosphere, Vernadsky (1945, p. 8) further argued that "man, for the first time in the history of the Earth, has known and embraced the entire biosphere, completed the geographical mapping of the planet Earth, and colonized its entire surface".

For the author, the concept of the noosphere emerges when human activity becomes a determining factor in the dynamics of the Earth system, meaning that "humanity, considered as a whole, is becoming a powerful geological force" (Vernadsky, 1945, pp. 8-9), which, based on science, technology, and social organization, becomes an agent capable of modifying the geosphere, the solid part of the Earth system, "from which the other spheres (atmosphere, hydrosphere, and biosphere) develop" (Bellaubi Fava, 2024).

The growing demand for mineral resources in the contemporary context results from intensified industrialization, urbanization, and technological advancement, factors that increase pressure on their exploitation. In addition to this are the expansion of international trade, the growth of global logistics chains, and the rising volume and complexity of freight transport, all of which drive an increased demand for port terminals, whether through the expansion of existing facilities, or the construction of new ones (Lima and Velasco, 1996).

[1] The book "Biosphere" by Vladimir Ivanovich Vernadsky was originally published in Russian as "биосфера" (in 1926), with translations into Spanish as "La Biosfera" (in 1997), English as "The Biosphere" (in 1997) and Portuguese as "Biosfera" (2019) (Vernadsky, 1997a, 1997b, 2019).

This context of growing demand for mineral resources, encompassing exploration, prospecting, and extraction, combined with the need to move and transport large volumes of natural resources, poses significant challenges related to sustainability, conservation, and environmental protection.

Considering this duality, this article aims at exploring the tension surrounding the role of geoscientists involved in the expansion of mineral exploitation, driven by increasing demand for natural resources, economic development, and technological advances, versus their role in the conservation of the environment, considering the impacts of these activities on natural systems.

It is within this field of tensions that geoethics is situated, a topic widely discussed in the scientific literature, whose historical development reflects the growing awareness of human impacts on the Earth system. Initially focused on professional conduct in the geosciences (Peppoloni and Di Capua, 2012), geoethics has expanded, especially from the late 20th and early 21st centuries onward, to encompass social, cultural, and political issues, consolidating itself as an interdisciplinary field aimed at promoting responsibility, sustainability, and intergenerational justice (Peppoloni and Di Capua, 2015; Peppoloni et al., 2015; Bobrowsky et al., 2017; Peppoloni et al., 2019; Bohle and Marone, 2021).

More recently, initiatives such as the International Geoethics Research Infrastructure (IGRI) have reinforced this perspective by integrating geosciences, the humanities, and society in the search for ethical solutions to global challenges (Peppoloni and Di Capua, 2024b; Di Capua and Peppoloni, 2025).

In this sense, two case studies in Brazil are analysed (Figure 1): mining in the *Quadrilátero Ferrífero*, with emphasis on the *Serra do Curral* area and Pico de Belo Horizonte, in Minas Gerais State, and the proposal to construct a Liquid Bulk Port Terminal and a Shipyard for Naval Construction and Repairs, more directly referred to as the so-called *Ponta Negra* Port Terminal (TPN in Portuguese), in the municipality of Maricá, in Rio de Janeiro State, considering historical, territorial, and environmental aspects.

2. Methodology

Our research is based on a concise literature review on the concept of geoethics, aiming at understanding its development and main approaches over time. It starts from the recognition of the impacts of human activities on nature, moves through the consolidation of a normative field focused on ethical conduct in geoscience research and practice, and extends to its expansion beyond the professional sphere, incorporating the relationships between science, society, politics, and education.

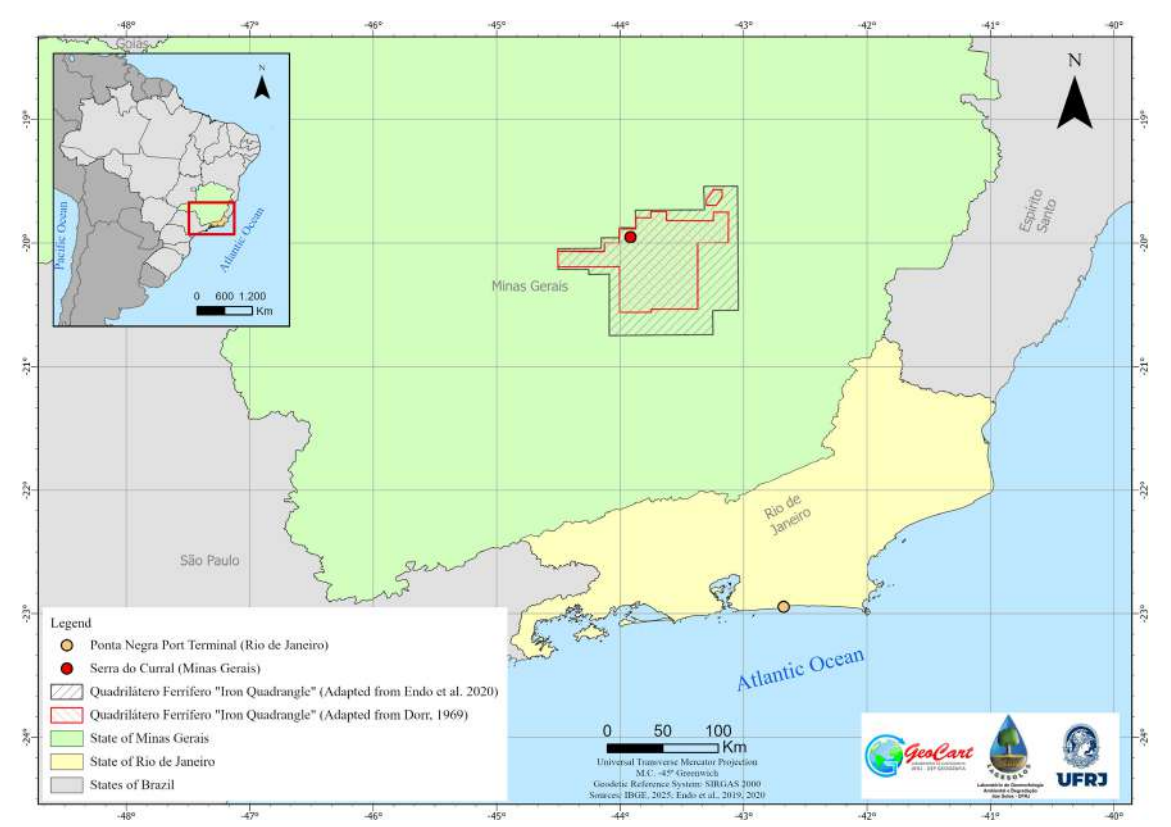

Figure 1. *Location map of the Quadrilátero Ferrífero in Minas Gerais and the Ponta Negra Port Terminal (TPN) project in Rio de Janeiro, Brazil. Created with ArcGIS Pro (Version 3.7) by Esri.*

Within this trajectory, presented chronologically in the literature review (Figure 1), geoethics has been taking shape as a global ethical project aimed at addressing contemporary crises. This occurs through the guidance of social actions, the promotion of planetary citizenship, the defence of intergenerational justice, and the encouragement of interdisciplinary and multidisciplinary dialogue in the search for sustainable solutions to global socio-environmental challenges. These concepts are presented within a particular normative framework, recognizing that alternative value systems and normative perspectives may also offer valid approaches to understanding and addressing socio-environmental issues.

The article adopts a qualitative methodological approach to analyse the tension between the need for mineral exploitation and environmental conservation,

highlighting the dual role geoscientists are expected to play from a geoethical perspective (Figure 2).

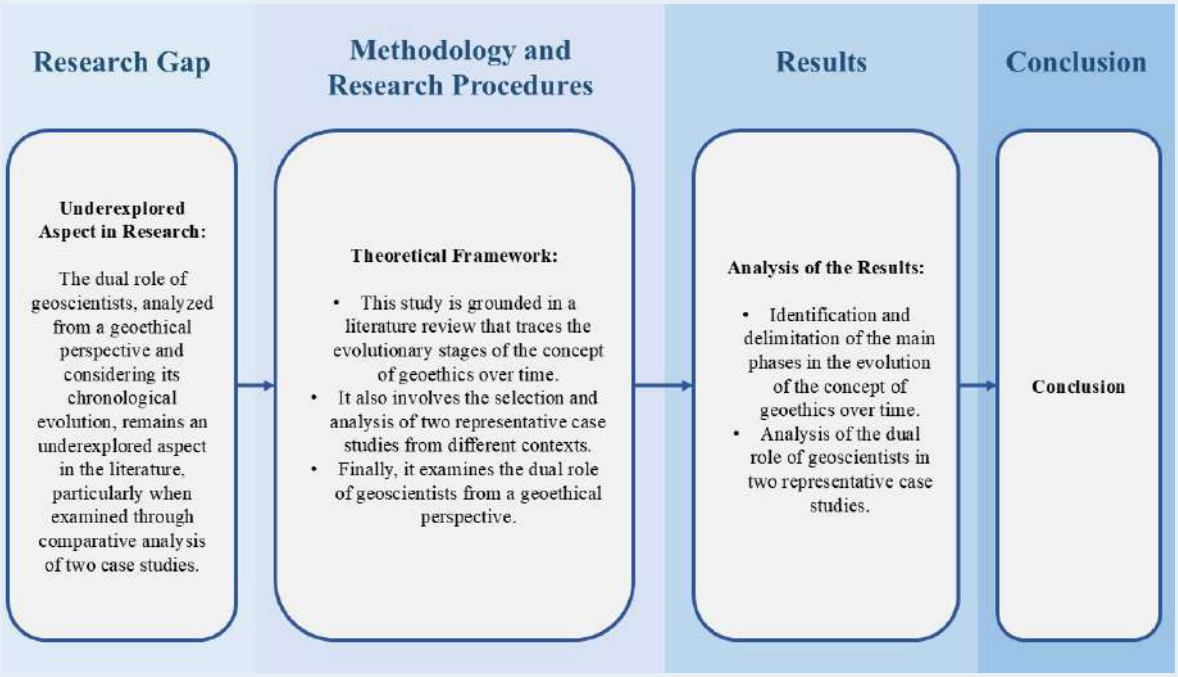

Figure 2. *Flowchart of the research methodology and procedures on the dual role played by geoscientists.*

For this purpose, these two representative case studies from different contexts are analysed, highlighting the characteristic features of each historical period: the mining activities in *the Quadrilátero Ferrífero*, located of Minas Gerais State (Simmons, 1968; de Andrade, 1976; MPMG, 2022), and the debate surrounding proposed construction of a port terminal in *Ponta Negra*, located in Rio de Janeiro State (GAEMA/MPRJ and MPF, 2019; Silveira et al., 2023; Souza et al., 2025).

The analysis seeks to highlight the dual role played by geoscientists, who act both in the exploration, prospecting, and exploitation of mineral resources and in environmental protection and conservation.

3. Results

The results focus on analysing the tension between economic interests and environmental preservation across different historical and territorial contexts. In this scenario, geoscience provides the scientific basis for understanding Earth systems, while geoscientists working in diverse professional and institutional settings may find themselves in an ambivalent position between mineral resource development and environmental conservation.

This ambivalence does not arise from geoscience as a scientific discipline but from the different roles assumed by geoscientists. In carrying out their professional responsibilities, geoscientists may face ethical dilemmas arising from conflicts between institutional expectations and their own values and principles. These dilemmas illustrate key issues and challenges addressed by geoethics.

Through a literature review on the emergence and evolution of this concept, as well as the analysis of the two selected case studies, it was possible to identify patterns and specificities, in the relationship between natural resource exploitation and environmental conservation, particularly in the context of mining in the *Quadrilátero Ferrífero*, with emphasis on the *Serra do Curral* area (MG), and the proposed construction of a port terminal in *Ponta Negra* (RJ).

3.1. Brief literature review on the emergence and evolution of the concept of geoethics

From the literature review on the emergence and evolution of the concept of geoethics, the dual role of geoscientists becomes evident. While they technically contribute to the identification, assessment, and exploitation of mineral resources, they are also called upon to act ethically and responsibly, taking into account the social, environmental, and intergenerational impacts of their practices.

The historical evolution of geoethics (Figure 3) is a subject widely discussed in the scientific literature (Peppoloni and Di Capua, 2012; Peppoloni et al., 2015; Di Capua et al., 2017; Bobrowsky et al., 2017; Bohle, 2019; Peppoloni et al., 2019; Castro et al., 2021; Imbernon et al., 2021; Peppoloni and Di Capua, 2021a; Peppoloni and Di Capua, 2024a; Peppoloni and Di Capua, 2024b; Peppoloni and Di Capua, 2026).

It begins with the emergence of an awareness of human impacts on planet Earth, especially from the 18th and 19th centuries onward, "when anthropogenic impacts on nature began to be recognized and documented," and into the early 20th century. This awareness then evolves from the mid-20th century, driven by the intensification

of environmental degradation and imbalances in natural systems, largely caused by human activities (Peppoloni et al., 2019).

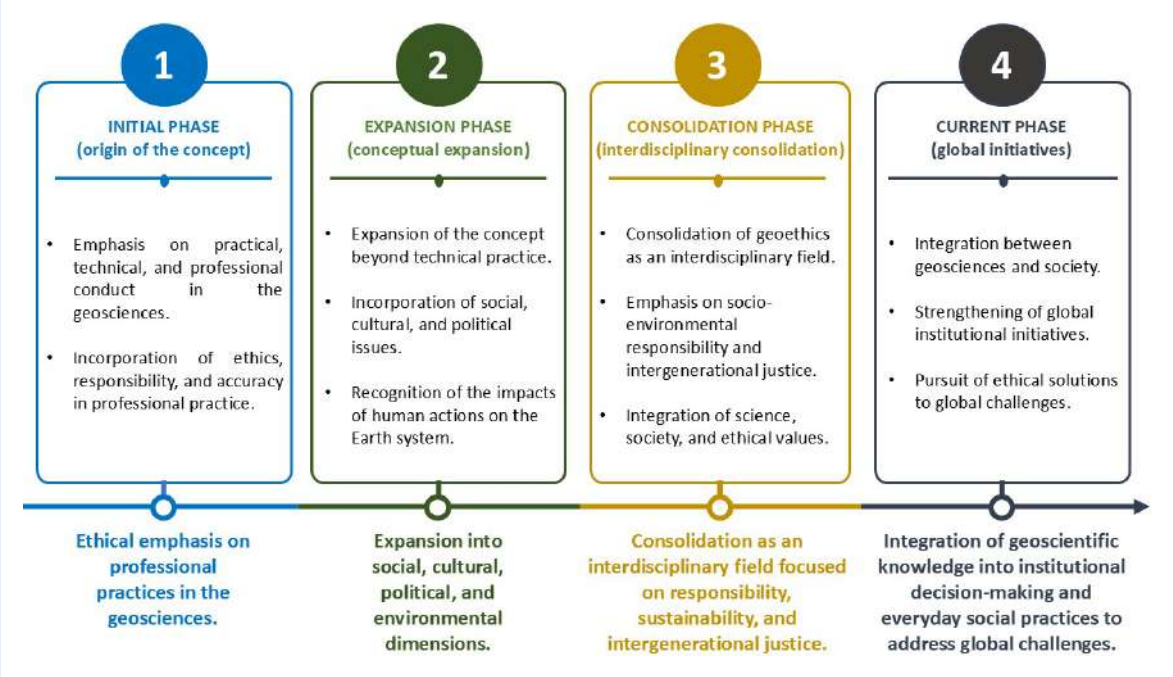

Figure 3. *Timeline of the evolution of the concept of geoethics: increasing awareness of impacts, integration between geosciences and society, commitment to present and future generations, and the search for ethical solutions to global challenges.*

In the 1990s (Initial Phase), the term geoethics emerged more effectively, initially focused on discussing the ethical implications of geosciences, with an emphasis on professional practice grounded in responsibility, awareness, accuracy, cooperation, impartiality, and the application of appropriate methods and technologies (Peppoloni and Di Capua, 2012; Bohle, 2019; Peppoloni et al., 2019).

From the beginning of the 21st century onward, the concept of geoethics became consolidated with the formation of a scientific community, dedicated to the topic and the expansion of debates on the values that guide human actions in relation to the Earth system (Peppoloni and Di Capua, 2015). In this sense, "geological heritage, geodiversity, and geoconservation are practical expressions of a geoethical vision of the planet" (Peppoloni et al., 2019).

From 2010 onward (Expansion Phase), the concept of geoethics began to consolidate, becoming understood as "an opportunity for geoscientists to increase awareness of their individual and social responsibility," as well as to strengthen the links between places of origin and individual and collective memories, and to "enhance our understanding of space and time" in light of human and economic development (Peppoloni and Di Capua, 2012).

An internationally shared understanding of geoethics emerged through discussions within the international geoscience community, beginning at the European Geosciences Union General Assembly in 2011, continuing at the 34th International Geological Congress in Brisbane, Australia, in 2012, and culminating in the adoption of the Cape Town Statement on Geoethics at the 35th International Geological Congress in Cape Town, South Africa, in 2016. The Statement articulated the ten fundamental values of geoethics (Di Capua et al., 2017).

According to Abbott (2020, p. 21), "the first six of these values are more or less standard components of codes of ethics in the geosciences," but as an innovation, particular emphasis is placed on the protection of geodiversity, the appreciation of geological heritage, the assurance of intergenerational sustainability, and the promotion of geoeducation and scientific communication.

It is also worth highlighting the first normative formulation, particularly through the proposal of a "geoethical oath," emphasizing the social responsibility of geoscientists and the preservation of the planet (Matteucci et al., 2014), as well as on the reflection of ethical, scientific, social, and cultural values that guide human practices in their interaction with the physical, biotic, social, and technological components of the Earth system (Peppoloni and Di Capua, 2015).

During this period, geoethics becomes established as a scientific and professional field within the geosciences, highlighting the role of geoscientists as social agents, as well as the importance of interdisciplinarity, in structuring values for both science and society (Bobrowsky et al., 2017; Peppoloni et al., 2019).

From 2020 onward (Consolidation Phase), geoethics has come to be understood as a political, educational, and social project with global reach, in which issues such as responsibility, sustainability, and risk are addressed as global challenges. This understanding is reflected in proposals involving changes in social behaviour, based on integration with nature and in a perspective of "ecological humanism" (Peppoloni and Capua, 2021).

As well as in the adoption of geoethical principles and values aimed at building a new society, with "new forms of communication, new ways of building relationships, new tools to educate people to be respectful and inclusive, new structures of social organization, and new approaches to the environment" (Peppoloni and Di Capua,

2021). It therefore represents an educational and political application grounded in ethical formation.

From 2024 onward (Current Phase), geoethics has come to be understood as a response to multiple crises, effectively marking the transition from a concept associated with the professional ethics of geoscientists to a global ethic aimed at guiding the future of humanity. It is based on a critical global approach that frames the current situation as a convergence of crises, such as a socio-ecological crisis, a civilizational crisis, or even a crisis of humanity itself (Peppoloni and Di Capua, 2024a, 2024b).

It is also worth highlighting the more recent emergence of the International Geoethics Research Infrastructure (IGRI), resulting from the articulation between the International Association for Promoting Geoethics (IAPG), the Geoethics Commission of the International Union of Geological Sciences (IUGS), and the Geoethics Chair of the International Council for Philosophy and Human Sciences (CIPSH). This initiative promotes geoethics through the integration of geosciences, humanities, and society, fostering interdisciplinary and multidisciplinary dialogue, as well as research and education, with the aim of aligning scientific knowledge with ethical values in the search for sustainable solutions to contemporary environmental and social challenges (Di Capua and Peppoloni, 2025).

Faced with new challenges such as the intensive exploitation of natural resources, social inequalities, and the fragility of global governance structures, many geoscientists and various sectors of society have been prompted to reconsider current development models. However, this debate reflects normative frameworks and value systems that are particular rather than universal, given the existence and legitimacy of alternative normative frameworks and value systems.

This shift in thinking represents a new paradigmatic event, in which human beings are effectively understood as an integral part of nature. The search for a balance between human progress and ecological limits reflects this duality, which is historically referred to as “ecological humanism” (Morris, 2017). It is important to highlight that, for Peppoloni and Di Capua (2025), “ecological humanism” does not merely advocate for a balance between human development and ecological constraints but proposes a new understanding of human flourishing, viewed as inseparable from the well-being of the Earth system.

The search for interdisciplinary solutions, grounded in scientific evidence and in the expansion of engagement of public institutions and different social actors in decision-making processes, is methodologically based on a Relational Geoscientific Pragmatism (RGP). Its priorities include the ethical use of geospatial technologies, the promotion of environmental justice, and the strengthening of geoethical education, configuring themselves as emerging trends for the future (Peppoloni et al., 2025).

3.2. Case study: mining in the *Quadrilátero Ferrífero*, with emphasis on *Serra do Curral*, located in Minas Gerais State (MG)

Regarding the implementation of mining projects, the case of *Serra do Curral* and, consequently, *Pico de Belo Horizonte*, located across the municipalities of Belo Horizonte, Sabará, and Nova Lima in Minas Gerais State, is of particular importance because it exemplifies the tensions between mineral resource exploitation and environmental conservation while also revealing the ethical, social, cultural, and economic conflicts inherent in mining activities. An analysis of this case thus makes it possible to identify the historical stages underlying the contrast between the promotion of and the criticism directed at mineral exploitation.

Since colonization, Brazilian territory has been seen as a potential source of mineral wealth; however, the technical limitations of extraction in the 15th and 16th centuries meant that this search proved unsuccessful or economically unfeasible (Figueirôa, 2006). This scenario was only reversed in the 17th and 18th centuries, with the exploitation of gold and diamonds becoming economically viable, especially in the state of Minas Gerais, when "Brazil accounted for approximately 50% of the world's gold and diamond production" (Machado and Figueirôa, 2001).

However, with the depletion of alluvial deposits, mineral exploitation once again became economically unviable, a situation further aggravated in the 19th century by new constraints, such as the lack of adequate training for mining professionals and legal issues arising from complex and incomplete legislation (Figueirôa, 2006). The late 19th and early 20th centuries were marked a period of institutional and legal modernization of Brazil's mining sector, characterized by the establishment of key institutions, including the *Ouro Preto* School of Mines, the Geological and Mineralogical Survey of Brazil, and the National Department of Mineral Production (DNPM), as well as the enactment of the 1934 Mining Code (Brasil, 1934; Calógeras and Guimarães, 1938; Dorr, 1969; Machado and Figueirôa, 2001; Figueirôa, 2006).

Following the signing of a cooperation agreement in 1945 between Brazil, represented by the National Department of Mineral Production (DNPM), and the United States of America, represented by the United States Geological Survey (USGS), geological research and professional training expanded significantly throughout the country. This collaboration led to the establishment of undergraduate geology programs under the National Campaign for the Training of Geologists (1957) and culminated in the regulation of the geology profession in 1962 (Brasil, 1957, 1962; Rabbitt, 1989; Barroso, 1996; Machado and Figueirôa, 2001; Reis et al., 2019).

During the same period, the Brazilian government promoted the expansion of the mining sector through both public and private initiatives, including projects in the *Serra do Curral* region. Within the framework of this international cooperation,

extensive geological mapping and mineral resource assessments were carried out across the *Quadrilátero Ferrífero*. These efforts culminated in the landmark studies of Dorr (1963, 1969) and Simmons (1968), which documented the region's geology, assessed its mineral potential, and demonstrated the feasibility of iron ore exploitation (Belo Horizonte, 1961; Dorr, 1963; Simmons, 1968; Dorr, 1969; Custódio and Ribeiro, 2021).

During this period, geoscientists were primarily focused on professional practices, especially the application of best techniques for geodetic and geological surveys. Ethical aspects were centred on professional responsibility, scientific integrity, data accuracy, as well as the execution of technical and economic feasibility studies and the estimation of mineral resource quantities for exploitation purposes.

Conversely, from the 1960s onward, social, cultural, and political dimensions began to develop in parallel with mineral resource exploitation, particularly iron ore, which was predominantly carried out through open-pit mining, increasing environmental degradation in the affected areas. In this context, initiatives aimed at landscape protection emerged, based on Law†No. 378 of January 13, 1937, which created the National Historical and Artistic Heritage Service (SPHAN), later renamed the National Institute of Historic and Artistic Heritage (IPHAN) (Brasil, 1937, 1988).

It is a public institution whose mission is to protect, preserve, and to promote Brazilian cultural heritage, understood in a broad sense, as the set of spaces where society and nature interact and that, over time, have acquired historical, aesthetic, and symbolic values (Brazil, 1937, 1988).

Serra do Curral was listed as a heritage site under Brazilian legislation on September 20, 1961. This legal instrument constitutes a protection mechanism that recognizes the cultural and landscape significance of a given site, establishing the requirement for prior authorization for any interventions capable of affecting the attributes that justify its preservation (Custódio and Ribeiro, 2021).

In the *Serra do Curral* area, iron ore mining took place both in Belo Horizonte Municipality and in Nova Lima, causing significant alteration of the mountain landscape, even after its heritage listing, although with different dynamics in each locality.

This period was marked by the expansion of mining activities, which advanced toward the summit of *Serra do Curral*. Such degradation of the natural landscape raised numerous concerns within society, which began to advocate for its preservation in the face of real estate and mining pressures.

Among these manifestations, the work of the poet Carlos Drummond de Andrade (1902-1987) stands out (de Andrade, 1976), who, distressed by the degradation of the landscape he deeply valued, decided to leave Belo Horizonte and move to Rio de

Janeiro. Before that, however, as a form of protest, he published the poem titled *Triste Horizonte* in *Jornal do Brasil* on August 14, 1976. An excerpt from the poem reads:

> *"Prohibited to feel the air of freedom of these heights,*
> *prohibited to live the wild intimacy of these stones that are being turned into money.*
> *This mountain has an owner.*
> *Nature no longer governs it.*
> *An ancient alliance, a rite of the city, dissolves with the ore.*
> [...]
> *I saw the mountains, and behold, they trembled.*
> *And all the hills shook.*
> *I looked at the land, and behold, it was empty, nothing nothing nothing"* (de Andrade, 1976).

It should be noted that, from the 1970s onward, environmental issues gained increasing prominence with the emergence of the modern environmental movement and were subsequently institutionalized through the establishment of environmental policies, regulatory frameworks, and governmental agencies. During this period, in the United States of America, the National Environmental Policy Act (NEPA) was enacted on January 1, 1970, establishing the requirement for environmental impact assessments and the evaluation of socioeconomic effects prior to decision-making processes concerning applications for licenses to exploit mineral resources (EPA, 1969).

In the Brazilian context, such procedures were only incorporated into equivalent legislation with the enactment of Law No. 6,938, of August 31, 1981, which established the National Environmental Policy (PNMA). This law requires prior assessment of environmental impacts and socio-economic consequences as a condition for granting licenses for mineral resource exploitation (Brasil, 1891).

A differentiation can be observed in the practices adopted by civil society regarding mining exploitation in *Serra do Curral* and *Pico de Belo Horizonte*. In Belo Horizonte, civil society pressure aimed at the preservation of cultural and environmental heritage led to significant changes, such as the deactivation of Ferrobel's activities (in 1979) and the creation of a protected area, initially established by Decree No. 1,466 of October 14, 1966, later consolidated by Law No. 2,403 of December 30, 1974, and effectively implemented in the early 1980s (Custódio and Ribeiro, 2021).

In contrast, in the sector oriented toward Nova Lima Municipality, mining activities continued intensively under MBR, currently Vale S.A., remaining in operation until resource depletion in 2006. After this period, according to Custódio and Ribeiro (2021), mine closure activities began to follow state environmental regulations, such

as the Mine Closure Plan (PAFEM), regulated by the Normative Deliberation (DN) of the State Council for Environmental Policy (COPAM) No. 220 of 2018, under the supervision of the State Secretariat for Environment and Sustainable Development of Minas Gerais (SEMAD).

During this period, geoscientists began to incorporate social, cultural, environmental, and political issues into their professional practices, in recognition of human impacts on the Earth system. Ethical considerations thus came to encompass, not only an understanding of one's professional role, but also the notion of responsibility at both the individual level and toward society.

Decades later, the conflict between mineral exploitation and social concerns arising from the degradation of the natural landscape in *Serra do Curral* and *Pico de Belo Horizonte* persists, as well as debates over their historical, cultural, social, and environmental values and attributes.

This scenario is evident in the case of mineral exploitation carried out by *Taquaril Mineração* S.A. (TAMISA), in the sector located in *Nova Lima* Municipality, particularly in the *Serra do Taquaril* Mining Complex (CMST) project. The project sought licensing between 2013 and 2014 and later, in 2020, under administrative procedure SLA No. 218/2020. It was approved on April 29, 2022, by the Mining Activities Chamber (CMI) for an installation license in Nova Lima, although with potential impacts in Belo Horizonte and *Sabará* Municipalities. (MPMG, 2022).

On this premise, the Public Prosecutor's Office of the State of Minas Gerais (MPMG), jointly with the Federal Public Prosecutor's Office (MPF), filed a Public Civil Action (No. 5052107-55.2022.8.13.0024) against the aforementioned mining project, arguing that the issued licenses contained legal defects and could lead to unjustifiable environmental degradation in *Serra do Curral* area.

These grounds were considered sufficient to justify the annulment of the granted environmental licenses, as flaws were identified both in the application prepared by the geoscientists involved in the licensing studies and in the performance of those who, in theory, should have assessed their impacts in conjunction with civil society, within the scope of the Mining Activities Chamber (CMI) and the National Mining Agency (ANM) (MPMG, 2022).

In another Public Civil Action (No. 1013555-21.2018.4.01.3800) filed by the Federal Public Prosecutor's Office (MPF), in joint litigation with the Public Prosecutor's Office of the State of Minas Gerais (MPMG) and the Municipality of Belo Horizonte, against the National Mining Agency (ANM) and the Federal Government, the plaintiffs sought a declaration of illegality of IPHAN Ordinance No. 444/2016, arguing that it significantly reduced the protected area of *Pico de Belo Horizonte* (MPMG, 2022; JFMG, 2026).

In 2026, the legality of the reduction of the protected area of *Pico de Belo Horizonte* was challenged on the grounds that it violated IPHAN regulations and municipal

legislation prohibiting mining activities in listed heritage areas of *Serra do Curral*. A technical assessment conducted by the Public Prosecutor's Office of the State of Minas Gerais (MPMG) found that the protected area had been reduced from 42.25 to 9.23 hectares. In response to these irregularities, the Federal Court suspended 57 mining administrative proceedings affecting *Serra do Curral*, declared IPHAN Ordinance No. 444/2016, which was responsible for reducing the protected area, unlawful, and reinstated the validity of IPHAN Ordinance No. 198/2016 (JFMG, 2026). In view of this, the geoethical debate is embedded in the role of geoscientists, guided by the defence of the public interest and the integrity of scientific truth, as opposed to potential practices of instrumentalizing knowledge to validate strictly economic interests.

In parallel, geoscientists have begun to promote initiatives aimed at encouraging behavioural change based on integration with nature, such as the creation of geoparks grounded in an integrated set of scientific, social, and cultural criteria. In this context, the proposal by Azevedo et al. (2012) (Figure 4) stands out. The authors characterize the *Quadrilátero Ferrífero* in its natural, socioeconomic, and infrastructural aspects, highlighting its potential for recognition as a UNESCO Global Geopark (UNESCO, 2022).

In terms of significant geological heritage, the authors emphasize the historical importance of the area for mining in Brazil, as well as its geological relevance, since 31 sites of geological, historical, ecological, and cultural interest have been identified there, along with initiatives in geoconservation, geotourism, and education (Azevedo et al., 2012).

The highlights include geosite No. 7, *Serra do Curral*, characterized as being of "national interest from a scientific, educational, aesthetic, cultural, historical, and touristic perspective, located in the municipalities of Belo Horizonte and Nova Lima," as it still preserves "part of the original name of the settlement that developed at its base, *Curral Del Rey*, today Belo Horizonte." Geosite No. 15, known as *Mina de Águas Claras*, in Nova Lima, is described as a "site of regional interest from a scientific and educational perspective, located in *Serra do Curral*, next to *Parque das Mangabeiras*." More broadly, the non-geological site No. 1, *Parque das Mangabeiras*, is described as "located at the foot of *Serra do Curral*" and "designed by landscape architect Roberto Burle Marx," preserving within its 2.8 million square meters 21 springs of the Serra stream, which is part of the *Rio das Velhas* Basin (Azevedo et al., 2012).

More broadly, this proposal suggests that recognition as a geopark can promote an integrated vision of environment, geology, and society, articulating different fields of knowledge (Azevedo et al., 2012). Beyond the scientific and environmental dimensions involved in the geopark proposal, its implementation also invites reflection

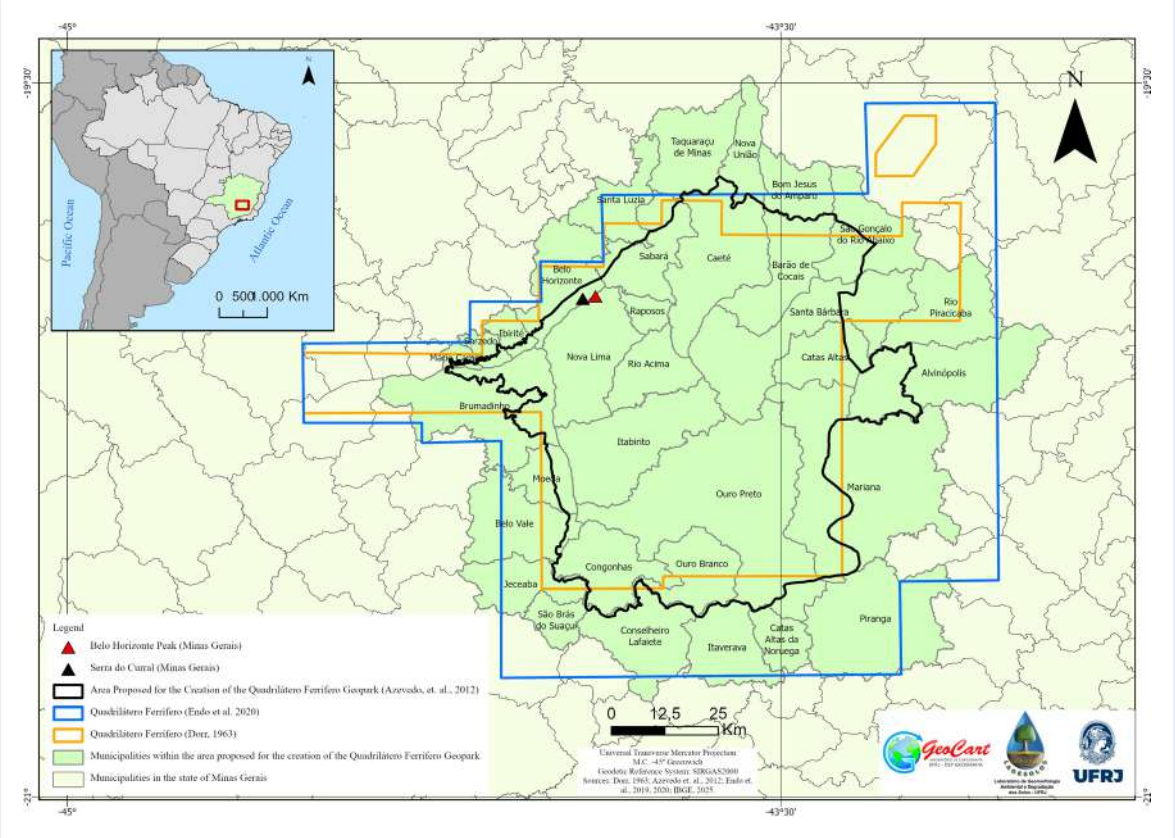

Figure 4. *Map comparing the proposed boundaries for the creation of the Quadrilátero Ferrífero Geopark in 2012 with the boundaries of the Quadrilátero Ferrífero as defined in 1963 and 2019-2020. Created with ArcGIS Pro (Version 3.7) by Esri.*

on the role and responsibilities of the geoscientists and consultants involved in this process.

According to Smith (2021, p. 159-162), professionals engaged in consulting activities, compared with those employed directly by large corporations, may enjoy relatively greater autonomy in selecting clients and projects that are more closely aligned with their professional and social values. However, this autonomy is limited, as these professionals exercise little control over how their work is subsequently used by the contracting companies, which may give rise to ethical tensions and diffuse responsibility. Thus, although they retain some degree of discretion, they remain embedded within corporate structures on which they are economically

dependent and may ultimately contribute to legitimizing certain mining projects. Faced with these dilemmas, many adopt a pragmatic stance, seeking to promote gradual changes in existing practices rather than advocating for a structural transformation of the system.

These ethical concerns have become increasingly relevant in contemporary geoscientific practice. Greater emphasis has been placed on professional conduct, scientific integrity, data accuracy, and the application of best techniques in updating geodetic and geological surveys.

In this context, Endo et al. (2020) produced a new geological mapping of the *Quadrilátero Ferrífero* at a scale of 1:150,000. The project was developed to commemorate the fiftieth anniversary of Dorr's (1969) work and resulted in an expansion of the *Quadrilátero Ferrífero* area from approximately 7,000 km^2 to about 12,785 km^2.

The study also incorporated new stratigraphic and structural geology data, aiming at improving the understanding of the connections between *Quadrilátero Ferrífero* and terrains affected by Neoproterozoic-Cambrian deformation (Castro et al., 2020; Endo et al., 2020).

3.3. Case study: proposal for the construction of the *Ponta Negra* Port Terminal (TPN), located in Rio de Janeiro State (RJ)

From the colonial period until the opening of the ports in 1808, Brazilian ports were primarily oriented toward the export of sugar, gold, and later coffee. After that date, a process of investment in port infrastructure began, intensifying in the early 20th century, driven by industrialization and state intervention.

In the late 20th and early 21st centuries, important reforms took place, such as Law No. 8,630 of February 25, 1993, which "restructured the Brazilian port sector, opening space for private sector participation in the operation of ports and terminals," and later Law No. 12,815 of June 5, 2013, which repealed it and "regulated the direct and indirect exploitation of ports and port facilities in the country." Both contributed to the modernization of port management and to the expansion of private sector participation in the industry (Brasil, 1993; Lima and Velasco, 1996; Brasil, 2013).

Among the innovations introduced by this latter law, the modernization of the regulatory framework of the port sector stands out, aiming at increasing competitiveness, attract private investment, and reduce logistics costs, as well as the expansion of the possibility for private-use terminals (TUPs) to handle third-party cargo, with greater flexibility in authorization rules (Brasil, 2013).

In contrast, areas designated for the installation of port terminals generate impacts on biodiversity and geodiversity, such as the removal of coastal ecosystems,

destruction of geosites, and alteration of geomorphological processes, as well as socio-environmental impacts, including conflicts with fishing communities and pressure on urban infrastructure.

It should be noted that the term geosite is used across different fields of knowledge, and its definition varies according to the adopted approach. From a geographical perspective, a geosite corresponds to a geographically defined occurrence of geodiversity that presents scientific, aesthetic, ecological, touristic, cultural, and educational values (Jorge and Guerra, 2016). In contrast, Brilha (2016), adopting a more restrictive perspective centred on geology and the scientific value of geological heritage, proposes that the term geosite should be used to characterize locations with recognized scientific relevance, based on criteria such as rarity, integrity, and scientific or educational potential. Other sites that present touristic, cultural, or educational values, but lack significant scientific relevance, are classified as geodiversity sites.

In the context of port infrastructure development, it is relevant to analyse the case of the *Ponta Negra* Port Terminal (Ponta Negra) project, whose construction is planned in the municipality of Maricá, in the state of Rio de Janeiro, specifically in the *Ponta Negra* area, adjacent to Jaconé Beach. This area presents high geological, historical, archaeological, and cultural relevance, as demonstrated by existing studies (GAEMA/MPRJ and MPF, 2019).

The area exhibits outstanding scenic beauty and encompasses significant cultural, historical, archaeological, and scientific values, characterized by historical sites associated with human occupation of Brazilian territory, prehistoric sites such as shell middens and lithic workshops, as well as biodiversity characterized by the presence of endemic species. From a geological perspective, the region stands out for its internationally significant geosites, which provide essential information for understanding the evolution of the Earth. The territory contains rocks ranging in age from the Paleoproterozoic to the Holocene, reflecting a long geological history and the diversity of geological processes responsible for its evolution (Mansur et al., 2012).

In contrast, it is also important to highlight the antagonism between port development projects and tourism initiatives associated with the region's scientific, historical, cultural, geological, and archaeological heritage (Figure 5) (GAEMA/MPRJ and MPF, 2019).

According to Silveira et al. (2023), the studies submitted by the project developer did not adequately consider relevant scientific works, and the analytical techniques and methodologies adopted were considered inappropriate, raising concerns regarding the professional and ethical responsibilities that geoscientists have toward society. Furthermore, as Silveira et al. (2023) point out, the responsibility of geoscientists toward society and the environment becomes particularly evident in the assessment of large-scale development projects. In this context, special attention should be

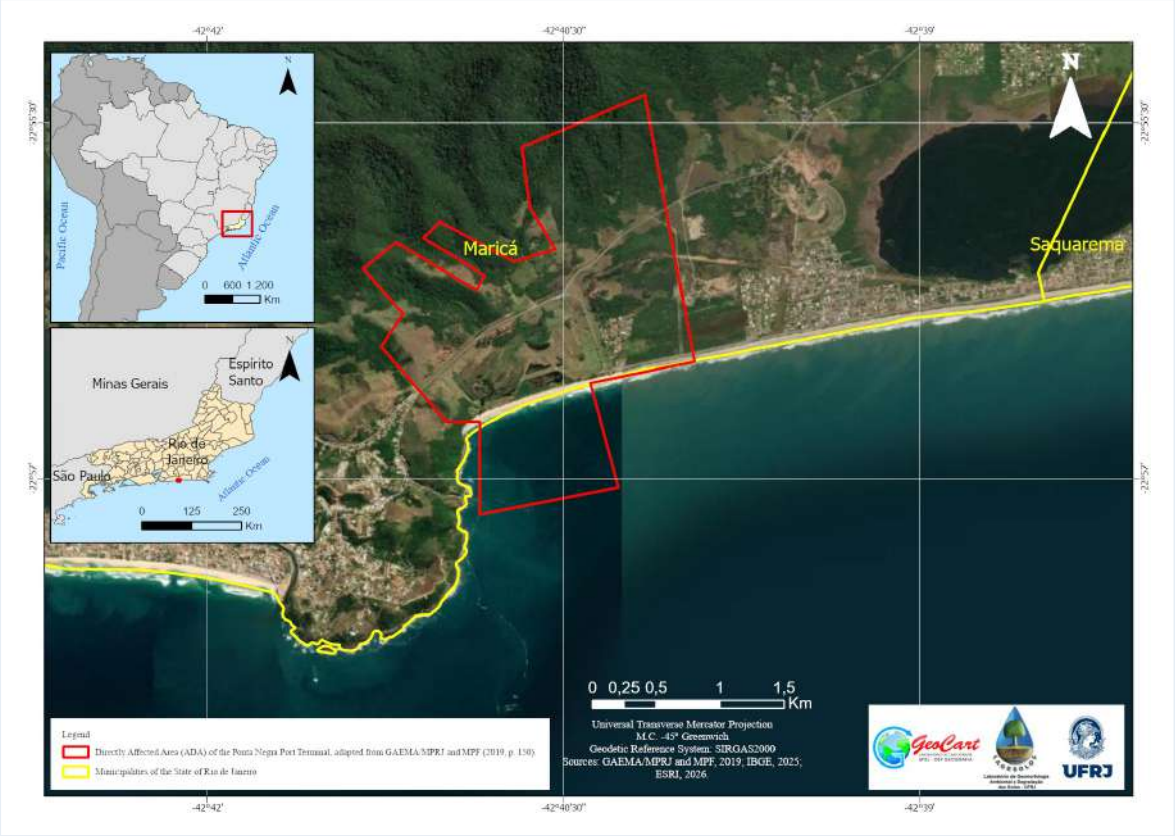

Figure 5. *Map of potential land-use conflicts. Source: GAEMA/MPRJ and MPF (2019). Created with ArcGIS Pro (Version 3.7) by Esri.*

given to the proposed *Ponta Negra* Port Terminal, as it may affect an area containing coastal sedimentary deposits cemented by carbonate precipitation, first described by Charles Darwin (1809-1882) in 1832 and known as the *Darwin beachrocks*. These deposits constitute a site of recognized geological and historical significance, representing a unique example of coastal geological heritage in Brazil.

From a geoethical perspective, this study analyses the proposal for the construction of the *Ponta Negra* Port Terminal (TPN), located in the state of Rio de Janeiro, Brazil, examining how economic, social, environmental, and political considerations are addressed and negotiated in decision-making processes related to the implementation of the project. The analysis focuses particularly on aspects related to geodiversity, geoconservation, and the protection of geological heritage. The limitations identified

in the environmental assessment have become the subject of legal proceedings involving the project developer, government authorities, scientists, civil society organizations, and the Public Prosecutor's Office of the State of Rio de Janeiro (GAEMA/MPRJ and MPF, 2019).

However, it is important to emphasize that, in the decision on the preliminary injunction request issued by the Federal Supreme Court (*Supremo Tribunal Federal*) in Extraordinary Appeal No. 1,478,946/RJ, dated March 4, 2024, the Court held that the documents presented by the project developer, environmental agencies, and the State of Rio de Janeiro, particularly the technical opinion issued by geoscientists from the State Environmental Institute (INEA), indicated the absence of *beachrocks* in the area. Conversely, the material submitted by the Public Prosecutor's Office did not prove otherwise. The Court concluded that the responsible agencies are carrying out adequate oversight and that there are no indications of non-compliance with the previous decision (STF, 2024).

The dual role of geoscientists is noteworthy, encompassing both those who collaborate with development projects and those who work alongside the Public Prosecutor's Office, an institution permanently responsible for defending the legal order, the democratic regime, and diffuse and collective social interests, as well as those engaged in dialogue with civil society. In this context, by incorporating social, cultural, environmental, political, and ethical issues into their professional practice, these professionals expand their understanding not only of their own role, but also of responsibility at both individual and collective levels, including legal accountability. In this context, the geoethical debate concerns the role of geoscientists in safeguarding scientific integrity and ensuring that scientific knowledge is not selectively used or distorted to legitimize predetermined political outcomes or development objectives. Instead, scientific knowledge should contribute to transparent decision-making processes capable of balancing economic, environmental, and social interests.

In parallel, geoscientists have begun to encourage initiatives aimed at fostering behavioural change based on integration with nature, such as the creation of geoparks grounded in an integrated set of scientific, social, and cultural criteria.

In this context, the proposal by Mansur et al. (2012) stands out, in which the *Geoparque Costões e Lagunas* is characterized in its natural, socioeconomic, and infrastructural aspects, highlighting its potential for UNESCO recognition (UNESCO, 2022).

It should be noted that the proposed area for the creation of the *Costões e Lagunas* Geopark encompasses 16 municipalities, covering approximately 10,900 km^2 (Figure 6) (Mansur et al., 2012).

In terms of significant geological heritage, the authors emphasize the historical and cultural importance of the area since the discovery of Brazil, as well as its geological

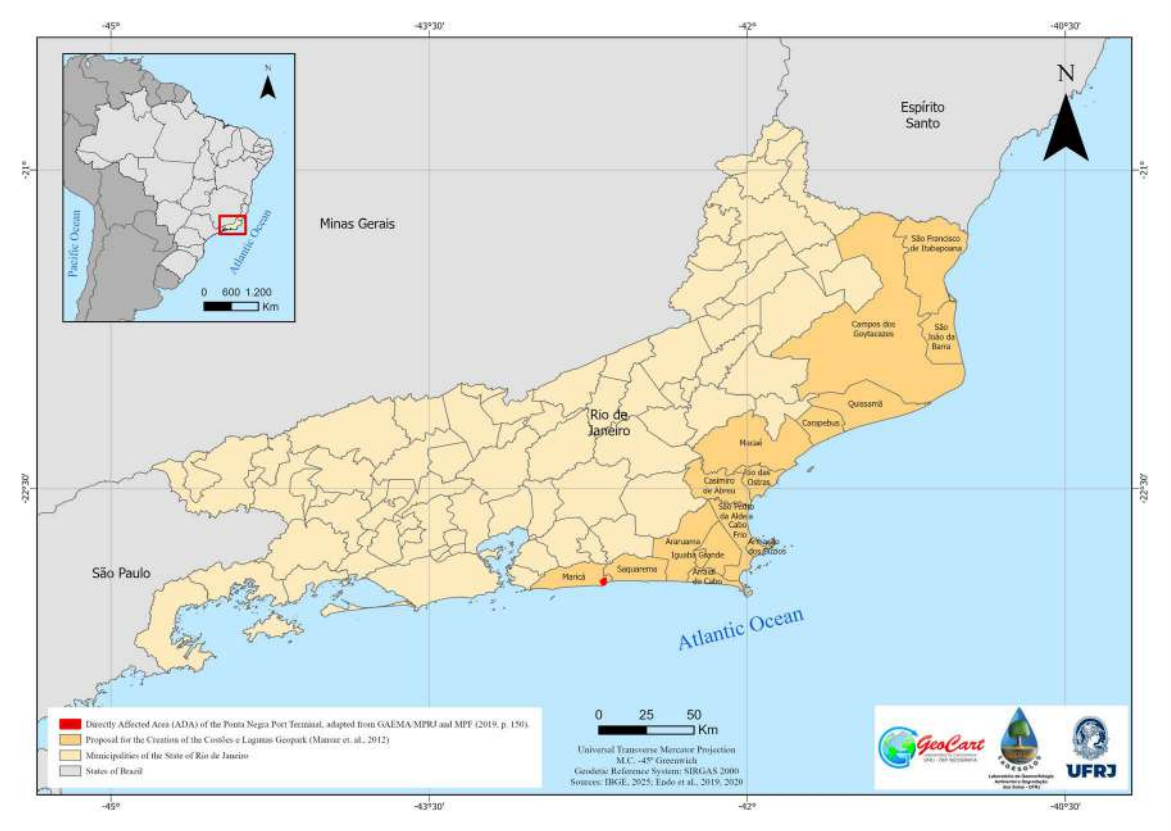

Figure 6. *Location map showing the direct area of influence of the Ponta Negra Port Terminal Project (Ponta Negra) and the area proposed for the establishment of the Costões e Lagunas Geopark. Source: Mansur et al. (2012). Created with ArcGIS Pro (Version 3.7) by Esri.*

relevance, since 52 geosites (out of more than 200 inventoried) were selected. These sites present unique features of international interest, including endemic flora and fauna and geosites essential for understanding the evolution of the planet, as well as initiatives in geoconservation, geotourism, and education (Mansur et al., 2012). The highlights include geosite No. 1, *Costão de Ponta Negra*, characterized as having "scientific, educational, and touristic value, as well as cultural importance" in the municipality of Maricá, and geosite No. 2, known as *Darwin Beachrocks*, located at Jaconé Beach, in the municipalities of Maricá and Saquarema. This site is described as a "rare sedimentary occurrence" and is of particular importance, because it "was described by Charles Darwin, then 23 years old, on April 9, 1832," with a spatial

occurrence exceeding "1,100 meters of continuous extension (potentially reaching 6 km in discontinuous stretches)" (Mansur et al., 2012).

Thus, the case studies related to the use of natural resources to meet societal needs, particularly in the context of mining in the *Quadrilátero Ferrífero*, located in the state of Minas Gerais, and the proposal for the construction of the *Ponta Negra* Port Terminal (TPN), located in the state of Rio de Janeiro, highlight the contrasting roles played by professional geoscientists.

On the one hand, these professionals work in corporate environments, where they are involved in activities related to the development of mineral resources and infrastructure projects. On the other hand, they participate in initiatives aimed at environmental protection, geoconservation, and the preservation of geological and cultural heritage, as exemplified by the proposals for the *Quadrilátero Ferrífero* and *Costões e Lagunas* geoparks, both presented in 2012.

In this context, geoscientists face ethical dilemmas arising from the need to reconcile the interests of their employers and society's demand for minerals, energy, and infrastructure with their professional responsibility to contribute to the protection of the environment and of geological, natural, and cultural heritage.

Finally, these case studies also highlight the recurring judicialization of conflicts related to the use of natural resources, resulting from the tension between development objectives and environmental protection. Such conflicts involve debates over different strategies for preservation and conservation.

In this context, the judiciary plays a central role. Beyond applying legal norms, it is called upon to balance competing systems of values, particularly those associated with economic interests, environmental protection, and the safeguarding of geological and cultural heritage. In carrying out this role, the judiciary recognizes that these interests are not mutually exclusive but rather interdependent, requiring harmonization in accordance with the principle of sustainable development.

4. Conclusions

The analysis of the two case studies, mining in the *Quadrilátero Ferrífero* (MG) and the proposed construction of the *Ponta Negra* Port Terminal (RJ), from a geoethical perspective, highlights the ethical tensions inherent in geoscientific decision-making. These case studies demonstrate the need to reconcile technical, economic, environmental, and social interests in the use of natural resources through decision-making processes involving geoscientists, society, and judicial authorities, while simultaneously considering the responsibilities of geoscientists toward both society and the protection of geological heritage.

The discussion of these case studies is supported by studies that emphasize the need for those responsible for such projects to adopt a geoethical approach, considering the existing scientific literature, the most appropriate techniques for each situation, and suitable methodological approaches. Such practices must be grounded in the ethical duty of geoscientists toward society and in the responsible use of geotechnologies for mapping and analysis.

Furthermore, unique geological landscapes, which are irreplaceable and cannot be recovered once altered because they constitute records of Earth's history, represent an important factor in geoethical decision-making due to their scientific and cultural value, as well as the principle of intergenerational equity.

Geoethical approaches seek to balance the conservation of geological heritage with society's demand for minerals, energy, and infrastructure, while simultaneously recognizing the responsibilities of geoscientists toward both their employers and society. This highlights the importance of promoting an ongoing dialogue between the geosciences and society on how ethically grounded approaches can address contemporary and future challenges.

The evolution of the concept of geoethics, together with the cases analysed, therefore highlights the need for comprehensive ethical conduct encompassing the entire mineral resource value chain, from subsurface research and exploration to extraction, processing, and transportation, while also ensuring compliance with legal frameworks and intergenerational rights on a global scale.

In this context, the geoethical debate becomes embedded in geoscientific practice as a guiding element for defending the public interest and scientific integrity, acting as a counterbalance to potential processes of knowledge instrumentalization aimed at legitimizing strictly economic interests.

The analysis of both cases highlights the ethical dilemma inherent in balancing the professional interests of geoscientists, particularly in mining and port infrastructure development, with broader societal interests, including environmental protection. This perspective expands the scope of ethical reflection, enabling not only a comparison of geoethical practices but also the identification of relevant lessons that reinforce the multiple possibilities for responsible professional engagement in the geosciences, as well as the implications and growing relevance of such practices in judicial decisions and socio-environmental controversies.

Finally, initiatives such as UNESCO Global Geoparks illustrate possible pathways for integrating conservation, education, and sustainable development, reinforcing a geoscientific practice committed to ethics, the preservation of geological heritage, and responsibility toward present and future generations.

Acknowledgments. Fábio da Silva Lima is grateful to the National Council for Scientific and Technological Development (CNPq), whose support through a doctoral scholarship made this research possible. He also thanks the Graduate Program in Geography at the Institute of Geosciences of the Federal University of Rio de Janeiro (PPGG/UFRJ), and Giuseppe Di Capua for his support and contributions to this important topic.

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