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Original Article

Analysis Comparison of the Normalized Difference Vegetation Index (NDVI) of Vegetation Cover from 1996 to 2024 in the Concession Perimeter of Sociedade Mineira de Catoca

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ABSTRACT

The mining industry, over the years, has played a crucial role in global economic development, providing essential inputs for various industrial activities. However, this sector also faces significant challenges, especially regarding the environmental impacts associated with the extraction of mineral resources. The search for more responsible and sustainable practices in mining has generated a global movement, driven by organizations and initiatives that seek to transform industry into a positive force for the environment and local communities. Given this scenario, this article developed a comparative analysis of the normalized difference vegetation index (NDVI) of vegetation cover between 1996 and 2024 in the concession perimeter of Sociedade Mineira de Catoca - a joint venture between Endiama (Angolan state company) and Alrosa, responsible for exploring the largest diamond mine in Angola. Located in the province of Lunda Sul, the Catoca mine is considered one of the largest in the world in terms of diamond reserves and production. Through the analysis of satellite images and data collected in the field, it was revealed that during the period under analysis there was a significant improvement in vegetation cover, despite the impacts of mining activities on vegetation, the company implemented a series of effective environmental recovery measures, reforestation, and sustainable management, allowing the regeneration and strengthening of native vegetation in a large part of the area of influence.

Keywords: Geoprocessing; Environmental recovery in Minas Gerais; Catoca Mining Society; Environmental impact of mining; Recovery of degraded areas.

INTRODUCTION

The mining industry, over the years, has played a crucial role in global economic development, providing essential inputs for various industrial activities. However, this sector also faces significant challenges, especially with regard to the environmental impacts associated with the extraction of mineral resources. The search for more responsible and sustainable practices in mining has generated a global movement, driven by organizations and initiatives that seek to transform the industry into a positive force for the environment and local communities. Given this scenario, the interest arose in developing a comparative analysis of the normalized difference vegetation index (NDVI) of vegetation cover between 1996 and 2024 in the concession perimeter of Sociedade Mineira de Catoca. Using satellite images, aiming to understand the state and evolution of the region's natural ecosystems, as well as the impact of mining activities on vegetation and allowing the identification of areas with preservation potential or that require special attention over time.

Detecting changes in land cover and use involves employing multi-temporal datasets to discriminate areas imaged on different dates. The analysis of time series using satellite images has been widely used in studies of landscape dynamics (Sader et al., 1990; Brondízio et al., 1993; Morán et al., 1994; Alencar et al., 1996; Venturieri et al., 1998; Watrin et al., 1996, 1998, among others). The application of geotechnology techniques in systematic dynamic monitoring studies of vegetation according to Ponzoni et al., (2012) allows the analysis of correlations between geophysical parameters of the environment with biophysical parameters of vegetation such as the electromagnetic radiation-absorption relationship, leaf area , biomass and land cover.

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The spatio-temporal transformations occurring in the vegetation cover can be analyzed using the Normalized Difference Vegetation Index (NDVI). This index is based on the use of the red and near-infrared bands, which correspond to 90% of the variation in the vegetation's spectral response (ROSENDO and ROSA, 2007), highlighting the vegetation's spectral behavior, thus providing a better correlation between the orbital data.

The Normalized Difference Vegetation Index (NDVI) is a remote sensing tool used to monitor the health and density of vegetation in a given area. NDVI is widely used in environmental monitoring studies, land use planning, detection of changes in vegetation cover and estimation of agricultural productivity.

1. Characterization of the study Area

Sociedade Mineira de Catoca is a diamond prospecting, exploration, treatment-processing and marketing company, set up on the initiative of the Angolan government to explore the first kimberlite, under Angolan law and mixed capital. The partners that from Catoca, are:

- Endiama EP: representing the Angolan state, with a 59% stake.
- Alrosa, a Russian publicly owned company, with 41% shares.

Under the mining exploration title, the Sleisure Mineira de Catoca, occupies 357 km2 of concession area, consisting of a residential village, industrial infrastructure and various enterprises to support the exploration process.

2.1 Geographic Location

In administrative-geographic terms, Sociedade Mineira de Catoca is in the Northeast of the National Republic of Angola, in the northwest part of the Province of Lunda – Sul, close to the city of Saurimo, at a distance of 35 km and around 1000 km from the city of Luanda, capital of the country. The territory of the SMC concession area lies within topographic sheet 121-SG 34, with a scale of 1:1000000, of the topographic cadastre of the Angolan state, in a region located on the boundaries between the provinces of Lunda Norte and Lunda Sul.

Figure 1: Geographical location of the Catoca Mine. (source: Catoca website).

2.2 Access Routes

Access to the region can be done both by air and land. By air, large and small planes are used that land, respectively at Saurimo airport and Catoca mine airport (figure 2), and by land, via the national roads (EN180) that connects the cities of Saurimo to Dundu (Lunda Norte), and national road (EN230) between the cities of Malange and Saurimo (Lunda Sul).

The study site is accessed by a main road, paved by the Company – Catoca, from the National Road detour (EN180), in Bairro Muacumbi; Several secondary roads in the residential village are paved and others in the production areas have been leveled, they are constantly maintained and sprayed with water to eliminate dust.

Figure 2: Plane landing at the Aerodrome of the Sociedade Mineira de Catoca facilities (Authors).

2.3 Hydrography

The region's hydrographic network is oriented towards the North, where it drains its water into the Zaire River, through the Kassai River, one of its largest tributaries, whose tributaries, fed by numerous sub-tributaries, cross the region from the South to the North. The main tributaries of the Kassai River, from West to East, are the Kuango River, Kuilo River, Luangue River, Luxico/Luele River, Lovua River,

Chikapa River, Luachimo River, Chihumbe River and Luembe River.

Figure 3: Chikapa River Falls (Coqueia, 2014)

2.4 The weather

The region's climate is tropical, favorable for agricultural activities, livestock and fishing. The region has two main seasons during the year:

- The rainy season, which lasts from the 15th of August until the 15th of May;
- The dry season, commonly known as cacimbo, lasts 90 days, starting on the 15th of August and ending on the 15th of May.

According to the meteorological control center installed at Catoca airport, the rainiest season occurs from November to March, in which the average annual estimate for atmospheric precipitation is 1366 mm. As for other meteorological data, the following stand out:

- The temperature throughout the year varies between 12º C minimum and 34º C maximum;
- The annual average relative humidity is 63%;
- Depending on the year, the predominant wind directions can vary from North to Northeast and South to Southwest.

2.5 Fauna and Flora

The Saurimo region is characterized by being a transition zone between the savannah domains to the south, tropical forest to the north, gaining extensive areas. The fauna of the region is characterized by the great diversity of animals: (i) the hippopotamus (Hippopotamus amphibius); (ii) the red sable (Hippotragus equinus); (iii) the caffer (Syncerus caffer); (iv) the woodpecker (Tragelaphus strepsiceros); (v) chissema (Kobus defends); (vi) the lion (Panthera Leo); (vii) the springbok (Antidorcas marsupialis); (viii) the saccara (Otocyon megalotis); (ix) wild dogs (Lycaon pictus); (x) the gene (Genetta angolensis); (xi) the wild cat (Felis sylvestris); (xii) the hunting leopard (Acinonyx jubatus); (xiii) the brown hyena (Parahyaena brunnea); (xiv) the wild chicken (Numida meleagris); (xv) snakes, etc.

Figure 4: Wooded savannah area (Coqueia, 2014)

2. Methodology

The methodology of this article is based on the analysis of the normalized difference vegetation index (NDVI) from satellite images. NDVI is an indicator that measures the quantity and health of vegetation, ranging from -1 to 1, where higher values indicate denser and healthier vegetation cover.

For the analysis, images from the Landsat 8 satellite, Operational Land Imager (OLI) sensor obtained through the United States Geological Survey and the Landsat 5 satellite, Thematic Mapper (TM) sensor from the years 1996 and 2024 were used, which cover the region of influence of the Catoca Mining Society. These images were processed and analyzed to calculate the NDVI in each year, allowing comparison of vegetation cover over time.

The study used high-resolution satellite images of the region of interest, collected on May 14, 1996 and May 4, 2024. The images were acquired in months that correspond to the rainy season in Angola, so that the analyzes of the spectral responses of vegetation would not suffer interference from seasonal climate issues.

The images were obtained from remote sensors and provide detailed information about vegetation cover and land use in the perimeter of the Catoca mining concession. However, those from 1996 represent the initial condition of the vegetation before the start of mining exploration activities by Sociedade Mineira de Catoca, while the images from 2024 reflect the current situation, after approximately 28 years of mine operation. To calculate the vegetation indices from the OLI sensor, band 4 (red – 0.64 µm to 0.67 µm) and band 5 (near infrared – 0.85 µm to 0.88 µm) were used, while for the TM sensor the bands used were, band 3 (red – 0.63 µm to 0.69 µm) and band 4 (infrared – 0.77 µm to 0.89 µm). From this raw data, the images were processed in a GIS environment, using the ArcGis 10.8 software.

NDVI was calculated using the equation proposed by Rouse et al., (1973):

$$NDVI = NIR - Red / NIR + Red \quad (1)$$

Where, NIR represents the reflectance of the near infrared band and Red represents the reflectance of the visible infrared band.

The calculation is performed on each pixel resulting in values that vary from -1 to 1, with values close to 1 indicating healthy and dense vegetation, while negative values or close to 0 indicate areas of bodies of water, buildings, exposed soil or other surfaces where there is little or no chlorophyll activity.

To better represent the vegetation indices, the NDVI images from the years 1996 and 2024, the Spatial Analyst Tools tool and the Reclassify function belonging to the ArcGIS GIS version 10.8 were used, to observe the variation of the NDVI in the intervention area; subsequently classified into six categories, table I;

Table I. Range, assigned classes and grades for the vegetation index by normalized difference.

Intervalo do NDVI	Classes Atribuídas	Notas
0,6 a 0,8	Vegetação muito densa	1
0,4 a 0,6	Vegetação densa	2
0,2 a 0,4	Vegetação esparsa	3
0,1 a 0,2	Vegetação bastante esparsa	4
0 a 0,1	Áreas não vegetadas	5
<0,1	Corpos hídricos	_

RESULTS AND DISCUSSION

The representation and analysis of the image from the year 1996, fig. 5., served as a starting point to understand the changes in vegetation cover that occurred over the 28 years of operation of the Catoca mine. However, the aforementioned figure represents the vegetation cover of the region at the time, it was predominantly natural, with the values estimated as a percentage according to its classification as very dense vegetation 15%, dense vegetation 28%, sparse vegetation 22%, very sparse vegetation 23%, non-vegetated areas 11% and water bodies 2%. This scenario represents the state of the concession perimeter of Sociedade Mineira de Catoca, before the start of mining exploration activities. Conclusively, the values recorded in fig.6. reflect values from the Normalized Difference Vegetation Index (NDVI), indicating an area with photosynthetic activity and green biomass.

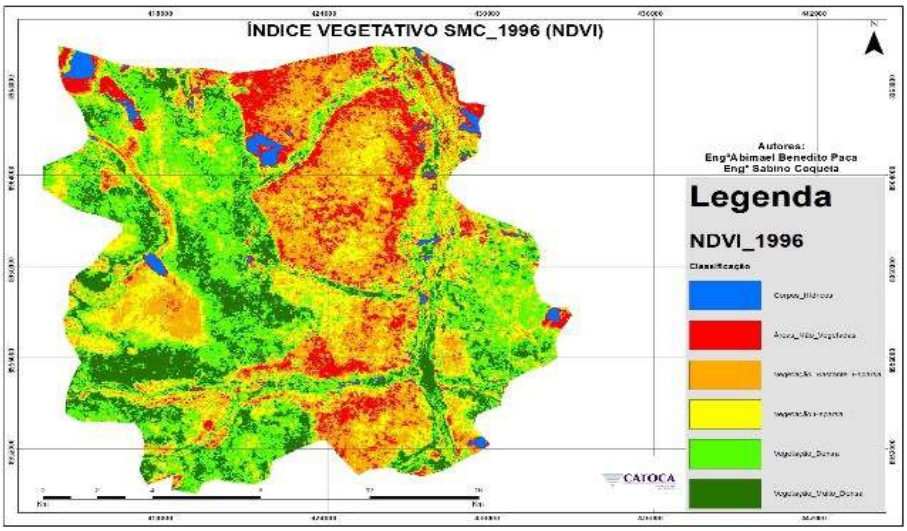

Figure 5:Vegetation index of the Catoca concession perimeter, in 1996.

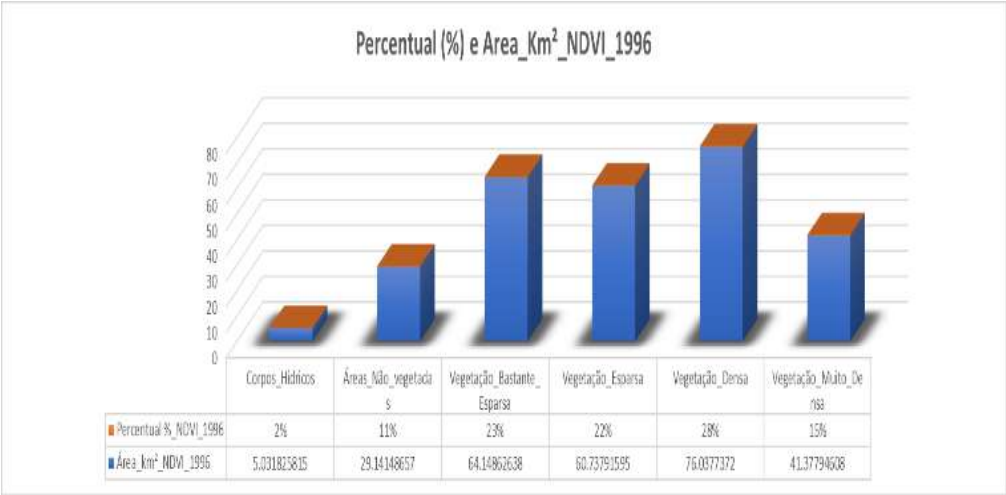

Figure 6:Percentage of Classes and the equivalent in km2 of the 1996 Normalized Difference.

In 2024, fig.7. After 28 years of operation of Sociedade Mineira de Catoca, although some areas have been deforested for the development of mining activities, construction of support infrastructures, modifying the original pattern of vegetation cover, it is possible to observe through the data in fig.8 . a considerable increase in the Normalized Difference Vegetation Index (NDVI) compared to 1996, indicating a significant improvement in the health and vigor of the vegetation surrounding the Catoca concession.

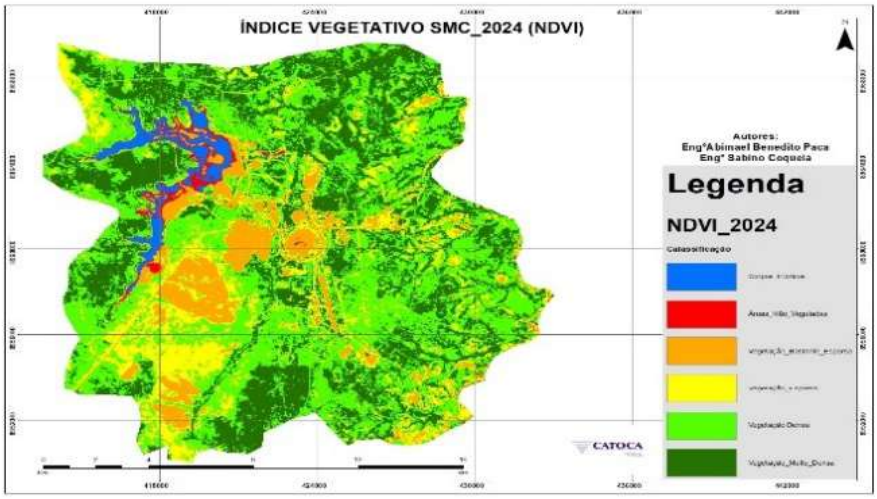

Figure 7: Vegetative index of the Catoca concession perimeter, in 2024.

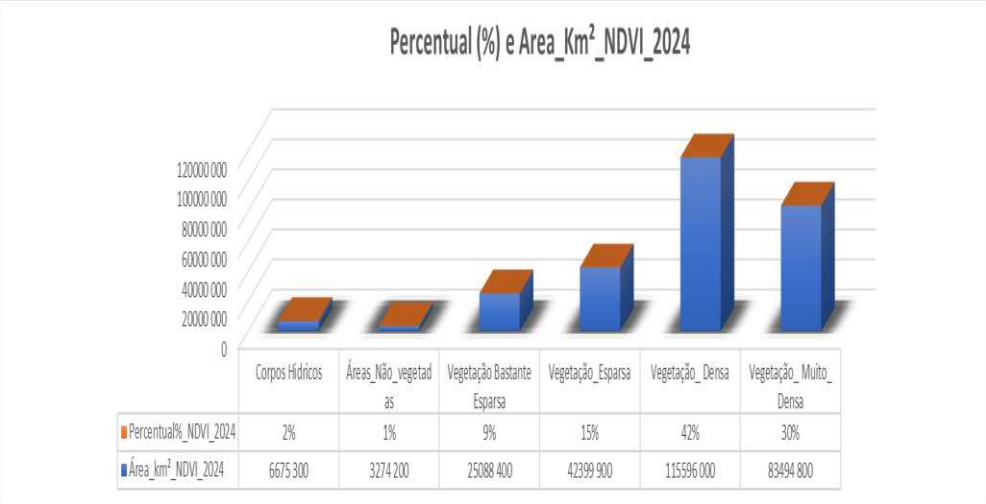

Figure 8: Percentage of Classes is the equivalent in Km2 of the 2024 normalized Difference.

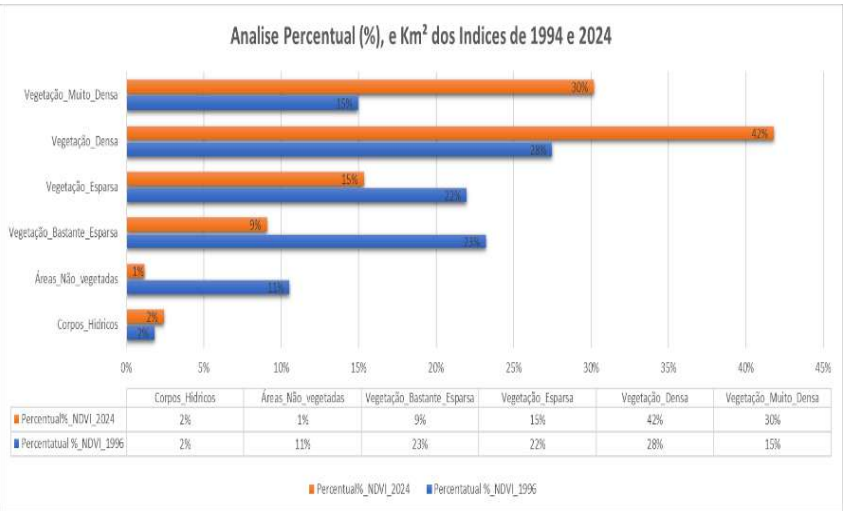

Figure 9: Comparative analysis of classes and the equivalent in Km2 of the normalized difference from 1996 to 2024.

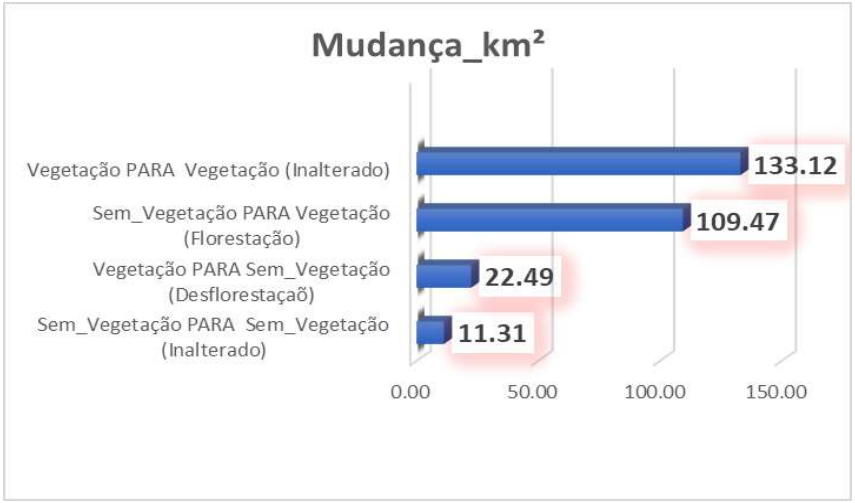

Figure 10: Comparative analysis of the temporal change of the classes and the equivalent in Km2 of the normalized difference from 1996 to 2024.

Based on the data in fig. 10. we observed two distinct phenomena: **afforestation** and **deforestation**. Afforestation refers to the class transition "**No vegetation**" to the class **"Vegetation"**, with a total area of **109.47 km²** throughout the 28 years of operation of the Catoca mine. On the other hand, deforestation represents the opposite transition, from the **"Vegetation"** for the class **"No vegetation"**, in a total area of **22.49 km²** during the same period, as can be seen in fig.11.

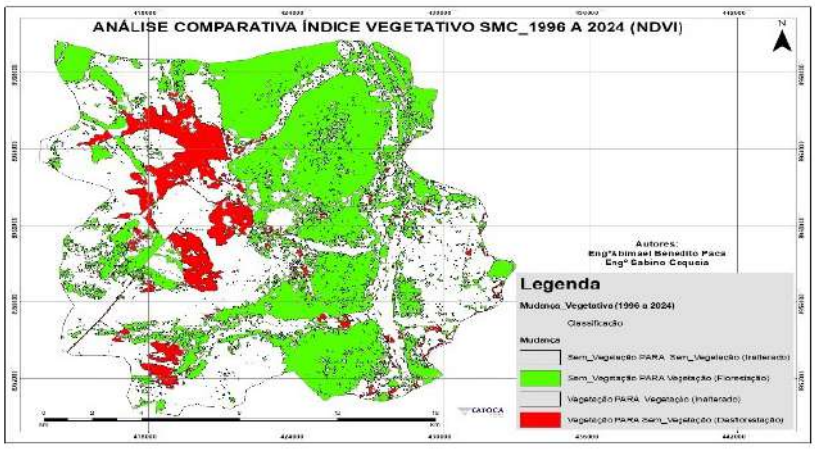

Figure 11: Comparative analysis of the vegetative index from 1996 to 2024.

Furthermore, in addition to the analysis carried out in fig.11, fig.12. presents a positive evolution of the NDVI, thus suggesting that despite the impacts of mining activity, Sociedade Mineira de Catoca implemented environmental mitigation and recovery measures, allowing the regeneration and strengthening of vegetation cover in a large part of the mining concession perimeter.

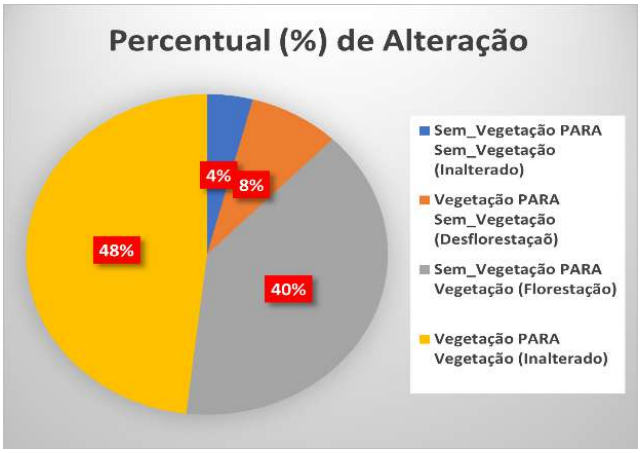

Figure 12: Percentage of NDVI Change from 1996 to 2024.

In the data presented in Fig.12, we can observe that there was afforestation totaling approximately 40% of the area studied over the 28-year period. Furthermore, there was deforestation corresponding to around 8% of the same area. This demonstrates that the efforts that Sociedade Mineira de Catoca has made in producing and planting 10,000 annual seedlings of native and exogenous species, to promote the natural regeneration of vegetation, have been effective in recovering degraded ecosystems and promoting local biodiversity. In addition to the facts stated in the previous paragraph, the improvement observed in the Normalized Difference Vegetation Index (NDVI) of the Sociedade Mineira de Catoca concession perimeter between 1996 and 2024 can be attributed to the following factors:

- The adoption of more sustainable environmental management practices, such as the preservation of ecological corridors, the restriction of deforestation and the control of erosion, contributed significantly to the improvement of vegetation cover indicators;
- Continuous environmental monitoring of rehabilitated areas and investments in the recovery of degraded areas;
- The involvement and participation of the local community were fundamental to the success of vegetation preservation and recovery actions, through the dissemination of information, training and adoption of sustainable land use practices;
- Invest in scientific studies and research to better understand the region's ecosystems and develop effective environmental recovery strategies. This in-depth knowledge allowed the implementation of ecological restoration techniques adapted to local needs, accelerating vegetation regeneration and improving NDVI.

CONCLUSION

In conclusion, the analysis of the evolution of the Normalized Difference Vegetation Index (NDVI) in the Sociedade Mineira de Catoca region between 1996 and 2024 revealed a significant improvement in vegetation cover. Despite the initial impacts of mining activities, the company implemented a series of effective environmental recovery, reforestation and sustainable management measures, allowing the regeneration and strengthening of native vegetation in a large part of the area of influence;

The comparative analysis of the NDVI between 1996 and 2024 allowed continuous monitoring of the evolution of vegetation cover in the region. This assessment over time is essential to identify trends, evaluate the effectiveness of mitigation and recovery actions, and direct future investments in environmental projects by Sociedade Mineira de Catoca;

Awareness-raising and awareness-raising actions about burning practices in local communities were fundamental in obtaining these positive results, signaling the effectiveness of an integrated and participatory approach to the sustainable management of natural resources;

Although the results are encouraging, continuous monitoring of vegetation cover is necessary in order to identify possible threats and implement long-term actions to maintain the observed improvement.

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