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The impact of gold mining on regional development in Brazil

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ABSTRACT

The mining industry plays a vital role in the economy of some Brazilian states. This research aims to evaluate the degree of influence of mining activity on the human development index (HDI) and the gross domestic product (GDP) in the Brazilian states of Bahia, Goiás, Minas Gerais, and Pará. The data used in the calculations were extracted from the Brazilian Institute of Geography and Statistics database from 2010 to 2020. Using the Pearson correlation method, we analyzed the impact of the mining economic activity on the regional income and HDI. The results showed a low correlation between gold mining production and HDI and GDP *per capita* indices of the states studied. It was found that Bahia State presented slight correlation rates (61.39% and 60.76%) for HDI and GDP *per capita*, respectively. The rates presented for the other states were below 35.00%, suggesting that mining activity does not influence the regional development of Goiás, Minas Gerais, and Pará. We concluded from the gold mining data that the mining industry did not impact regional development in the studied ten-year range. Further analysis should be carried out to verify the cost-benefit of gold mining, considering the environmental cost of mining activity.

Keywords: economic growth, income, gold mining activity, living standards

INTRODUCTION

Gold mining has been a significant part of Brazil's history and economy for centuries. The country's gold deposits are among the richest in the world, and Brazil is consistently one of the top-10 producers of gold globally (Machado & Figueirôa, 2022).

The history of gold mining in Brazil traces back to the early colonial period and spans centuries of exploration and development. Upon the arrival of Portuguese settlers in 1500, there was a keen interest in discovering precious metals and gems, leading to an extensive search for gold. It was not until the 18th century that significant and economic gold deposits were discovered in Minas Gerais State, bringing wealth to the Portuguese crown, and marking a golden era for Brazil. This period was characterized by the extraction of gold and diamonds from alluvial deposits. Despite initial successes, the depletion of alluvial deposits and a series of failures led to a decline. However, the 20th century saw a resurgence in gold mining activities, with Brazil diversifying its mining industry and becoming one of the six largest mineral producers globally (Machado & Figueirôa, 2001).

Brazil experienced several gold rushes, notably in the 18th and early 19th centuries. The discovery of alluvial gold deposits in the Amazon by informal miners in the 1970s and the opening of several mines in the 1980s led to significant gold production. However, production from alluvial mining decreased rapidly in the 1990s, while company production saw a significant increase (Thorman et al., 2001).

Despite being a slave-based economy until May 1888, gold mining contributed to Brazil's economy as the industry generated employment, tax revenue, and foreign exchange earnings. However, ongoing debates exist about balancing economic benefits with environmental and social considerations (Barcelos et al., 2020; Hirons, 2020; Macedo et al., 2003). Industrial gold mining in Brazil involves various mining methods, including open-pit and underground mining. The choice of method depends on factors such as the depth of the gold deposits, geological conditions, and economic considerations (Machado & Figueirôa, 2022). The mining industry's impact has not been solely economic; it has also led to significant environmental and social changes (Wasserman, 1992).

Worldwide, mining brings economic benefits for the countries. A study in Mongolia calculated the impact of the mining sector on the sustainable development of economies based on extracting natural resources, considering a share in the gross domestic product (GDP) and exports (Ponomarenko et al., 2020). Russian economy also relies heavily on gas and mineral mining (Gulyaev, 2016). South Africa has a rich geological endowment, boasting the world's largest reserves of manganese and platinum group metals and among the largest reserves of gold and diamonds (Nex & Kinnaird, 2019). On the

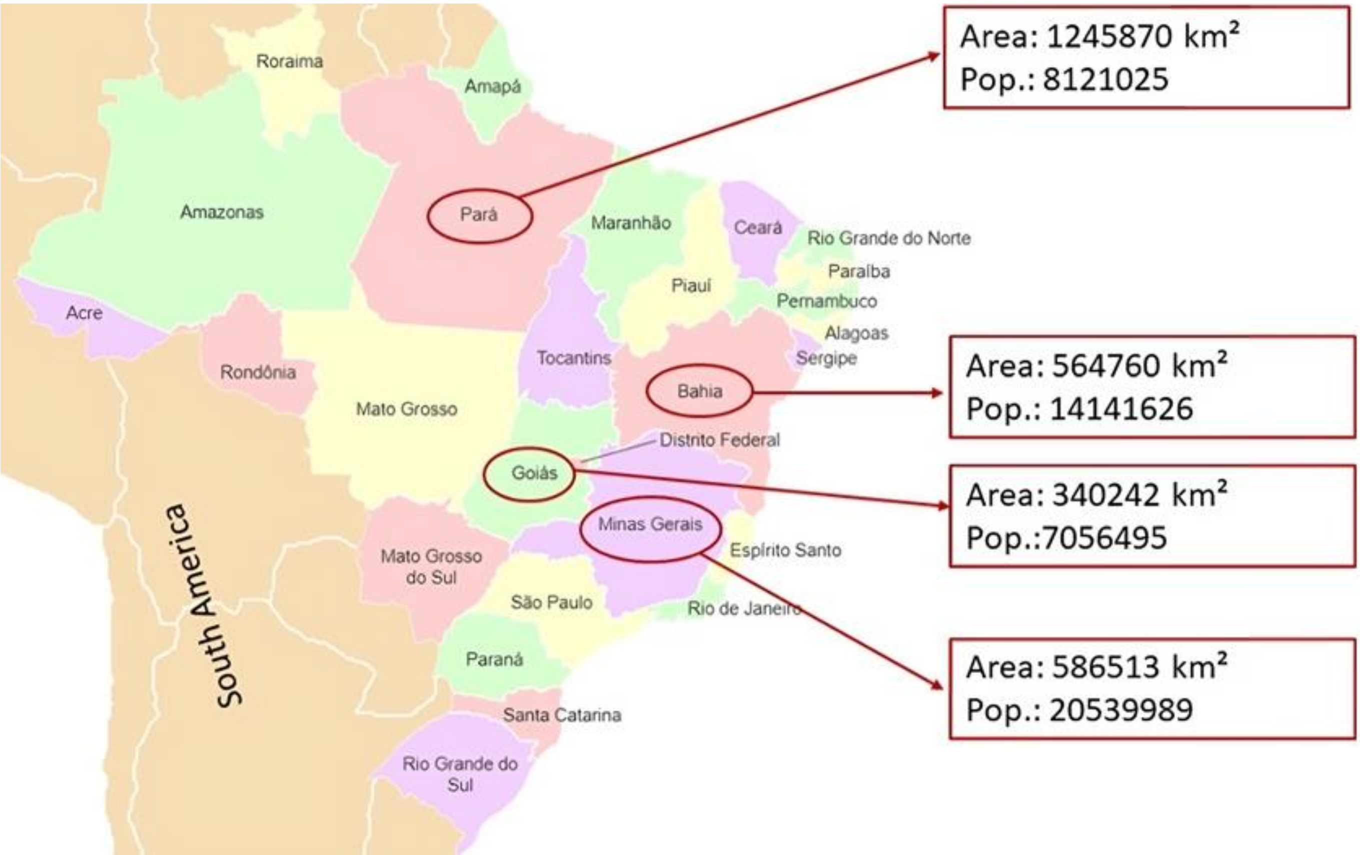

Figure 1. Schematic view of gold-producing studied Brazilian states & their area & population (IBGE, 2022)

other hand, focusing on the 17th United Nations sustainable development goal, there is the consolidation of the means of completion and revitalization of sustainable development worldwide. The 8th United Nations sustainable development goal promotes sustained, inclusive, sustainable economic growth, full and productive employment, and decent work. When focusing on both sustainable development goals applied to mining development, the mining economic sector remains behind the goals despite some isolated initiatives (Calderon et al., 2016; Maswanganyi, 2021).

Gold mining in the developing world presents significant environmental and socioeconomic challenges. These issues encompass deforestation, acid mine drainage, and air, water, and soil pollution by substances such as arsenic, cyanide, and mercury. The negative impacts extend to social aspects (Bezerra, 2013). The severity of these environmental issues is particularly notable in developing nations, and empirical evidence underscores that mining enterprises fail to address environmental concerns (Barcelos et al., 2020). The paradox inherent in gold mining in developing nations is evident: while increased investment in gold mines is essential for economic advancement, the expansion of mining operations frequently leads to persistent environmental and socioeconomic issues.

The human development index (HDI) is a valuable tool for comparing the levels of human development in different countries. It can also be used to track changes in human development over time (Jalles & Mello, 2019). HDI is not an ideal measure of human development since it does not consider many important factors, such as poverty, inequality, and environmental sustainability (Chen et al., 2020). GDP provides a picture of a country's economic activity, a widely used metric to compare the size and growth of different economies. While traditional economic measures like GDP focus primarily on monetary growth, alternative measures of economic well-being offer a more comprehensive assessment of a nation's prosperity and sustainability. Integrating these well-being indicators, such as GDP with HDI, can create a more holistic macroeconomic assessment, enabling policymakers to make informed decisions that promote sustainable and inclusive economic growth (Cook & Daviosdottir, 2021; Fadillah & Setiartiti, 2021).

Within this scenario, we proposed a research question: Does gold mining improve the regional development of the regions in Brazil? Therefore, the present study analyzed the impact of gold mining activity in the regional development of Bahia, Goiás, Minas Gerais, and Pará, the country's most important regions of gold production.

METHOD

Brazil's four states that produce the highest gold are Bahia, Goiás, Minas Gerais, and Pará. Figure 1 shows the locations of the states and their respective areas and populations.

The min-max deviation normalization was adopted to eliminate the influence of the magnitude of different dimensional data on the prediction model (Ali & Faraj, 2014). Normalization linearly transforms the original data to improve the result convergence (Eq. [1]).

$$Xnorm = \frac{Xi - Xmin}{Xmax - Xmin}, \quad (1)$$

Table 1. Results of GDP *per capita*, HDI, & gold production from 2010 to 2020 for Minas Gerais State (IBGE, 2022)

Year	Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)	Normalized data		
				Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)
2010	48.065	0.731	3.511	0.550	0.000	0.000
2011	47.982	0.731	4.001	0.540	0.000	0.150
2012	56.571	0.750	4.422	0.860	0.310	0.270
2013	59.808	0.758	4.880	0.990	0.440	0.410
2014	58.497	0.770	5.166	0.940	0.630	0.500
2015	52.290	0.774	5.193	0.710	0.690	0.510
2016	52.316	0.776	5.446	0.710	0.730	0.580
2017	33.372	0.784	5.762	0.000	0.850	0.680
2018	53.266	0.784	6.149	0.740	0.850	0.800
2019	55.285	0.793	6.519	0.820	1.000	0.910
2020	60.208	0.789	6.828	1.000	0.940	1.000
Correlation (%)		7.88			17.01	

where *Xnorm* is the normalized measurement, *Xi* is the i^{th} measurement, *Xmax* is the maximum value of the measurement, and *Xmin* is the minimum value of the measurement.

We applied the correlation analysis to the normalized data set. Correlation analysis aims to determine the degree of description or explanation of a linear equation regarding the relationship between two variables (Spiegel, 1977). Correlation analysis measures how much and how two variables are related (Lapponi, 2008). Through the correlation calculus, the obtained results vary between -1 and one, where -1 is the best negative correlation, and one is the best positive correlation. When the result is closer to zero, the correlation is weak; when the result is equal to zero, there is no correlation. Pearson's correlation coefficient (r) is defined as the ratio between covariation and the square root of the product of variations in two variables (X and Y) (da Fonseca et al., 1995), as shown in Eq. (2):

$$r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\left[\sum(X-\bar{X})^2\right]\left[\sum(Y-\bar{Y})^2\right]}}, \quad (2)$$

where the basic scheme of the study can be described, as follows: Let *f(x)* be the phenomenon to be studied. In this case, the mining industry's influence on HDI index and GDP *per capita* in the Brazilian states of Bahia, Goiás, Minas Gerais, and Pará. The Pearson correlation was the statistical technique used to estimate this degree of impact. As the present study essentially seeks to evaluate the degree of correlation between mining industry production and HDI index and GDP *per capita* in the Brazilian states of Bahia, Goiás, Minas Gerais, and Pará, respectively, the research is reduced to three steps, as follows:

(1) correlation calculations were performed between the mining industry production sample and HDI index and correlation calculations between the mining industry production sample and *per capita*,

(2) two correlation calculations were carried out since this method evaluates variables in pairs, and

(3) the analysis and comparison of results obtained by Pearson correlation calculations between paired samples.

Microsoft Excel® application was applied to calculate the correlation. This tool was chosen due to its quick response as it tabulates data in tables and updates graphs.

RESULTS & DISCUSSION

The results obtained from the experiments present the correlation rate, in pairs, that exists between the variables gold production and, respectively, the variables HDI and GDP *per capita*. These calculations were carried out using data from four Brazilian states (Bahia, Goiás, Minas Gerais, and Pará), and the results are available in tables.

Table 1 presents the samples collected from Minas Gerais State for the variables studied. The correlation rates obtained between the variable "gold production" and the variables "HDI" and "GDP *per capita*" were 7.88% and 17.01%, respectively. These values indicate a low influence of mining activity on the aspects examined (HDI and GDP *per capita*).

Figure 2 shows the dispersion of points referring to pairs of normalized values of the variables researched in Minas Gerais State. The normalized values of the studied data were used to plot the scatter plots. Such an approach was needed due to the differences in magnitude between the recorded variables. Therefore, the variables are renamed, as shown in **Table 2**. Therefore, each point in **Figure 2** refers to the ordered pairs of points (*x, y*) for "gold production" and "HDI" and (*x, z*) for "gold production" and "GDP *per capita*". **Figure 2** shows that the points are dispersed for the ordered pair (*x, y*) and the ordered pair (*x, z*). The more dispersed the points are, the lower the correlation rate (da Fonseca et al., 1995; Lapponi, 2008; Spiegel, 1977).

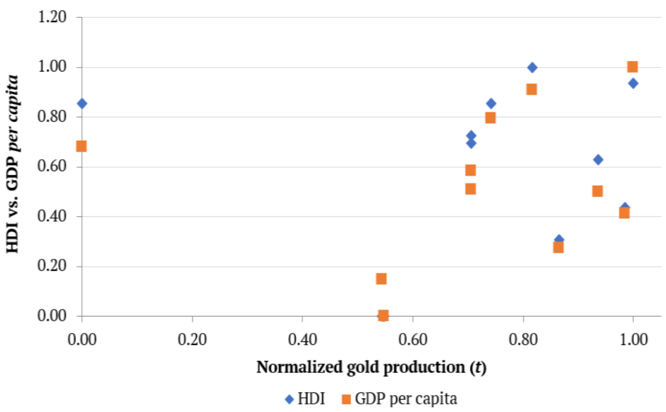

Figure 2. Scatterplot of normalized data of gold mining, HDI, & GDP *per capita* for Minas Gerais State (Source: Authors' own elaboration)

Table 2. Variable collected & renamed for calculating correlation between regional development & gold mining

Variable	Renamed xariable
Gold production (*t*)	*X*
HDI	*Y*
GDP *per capita*	*Z*

This result means that the influence of gold production (variable "*x*") over HDI (variable "*y*") is weak or none. The same occurs between variables gold production (variable "*x*") and GDP (variable "*z*").

The correlation rates obtained between the variable "gold production" and the variables "HDI" and "GDP *per capita*" were 61.39% and 60.76%, respectively. Data from Bahia State provided the highest calculated correlation rate, indicating that gold production in that state may have influenced HDI and GDP *per capita* aspects. **Figure 3** shows the dispersion of points referring to pairs of normalized values of the variables explored in Bahia State. **Table 3** shows the data used to calculate the correlation between the variables studied in Bahia State.

As shown in **Figure 3**, there is less dispersion of the plotted data, indicating a higher correlation rate between the variables. The dotted line enhances the slight alignment with the variables of regional development. In this case, the plotted data suggest that there is some influence of gold production (variable "*x*") over HDI (variable "*y*") and GDP (variable "*z*"), respectively. Also, it is essential to mention that correlation results indicate that this influence is positive, which means that if the gold production level goes up, then HDI and GDP levels go in the same direction. **Table 4** contains the data used to calculate the correlation between the variables studied in Pará State.

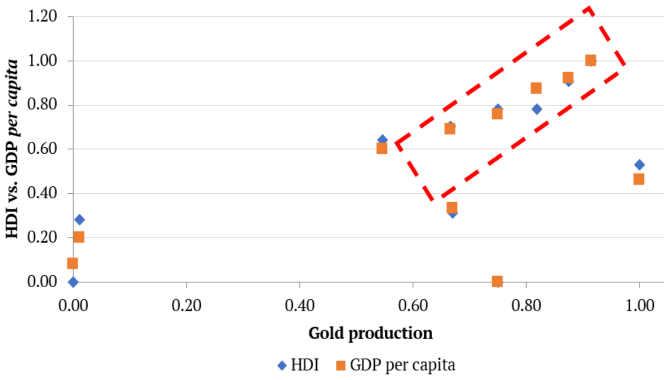

Figure 3. Scatterplot of normalized data of gold mining, HDI, & GDP *per capita* for Bahia State (Source: Authors' own elaboration)

The correlation rates obtained between the variable "gold production" and the variables "HDI" and "GDP *per capita*" were 13.18% and -12.13%, respectively. As shown in **Table 1** and **Table 3**, the values indicate a low influence of mining activity on the aspects researched (HDI and GDP *per capita*) with something new. The correlation rate between "gold production" and "GDP *per capita*" is negative, indicating an inverse correlation. **Figure 4** shows the dispersion of points referring to pairs of normalized values of the variables studied in Pará State.

Table 3. Results of GDP *per capita*, HDI, & gold production from 2010 to 2020 for Bahia (IBGE, 2022)

Year	Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)	Normalized data		
				Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)
2010	3.275	0.660	0.150	0.750	0.000	0.000
2011	0.984	0.660	1.700	0.000	0.000	0.080
2012	1.019	0.678	1.850	0.010	0.280	0.200
2013	3.033	0.680	2.050	0.670	0.310	0.330
2014	4.039	0.694	2.240	1.000	0.530	0.460
2015	2.654	0.701	2.450	0.550	0.640	0.600
2016	3.019	0.705	2.580	0.670	0.700	0.690
2017	3.274	0.710	2.687	0.750	0.780	0.760
2018	3.483	0.710	2.862	0.820	0.780	0.870
2019	3.656	0.718	2.932	0.870	0.910	0.921
2020	3.778	0.724	3.053	0.910	1.000	1.000
Correlation (%)		61.39			60.76	

Table 4. Results of GDP *per capita*, HDI, & gold production from 2010 to 2020 for Pará (IBGE, 2022)

Year	Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)	Normalized data		
				Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)
2010	17.865	0.646	0.826	0.220	0.000	0.000
2011	15.368	0.646	0.987	0.190	0.000	0.120
2012	20.803	0.666	1.071	0.260	0.270	0.180
2013	25.588	0.671	1.212	0.330	0.340	0.290
2014	33.995	0.684	1.246	0.450	0.520	0.310
2015	57.543	0.689	1.309	0.780	0.590	0.360
2016	71.915	0.687	1.381	0.980	0.560	0.420
2017	13.315	0.694	1.552	0.160	0.660	0.54
2018	73.080	0.707	1.614	1.000	0.840	0.59
2019	2.553	0.704	1.784	0.010	0.790	0.72
2020	2.178	0.719	2.159	0.000	1.000	1.00
Correlation (%)		13.18			-12.13	

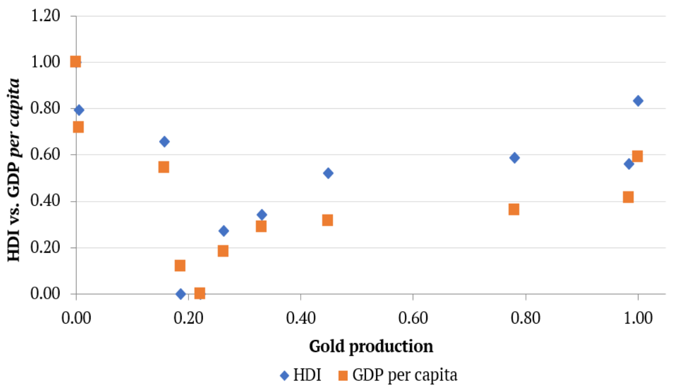

Figure 4. Scatterplot of normalized data of gold mining, HDI, & GDP *per capita* for Pará State (Source: Authors' own elaboration)

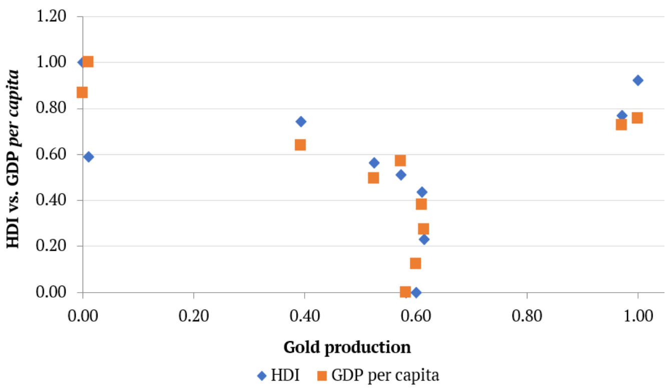

Figure 5. Scatterplot of normalized data of gold mining, HDI, & GDP per capita for Goiás State (Source: Authors' own elaboration)

Table 5. Results of GDP *per capita*, HDI, & gold production from 2010 to 2020 for Goiás State (IBGE, 2022)

Year	Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)	Normalized data		
				Gold production (*t*)	HDI	GDP *per capita* (10^5 R$)
2010	22.646	0.735	1.068	0.580	0.000	0.000
2011	23.286	0.735	1.218	0.600	0.000	0.120
2012	23.766	0.744	1.388	0.610	0.230	0.270
2013	23.654	0.752	1.513	0.610	0.440	0.380
2014	20.682	0.757	1.650	0.520	0.560	0.500
2015	22.348	0.755	1.736	0.570	0.510	0.570
2016	16.149	0.764	1.817	0.390	0.740	0.640
2017	36.038	0.765	1.919	0.970	0.770	0.730
2018	37.026	0.771	1.957	1.000	0.920	0.760
2019	2.624	0.774	2.087	0.000	1.000	0.870
2020	2.987	0.758	2.242	0.010	0.590	1.000
Correlation (%)		-10.95			-33.62	

In **Figure 4**, as in **Figure 2**, we noticed that the points are dispersed for the ordered pair (*x, y*) and the ordered pair (*x, z*), indicating a low correlation rate between the variables. In this case, as occurred with results for Minas Gerais State, the influence of gold production (variable "*x*") over HDI (variable "*y*") and GDP (variable "*z*") is weak or none, respectively. **Table 5** contains the data used to calculate the correlation between the variables studied in Goiás State.

The correlation rates obtained between the variable "gold production" and the variables "HDI" and "GDP *per capita*" were -10.95% and -33.62%, respectively. As shown in **Table 1**, **Table 3**, and **Table 4**, the values indicate a low influence of mining activity on the aspects verified (HDI and GDP *per capita*). The novelty in this case is that both correlation rates are negative. **Figure 4** shows the dispersion of points referring to pairs of normalized values of the variables studied in Goiás State.

In **Figure 4**, as also occurred in **Figure 1** and **Figure 3**, the points are dispersed for the ordered pair (*x, y*) and the ordered pair (*x, z*), indicating a low correlation rate between variables. In the case of Goiás State, shown in **Figure 4**, the conclusion is negative for some influence of gold production (variable "*x*") over HDI (variable "*y*") and GDP (variable "*z*").

The results presented in tables showed that there is evidence of low influence between "gold production" and the "HDI" and "GDP *per capita*" aspects of the states studied. A slightly higher correlation rate (60.00%) was obtained between the variables in Bahia State. An example of the application of correlation analysis was found in Oliveira et al. (2018). The authors propose expanding the perception of the impact of unplanned maintenance and examining how correlation and regression analysis can assist in managing port industrial maintenance. The results showed a significant correlation between the variables reliability, corrective maintenance, and preventive maintenance, concluding that corrective maintenance harms the reliability of industrial equipment.

We only found a slight correlation between the studied variables of regional development associated with gold mining production in Bahia State. At the same time, the other states did not show any correlation between regional development data and gold production. Gold mining ventures demand substantial capital, and developing nations rely heavily on foreign direct investments to secure funding for such projects (Aydin &Tilton, 2000; Nguyen et al., 2018). The extent of foreign investments is typically influenced by a country's economic and political conditions. In previous literature (Kumah, 2006; Otto, 1997), key factors influencing a company's investment decision include security of tenure or contractual stability, the right to repatriate profits, access to foreign exchange at market rates, management control, equity control, fixed tax terms, and the adequate support and monitoring of private mining investments by well-organized government institutions.

Hilson and Murck (2000) highlight that environmental regulations vary considerably globally, and mere compliance with these regulations does not guarantee environmentally responsible practices. Environmental laws in developing countries are often rudimentary and inadequately enforced. Consequently, a mine operating within or exceeding legal standards may not contribute to environmental improvement or sustainable development. Because of the lucrative bounds, the company may impose workers on unhealthy work (da Silva Dias et al., 2021). According to Kumah (2006), in developing countries, attaining sustainability requires outstanding minimum requirements set by local legislation.

The impact of gold mining on regional development is complex and multifaceted, with both positive and negative consequences (Barcelos et al., 2020; Cook & Daviosdottir, 2021). Gold mining can contribute to economic growth, job creation, and infrastructure development in remote and underdeveloped regions (Betancur-Corredor et al., 2018). The influx of capital and resources associated with gold mining can stimulate local businesses, improve transportation networks, and provide access to essential services like healthcare and education. However, careful management is needed to minimize its harmful environmental effects (Chen et al., 2020; Murck, 2000). The return investment of the taxes depends on the local government's goals, and citizens should follow its application for social benefit.

Environmental impact assessments and follow-up studies reveal regional variations in implementation due to social, environmental, economic, and political factors. Such a scenario underscores the complexity of managing mining impacts and the necessity for tailored approaches to mitigate adverse outcomes and enhance positive contributions to regional development (Aydin & Tilton, 2000; Jha-Thakur, 2011). This approach indicates the need for strategic policy formulation and implementation to ensure that mining contributes positively to the economic development of the regions in which they are located, balancing economic benefits with environmental and social impacts (Aroca, 2001; Radetzki, 1982).

Environmental problems in mining regions are particularly severe today, further strained by the current economic climate. Addressing this challenge requires a comprehensive strategy that prioritizes preventative measures, including leveraging corporate social responsibility initiatives to promote sustainable social and economic development in the region (Egorova et al., 2018). An organizational and economic mechanism can be established to achieve these goals (Otto, 1997). This mechanism would facilitate sustainable social and economic development through coordinated stakeholder collaboration. By strengthening the interconnectedness of these elements, the mechanism would ultimately bolster the resilience of regional ecological and economic systems.

In the regions studied in Brazil, from 2010 to 2020, there is a slight positive correlation between the variables HDI and GDP *per capita* only in Bahia State, inferring that gold production did not result in the regional development of the other states. One possibility for the low correlation rates calculated may be due to the sizes of the samples collected. However, one should also not rule out the possibility of no influence between "Gold production" and the selected aspects ("HDI" and "GDP *per capita*").

Regional development involves a multifaceted approach that considers economic, social, environmental, and political factors to enhance people's living standards and economic well-being in specific regions (Bezerra, 2013). Since we did not find a significant correlation between gold production and the social and economic development index, the answer to our research question remains fragile. There has been some development in the studied regions since both values grew during the studied period. However, we could not establish a positive correlation to gold mining.

Although previous research (Al-Nasser & Al-Hallaq, 2019; Sjoerd & Lewis, 2014) underscores the importance of regional development strategies in improving HDI, with a notable focus on health and income levels. Capital and major city regions often exhibit higher HDI scores, indicating disparities that need addressing to ensure balanced regional development. Therefore, HDI and GDP might not be sufficient for assessing regional development.

Since we did not compute the environmental cost of gold mining, we suggest that future research address this topic. Future research could incorporate more diverse data sources, including satellite imagery and big data analytics, to enhance the precision of environmental cost quantification. Additionally, exploring the integration of these costs into regional planning and policy-making processes through participatory approaches involving stakeholders at all levels could ensure that environmental considerations are effectively balanced with economic development objectives.

CONCLUSIONS

The present study aimed to verify if gold mining influenced the regional social indicators "HDI" and "GDP *per capita*" in the development of Bahia, Goiás, Minas Gerais, and Pará states in the last ten years. The method used was to apply Pearson's correlation, and the results obtained showed a low correlation rate for both ordered pairs (x, y) and (x, z). The only evidence of correlation occurred in Bahia State, with values obtained relating to the variable "gold production" and the variables "HDI" and "GDP *per capita*" of 61.39% and 60.76%, respectively. Therefore, we did not find clear evidence of a significant contribution of gold mining to regional development in the regions studied, focusing on the evolution of HDI and GDP.

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Ethics statement: The authors stated that the study is based on existing open-source governmental database available on-line at https://www.ibge.gov.br/.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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