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Mining-Ecological Footprint Nexus in the Global South: A Panel Data-Driven Approach

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Abstract

This research investigates the environmental effects of mining activities in countries in the Global South, specifically focusing on Brazil, China, India, Indonesia and Pakistan, from 1990 to 2020. Utilizing advanced econometric techniques, especially panel data methods, the study identifies considerable variations in how key factors – such as mineral rents, forest areas, GDP per capita and freshwater resources – affect the ecological footprint. The results support the environmental Kuznets curve hypothesis and show that while mineral rents tend to decrease the ecological footprint, increased renewable freshwater resources are associated with a higher footprint (but the effect reverses in higher quantiles). No conclusive evidence can be found regarding the nexus between forest areas and the ecological footprint. By comparing the results with existing environmental standards and management practices, a significant gap between policy and practice is found, which contributes directly to the current environmental challenges and points out the need for country-specific strategies to increase environmental sustainability in the mining sector.

Keywords: Ecological footprint, environmental sustainability, mining activities, Global South

JEL Codes: O13, K32, Q51

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1. Introduction

This research enhances the existing body of knowledge by incorporating data up to 2020, allowing a more current analysis of how mining activities affect the environment across countries of the Global South. One of the main objectives of the study is to close the gap between environmental regulations and the actual practices seen in the mining sector nowadays, by offering practical advice for policymakers. The study brings attention to the pressing need for sustainable mining operations in the Global South in general.

Many countries depend heavily on their mining sectors when it comes to economic development, employment and export revenues (Xue *et al*., 2021; Ullah *et al*., 2021), which is the case for countries of the Global South, including Brazil, China, India, Indonesia and Pakistan. In these countries, mining activities play a vital role, affecting the economic development positively but, at the same time, these activities present serious environmental challenges that lead to ecological deterioration (Asmiani *et al*., 2023; Kayani *et al*., 2024). For this reason, the concept of the ecological footprint is used to provide further understanding of the sustainability of mining practices since it offers a general measure of impact (Pourebrahim *et al*., 2023; Biyase *et al*., 2023).

According to Sahoo and Sethi (2021), the environmental Kuznets curve (EKC) hypothesis shows that environmental degradation increases with economic growth but then falls as countries mature and adopt more sustainable practices. However, empirical evidence for the EKC theory in the mining sector of the Global South is inconsistent and limited (Tinov *et al*., 2022; Wang, 2024), which is a challenge for research and practice alike. Understanding the variables that affect the ecological footprint is a must to build sustainable practices, especially nowadays that we have a noticeable gap between regulatory frameworks and management practices (He, 2023).

In this study, an attempt is made to study the relationship between the ecological footprint and relevant macro-economic and environmental factors including mineral rents, forest area, GDP per capita and renewable internal freshwater resources per capita by making use of advanced econometric techniques such as pooled regression, fixed-effects and random-effects regression, cross-sectional dependence test, cointegration test and quantile regression. These methods were chosen for their ability to estimate panel data efficiently and deal with questions such as cross-sectional dependence and heterogeneity.

Additionally, this research aims to compare the current environmental standards and managerial practices. By focusing on exposing major differences that exist between policy and practice, which continue to contribute to environmental problems, we aim to help policy makers and other stakeholders develop and implement policies to bring environmental standards in line with sustainable management practices, which may reduce the negative effects of mining on the environment while promoting economic development.

This research is novel in its approach of examining the heterogeneity across multiple countries using recent data and employing advanced econometric methods such as augmented mean group (AMG) regression and quantile regression. The novelty lies in the comparison of the ecological impact of mining across a diverse set of Global South countries, highlighting the different outcomes based on policy frameworks, environmental standards and management practices.

This article addresses the following key questions: How do mineral rents, GDP per capita, forest area and renewable freshwater resources affect the ecological footprint in the Global South? What specific gaps exist between environmental regulations and management practices, and how do these gaps affect environmental sustainability in the mining sector? This study aims to answer these concerns comprehensively using data analysis and critical evaluation, providing useful insights for improving environmental sustainability in the Global South.

2. Literature Review

Mining activities are essential to economies that have natural resources, but one should not neglect the fact that it can lead to devastating environmental consequences (Ruppen *et al.*, 2021). Extraction of mineral resources causes biodiversity loss and environmental damage that can go beyond the local regions where mining occurs, which can lead to habitat destruction, deforestation, soil, water and air quality deterioration, affecting various ecosystems and species (Hudson-Edwards, 2018).

2.1 Environmental impact of mining

Mining has a huge impact on various environmental aspects such as deforestation and habitat distribution, according to Asner *et al.* (2013). The authors highlighted that mining operations, particularly gold mining, have contributed to high rates of deforestation especially in regions such as the Amazon rainforest; beside that, the average annual rate of forest loss tripled following the global economic recession, associated with increased gold prices. Espejo *et al.* (2018) also highlighted artisanal-scale gold mining (ASGM) as a major cause of deforestation in the Peruvian Amazon rainforest, which has extensive environmental and social impacts, including carbon emissions and mercury pollution. Sonter *et al.* (2017) also showed that mining activities in the Amazon basin significantly increased forest loss up to 70 km beyond mining lease boundaries, which caused substantial deforestation. Because of the continuation of mining operations that destroy natural habitats and change the distribution of resources throughout the landscape, deforestation and habitat loss are expected to increase over the next decades. Also, richness of species and ecosystem functions will be more likely affected directly and indirectly by the clearing of vegetation and disturbance of ecosystems created by mining operations (Lawer *et al.*, 2020; Cowan, 2024).

Mining also causes water and soil pollution because acid mine drainage, which carries heavy metals such as copper, lead and cadmium, is frequently discharged by mining operations. This can extend beyond mining sites to harm rivers and aquatic ecosystems, resulting in a decline in biodiversity; that poses a serious threat to water supplies and human life. Pollution of water resources affects not only aquatic ecosystems, but also human communities, since they depend on water resources for various purposes such as drinking and agriculture; this exposes them to health risks and other toxic effects (Yoon and Yoon, 2022; Gabrielyan *et al*., 2018; Ruppen *et al*., 2021).

The effect of mining on air pollution should also be mentioned – excavation, transportation, material handling and other mining processes tend to contribute to increased levels of emissions and dust in the air; they include a range of pollutants, including heavy metals and other contaminants that have adverse effects on air quality and human health (Sternberg and Edwards, 2017). As different emissions of fugitive dust caused by mining activities lead to poor air quality on and off-site, mine workers and nearby communities are exposed to pollutants that lead to health risks such as respiratory issues, cardiovascular problems and other health complications (Cooke and Drevnick, 2022).

2.2 Ecological footprint

Lin *et al*. (2018) defined the ecological footprint (EF) as a measure used to assess the impact of human activities on the environment by qualifying the amount of biologically productive land and water area required to support a population or activity and absorb the waste generated. This concept was developed to evaluate the sustainability of human activities in relation to the regenerative capacity of the Earth's ecosystems since it represents the demand placed on natural resources and ecosystems by human consumption and waste production.

When talking about mining practices, the ecological footprint is used to describe how mining methods are measured in terms of sustainability by evaluating the effects of resource extraction, processing and waste generation on the environment. Due to their significant use of land, energy and water and waste creation, mining activities typically leave a huge ecological imprint. The ecological footprint is now making it easy to assess the degree to which mining operations contribute to environmental degradation and exceed the regeneration capacity of ecosystems (Venetoulis and Talberth, 2007).

Many environmental elements can be considered parts of the ecological footprint of mining operations, such as land disturbance, habitat damage, water pollution, air pollutants and energy use. This justifies the use of the ecological footprint to analyse how mining operations affect the environment and finding ways to reduce resource consumption, minimize waste production and boost sustainability practices. The ecological footprint analysis provides a thorough framework for assessing how sustainable mining operations are and guiding decision-making towards more ecologically conscious methods (Guo, 2022).

By considering the ecological footprint of mining activities, it is possible to promote sustainable resource management, biodiversity conservation and ecosystem protection. Regulators, policymakers and mining companies can use it as an indicator for better understanding the long-term environmental impacts of mining operations, which will facilitate development of strategies to mitigate those consequences (Shut'ko *et al*., 2020).

2.3 Key variables influencing ecological footprint of mining

The revenues obtained from mining minerals, such as coal, oil and natural gas, are called mineral rents. These revenues tend to have a significant impact on the ecological footprint (Kirisci and Demirhan, 2019).

According to Li *et al*. (2022), increases in natural resource rents go hand in hand with a short-term, marginal increase in the ecological footprint. This shows how increasing ecological footprint levels are a result of the exploitation of natural resources, particularly minerals. Sofuoğlu and Kirikkaleli (2023) confirmed the positive impact of mineral saving, which is closely related to mineral rent, on the ecological footprint. This suggests that efficient management and conservation of mineral resources can help reduce the ecological footprint. On the other hand, Li (2024) showed the opposite, regarding how natural resource rent affects environmental quality in a mixed way, especially the ecological footprint. According to He *et al*. (2024), mineral rents can reduce the ecological footprint. The authors argued that governments can make mining companies fund environmental protection projects. This uncertainty shows how complex the relationship between mineral rent and the ecological footprint is and further research as well as advanced econometric techniques are needed to fully understand its implications.

Mineral rents are not the only factor affecting the ecological footprint; economic activity (captured as gross domestic product [GDP] per capita) is one of the main factors as well: According to Chen (2023), Alola *et al*. (2021) and Erkut (2022), an increase in GDP per capita leads to an increase in the ecological footprint. Some other studies indicate that GDP per capita and the ecological footprint initially increase together until a certain point where the relationship decouples. This means that while higher GDP per capita initially leads to a larger ecological footprint, beyond a specific threshold, higher GDP growth does not proportionally increase the ecological footprint, which results in an inverted U-shaped relationship (Kubiszewski *et al*., 2013; Alola et al., 2021; Sharma *et al*., 2021; Šatrović and Adedoyin, 2022).

Additionally, forest areas are also considered important and relevant. Chen and Chen (2021) found that the ecological footprint is aligned with forest areas, croplands, built-up lands, grazing lands, fishing grounds and carbon emissions. This shows how important forest areas are in calculating the overall ecological footprint. Jorgenson (2003) also found that the ecological footprint is linked to deforestation. Rainham *et al*. (2013) emphasized that using forest land for making paper and wood products adds significantly to the ecological footprint, showing how forest areas affect environmental degradation and Deng *et al*. (2018) also noted that in some regions, forest land makes up a large part of the total ecological footprint, highlighting its significant impact on the environment. According to Yasin *et al*. (2024), we can notice that forest rents in particular contribute to an increased ecological footprint.

Finally, renewable internal freshwater resources can also be considered a variable of interest, since studies have shown that renewable energy sources, especially freshwater, contribute significantly to reducing the ecological footprint (Sharif *et al*., 2020; Ulucak and Khan, 2020). According to Zhang *et al*. (2021), there is empirical evidence that the ecological footprint increases with economic expansion and natural resources and decreases with renewable energy. This shows how important it is for attempts to promote environmental sustainability to take renewable internal freshwater supplies into account.

2.4 Regulatory frameworks and management practices

Regulatory frameworks are essential for reducing the negative effects of mining activities, reasoning why the mining sector in the Global South has been at the centre of implementing corporate social responsibility (CSR) activities to minimize the negative operating effects of mining (Ackers and Grobbelaar, 2021). Mining companies tend to adopt these self-regulated frameworks frequently to respond to conflicts that may arise and to ensure local ownership (Matebesi and Twala, 2023). By pushing mining companies to think about their social and environmental responsibilities, CSR plays a key role in promoting sustainable mining practices. Within the context of sustainable development, the global standard of CSR proposes a dynamic approach to promoting standards of behaviour relevant to the mining industry (Dong and Xu, 2016). Also, CSR is seen as a tool towards sustainability in the mining industry, reflecting practical implementation of sustainability goals and the acknowledgment of the significant potential social and environmental impacts of mining activities on local communities (Fragkoulis and Koemtzi, 2023).

When evaluating the performance of CSR programmes in the mining industry, it is important to analyse their alignment with actual community needs and other socio-cultural factors because certain CSR programmes may fail to effectively address community needs, adapt to the cultural context of the recipients or ensure long-term sustainability, and as a result, there is a call for mining management, governments and policymakers to improve the effectiveness of CSR programmes by addressing these deficiencies and ensuring that CSR efforts are relevant and sustainable in the long run (Devenin and Bianchi, 2018).

Despite the existence of all the regulations that seek to decrease the environmental impacts of mining activities, enforcement and compliance within the sector is still facing notable obstacles since environmental management bodies in mineral-rich countries frequently lack the financial and human resources needed for independent monitoring and efficient regulatory enforcement, resulting in poor implementation of national environmental regulations. This gap between regulations and practices in the Global South adds to the ongoing environmental challenges and limits sustainability initiatives, since it has many negative effects on the ecosystem, including atmospheric emissions, land disturbance, soil contamination, biodiversity loss and water pollution – all causing environmental degradation and preventing sustainable development (Ruppen *et al*., 2021; Tampushi *et al*., 2021). An important factor that expands the gap between regulations and practices is the unwillingness of some stakeholders, particularly law enforcement agencies, to encourage mining businesses to operate sustainably, which prevents effective sustainability measures (Amoako, 2023).

Table 1 provides an overview of recent literature on the nexus between the ecological footprint and mining.

3. Methodology

3.1 Theoretical framework

This study uses the STRIPAT model as its theoretical framework. STRIPAT stands for stochastic and recursive impacts by regression on population, affluence and technology. STRIPAT is an advanced extension of the IPAT equation that posits that the environmental impact (I) is a function of population (P), affluence (A) and technology (T) (Muthoni, 2014). This model allows a more comprehensive and dynamic analysis by accounting for random effects, data variability and recursive relationships among the variables and provides a more robust understanding of the relationship between economic, technological and demographic factors and their environmental impact.

3.2 Data and variables

The analysis studies the environmental impacts of mining activities in the Global South employing panel data, studying the years from 1990 to 2020 and incorporates advanced econometric techniques. The study focuses on a sample of 5 countries (Brazil, China, India, Indonesia and Pakistan) selected on the basis of being a Global South country and having a mining industry.

The dependent variable is the ecological footprint (*EF*), whereas the five independent variables are mineral rents (MR in % of GDP), GDP per capita (*GDPPC*), GDP per capita squared (*GDPPCS*), forest area (*FA*) and renewable internal freshwater resources per capita (*RFWR*).

Table 1: Overview of recent literature

Authors	Countries involved	Period	Methods	Conclusions
Sofuoğlu and Kirikkaleli (2023)	Turkey	1975–2017	Autoregressive delay distributed (ARDL) cointegration test, Fourier ADF and traditional ADF unit root tests, Fourier ARDL bounds test	Positive impact of mineral saving, which is closely related to mineral rent, on the ecological footprint
Chen (2023)	54 member countries of the Belt and Road Initiative (BRI)	2000–2018	Spatial econometric approach, principal component analysis (PCA)	An increase in GDP per capita leads to an increase in the ecological footprint.
Alola *et al.* (2021)	China	1971–2016	Quantile-on-quantile (QQ) technique, quantile regression	U-shaped relationship between GDP per capita and ecological footprint
Kubiszewski *et al.* (2013)	Europe (Austria, Belgium, Germany, Italy, Netherlands, Poland, Sweden, United Kingdom), North America (USA), South America (Chile), Oceania (Australia, New Zealand) and Asia (China, India, Japan, Thailand, Vietnam)	1950–2003	Genuine progress indicator (GPI), comparison between GPI, gross domestic product (GDP), human development index (HDI), ecological footprint, biocapacity, Gini coefficient and life satisfaction scores. Global GPI per capita was estimated over the same period, highlighting trends and variations among the countries	U-shaped relationship between GDP per capita and ecological footprint
Šatrović and Adedoyin (2022)	Japan, Switzerland, South Korea, Germany, Singapore, Austria, Czechia, Sweden, Hungary and Slovenia	1998–2017	Cross-sectional dependence (CD) test, cross-sectional augmented panel unit root test (CIPS), panel cointegration tests, FMOLS and PMG-ARDL estimation	U-shaped relationship between GDP per capita and ecological footprint
Deng *et al.* (2018)	Hunan Province, China	2005–2015	Data envelopment analysis and energy-based ecological footprint methodology, ecological footprint analysis An ecological security evaluation method based on the ecological footprint was developed and implemented	The ecological footprint is closely related to the forest area.
Zhang *et al.* (2021)	Top ten remittance-receiving countries (India, Mexico, Philippines, France, Egypt, Nigeria, Pakistan, Bangladesh, China, Vietnam) and Germany	1990–2018	Cross-sectional dependence tests, panel unit root test, Westerlund cointegration test, panel cointegration test, panel causality test	Positive and statistically significant relationship between ecological footprint and renewable internal freshwater resources

Source: Authors' own elaboration

Data on the independent variables were sourced from the World Bank and data on the dependent variable were obtained from the Global Footprint Network. By examining these relationships, the study aims to shed light on the intricate interplay among the variables, ultimately contributing to our understanding of these critical dynamics.

3.3 Research methodology

In this study, we employ a variety of econometric techniques to investigate the relationship between the ecological footprint and key variables. The methods used include pooled OLS regression, a fixed-effects model, a random-effects model, the Arellano-Bond dynamic panel estimator, the augmented mean group (AMG) estimator and quantile regression. Additionally, panel unit root tests and panel cointegration tests are conducted to examine the stationarity and long-term relationships among the variables. All the analyses are conducted using STATA 17.0 to ensure robust and comprehensive results, and the following regression equation (1) is anticipated:

$$Y = a + bX + cZ + dK + eH + fI + gJ + u \tag{1}$$

where *Y* is the ecological footprint (*EF*), *X* is the mineral rents (*MR* in % of GDP), *Z* is GDP per capita (*GDPPC*), *K* is GDP per capita squared (*GDPPCS*), *H* is forest area (*FA*), *I* is renewable internal freshwater resources per capita (*RFWR*) and u is an error term.

Thus, the equation reads:

$$EFP_t = \beta_0 + \beta_1 MR + \beta_2 GDPPC + \beta_3 GDPPCS + \beta_4 FA + \beta_5 RFWR + \varepsilon_t \tag{2}$$

4. Results

4.1 Panel data tests

Table 2 gives an overview of the variables of interest. Five variables of interest are presented accordingly, where *GDPPC* appears twice in our estimation, once as it is and once in its squared form.

Table 2: Descriptive statistics

Variables	Mean	Standard deviation	Min.	Max.
EF	1.655	0.915	0.68	3.53
MR	0.586	0.576	0.00	2.65
FA	1,797,616.0	1,887,583.0	37,259.0	5,888,890.0
RFWR	8,739.617	11,645.46	242.08	37,563.09
GDPPC	2,795.735	3,100.162	301.50	13,200.56

Source: Authors' own calculations

Table 3 provides the results of the cross-sectional dependence tests.

Table 3: Cross-sectional dependence test

Test	Test statistic	*p*-value	Conclusion
Frees	0.378 (>0.1794)	–	Presence of CSD
Friedman	20.946	0.0003	Presence of CSD

Source: Authors' own calculations

Taking the results of the cross-sectional dependence tests, it is evident that there is cross-sectional dependence in the data, rejecting H0 of cross-sectional independence.

Table 4: Pesaran–Yamagata (2008) slope homogeneity test

Statistic	
Δ	7.953***
Δ adj.	9.074***

Note: *** indicate statistical significance at 1%.
Source: Authors' own calculations

The Pesaran–Yamagata test of slope homogeneity is presented in Table 4. Slope coefficients are heterogeneous in their nature, rejecting the null hypothesis of slope homogeneity.

Table 5: Blomquist-Westerlund slope homogeneity test with HAC

Statistic	
Δ	4.933***
Δ adj.	5.628***

Note: *** indicate statistical significance at 1%.
Source: Authors' own calculations

Slope coefficients are heterogeneous across the panels, even when using the HAC kernel (Bartlett) for robust standard errors, as presented in Table 5 with respect to the test results of the Blomquist–Westerlund slope homogeneity test.

Table 6: Panel unit root test

Variables	I(0)	I(1)
EF	–1.580	–3.140***
MR	–0.317	–4.719***
GDPPC	–1.717	–4.108***
FA	–0.897	–4.561***
RFWR	–3.162	–4.566***

Note: *** indicate statistical significance at 1%.
Source: Authors' own calculations

The stationarity tests shown in Table 6 indicate that the variables are non-stationary at levels but become stationary after differencing.

Table 7: Cointegration test

Test statistic	Value
Variance ratio	–1.5435*

Note: * indicates statistical significance at 10%.
Source: Authors' own calculations

The Westerlund cointegration test suggests weak evidence of cointegration among the variables, indicating potential long-term relationships among the variables in the model, as shown in Table 7.

4.2 Regression models

To explore the relationships between the ecological footprint and key variables, several regression models are estimated, where all the variables are represented in logarithmic terms.

Table 8: Dynamic panel data model (Arellano–Bond)

Variables	Coefficient	Standard error
***EF*(Lag 1)**	0.7607941***	0.0465006
MR	0.0037377	0.0029879
GDPPC	0.2259444***	0.0675002
GDPPCS	−0.0100099***	0.0039103
FA	0.0992813	0.0935545
RFWR	0.2506289***	0.0781260

Note: *** indicate statistical significance at 1%.
Source: Authors' own calculations

The Arellano–Bond dynamic panel data estimation results in Table 8 indicate that the ecological footprint is highly persistent over time. Higher GDP per capita and renewable freshwater resources significantly increase the ecological footprint, while the impact of mineral rents and forest area are not significant. The non-linear relationship with GDP per capita suggests that the ecological footprint grows with income but at a decreasing rate. In addition, we notice a positive and significant impact of renewable freshwater resources.

Table 9: Pooled OLS regression

Variables	Coefficient	Standard error
MR	−0.0860***	0.0117
GDPPC	0.7996***	0.2302
GDPPCS	−0.0342**	0.0153
FA	0.2975***	0.0236
RFWR	−0.0449**	0.0193

Note: *** and ** indicate statistical significance at 1% and 5%, respectively.
Source: Authors' own calculations

The pooled OLS regression results show a significant relationship between the ecological footprint and the independent variables. Higher mineral rents are associated with a lower ecological footprint. GDP per capita is positively associated with the ecological footprint, but only up to a certain point, as indicated by the negative coefficient of GDP per capita squared. Increases in forest area are associated with a higher ecological footprint, while increases in renewable freshwater resources per capita are associated with a lower ecological footprint.

Table 10: Fixed-effects model

Variables	Coefficient	Standard error
MR	−0.0052	0.0051
GDPPC	0.4549***	0.1081
GDPPCS	−0.0157**	0.0064
FA	0.8862***	0.1195
RFWR	0.2182*	0.1165

Notes: ***, ** and * indicate statistical significance at 1%, 5% and 10 %, respectively.
Source: Authors' own calculations

The results of the fixed-effects estimation show that within countries, an increase in GDP per capita is associated with increases in the ecological footprint, but this relationship is non-linear. Forest areas show a significant positive effect on the ecological footprint, while the impact of renewable freshwater resources is positive, but only significant at the 10% level.

Table 11: Random-effects model

Variables	Coefficient	Standard error
MR	−0.0860***	0.0117
GDPPC	0.7996***	0.2302
GDPPCS	−0.0342**	0.0153
FA	0.2975***	0.0236
RFWR	−0.0449**	0.0193

Note: *** and ** indicate statistical significance at 1% and 5%, respectively.
Source: Authors' own calculations

The random-effects model considers both within-country and between-country variations. The results indicate that increases in mineral rents and renewable freshwater resources are associated with a lower ecological footprint, while increases in GDP per capita and forest area are associated with a higher ecological footprint. The non-linear relationship with GDP per capita is also evident throughout the positive relationship between GDP per capita squared and the ecological footprint.

Table 12: Hausman test

Test statistic	Value
χ^2	130.69***

Note: *** indicate statistical significance at 1%.
Source: Authors' own calculations

The Hausman test indicates that the fixed-effects model is the appropriate model for this analysis.

4.3 Least-squares dummy variable (LSDV) regression analysis

Table 13: Regression output

Variables	Coefficient	Standard error
MR	−0.0052	0.0051
GDPPC	0.4549***	0.1081
GDPPCS	−0.0157**	0.0064
FA	0.8862***	0.1195
RFWR	0.2182	0.1165

Note: *** and ** indicate statistical significance at 1% and 5%, respectively.
Source: Authors' own calculations

For understanding whether pooled or fixed-effects regression would be relevant, we estimate a LSDV regression. Table 13 shows that higher GDP per capita increases the ecological footprint up to a certain point, but beyond a certain point there is a negative effect. Larger forest areas increase the ecological footprint; in addition, there is a positive but insignificant relationship between internal freshwater resources and the ecological footprint.

Table 14: Test for joint significance of country effects

Test statistic	Value
$F(4, 141)$	321.89***

Note: *** indicate statistical significance at 1%.
Source: Authors' own calculations

With an *F*-statistic of 321.89 we can rule out the possibility of using pooled OLS and stick with fixed OLS. Country fixed effects are jointly significant, indicating the importance of accounting for country-specific factors, as shown in Table 14.

Table 15: Augmented mean group (AMG)

Country	Variables	Coefficient	Standard error
Brazil	*MR*	–0.0101362	0.0096039
	GDPPC	–2.259274***	0.4254531
	GDPPCS	0.1374161***	0.0249291
	FA	7.876528***	1.777326
	RFWR	–1.65758*	0.8754964
China	*MR*	0.0109955	0.0100612
	GDPPC	0.6632161***	0.224237
	GDPPCS	–0.037748***	0.0134426
	FA	4.624716***	1.109811
	RFWR	7.086527***	1.573023
India	*MR*	–0.0055107	0.0086217
	GDPPC	–0.8179345***	0.3016893
	GDPPCS	0.0695567***	0.0203256
	FA	–1.180314	2.107069
	RFWR	0.57184	0.6405522
Indonesia	*MR*	–0.0093203	0.0085061
	GDPPC	–0.5156841**	0.2382987
	GDPPCS	0.040693**	0.0173024
	FA	–0.8921175	0.5648918
	RFWR	1.774258***	0.4886872
Pakistan	*MR*	–0.0011394	0.0079264
	GDPPC	0.9538845	1.225424
	GDPPCS	–0.0712431	0.0897602
	FA	0.2019223	1.56301
	RFWR	0.990567	0.726938

Note: *** and ** indicate statistical significance at 1% and 5%, respectively.
Source: Authors' own calculations

The group-specific coefficients highlight the heterogeneity in the relationships between the ecological footprint and the key variables across different groups. The impact of GDP per capita and forest area on the ecological footprint varies significantly among groups, with some groups showing a negative relationship while others show a positive one. Renewable freshwater resources also show varied effects across groups as per Table 15.

Table 16: Quantile regression

Quantile	Variables	Coefficient	Standard error
Q10	*MR*	−0.0593712***	0.0108693
	GDPPC	0.2439786	0.2018668
	GDPPCS	0.0017577	0.0140973
	FA	0.1203017***	0.0354949
	RFWR	0.0962896***	0.0238164
Q25	*MR*	−0.0719227***	0.0160322
	GDPPC	0.5426453**	0.2678406
	GDPPCS	−0.0179936	0.0173666
	FA	0.1390589**	0.0639739
	RFWR	0.0964689*	0.0551592
Q50	*MR*	−0.0873181***	0.0134361
	GDPPC	−0.9000337***	0.327104
	GDPPCS	−0.0417603**	0.0201599
	FA	0.337632***	0.0657765
	RFWR	−0.0810052	0.069976
Q75	*MR*	−0.0547471***	0.0077808
	GDPPC	0.9419376***	0.1756182
	GDPPCS	−0.0471796***	0.0112844
	FA	0.3430178***	0.0203142
	RFWR	−0.1188371***	0.0213882
Q95	*MR*	−0.0458255***	0.0140756
	GDPPC	0.2245439	0.5324248
	GDPPCS	−0.0016809	0.034969
	FA	0.3591758***	0.0396013
	RFWR	−0.1360469***	0.0261184

Notes: ***, ** and * indicate statistical significance at 1%, 5% and 10 %, respectively.
Source: Authors' own calculations

The quantile regression results in Table 16 show the varying impact of key variables across different quantiles. Higher mineral rents consistently reduce the ecological footprint, while GDP per capita generally increases it in most quantiles. Forest areas tend to increase the ecological footprint, especially at higher levels. The effect of renewable internal freshwater resources varies, with positive effects at lower levels of the ecological footprint and negative effects at higher levels.

5. Discussion

This study examined the relationships between key factors and the ecological footprint using various regression models, and many results were highlighted. We found that higher mineral rents generally lead to a reduced ecological footprint, which confirms the findings of Li *et al*. (2022), Kaur *et al*. (2023) and He *et al*. (2024), who noted that good management and conservation can fix the initial increase in the ecological footprint caused by natural resource rents such as mineral rents. On the other hand, when GDP per capita goes up, the ecological footprint increases, but it starts to go down over time. This supports the idea that environmental damage initially gets worse with economic growth but then improves as countries become richer and adopt better practices. Chen (2023), Sharma *et al*. (2021) and Kubiszewski *et al*. (2013) noticed this pattern too.

The results concerning forest areas are not conclusive, and the impact of renewable freshwater resources on the ecological footprint varied depending on their levels. The approach of Yasin *et al*. (2024) argues that forestation may affect forest rents, which, in return, increase the ecological footprint; however, our results bring no conclusive evidence of this effect. Zhang *et al*. (2021) found out that changes in water resources significantly affect the ecological footprint, emphasizing the important role of water in environmental sustainability.

This study highlights the need for specific policy measures since diverse factors influence the ecological footprint in many ways. Policymakers should consider these changes and effects to develop strategies that effectively balance economic growth with environmental sustainability. Governments in the Global South need to focus on reducing the ecological footprint of mining activities by implementing more stringent regulations, improved management practices and incentives for sustainable mining practices. In line with Bansal and Aggarwal (2017), a common public policy framework may be optimal to address the need to implement more stringent regulations on mining activities. Additionally, international NGOs and IGOs should focus more on sustainable resource management since it is important to avoid the negative environmental impacts of mining activities.

6. Conclusion

This paper studied the environmental effects of mining in Brazil, China, India, Indonesia and Pakistan using data from 1990 to 2020 to see how factors such as mineral rents, forest area, GDP per capita and freshwater resources per capita affect the ecological footprint.

Firstly, it was found that as these countries become richer, their ecological footprint initially grows but then starts to decrease when they adopt more sustainable practices. This means that while economic growth can harm the environment at first, it can also lead to improvements later. For example, higher mineral rents were linked to a smaller ecological footprint, suggesting that good management can help reduce environmental damage. On the other hand, evidence on the nexus between forest areas and the ecological footprint was mixed. This shows that the relationship between economic activities and the environment is complex. More forests might mean more resources being used, which increases the ecological footprint. With regard to the nexus between mining rents and the ecological footprint, we found a negative relationship, indicating that mineral rents decrease the ecological footprint. On the other hand, for renewable freshwater resources, we found a positive relationship with the ecological footprint.

These findings highlight the need for capturing the complex nature of the variables of influence in environmental policies. Each country needs strategies that fit its own unique situation to improve sustainability in mining. Policymakers should think about the specific economic and environmental conditions of their country when making policies. By doing this, they can help reduce the negative impacts of mining while still supporting economic growth to balance economic growth with protecting the environment, which can help reduce the ecological footprint and promote better management of resources.

Despite the comprehensive findings of this study, it is important to mention its limitations in the scope of analysis. Future research could expand by adding more countries to the study or a longer timeline, exploring the impact of renewable energy sources on the ecological footprint and considering additional environmental indicators. Further research is also encouraged regarding the long-term impacts of ecological degradation on local populations' health and socio-economic conditions. In addition, the gap between legislation and practice can also be explored to understand the socio-economic context of mining activities.

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