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Investigation on the environmental Kuznets curve in the São Francisco River Basin in Minas Gerais State, Brazil

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Abstract: ***This research investigates the Environmental Kuznets Curve hypothesis in the São Francisco River Basin in Minas Gerais State using variables related to the water quality as an indicator of environmental degradation. The São Francisco River has the largest basin fully contained within Brazil. A total of 128 municipalities were studied using variables related to GDP and mining activities. Robust multivariate statistical techniques were used in this study. The results showed that the Kuznets hypothesis was valid in the studied region. In terms of the presence of an inverted U-shape association between the studied variables, the estimates have the expected signs and are statistically significant, yielding empirical support to the presence of an Environmental Kuznets Curve hypothesis. It was found that the region is in the early stages of development, in which a surge in the population of the economy increases environmental degradation. From the results of this study, a series of recommendations have been provided for the investigated municipalities. Economic growth does not guarantee the cure for the region's environmental problems. Proper institutional performances do have a fundamental role in the improve of life and water quality in the region. The used methodology is simple, and the software is free, allowing it to be used in different conditions and regions.***

Keywords: Environmental Kuznets Curve, Robust multivariate statistical techniques, São Francisco River Basin.

1. Introduction

The history of people's occupation in the Minas Gerais State, Brazil, region has a direct relationship with the São Francisco River and its degradation. Exploration of this region began with the discovery and extraction of gold and precious stones and, later, iron ore. This was followed by a cycle of industrialization, agricultural development, and disorderly urbanization. The ancient history of the Minas Gerais region has associated economic development with environmental degradation [1].

In recent years, studies on economic and social development have focused more on the environment, and not merely on simple growth [2] [3] [4] [5] [6] [7] [8] [9] [10]. Earlier studies have indicated that economic development, consisting of activities such as agriculture, industrialization, and urbanization, affects water quality. Through these studies, an inverted-U-shaped curve (Kuznets environmental curve) was proposed to define the relationship between the emission of environmental contaminants and socio-economic variables (Gross domestic product (GDP), occupation, income, etc.; Figure 1).

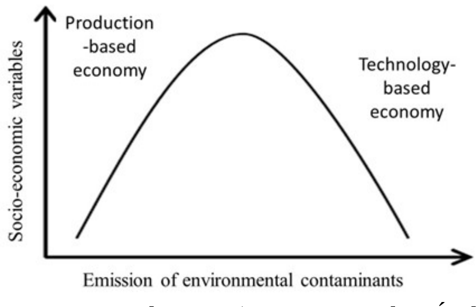


Figure 1: Kuznets Environmental Curve (Source: Based in Ávila and Diniz, 2015 [11].)

During the early stages of development of a region or country, the rise in the activities of the people in the economy increases environmental contamination until a certain point is reached, after which the relationship between these variables becomes negative. This change can be addressed using more efficient technologies, population awareness, environmental education, legislation, and adequate supervision [2] [3] [4] [5] [6] [7] [8] [9] [10] [12].

The present research aimed to evaluate the relationships between the different economic variables and the water quality of the São Francisco River in the state of Minas Gerais. It was in the basin of this river that in 2019, Brumadinho´s collapse occurred.

> "… Brazil's Vale mining where happened the collapse of a dam which killed 186 people in the town of Brumadinho. At least 122 people are still missing more than a month after the accident at the dam, which collected waste from an iron ore mine in Minas Gerais state. Vale is the world's biggest producer of iron ore. The mining disaster was the second in the region since 2015, when a nearby dam co-owned by Vale collapsed. Brazilian authorities were severely criticized for being too slow and complacent over that accident. No-one has yet been imprisoned." (BBC [12])

In this research, a period prior to the collapse was studied because the after data is not yet available. Most activities that support economic growth in the São Francisco River Basin requires water [13]. Fresh waters classified in Brazil as Class II were studied. This type of water is used for the following purposes: (a) human consumption after conventional treatment; b) protect aquatic communities; c) recreational purposes such as swimming, water skiing, and diving, according to CONAMA Resolution No. 274, 2000; d) irrigation of vegetables, fruit plants and parks, gardens, sports, and leisure fields, with which the public may have direct contact; and e) aquaculture and fishing activities [14].

2. Methodology

We used the databases (BDs) of the Águas de Minas Project [15], IBGE [16], and DNPM [17]. These databases are free and available on the internet. The study was carried out in 2016, as it is the most recent in BDs. The related variables that were used are as follows (5 R$=1 US in January 2021):

1) GDP [16], "Gross value added of agriculture at current prices (R $ 1,000)", "Gross added value of industry at current prices (R$ 1,000)", "Gross added value of services at current prices—exclusive administration, defence, education and public health and social security, (R$ 1,000)", "Gross added value of the administration, defence, education, and social security, (R$ 1,000)", "Total gross added value at current prices (R$ 1,000)", "Taxes and net subsidies on products at current prices (R$ 1,000)", "Gross Domestic Product at current prices (R$ 1,000)"
2) IQA [15] : coliforms, pH, BOD (biochemical oxygen demand), nitrate, phosphate, turbidity, total solids, and DO (dissolved oxygen);.
3) CFEM [17]: Financial Compensation for the Exploitation of Mineral Resources (CFEM) is a countervailing payment paid to the Union for the use of these mineral resources.

The analysis was conducted using robust multivariate statistics, including multivariate methods, which are statistical models that consider many variables concurrently [18]. This methodology allowed for the generation of a multitude of information through statistical analysis, with the objective of understanding the complexity of environmental impacts along the São Francisco River. This type of analysis was conducted in different locations, thus generating useful information. (Appendix A).
For the statistical studies, R software [19] was used, which encompasses robust techniques for data analysis. The packages used were StatDA [20] and rrcov [21].
The centralized database obtained presented variables with different orders of magnitude and units, for example, phosphorus concentration, in the order of 10^{-2} mg/L and the GDP of a municipality, up to R$ 10^7 (US$ 0.2 x 10^7). This can lead to a problem in multivariate analysis as all variables are considered simultaneously; the variable with the highest variance will have the greatest influence on the result. Variance is related to absolute magnitude [22]. GDP per capita is related to the development of a country, state, or municipality [16] [23] [24], and it was necessary to normalize the variables in relation to the number of inhabitants. For these above-mentioned reasons, data in the database were normalized by dividing each data point (Xi,j) by the median of the variable (med(i)) and the population of the municipality (n), where i denotes the variable and j denotes the municipality (Eq. 1):

$$x_{i,j} = \frac{X_{i,j}}{[n * med\ (i)]} \qquad (1)$$

One of the first stages in statistical analysis is the careful study of the distribution of variables. In the present study, the Shapiro–Wilks test (SW) was performed, considering a significance level of 5% [22].
The descriptive statistics of the variables were then attempted according to the method suggested by Reimann et al. (2008) - [22]. Variables that presented median absolute deviation (MAD) with zero values and/or CVR% (robust coefficient of variation) below 100% did not have sufficient significant multivariate variability to be used in multivariate statistical calculations. These were, then, not considered. MAD is calculated by (Eq. 2):
MAD = 1.4256 * median * (|median - xi|) (2)
Environmental data should normally be processed before subjecting them to statistical calculations. Several authors use logarithmic transformations [7] [8] [25] [26] [27]. However, these do not avoid the characteristic inaccuracies of the compositional data, such as the concentrations of contaminating elements used in analyses related to water quality. In this study, the centeredlog-ratio is preferred, which is suitable for work involving data, such as the concentration of a chemical compound [28]. This aimed to match the units, considering that the transformation "clr" uses the geometric mean. The clr transformation is defined by the following equations (Eq. 3,4):

$$y = (y_1, \dots\dots\dots, y_D) = \left[\log\frac{x_1}{\sqrt[D]{\prod_{i=1}^{D} x_i}}, \dots\dots\dots\dots\dots\dots\dots, \log\frac{D}{\sqrt[D]{\prod_{i=1}^{D} x_i}}\right]^t \qquad (3)$$

$$\sqrt[D]{\prod_{i=1}^{D} x_i} \quad geometric\ mean \qquad (4)$$

where, "y" stands for the transformed values, "xi" is the value of the variable "x" in the collection "i", and "D" is the number of collections considered for the calculations [22].
Cluster analysis was used to select variables. This is a multivariate technique used to aggregate variables based on the characteristics that are relocated. The results are the clusters that exhibit maximum homogeneity of variables within the

groups and, concurrently, maximum heterogeneity between the groups [28]. The hierarchical agglomeration method used was called "Average Linkage", this method is best suited for environmental data [22].
According to the same authors, the ideal dimension of databases for multivariate analysis (Eq. 5) is:

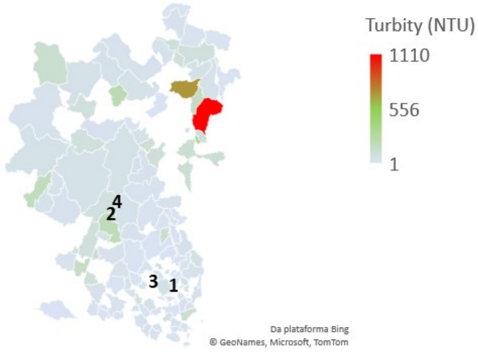
$$n > p^2 + 3p + 1 \qquad (5)$$

where “n” is the number of observations (rows) and “p” is the number of variables (columns) to be analysed. This requirement was followed for the selection of variables from cluster analysis.
The variables were selected, and multiple regression analysis was performed [29].
In the regression analysis, the existence of outliers was investigated, which may have affected the results of the statistical analysis. In multidimensional data, an observation is considered an outlier if it presents extreme values in the multivariate distribution. To detect incorrect data points, a multivariate comparison was made between the Mahalanobis distance and robust distance [30]. After the identification of the observations, outlier data were excluded, following the criteria established [30].
To evaluate the validity of the regression, the following standards were used: standard residual error (depending on the number of degrees of freedom), F statistic, multivariate R-, and p values [30] .

3. Results

This study commenced in 2016, the most recent year, at the junction of the BDs. A total of 128 municipalities were studied in this research. (Figure 2). The maximum allowable value (MAV) for turbidity, by Brazilian environmental regulations for water, was 100 NTU [14] . A total of 97% of the municipalities presented turbidity values above the regulated levels.

Figure 2: Turbidity and municipalities in studied region



1 Brumadinho 2 Três Marias 3 Nova Serrana 4 Pirapora e Juramento

A total of 15 variables met the established requirements (Table 1). None of the variables presented a normal distribution, which is expected for this type of analysis [30].

Table 1: Some parameters related to the used variables.

N	Variable	Definition	Median	Average	SD	MAD	CVR %
1	CFEM	Financial Compensation for The Exploitation of Mineral Resources	0.2458	95.75	613	0.3644	148.3
2	Industry	Gross value added of industry, at current prices (R$ 1,000)	24,150	386,900	1,509,000	32,500	134.6
3	Taxes	Taxes, net of subsidies, on products, at current prices (R$ 1,000)	14,960	207,000	1,146,000	19,990	133.7
4	Services	Gross value added for trade, transport and education activities (R$ 1,000)	77,310	786,500	4,744,000	96,590	124.9
5	GDP	Gross domestic product (R$)	224,600	1,672,000	8,106,000	272,500	121.3
6	Prices	Total gross value added at current prices (R$ 1,000)	206,700	1,465,000	6,962,000	248,000	120
7	Agricultural	Gross value added of Agriculture, at current prices (R$ 1,000)	23,370	54,210	100,100	25,970	111.1
8	Turbidity	Water turbidity (UNT)	63.83	148.4	244.8	65.56	102.7
9	ADESS	Gross value added of the Services, at current prices - exclusive Administration, defence, education and public health and social security (R$ 1,000)	58,880	237,800	964,600	58,120	98.71

10	N	Nitrate concentration (mg/L N)	0.08	0.1485	0.17	0.0593	74.13
11	P	Phosphorus concentration in lyotic environments (mg/L P)	0.51	0.9648	1.213	0.3706	72.68
12	ST	Total solids(mg/L)	190.9	253.6	218.5	114	59.73
13	Coliforms	Number of coliforms / 100 mL	16,200	31,880	34,140	9,398	58.02
14	DBO	Biochemical oxygen demand (BOD 5 days at 20°C)	2.2	5.835	17.29	0.2965	13.48
15	pH	water pH	7.1	6.879	1.293	0.3706	5.22

Figure 3 shows a cluster analysis of the economic variables. To increase the number of degrees of freedom, the variables that presented the highest CVR% values were selected in each cluster:

Figure 3: Result of cluster analysis of economic variables

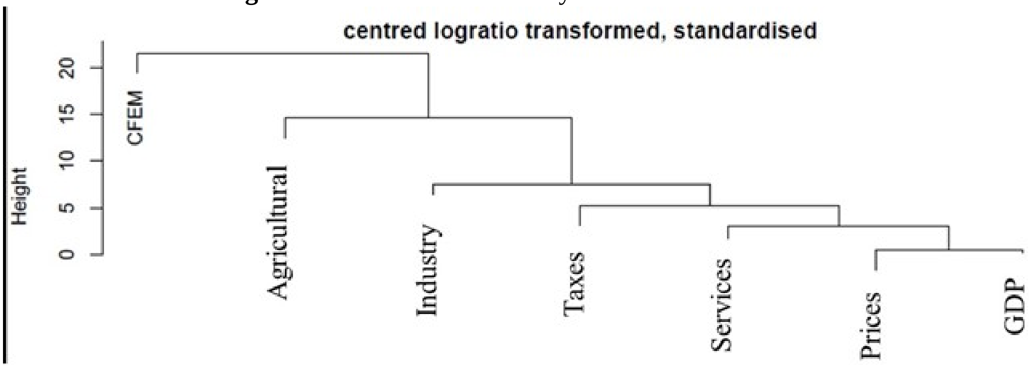


Figure 3: Kuznets Environmental Curve (Source: Based in Ávila and Diniz, 2015.)

The outlier analysis identified the following outliers Juramento (small town), Nova Serrana (intense industrial activity), Pirapora, and Três Marias (intense farming and industrial activities). The clr transformation was then performed, and the multiple regression analyses between turbidity and the selected economic variables were conducted. Turbidity was selected because it was the only environmental variable that presented CVR% greater than 100%. Table 2 presents the regression residues. Symmetry can be observed in relation to the mean zero value, which justifies the use of this model [28].

Table 2 -Multiple regression residues

Waste				
Min	1Q	Median	3Q	Max
-0.00702	-0.00186	-0.00047	0.002186	0.009146

The coefficients of the model are listed in Table 3. The standard error measures the average amount that the coefficient estimates vary from the actual average value of our response variable. The low values observed in Table 3 (<0,5 %) suggest the accuracy of the model. The Pr(>t) acronym found in the model output relates to the probability of observing any value equal or larger than t. A small p-value (<5%) indicates that a relationship between predictor variables and change-related responses is unlikely to exist. Typically, a p-value ≤ 0.05 is a good cut-off point. In the present study, Pr values (> t) were acceptable [28].

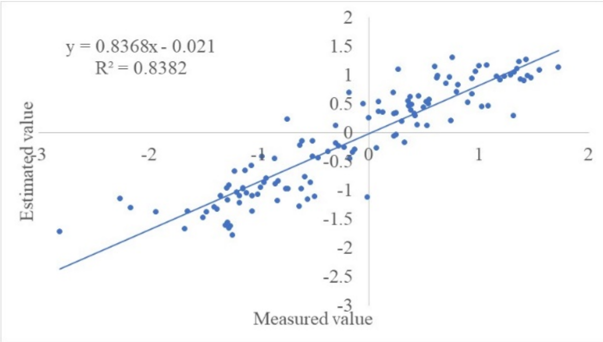
Table 3 - Parameters related to multiple regression model.

	Estimate	Standard error	Pr(>|t|)
Intersession	-0.0028	0.00037	7.10E-12
Agricultural	-1.0028	0.00086	2.00E-16
Industry	-1.0063	0.00157	2.00E-16
Services	-1.0276	0.00379	2.00E-16
Taxes	-0.9094	0.0027	2.00E-16
GDP	-2.0546	0.00463	2.00E-16
CFEM	-1.0002	0.00047	2.00E-16

The residual standard error is a measure of the quality of a linear regression adjustment. Theoretically, every linear model is assumed to contain an error term, €. Due to the presence of this error term, it is not possible to accurately predict the response variable from the predictor. The residual default error is the average value by which the response will deviate from the true regression line. After taking these parameters into account, the obtained value of 0.003652 with 118 degrees of freedom was acceptable [28].

The R^2 method provides a measure of how well the model adjusts to the actual data. It takes the form of a proportion of the variation. R^2 is a measure of the linear relationship between the forecasted variable and the response or target variable. The value of R^2 is always between 0 and 1 (a number close to 0 represents a regression that does not adequately explain the variance in the response variable, and a number close to 1 explains the variance observed in the response variable). In our study, the R^2 value obtained was 0.84. Thus, approximately 84% of the variance found in the response variable can be explained by the predictor variable [28]. The regression result is presented in Fig 4.

Figure 4: Multiple regression result.



The F method coefficient was 1,424 × 10^6 for 6 variables and 118 degrees of freedom. The F value is a good indicator of the existence of the relationship between the predicted and response variables. The further the F value is away from 1, the better the results. However, the F method depends on the number of data points and predicted variables. The p-value was $< 2.2 \times 10^{-16}$. This suggests that the adjustment of the model was good/bad [28].

4. Discussions

Turbidity represents the degree of interference during the passage of light through water, which leads to a blurred appearance of the light [29]. Turbidity is facilitated by the presence of suspended particles such as rock particles, clay, silt, algae, microorganisms, and domestic and industrial sewage, among others. High turbidity reduces the photosynthetic capability of submerged rooted vegetation and algae [15], causing the extinction of biological communities. The municipalities detected as outliers were Juramento, Nova Serrana, Pirapora, and Três Marias (Table 4).

Table 4 - Outliers detected for the variables studied.

City	CFEM	Agricultural	Industry	Services	Taxes	GDP
Juramento	0.01	6,552	1,525	8,7194	1,025	34,481
NovaSerrana	96,388	10,512	738,710	607,431	198,864	1,838,089
Pirapora	6,187	38,621	603,969	537,633	226,285	1,605,428
Três Maria	3,172	68,584	552,606	264,505	201,578	120,7171

In Três Marias and Pirapora, monoculture helped to characterize a scenario of large-scale agricultural activities, with many farms (Ribeiro et al., 2012). The primary activities in these municipalities are agriculture, silting, mining, livestock, diffuse load, urbanization, industrial activities, and forestry [15].

Nova Serrana is known to produce sports shoes; in 2019, the local production was 105 million pairs. The main factors associated with the degradation of water quality in this municipality are the absence of adequate treatment facilities for sewage and industrial effluents, animal slaughter activities, and inadequate soil management practices [31]. Juramento presents one of the lowest GDP in the basin, owing to the absence of significant economic activities.

The variables related to economic activities contributing to the degradation of water quality in the São Francisco River Basin in Minas Gerais were agriculture, industry, services, taxes, GDP, and CFEM. This degradation in water quality is a result of non-compliance with environmental laws, human settlements, real estate growth in marginal areas of water bodies, destruction of forests along the river, and lack of awareness regarding the need for sustainability of natural resources [32].

The presence of an agro-industrial production model in the basin has been causing a chain of environmental problems. Since the 1970s, the basin has seen an accelerated and unbridled expansion of intensive agricultural practices [33]. Agricultural activities have the potential to contaminate water resources because the water supplied to an irrigated area that is not absorbed by the crops returns to rivers by surface runoff, carrying soluble salts, fertilizers, and toxic elements [34] .

As for mining, the São Francisco River Basin accounts for about 20% of the country's official mineral activity, which contrasts with the finding that the mineral sector is one of the major water polluters in the basin [34] ..

The municipalities in the southeast have most of their waterways filled with tailings from mining, industrial processes, and agriculture [35] .

The results report that, in the studied region, the hypothesis of the Kuznets environmental curve is valid and the increase in economic development reflects environmental degradation. Alam et al. (2016) [36], who applied the Kuznets curve hypothesis in Brazil, also validated the Kuznets environmental curve considering the CO_2 emission.

From the economic and environmental perspectives, the development process in the region has not yet improved the living conditions of the residents or environmental quality. Amidst development and the lack of sustainable policies, the regions experience degradation of soil and waterways because of various production processes and general human activities. In this sense, environmental, social, political, and economic conditions are closely associated and may both improve and deteriorate the lives of the population [35] .

5. Conclusions

The aim of this study was to examine the validity of the Kuznets environmental curve hypothesis in the São Francisco River Basin in Minas Gerais. Strong evidence of a correlation between economic variables and those related to water quality was obtained in this study.

As expected, the release of domestic sewage throughout the region, agricultural, mining, and urbanization activities contribute to the bulk of the water pollution during the studied period.

Due to the pressure of development and lack of sustainable policies, the natural resources in the São Francisco River Basin in Minas Gerais face a critical threat of degradation.

In conclusion, we have found the occurrence of the often-hypothesized inverted-U shaped relationship between income and environmental degradation, known as the Environmental Kuznets Curve, in the studied region. Throughout the region, water is contaminated, especially in places with higher income. The data indicate that the municipalities are at lower stages of development. In these stages, the amount and intensity of environmental degradation are related to the impacts of subsistence economic activity and a large amount of biodegradable waste.

Acknowledgements

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APPENDIX A - SELECTED ARTICLES

No.	Author	Independent variables	Dependent variables	Local	Model*
1	Apergis and ozturk (2015)[37]	CO_2 emission	GDP per capita Population density Land use Industry	Asian countries	II
2	Usama et al. (2015)[38]	CO_2 emission	GDP per capita Energy consumption per capita Economic development	Latin America and the Caribbean	I
3	Dong et al. (2018)[7]	CO_2 emission per capita	GDP per capita Non-renewable energy consumption per capita Renewable energy consumption per capita	China	I
4	Solarin et al. (2017)[27]	CO_2 emission	Consumption of hydroelectric power Urbanisation rate GDP per capita	China	I
5	Alam and Paramati (2016)[25]	Gini	Foreign direct investment Economic inequality Inflation Commercial opening Renewable tourism GDP per capita	49 developed countries	I
6	Katircioğlu and Taşpinar (2017)[23]	CO_2 emission	GDP, Energy consumption	Turkey	Ii
7	Sugiawan and Managi (2016)[39]	CO_2 emission	GDP Renewable energy consumption per capita	Indonesia	Ii
8	Alam et al. (2016)[36]	CO_2 emission	GDP per capita	India, Indonesia, China and Brazil	Ii

			Kg consumed of oil per capita		
			population growth		
9	Mehdi and Slim (2015)[40]	CO_2 emission	GDP	Tunisia	I
			Renewable energy consumption per capita		
			International trade		
10	Javid and Sharif (2016)[8]	CO_2 emission	GDP per capita	Pakistan	I
			Oil consumption		
			Commercial growth		
			International trade		
			Foreign direct investment		
11	Tingting et al. (2016)[41]	Emission liquid effluents	Economic development	28 provinces in China	II
		Solid effluent emission	Energy consumption		
		CO_2 emission	Commercial opening		
			Urbanisation		
	Ahmad et al. (2017)[42]	CO_2 emission	GDP	Croatia	I
13		CO_2 emission	GDP	Cambodia	I
			Total electricity consumption		
			Corruption index		
			Government reliability		
			Government effectiveness		
14	Wang (2013)[43]	Forest cover	Population density	Human Development Report	I
			% of rural population		
			Tropical model		
			GDP per capita		
15	Taghvaee and Shirazi (2014) [44]	CO_2 emission per capita	GDP per capita	IRAN	I
		BOD per capita	Pi		

			Deforestation		
16	Omay (2013)[45]	CO_2 emission	Economic growth	Turkey	Ii
			GDP		
17	Özokcua and Özdemir[46](2017)	CO_2 emission	GDP per capita	26 OECD countries	Ii
				52 emerging countries	
18	Tingting [47](2016)	CO_2 emission	Emission of industrial effluents per capita	China	Ii
			Solid tailings emission per capita		
	*I = Multiple regression, II = Multiple log-linear regression simple and quadratic terms				