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Article

Geographical Indication Clustering for Cassava: Producing Municipalities in Rio de Janeiro State Based on Edaphoclimatic Similarities Using Geotechnologies

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RESUMO

A Indicação Geográfica (IG) é um importante instrumento de valorização territorial e diferenciação de produtos agroalimentares com características específicas associadas à sua origem. Neste contexto, esta dissertação teve como objetivo identificar agrupamentos de municípios produtores de mandioca no estado do Rio de Janeiro com características edafoclimáticas semelhantes, por meio da utilização de geotecnologias e Análise de Componentes Principais (ACP), visando fornecer uma justificativa técnica para a potencial obtenção de uma IG coletiva. Foram utilizadas as variáveis edafoclimáticas de precipitação, temperatura, relevo e tipos de solo. A partir da ACP, foi possível reduzir a dimensionalidade dos dados e, por meio da estatística de agrupamento, identificar padrões de similaridade entre os municípios analisados. Como resultado, foram definidos três grupos: Grupo 1, composto por Duque de Caxias, Magé, Guapimirim, Cachoeiras de Macacu, Silva Jardim e Casimiro de Abreu; Grupo 2, com São Francisco de Itabapoana, Campos dos Goytacazes e Quissamã; e Grupo 3, formado por Rio de Janeiro, Nova Iguaçu e Japeri. Esses agrupamentos revelam a existência de territórios com semelhanças edafoclimáticas, o que fortalece o argumento para a utilização de geotecnologias no auxílio à elaboração da documentação para pedidos de IG, baseado em critérios técnicos e científicos. Conclui-se que a metodologia aplicada pode servir como base para estudos iniciais de potencialidade de IG para produtos agroalimentares.
Palavras-chave: indicação de procedência; denominação de origem; farinha de mandioca; região produtora; segurança alimentar.

ABSTRACT

The Geographical Indication (GI) is an important instrument for territorial valorization and differentiation of agri-food products with specific characteristics associated with their origin. In this context, this dissertation aimed to identify clusters of cassava-producing municipalities in the state of Rio de Janeiro with similar edaphoclimatic characteristics through the use of geotechnologies and Principal Component Analysis (PCA), seeking to provide a technical justification for the potential acquisition of a collective GI. Edaphoclimatic variables of precipitation, temperature, relief, and soil types were used. Through PCA, it was possible to reduce data dimensionality and, using cluster statistics, identify similarity patterns among the analyzed municipalities. As a result, three groups

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were defined: Group 1, composed of Duque de Caxias, Magé, Guapimirim, Cachoeiras de Macacu, Silva Jardim, and Casimiro de Abreu; Group 2, consisting of São Francisco de Itabapoana, Campos dos Goytacazes, and Quissamã; and Group 3, formed by Rio de Janeiro, Nova Iguaçu, and Japeri. These clusters reveal the existence of territories with edaphoclimatic similarities, which strengthens the argument for using geotechnologies to aid in the preparation of documentation for GI applications, based on technical and scientific criteria. It is concluded that the applied methodology can serve as a foundation for initial studies on the GI potential of agri-food products.
Keywords: indication of provenance; designation of origin; cassava flour; producing region; food security.Introduction

Introduction

Cassava (*Manihot esculenta* - Euphorbiaceae) is one of the most important crops for global food security and the socioeconomic development of several regions in the southern hemisphere. Considered by the United Nations (UN) as the "food of the 21st century," cassava is a significant energy source for millions of vulnerable people due to its high caloric value, hardiness, and adaptability to different soil and climate conditions (FAO 2020).

In 2023, cassava was cultivated in 99 countries, with a production of over 338 million tons of fresh cassava. The largest producer was Nigeria, with over 62 million tons, followed by the Democratic Republic of Congo, Thailand, Ghana, and in fifth place, Brazil, with a production of over 18 million tons (FAOSTAT 2023).

In Brazil, cassava is the third-largest agricultural product in terms of quantity produced (tons), behind only soybeans and corn, and the second in average yield (kilograms per hectare), behind only oranges. The states with the highest production value in 2023 were Pará and Paraná, with over 4 and 3 billion reais, respectively (IBGE 2023).

In the state of Rio de Janeiro, cassava production maintains relevance both for subsistence and regional commercialization. According to the latest Agricultural Census (2017), there are 10,645 cassava-producing establishments in the state, many of which are managed by family farmers, where traditional knowledge has been passed down through generations (Paes e Zappes 2016). Although agriculture has a small share in the state's GDP, it strongly impacts the subsistence of Rio de Janeiro's population, which already exceeds 16 million inhabitants (IBGE 2022). In 2023, 12,168 hectares of planted area were recorded, with 164,623 tons produced and a production value exceeding 249 million reais (IBGE 2023).

The municipality of São Francisco de Itabapoana is the largest cassava producer in the state of Rio de Janeiro, followed by the capital, Rio de Janeiro, and Cachoeiras de Macacu. This municipality has a long history with cassava cultivation, dating back to the first half of the 20th century, a period when it experienced its peak, and has since been tied to the cultural identity of São Francisco (Gantos 2013). Currently, it is the municipality in Rio de Janeiro state closest to obtaining a Geographical Indication (GI) for cassava flour, with government and university partnerships for studying and aligning requirements and documents (Prefeitura Municipal de São Francisco de Itabapoana-RJ 2025).

Indication of Provenance (IP) and Designation of Origin (DO) in Brazilian legislation are part of GIs, aimed at protecting notable products and services that have become known or that possess specific characteristics linked to the location. The National Institute of Industrial Property (INPI) is responsible for registering and recognizing GIs, aiming to identify and value Brazilian regional products. The implementation of a GI is an important collective tool for valuing products with unique characteristics linked to their place of origin and the producer's traditional knowledge. It also promotes producer unity through the creation of cooperatives, protects the environment through the adoption of conservationist agricultural practices, and boosts rural tourism (Arruda 2021; Paulo 2023; INPI 2025a).

However, obtaining GI registration requires the submission of a series of documents. According to Article 15 of INPI Ordinance No. 4/2022, these are: "technical specifications booklet; power of attorney; proof of the applicant's legitimacy; documents proving that the geographical name has become known (in the case of IP) or that prove the influence of the geographical environment on the qualities or characteristics of the product or service (in the case of DO); official instrument delimiting the geographical area; and representation of the GI." Regarding geographical delimitation, it is not necessary to respect political-administrative boundaries; it may encompass parts of a municipality or even municipalities from another state, if their similarity in terms of reputation or edaphoclimatic characteristics is proven (INPI 2025b).

In this context, the use of geotechnologies can be an interesting methodology to assist in delimiting the scope area of a GI, especially when seeking technical justification for including different municipalities or regions. The choice of this approach is justified by the growing demand for analytical tools that allow territorial characterization based on edaphoclimatic data, as well as the proven effectiveness of using PCA in studies that applied it to meteorological and environmental data (Amanajás e Braga 2012; Moura et al. 2018; Lima et al. 2024).

Therefore, the objective of this study was to conduct an edaphoclimatic analysis (precipitation, temperature, elevation, and soil) of the fifteen municipalities representing the four main cassava-producing micro-regions in the state of Rio de Janeiro, aiming to identify clusters and similar areas that could technically justify the potential for obtaining a GI for a group of cassava-producing municipalities, highlighting the use of geotechnologies as a scientific tool for this purpose.

Materials and Methods

Study Area

The study area of this work is located in the state of Rio de Janeiro, encompassing fifteen municipalities: São Francisco de Itabapoana, Campos dos Goytacazes, Quissamã, Casimiro de Abreu, Silva Jardim, Araruama, Cachoeiras de Macacu, Tanguá, Sumidouro, Guapimirim, Magé, Duque de Caxias, Nova Iguaçu, Japeri, and the capital, Rio de Janeiro. These municipalities were grouped into four distinct micro-regions: Campos dos Goytacazes, Cachoeiras de Macacu, Sumidouro, and Rio de Janeiro (Figure 1).

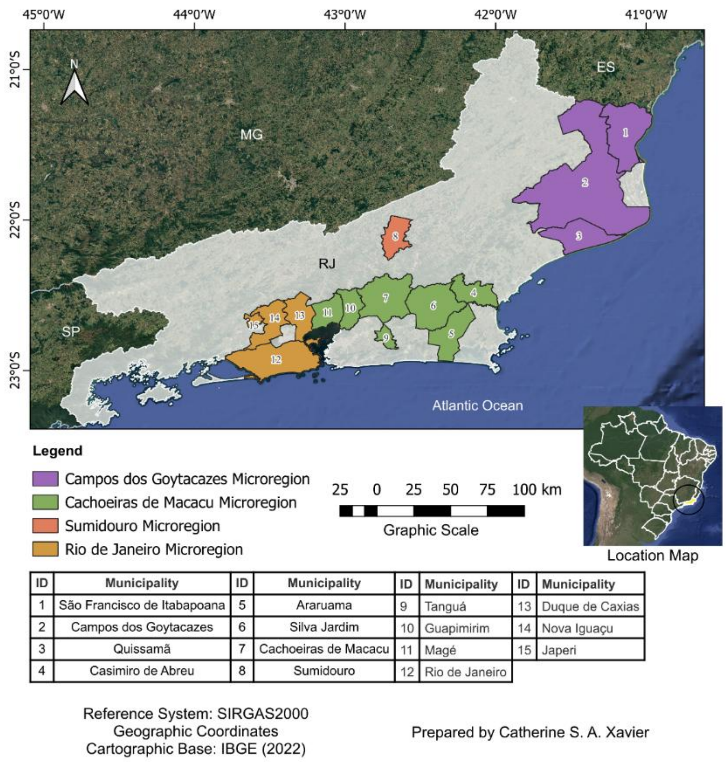

Figure. 1. Map of the micro-regions of the study area. Source: prepared by the authors.

The municipalities chosen are those that had a production value exceeding 3.5 million reais in the year 2023 (Table 1). The municipality of São Francisco de Itabapoana achieved the highest revenue in the state, followed by Rio de Janeiro and Cachoeiras de Macacu, in second and third place, respectively (IBGE 2024b).

Table 1. Cassava production value, in reais (R$ currency), in 2023.

Municipalities	Production (BRL)
São Francisco de Itabapoana	55,672,000
Rio de Janeiro	48,015,000
Cachoeiras de Macacu	19,038,000
Casimiro de Abreu	11,476,000
Duque de Caxias	11,070,000
Silva Jardim	10,541,000
Magé	8,424,000
Guapimirim	7,432,000
Nova Iguaçu	6,895,000
Tanguá	6,341,000
Japeri	6,268,000
Sumidouro	6,087,000
Araruama	5,147,000
Quissamã	3,784,000
Campos dos Goytacazes	3,534,000

Source: IBGE (2023).

The fifteen municipalities together cover an area of 12,439.42 km² and have a population of 9,032,723 inhabitants (Table 2), which represents 56.26% of the state of Rio de Janeiro's population, according to IBGE (IBGE 2022, 2024a). This percentage highlights the strategic relevance of cassava production in this region, considering that more than half of the state's population is potentially impacted by cassava cultivation.

Table 2. Population and area of the studied municipalities.

Municipalities	Population (2022 Census)	Area (km²)
São Francisco de Itabapoana	45,059	1,118.037
Campos dos Goytacazes	483,540	4,032.487
Quissamã	22,393	719.643
Casimiro de Abreu	46,110	462.918
Araruama	129,671	638.276
Silva Jardim	21,352	937.755
Cachoeiras de Macacu	56,943	954.749
Sumidouro	15,206	413.407
Tanguá	31,086	143.007
Guapimirim	51,696	358.443
Magé	228,127	390.775
Rio de Janeiro	6,211,223	1200.33
Duque de Caxias	808,161	467.319
Nova Iguaçu	785,867	520.581
Japeri	96,289	81.697

Source: IBGE (2022, 2024b).

Campos dos Goytacazes Micro-Region

In the Campos dos Goytacazes micro-region, located in the Northern Fluminense region, are the municipalities of São Francisco de Itabapoana, Campos dos Goytacazes, and Quissamã, situated approximately between latitudes 21.195° and 22.234° South and between longitudes 40.958° and 41.888° West. In the UTM (Universal Transverse Mercator) plane coordinate system, they are located in zone 24 South. According to the Köppen climate classification (Alvares et al. 2013), these have Aw-type climate, tropical with dry winter.

Altitudes in this region range from 0 to 200 meters for the most part, except for a small area where the Desengano State Park Conservation Unit is located, which reaches altitudes above 1,600 meters, in the southwestern portion of Campos dos Goytacazes municipality and due to the presence of Residual Mountain Escarpments in the northwestern portion (Catanhede e Amorim 2016). Land cover in these municipalities together is predominantly agriculture and pasture (MapBiomas 2023).

Data Collection

The present study used as data sources the Brazilian Institute of Geography and Statistics (IBGE), the National Institute for Space Research (INPE), the National Institute of Meteorology (INMET), and the National Water Agency (ANA).

The IBGE website provides free access to the Digital Municipal Mesh (MMD), from which the shapefiles of the state of Rio de Janeiro and the municipalities studied in this work were extracted. The MMD provides data, in vector digital format, of municipalities, states, and regions, and this information is updated annually, according to IBGE (IBGE 2025).

Elevation data were obtained through Digital Elevation Model (DEM) images, made available by INPE, produced from Shuttle Radar Topography Mission (SRTM) data, a space mission that used two radar antennas to collect elevation data from 80% of the Earth's globe (EARTHDATA, 2000). Soil shapefiles for all of Brazil were also collected from the IBGE website. Through this document, it was possible to identify the soil types of each municipality studied.

The 10-year historical series of precipitation data were obtained from rainfall stations on the Hidroweb website, belonging to ANA, and the 3-year historical series of temperature data were obtained from automatic rainfall stations on the INMET website. In total, 43 rainfall stations operated by the Geological Survey of Brazil (SGB) and 18 INMET stations were used, totaling 61 stations.

Data Analysis

The development of the work occurred in four stages: data acquisition via the internet, data processing using Excel (Office 365 Package) and QGIS 3.34.13 software, data normalization in a spreadsheet using Excel (Office 365 Package), statistical application of Principal Component Analysis (PCA), and cluster statistics using PAST 4.03 software.

Multiple Linear Regression

On the Hidroweb website, the 10-year historical series (2015 to 2024) from 43 rainfall stations was downloaded; however, failures are common at some point during the year in these types of stations. To address this situation, gap filling at the monthly level was performed using the simple linear regression method, for stations with gaps that had only one neighboring station, and multiple linear regression, for stations with gaps that had two or more neighboring stations.

The regressions were performed in Microsoft Excel software using the data analysis tool, and with the generated statistical data, the estimated precipitation values were calculated using the simple linear equation (Equation 1) and multiple linear equation (Equation 2), depending on the number of neighboring stations with complete data.

$$y = \alpha + \beta x (1)$$

Where: y = precipitation of the station to be estimated; α = regression constant; β = estimated coefficient of the precipitation from the support station; and x = precipitation value recorded at the support station.

$$y = \alpha + \beta_1 \cdot x_1 + \ldots + \beta_n \cdot x_n \ (2)$$

Where: y = precipitation of the station to be estimated; α = regression constant; $\beta_1,\ldots,\beta_n$ = estimated precipitation coefficient for each support station; and x_1, ..., x_n = precipitation value recorded at each support station.

QGIS Software

Precipitation and Temperature Rasters

In QGIS 3.34.13 software, the Coordinate Reference System (CRS) was configured to SIRGAS2000 (EPSG: 4674). Through the data source manager, meteorological information was added and organized into a point shapefile (Figure 2).

For the generation of rasters with minimum and maximum values of average annual precipitation (Figure 3) and average annual temperature (Figure 4) for each municipality, interpolation was first performed using the Inverse Distance Weighting (IDW) Method, applied to the representative points of the rainfall stations in the state of Rio de Janeiro, and subsequently, clipping was performed for each municipality.

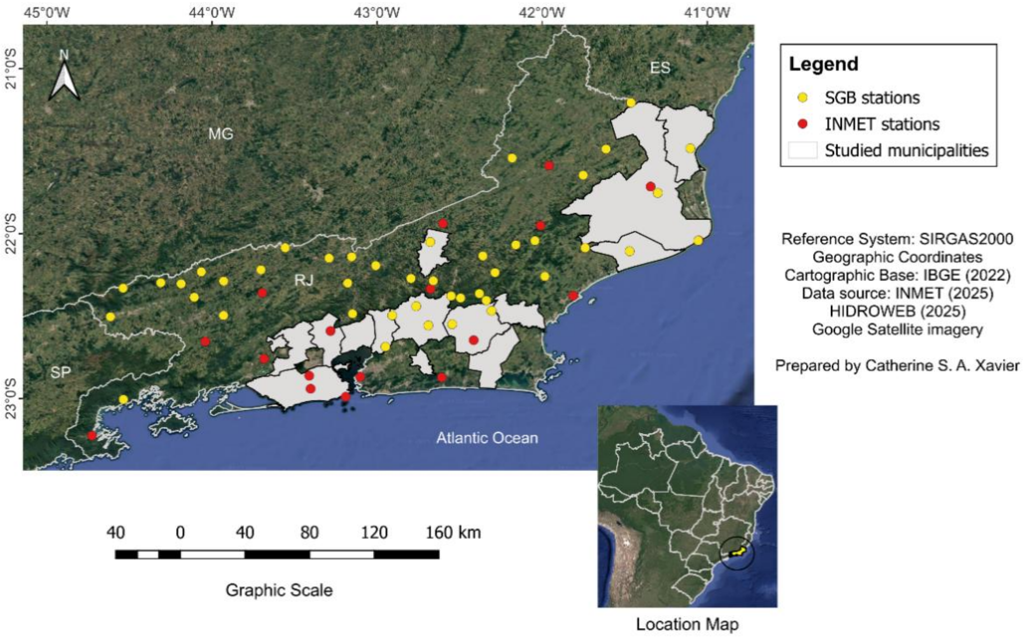

Figure. 2. Map of the rainfall stations used in the study. Source: prepared by the authors.

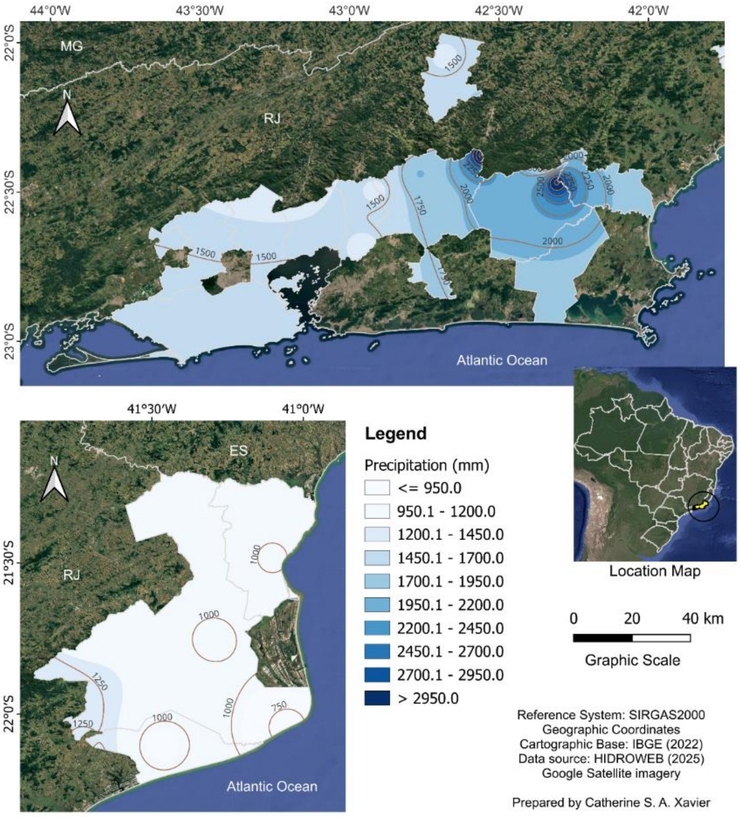

Figure. 3. Map of average annual precipitation over 10 years for the studied municipalities. Source: prepared by the authors.

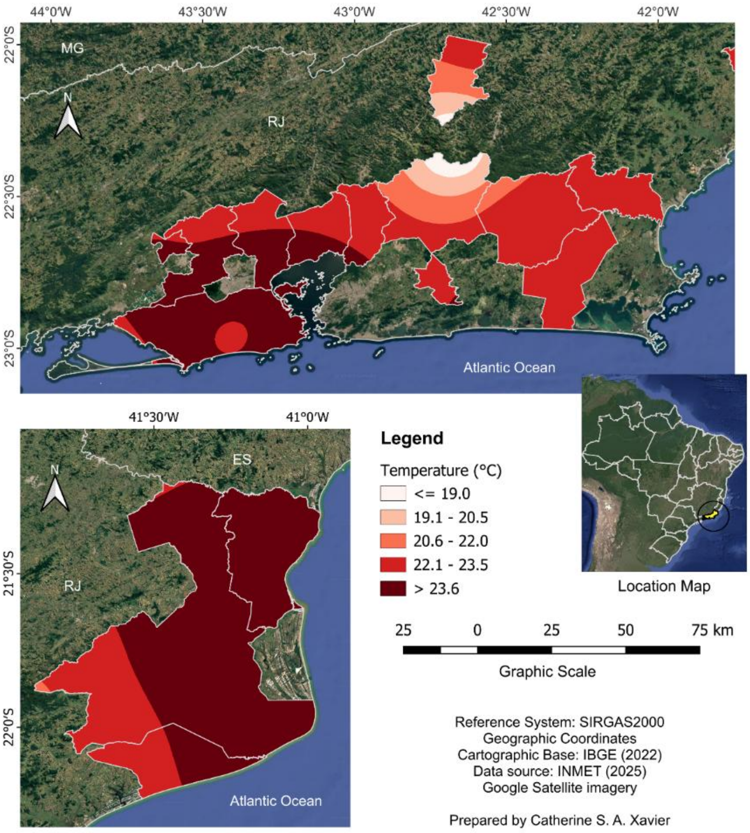

Figure. 4. Map of average annual temperature over 3 years for the studied municipalities. Source: prepared by the authors.

Digital Elevation Model

In this stage, seven images (Figure 5) captured by SRTM and made available by INPE were used, namely: a) 21S42 ZN; b) 21S435 ZN; c) 21S45 ZN; d) 22S42 ZN; e) 22S435 ZN; f) 23S435 ZN; and g) 23S45 ZN.

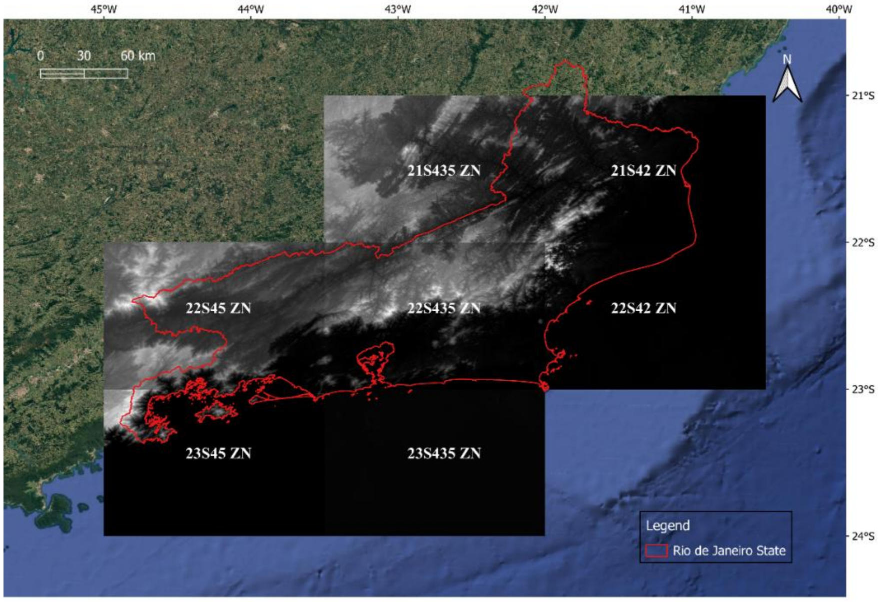

Figure 5. Images used for the Digital Elevation Model. Source: prepared by the authors.

The images were imported into the GIS, in QGIS software, reprojected to the SIRGAS2000 reference system (EPSG: 4674), and merged into a single image using the "Mosaic" command. Subsequently, with the "Clip raster by mask layer" command, it was possible to obtain the minimum and maximum elevations of the studied municipalities (Figure 6 and Figure 7).

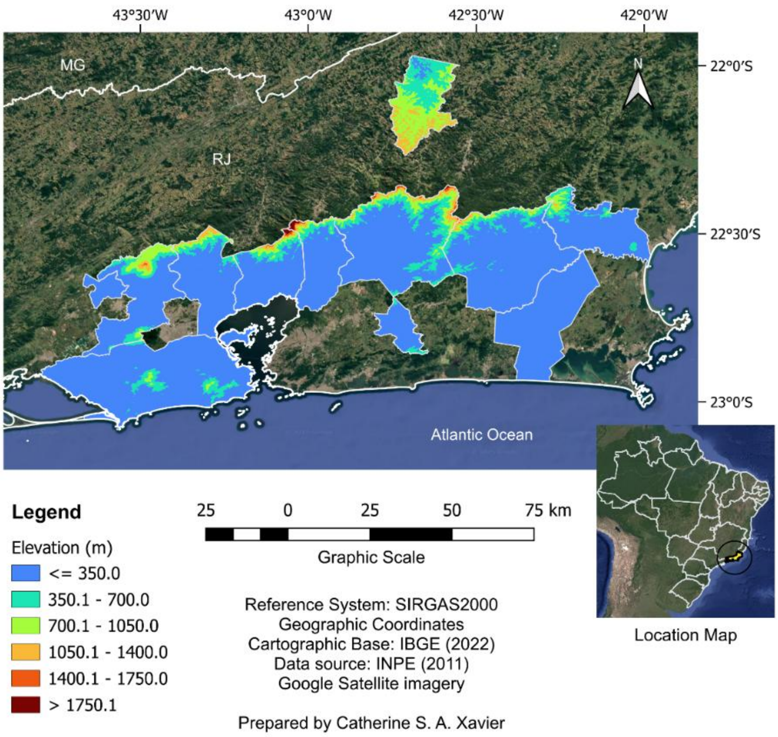

Figure 6. Digital Elevation Model of the studied area located in zone 23 south. Source: prepared by the authors.

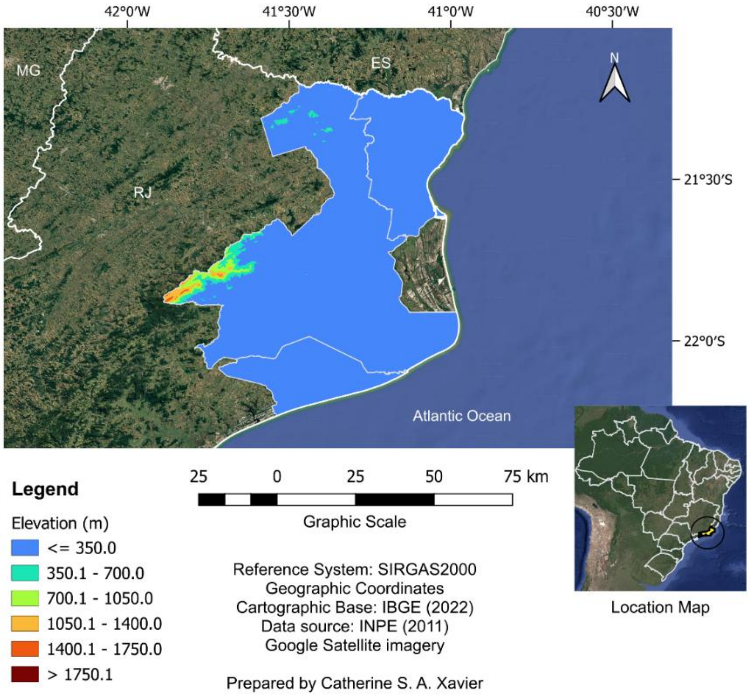

Figure 7. Digital Elevation Model of the studied area located in zone 24 south. Source: prepared by the authors.

Pedological Map

The soil data for Brazil, in shapefile format, were imported into the GIS and, already in the SIRGAS2000 reference system (EPSG: 4674), were clipped for each of the fifteen municipalities. Subsequently, the percentage of each soil type present in the area corresponding to each municipality was calculated. After this, the pedological map of the municipalities studied in this work was generated (Figure 8).

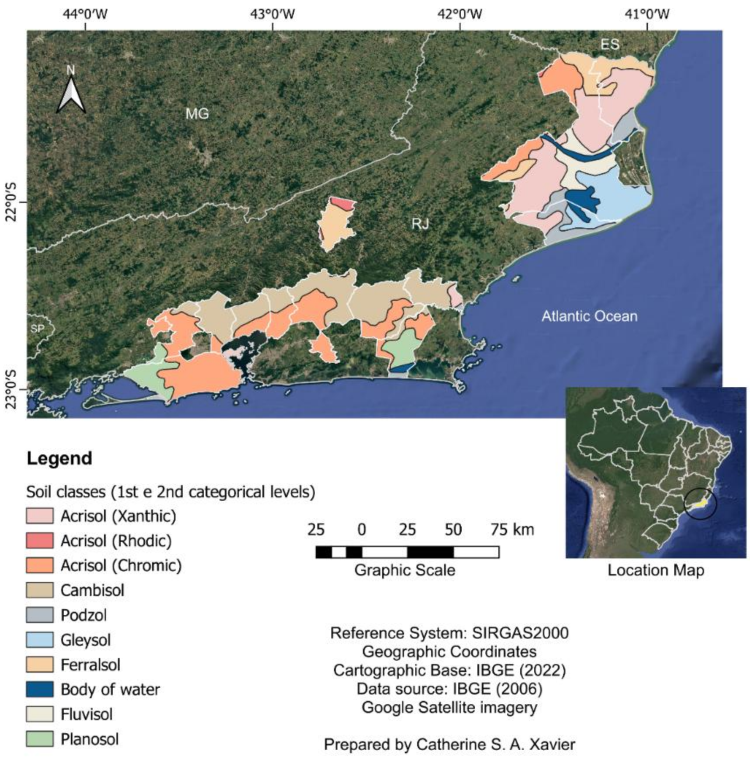

Figure 8. Pedological Map of the Studied Area. Source: prepared by the authors.

Spreadsheet

Averages and Percentages

Using the minimum and maximum values obtained from the IDW interpolation for each municipality, the averages of annual precipitation from 2015 to 2024, average annual temperatures from 2022 to 2024 (Table 3), and elevation (Table 4) were calculated.

Table 3. Average values, by municipality, of annual precipitation and average annual temperature.

Municipalities	Average Annual Precipitation (mm)			Average Annual Temperature (°C)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
São Francisco de Itabapoana	986.30	1,143.90	1,065.10	23.55	24.01	23.78
Campos dos Goytacazes	691.20	1,381.90	1,036.55	21.69	24.42	23.055
Quissamã	829.50	1,254.60	1,042.05	22.76	24.3	23.53
Casimiro de Abreu	1,757.40	3,269.30	2,513.35	22.31	23.11	22.71
Araruama	1,799.20	2,151.50	1,975.35	22.85	23.31	23.08
Silva Jardim	1,660.10	3,290.90	2,475.50	20.82	23.43	22.125
Cachoeiras de Macacu	1,399.10	3,651.40	2,525.25	17.74	23.07	20.41
Sumidouro	1,410.10	1,731.40	1,570.75	18.3	22.84	20.57
Tanguá	1,648.80	1,779.80	1,714.30	22.85	23.58	23.22
Guapimirim	1,399.00	1,569.00	1,484.00	21.85	23.85	22.85
Magé	1,425.30	1,500.30	1,462.80	22.86	23.87	23.37
Rio de Janeiro	1,509.00	1,586.50	1,547.75	23.28	24.51	23.895
Duque de Caxias	1,389.00	1,520.90	1,454.95	23.37	23.85	23.61
Nova Iguaçu	1,431.90	1,549.60	1,490.75	23.23	23.85	23.54
Japeri	1,476.80	1,510.60	1,493.70	23.37	23.81	23.59

Source: prepared by the authors.

Table 4. Average elevation values, by municipality.

Municipalities	Elevation (m)		
	Minimum	Maximum	Mean
São Francisco de Itabapoana	0	113.86	56.93
Campos dos Goytacazes	0	1627.39	813.70
Quissamã	0	72.17	36.09
Casimiro de Abreu	2.73	1,139.53	571.13
Araruama	0	114.19	57.10
Silva Jardim	3.32	1,499.82	751.57
Cachoeiras de Macacu	2.20	2,219.21	1,110.71
Sumidouro	267.26	1,414.82	841.04
Tanguá	16.41	855.44	417.09
Guapimirim	0	2,209.61	1,104.81
Magé	0	2,169.14	1,084.57
Rio de Janeiro	0	910.09	455.05
Duque de Caxias	0	1,470.25	735.13
Nova Iguaçu	2.36	1,453.03	727.70
Japeri	15.09	504.27	259.68

Source: prepared by the authors.

Table 5. Percentage values of the area occupied by each soil type.

Municipalities	Soils (%)									
	PA	PV	PVA	CX	ESK	GX	LVA	MA	RY	SX
São Francisco de Itabapoana	55.25	0.00	0.57	0.00	15.37	0.00	27.67	1.13	0.00	0.00
Campos dos Goytacazes	33.57	0.34	15.57	0.00	2.82	17.94	9.88	7.39	12.49	0.00
Quissamã	26.89	0.00	0.00	0.00	40.71	25.17	0.00	7.23	0.00	0.00
Casimiro de Abreu	14.27	0.00	0.01	81.89	3.83	0.00	0.00	0.00	0.00	0.00
Araruama	0.00	0.00	32.99	10.61	5.50	0.00	0.00	6.58	0.00	44.33
Silva Jardim	0.00	0.00	28.02	71.98	0.00	0.00	0.00	0.00	0.00	0.00
Cachoeiras de Macacu	0.00	0.00	36.91	62.25	0.00	0.00	0.83	0.00	0.00	0.00
Sumidouro	0.00	18.58	0.00	0.25	0.00	0.00	81.18	0.00	0.00	0.00
Tanguá	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guapimirim	0.00	0.00	54.34	45.66	0.00	0.00	0.00	0.00	0.00	0.00
Magé	0.00	0.00	35.47	64.53	0.00	0.00	0.00	0.00	0.00	0.00
Rio de Janeiro	3.61	0.00	68.33	0.00	1.44	0.00	0.00	0.00	0.00	26.62
Duque de Caxias	0.00	0.00	10.97	89.03	0.00	0.00	0.00	0.00	0.00	0.00
Nova Iguaçu	0.00	0.00	68.34	18.33	0.00	0.00	0.00	0.00	0.00	13.33
Japeri	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: prepared by the authors.

From the total area values of each municipality and the areas corresponding to each soil type, obtained from the attribute tables in QGIS software, it was possible to calculate the percentage of each soil class (Table 5).

Data Normalization

The normalization of average annual precipitation, average annual temperature, average elevation, and soil data was performed using the z-score technique by Altman (1968), Equation 1, with mean equal to zero and standard deviation equal to one, which was also used by other authors for normalization of meteorological data (Guimarães et al. 2013; Ghag et al. 2024).

$$Z = \frac{X - \bar{X}}{s} \quad (3)$$

Where: X is the original data, $\bar{X}$ is the mean of the data series, and is the standard deviation of the data series.

This normalization method was chosen because the data used in this work have different units (millimeters, degrees Celsius, meters, and percentages) which would hinder PCA from finding the most significant data. Through prior data normalization, each variable contributes equally, as the variance of the data is standardized to a unit value (Alves 2019).

PAST

PAST (Paleontological Statistics) is a free statistical software developed by Hammer, Harper, and Ryan (2001) aimed at statistical analysis of paleontological data. Through this software, it is possible to perform data plotting, basic statistics, multivariate analyses, geometric analyses, time series analyses, among others. It offers an interface similar to spreadsheets, facilitating the use of the program. In the present work, PAST software was used to perform PCA and clustering of its results. It was chosen due to its ease of use and because it is a free program.

First, the normalized data were entered into PAST software. Then, PCA was performed using the Multivariate, Ordination, and Principal components (PCA) commands. Subsequently, Matrix Correlation was chosen, and the data were recomputed. After PCA, the results were presented through tables and graphs.

For clustering the PCA results, the columns with the scores values, which represent the principal component value for each municipality, were entered into PAST software. The statistical clustering procedure must be performed individually for each obtained principal component. After entering the data column, clustering was performed using the Multivariate, Clustering, and Classical commands. Then, the Paired group (UPGMA) algorithm and the Euclidean similarity index were chosen. The results were presented in dendrogram format.

Results and Discussion

Through PCA, Principal Component 1 (PC1) explained 33.57% of the data, Principal Component 2 (PC2) explained 21.07%, Principal Component 3 (PC3) explained 13.97%, and Principal Component 4 (PC4) explained 10.56%, together they explained 79.17% of the data variability. Guedes et al. (2012) explain that PC1 will always seek to explain the maximum variability of all data, and what it does not explain will be explained in the subsequent PCs. The variables located at the extremes in Figure 9, farthest from the center (0,0), are those most explained by PC1 on the x-axis and by PC2 on the y-axis, whether positive or negative. Through cluster statistics, the data were separated into groups (Figure 9).

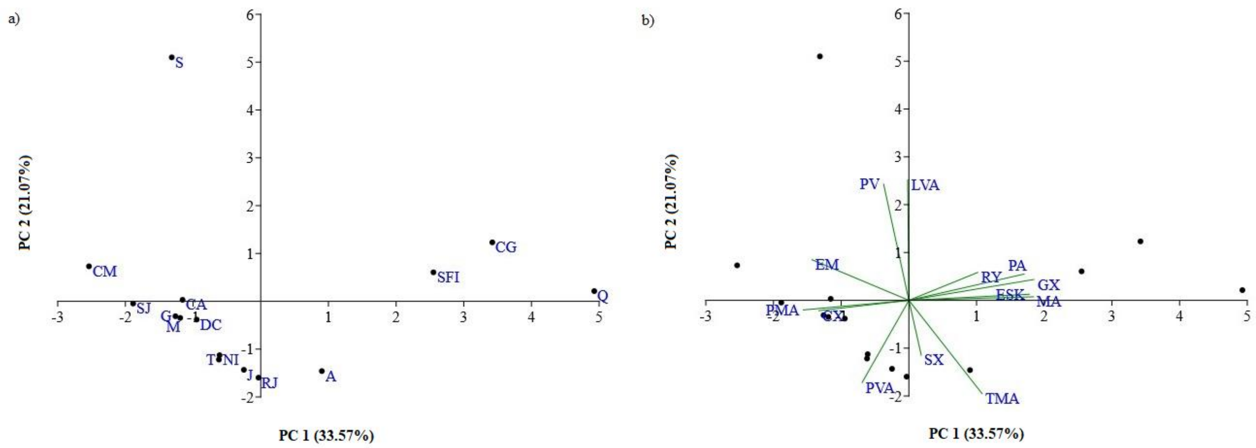

Fig 9. PCA plots (PC1 and PC2): a - score; b - loading. Note: SFI – São Francisco de Itabapoana; CG – Campos dos Goytacazes; Q – Quissamã; CA – Casimiro de Abreu; SJ – Silva Jardim; A – Araruama; CM – Cachoeiras de Macacu; S – Sumidouro; T – Tanguá; G – Guapimirim; M – Magé; DC – Duque de Caxias; NI – Nova Iguaçu; J – Japeri; RJ – Rio de Janeiro; PMA – Average Annual Precipitation; TMA – Average Annual Temperature; EM – Average Elevation; PA – Xanthic Acrisol; PV – Rhodic Acrisol; PVA – Chromic Acrisol; CX – Cambisol; ESK – Podzol; GX – Gleysol; LVA – Ferralsol; MA – Water Body; RY – Fluvisol; SX – Planosol. Source: Prepared by the authors.

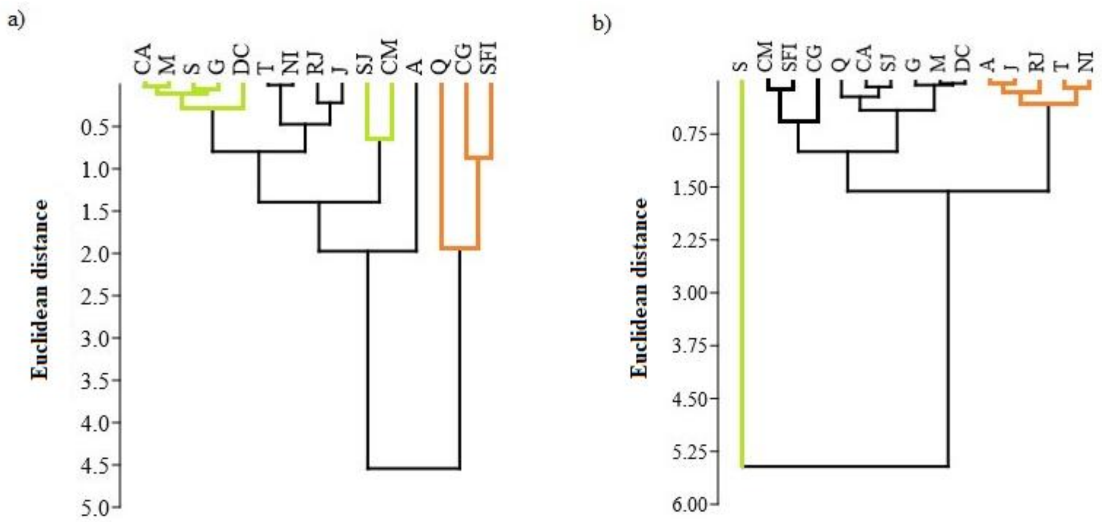

Figure 10. Figure 10. Data dendrograms: a) PC1 and b) PC2. Note: SFI – São Francisco de Itabapoana; CG – Campos dos Goytacazes; Q – Quissamã; CA – Casimiro de Abreu; SJ – Silva Jardim; A – Araruama; CM – Cachoeiras de Macacu; S – Sumidouro; T – Tanguá; G – Guapimirim; M – Magé; DC – Duque de Caxias; NI – Nova Iguaçu; J – Japeri; RJ – Rio de Janeiro. Source: Prepared by the authors.

In Figure 9, referring to PC1, SFI, CG, and Q showed a positive association with each other and a negative association with CA, M, S, G, DC, SJ, and CM. In Figure 9-b, there is a positive correlation between PMA and EM and a negative correlation of these with TMA. Regarding soils, PA, RY, GX, ESK, and MA showed a positive correlation, opposite to CX. The municipalities T, NI, RJ, J, and A presented values close to zero, indicating that they were not well explained by PC1.

Analyzing the results of Figures 9-a and 9-b together, it is observed that the municipalities SFI, CG, and Q showed a higher correlation with TMA and with the soils PA, RY, GX, ESK, and MA, and a lower correlation with PMA and EM, while CM, SJ, M, G, CA, DC, T, and NI showed a higher correlation with PMA, EM, and with CX soil.

In PC2, S does not show a positive correlation with other municipalities, only with PV and LVA soils and a low correlation with TMA. The municipalities T, NI, J, RJ, and A have a positive correlation with PVA and SX soils and with TMA. Table 6 shows the score values, and Table 7 shows the loadings. Figure 11 shows the PC3 and PC4 plots, followed by Figure 12 with the formed groups.

Table 6. Score values (PC1 and PC2).

Municipalities	CP 1	CP 2
São Francisco de Itabapoana	2.55	0.61
Campos dos Goytacazes	3.42	1.23
Quissamã	4.93	0.21
Casimiro de Abreu	-1.16	0.03
Araruama	0.90	-1.46
Silva Jardim	-1.89	-0.05
Cachoeiras de Macacu	-2.54	0.73
Sumidouro	-1.32	5.10
Tanguá	-0.62	-1.22
Guapimirim	-1.26	-0.31
Magé	-1.19	-0.35
Rio de Janeiro	-0.03	-1.60
Duque de Caxias	-0.95	-0.38
Nova Iguaçu	-0.61	-1.13
Japeri	-0.25	-1.43

Source: prepared by the authors.

Table 7. Loading values (PC1 and PC2).

Variables	CP 1	CP 2
PMA	-0,33	-0,04
TMA	0,23	-0,42
EM	-0,31	0,18
PA	0,36	0,12
PV	-0,08	0,52
PVA	-0,15	-0,37
CX	-0,28	-0,05
ESK	0,38	0,03
GX	0,39	0,09
LVA	0,00	0,54
MA	0,39	0,02
RY	0,22	0,12
SX	0,04	-0,24

Source: prepared by the authors.

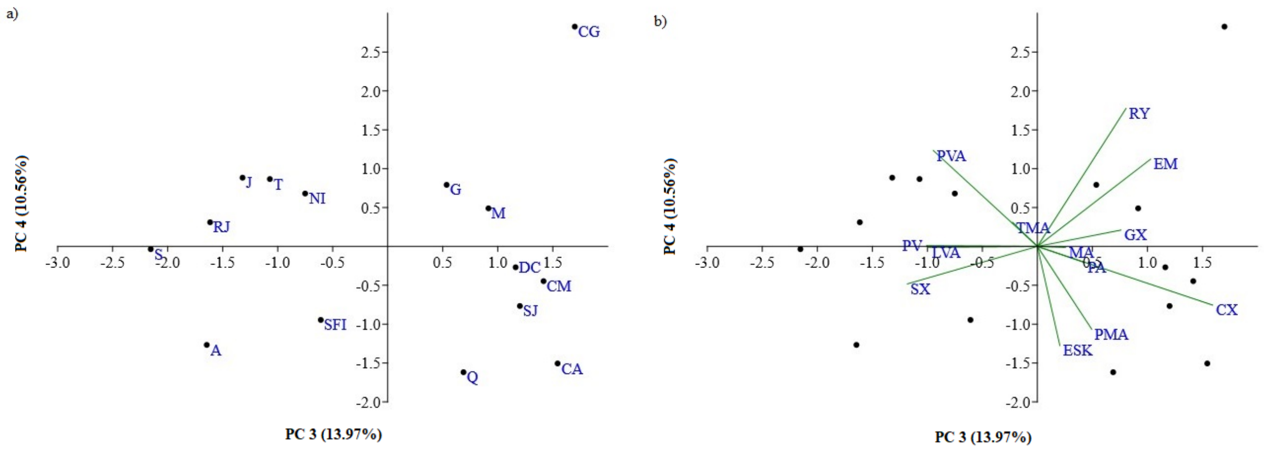

Figure 11. PCA plots (PC3 and PC4): a - score; b - loading. Note: SFI – São Francisco de Itabapoana; CG – Campos dos Goytacazes; Q – Quissamã; CA – Casimiro de Abreu; SJ – Silva Jardim; A – Araruama; CM – Cachoeiras de Macacu; S – Sumidouro; T – Tanguá; G – Guapimirim; M – Magé; DC – Duque de Caxias; NI – Nova Iguaçu; J – Japeri; RJ – Rio de Janeiro; PMA – Average Annual Precipitation; TMA – Average Annual Temperature; EM – Average Elevation; PA – Xanthic Acrisol; PV – Rhodic Acrisol; PVA – Chromic Acrisol; CX – Cambisol; ESK – Podzol; GX – Gleysol; LVA – Ferralsol; MA – Water Body; RY – Fluvisol; SX – Planosol. Source: prepared by the authors.

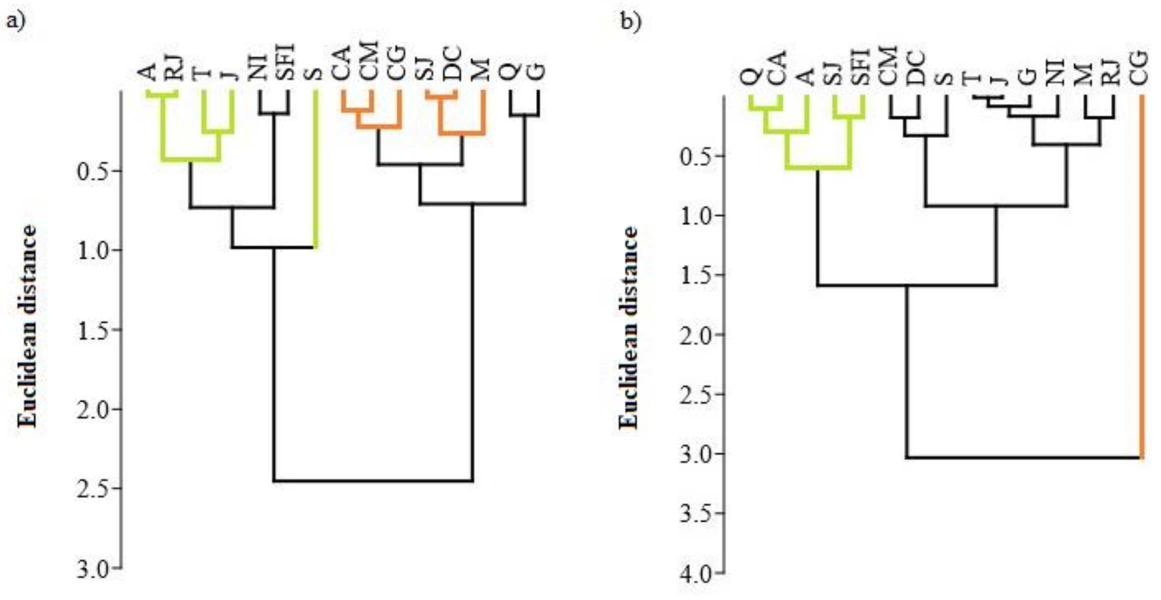

Figure 12. Data dendrograms: a) PC3 and b) PC4. Note: SFI – São Francisco de Itabapoana; CG – Campos dos Goytacazes; Q – Quissamã; CA – Casimiro de Abreu; SJ – Silva Jardim; A – Araruama; CM – Cachoeiras de Macacu; S – Sumidouro; T – Tanguá; G – Guapimirim; M – Magé; DC – Duque de Caxias; NI – Nova Iguaçu; J – Japeri; RJ – Rio de Janeiro. Source: Prepared by the authors.

In PC3, Figure 11, the municipalities CA, CM, CG, SJ, DC, and M showed a positive association with each other and a negative association with A, RJ, T, J, and S. Analyzing the results of Figures 11-a and 11-b together, it is observed that the municipalities CA, CM, CG, SJ, DC, and M showed a higher correlation with PMA and

EM, low correlation with TMA, and have correlation with PA, RY, GX, CX, ESK, and MA soils, while A, RJ, T, J, and S show a positive correlation with PV, PVA, SX, and LVA soils.

In PC4, CG has a positive correlation with PVA and RY soils, with EM, and low correlation with PMA. The municipalities Q, CA, A, SJ, and SFI have a positive correlation with ESK, CX, and SX soils and with PMA. Table 8 shows the score values, and Table 9 shows the loadings.

Table 8. Score values (PC3 and PC4).

Municipalities	CP 3	CP 4
São Francisco de Itabapoana	-0.61	-0.95
Campos dos Goytacazes	1.70	2.83
Quissamã	0.69	-1.62
Casimiro de Abreu	1.54	-1.51
Araruama	-1.64	-1.27
Silva Jardim	1.20	-0.77
Cachoeiras de Macacu	1.42	-0.45
Sumidouro	-2.15	-0.03
Tanguá	-1.07	0.87
Guapimirim	0.54	0.79
Magé	0.92	0.49
Rio de Janeiro	-1.61	0.31
Duque de Caxias	1.16	-0.27
Nova Iguaçu	-0.75	0.68
Japeri	-1.32	0.88

Source: prepared by the authors.

Table 9. Loading values (PC3 and PC4).

Variáveis	CP 3	CP 4
PMA	0.16	-0.34
TMA	-0.07	0.10
EM	0.33	0.36
PA	0.14	-0.07
PV	-0.32	0.00
PVA	-0.30	0.40
CX	0.51	-0.24
ESK	0.07	-0.41
GX	0.24	0.07
LVA	-0.32	0.00
MA	0.08	0.00
RY	0.26	0.57
SX	-0.38	-0.15

Source: prepared by the authors.

In PC1, two groups of municipalities showed a higher correlation among their variables. The first group consisted of the municipalities São Francisco de Itabapoana, Campos dos Goytacazes, and Quissamã, and the second group consisted of Casimiro de Abreu, Silva Jardim, Cachoeiras de Macacu, Guapimirim, Magé, Duque de Caxias, and Sumidouro. In PC2, the first group was formed by Japeri, Nova Iguaçu, Rio de Janeiro, Tanguá, and Araruama, and in the second, the municipality of Sumidouro remained isolated. In PC3, the first group was formed by Araruama, Tanguá, Sumidouro, Rio de Janeiro, and Japeri, and the other by Casimiro de Abreu, Silva Jardim, Cachoeiras de Macacu, Magé, Duque de Caxias, and Campos dos Goytacazes. In PC4, the first group was formed by Casimiro de Abreu, Silva Jardim, Araruama, Quissamã, and São Francisco de Itabapoana, and in the second, the municipality of Campos dos Goytacazes remained isolated.

In the four PCs analyzed, groups formed by municipalities that, in some cases, do not share territorial boundaries with each other were identified. In such situations, obtaining a Geographical Indication (GI) would depend on a broad geographical delimitation encompassing all municipalities within the same area (INPI 2025b), which represents an obstacle to the process. For this reason, municipalities that do not share a political-administrative boundary with at least one member of the group were disregarded. Figure 13 presents the groups identified based on the adopted methodology, which exhibit similar edaphoclimatic characteristics.

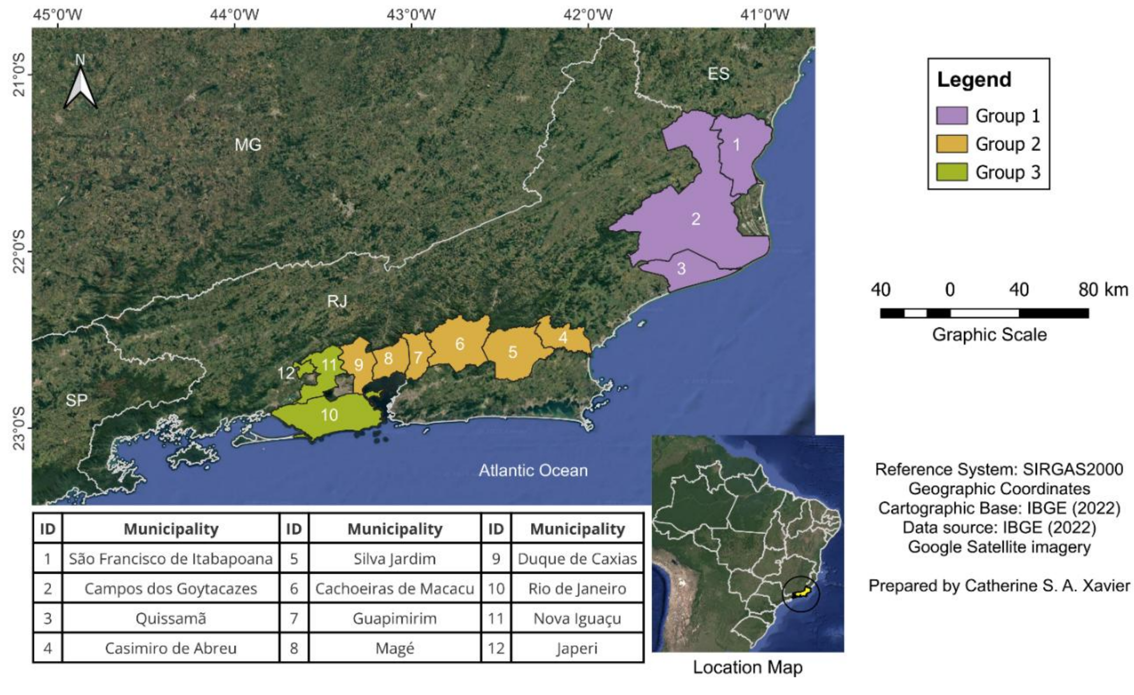

Figure 13. Map of groups with edaphoclimatic similarities. Source: prepared by the authors.

In this context, the strategic role that geoprocessing techniques can play in improving and standardizing the process of delimiting areas for GIs is highlighted. GIS tools, combined with multivariate statistical methods such as PCA, enable the identification of spatial patterns based on environmental attributes, providing greater scientific rigor, precision, and reproducibility to the analyses.

The use of geotechnologies allows technicians and evaluators to conduct more objective diagnoses of the potential of a given area for obtaining a GI. Analysis based on georeferenced environmental data can serve as an additional technical criterion to verify the pertinence or not of the proposed delimitation, increasing the robustness of the technical documents submitted to INPI.

It should be noted, however, that the application of technical and spatial criteria does not replace the historical, cultural, productive, and social analyses, which are fundamental for the recognition of a GI. On the contrary, the proposal presented here seeks to complement and strengthen the recognition process, adding a technical-methodological instrument that can facilitate the identification of territories with potential for obtaining a collective GI. Thus, it is argued that the adoption of geoprocessing techniques in the process of obtaining GIs could represent a significant advance for the strengthening of this public policy in Brazil, contributing to cultural preservation and the valorization of local production.

Final Considerations

The objective of this research was to identify, through the use of geotechnologies and principal component analysis, clusters of cassava-producing municipalities with similar edaphoclimatic characteristics, as a technical justification for the potential of obtaining a collective GI.

To this end, PCA achieved effective results, where the first four PCs explained more than 70% of the data, and it was possible to identify three distinct clusters of municipalities with potential for obtaining a GI. The first group, located in the Cachoeiras de Macacu and Rio de Janeiro micro-regions, comprises the municipalities of Duque de Caxias, Magé, Guapimirim, Cachoeiras de Macacu, Silva Jardim, and Casimiro de Abreu. The second group is located in the Campos dos Goytacazes micro-region and encompasses the municipalities of São Francisco de Itabapoana, Campos dos Goytacazes, and Quissamã. The third group is located in the Rio de Janeiro micro-region and encompasses the municipalities of Rio de Janeiro, Nova Iguaçu, and Japeri.

The results demonstrated that geographically close municipalities or those with similar edaphoclimatic characteristics can be jointly considered in strategies for obtaining a GI. This approach contributes so that technicians and specialists can apply the methodology in a clear, objective, and scientifically grounded manner, allowing for a more precise assessment of the potential of a given area or product for GI recognition.

Therefore, the methodology adopted in this dissertation proved to be efficient in identifying areas with potential for obtaining a collective Geographical Indication. It is expected that the results presented here may inspire further research with other agri-food products.

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