

# Spatial and urban transformations linked with COMPERJ in Eastern Metropolitan Rio de Janeiro

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## Abstract

Human activities have transformed nearly three-quarters of the Earth's land cover, with urbanization being one of the most irreversible forms of land use change. Large infrastructure projects often accelerate these transformations, reshaping landscapes and ecosystems. This study examines the spatial and urban transformations linked to the Rio de Janeiro Petrochemical Complex (COMPERJ) in Eastern Metropolitan Rio de Janeiro between 2006 and 2023. Using remote sensing data (MapBiomas Collection 9) and census data from the Brazilian Institute of Geography and Statistics (IBGE), we assess how the construction—and subsequent halt—of COMPERJ influenced land use and land cover (LULC) changes, urban expansion, and population dynamics. Results reveal accelerated urban growth (19.51%) and population growth (13.94%) between 2000 and 2010, driven by expectations of economic development, followed by population decline (-0.74%) after the project's suspension, while urban areas continued expanding (5.49%) at lower rates, at the expense of forest and productive areas. The findings demonstrate that large infrastructure projects can trigger irreversible urbanization, even when economic promises fail, leading to inefficient land use and reduced urban densities.

## 1. Introduction

About three-quarters of land cover has been altered by human activity over the last millennium, and different forms of land use can cause habitat and biodiversity loss, generate changes in the carbon cycle, convert agricultural land, and exacerbate social problems such as food insecurity (Winkler *et al.*, 2021). Understanding how these changes occur, on a global and regional scale, is important for advancing sustainable solutions.

Among the different forms of land use, urban use stands out as one of the main interactions between humans and the environment, characterized as one of the most irreversible forms of land use and land cover (LULC) and, therefore, requiring special care and planning in its implementation (Gao; O'Neill, 2020). Uncontrolled and unplanned urban expansion can lead to problems such as water pollution due to a lack of sewage treatment, increased local temperatures, and changes in precipitation patterns (Seto *et al.*, 2011; Qin; Su; Khu; Tang, 2014; Shehu; Rikko; Azi, 2023). A global meta-analysis of studies on urban growth using remote sensing, conducted by Seto *et al.* (2011), found that none of them showed any evidence of more compact and efficient urban development, as the per capita urban area ratio increased.

However, urbanization also provides opportunities for climate change mitigation and more efficient use of resources (Seto *et al.*, 2011; Pont *et al.*, 2020).

Planning and monitoring urbanization become even more important given that globally, both developed and developing countries are on a trajectory of increasing urbanized populations (United Nations, 2018), with the expectation of reaching 60.4% in 2030. In Brazil, from the 2010 census to 2022, there was a 16.6 million people increase, occurring in all regions of the country (IBGE, 2022). Urban development results from economic, demographic, and social dynamics, such as the availability of more jobs, international financial investment,

lower transportation costs, or better health and education conditions (Seto *et al.*, 2011; Gao; O'Neill, 2020).

Studies such as those by Aung, Fischer, and Buchanan (2020); Li *et al.* (2021); and Morshed *et al.* (2024) show that infrastructure projects lead to changes in LULC that negatively impact the environment, mainly through the expansion of built-up and agricultural areas, to the detriment of forests and other native vegetation.

### 1.1 The COMPERJ case

Located in Itaboraí, in the eastern part of the Rio de Janeiro Metropolitan Region, the Rio de Janeiro Petrochemical Complex (COMPERJ) was announced in 2006, with construction scheduled for completion in 2011, and expected to occupy an area of 45,000 km<sup>2</sup> (Silva; Irazábal-Zurita, 2019). In 2009, Itaboraí had about 200 thousand inhabitants. In 2011, according to the city government, there were 300 thousand inhabitants (Lima, 2015). The region considered affected by the project comprises 11 municipalities. The construction of COMPERJ in this location was seen as a great opportunity to create jobs and income for the region (Silva; Irazábal-Zurita, 2019).

According to Lima (2015), the Lava Jato investigations, which began in 2014, exposed corruption and overpricing schemes in COMPERJ contracts, diverting public funds through contractors such as Odebrecht and Andrade Gutierrez. The Lava Jato scandals deepened Petrobras' financial crisis, leading to investment cuts and the partial shutdown of COMPERJ. With the loss of credibility and the break with the main contractors, Petrobras faced difficulties in continuing the construction. The need for new bidding processes and the complexity of transferring projects already started to other companies further delayed the project, which had already accumulated years of delays (Lima, 2015).

As a result, COMPERJ left a legacy of underutilized infrastructure, public debt, and unfulfilled expectations in the region.

Remote sensing has gained prominence in various types of analysis, such as climate variation, humidity, and vegetation, due to the greater availability of free and/or quickly obtained data (Ma *et al.*, 2015; Parente *et al.*, 2019). In addition, financial and time savings are another crucial point that led to the adoption and improvement of remote sensing techniques. Mapbiomas is an initiative that seeks to make knowledge about land use and cover and its transformations accessible through the use of remote sensing, time series and machine learning, making remote sensing products readily available.

Considering evidence in the literature that links large infrastructure projects to deforestation, accelerated urbanization, and territorial reorganization, we start from the hypothesis that the implementation of COMPERJ caused significant spatial transformations in municipalities of the Intermunicipal Consortium for the Development of Eastern Rio de Janeiro (CONLESTE). These transformations would have occurred mainly through the conversion of natural and rural areas into urban areas, driven by expectations of regional development. The main question guiding this investigation is: how did the construction—and subsequent shutdown—of COMPERJ influence population dynamics, urban expansion, and forest cover in the region's municipalities between 2000 and 2023?

This study aims to analyze the territorial impacts of the construction and subsequent halt of COMPERJ between 2000 and 2023, based on multitemporal monitoring of changes in land use and land cover (LULC) and population dynamics in the municipalities of CONLESTE. To this end, MapBiomas products from Collection 9 via Google Earth Engine and census data from IBGE were used. Specifically, the study seeks to:

- (i) assess how the construction of COMPERJ influenced urban expansion and population growth in the region; and
- (ii) identify patterns of conversion of forest cover and other land use classes to urban areas associated with the implementation of COMPERJ over the period analyzed.

## 2. Main Body

### 2.1 Area of study

The study was conducted in the 11 municipalities that were members of the East Fluminense Consortium (CONLESTE) until 2011, in the eastern part of the Rio de Janeiro Petrochemical Complex, based on the 2007 RIMA (Petrobras, 2007) and the characterization by Silva and Irazábal-Zurita (2019), following the same characterization, as shown in Figure 1.

The state of Rio de Janeiro is located within the Atlantic Forest biome, and the selected municipalities have vegetation cover characterized as Ombrophilous Dense Forest, also falling within the coverage area of the Atlantic Forest Law (Brazil, 2006; IBGE, 2012).

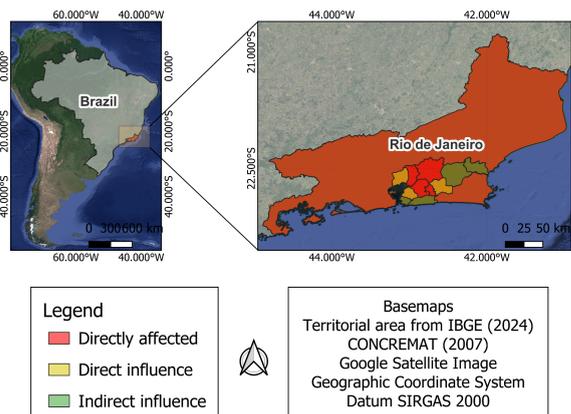


Figure 1. Location of the 11 municipalities studied.

There are two types of climate in the study area, with tropical savanna with dry winter being the predominant (Cachoeiras de Macacu, Casimiro de Abreu, Itaboraí, Maricá, Rio Bonito, São Gonçalo, Silva Jardim, and Tanguá) and tropical monsoon in the other municipalities (Guapimirim, Magé, and Niterói) according to the Köppen climate classification. The municipalities are shown in Figure 2.

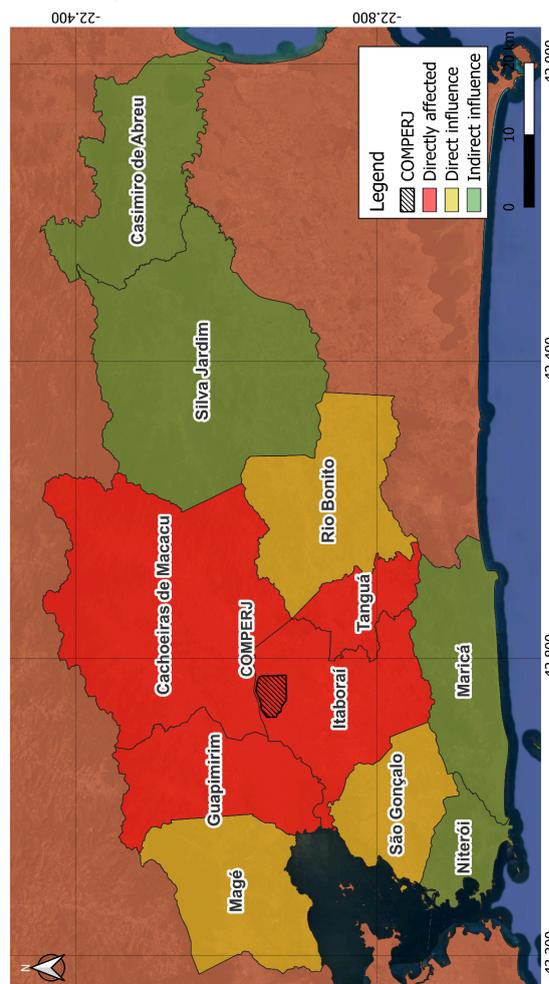


Figure 2. Distribution of the 11 municipalities as defined by the Environmental Impact Assessment (RIMA).

## 2.2 Data and Methods

Based on the delimitation shown in Figure 2, data was collected from the 2000, 2010, and 2022 Demographic Censuses, as well as the municipal layer corresponding to the 11 municipalities (IBGE, 2000, 2010, 2022, 2024).

Using the Google Earth Engine platform, TIF files were generated for the years 2006, 2014, and 2023 from Mapbiomas Collection 9, data based on Landsat images at a resolution of 30m. The first two dates were selected for the historical reasons already mentioned, and the last for being the most recent. The code used was provided by Mapbiomas itself. The overall accuracy of Mapbiomas mapping is 93.09% for Brazil as a whole and 91.67% for the Atlantic Forest region (Mapbiomas, 2025).

To enable a spatio-temporal analysis of the changes that have occurred, these images were processed in R Software (R Core Team, 2023), constructing a Sankey diagram, this type of chart is used for visually summarizing the direction and volume of the flow through different stages, here being the different years. The following land use classes were analyzed: Urban, Forest Formation, Pasture, and Mosaic of Uses, chosen because they are representative of the study area.

Forest Formation is a land use class that comprises Ombrophilous Dense Forest, which represents most of the vegetation in the region. Mapbiomas defines Pasture areas as directly related to agricultural activity, excluding natural pastures from the categorization. The Mosaic of Uses class indicates an impossibility of distinction between pastures or agriculture, but may also include peri-urban occupations, small farms, rural properties, and condominiums. Finally, the Urban class is characterized as an area with a high density of buildings or roads.

## 3. Results

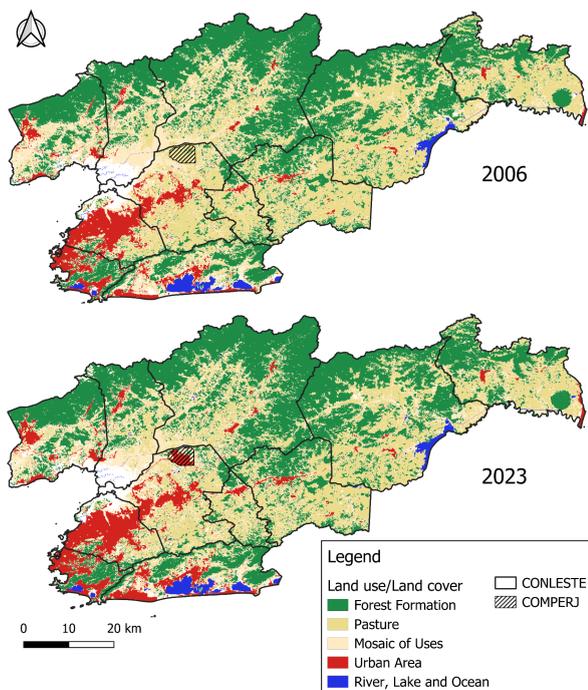


Figure 3. Change in LULC in the 4 categories studied for the 11 municipalities.

The variation in inhabitants for the 11 municipalities can be seen in Figure 4 (additional information can be seen in Appendix). The 2010 demographic census shows a population increase of 11.10% for the state of Rio de Janeiro. All municipalities included in the directly affected category exceeded the state's growth rate, registering a growth of 18.15% for the region. In absolute terms, these four municipalities had an increase of 54,465 people from 2000 to 2010.

The municipalities directly influenced by COMPERJ recorded a lower relative growth (11.86%) in comparison. However, absolute population growth stood out, as it included two of the three largest municipalities in terms of population, with an increase of 135,961 people. However, the decline in growth recorded in the second period, which affected all municipalities, was more abrupt: from 2010 to 2022, the population decreased by 101,454 people (-7.91%).

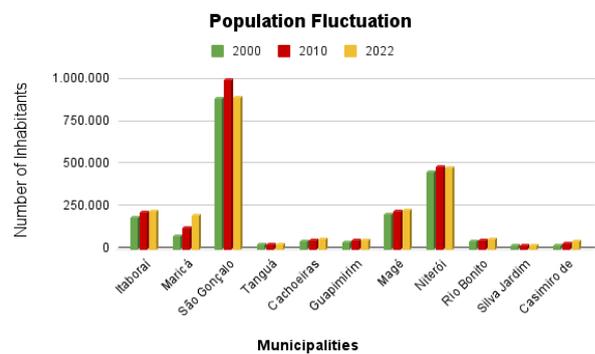


Figure 3. Population fluctuation across municipalities, drafted according to 2000, 2010 and 2022 IBGE demographic censuses.

The indirectly affected region was the least affected by the shutdown, with growth falling from 15.89% to 11.13%, contrasting with the directly affected region, which saw its population growth go from 18,15% to 2,68%.

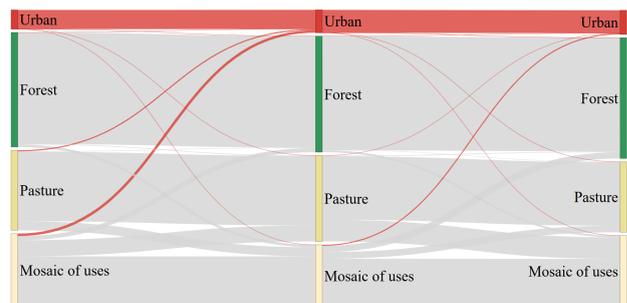


Figure 4. Sankey Diagram of the municipalities selected for the study, from left to right: 2006, 2014 and 2023. Forest represents Forest Formation. The chart should be read from left to right and the line's width represents a bigger flow. Red lines represent flows going to or coming from Urban class.

Population growth in the three regions was 13.94% in the first period and -0.74% in the second, while urban LULC expanded 19.51% and 5.49%, respectively, revealing a pattern of urban expansion above population growth and also urban expansion despite population decline, revealing an increase in urban area per capita.

As shown in Figure 4, all three classes contributed to the growth of the Urban class in 2014 and 2023, with a special contribution from the Mosaic of Uses class. In 2006-2014, the contribution

of Forest to the Urban class was 922.500m<sup>2</sup>, while Mosaic of Uses lost 44.713.800m<sup>2</sup> and Pasture lost 18.903.600m<sup>2</sup>.

In 2014-2023, the losses to urban LULC were 431.100m<sup>2</sup>, 17.703.900m<sup>2</sup>, and 3.832.200m<sup>2</sup>, respectively. In comparison, almost no area ceased to be urban, accumulating a loss of only 356400m<sup>2</sup>.

The fluctuation between Mosaic of Uses and Pasture is expected, given that, by Mapbiomas' own definition, it represents a difficulty in distinction, where there may be different uses, which with different maintenance regimes will take on the characteristics of other classes, such as pasture or agriculture.

Finally, Forest saw an increase in area in both 2006-2014 and 2014-2023, going from an initial 1.847.710.000m<sup>2</sup> to 1.947.590.000m<sup>2</sup> in 2023.

#### 4. Discussion

The results obtained support the hypothesis that the installation and subsequent shutdown of COMPERJ caused significant spatial transformations in the municipalities of CONLESTE. There was marked population and urban growth between 2000 and 2010, a period marked by economic expectations associated with the implementation of the petrochemical complex (Silva; Irazábal-Zurita, 2019). In contrast, the period from 2010 to 2022 saw a decline in population growth, with a negative growth in some municipalities—without, however, a proportional decline in urbanized areas.

This pattern suggests a growing dissociation between demographic dynamics and land use, reinforcing the irreversible nature of urban expansion, as discussed by Gao and O'Neill (2020) and Seto *et al.* (2011). The persistence of urban LULC even after population stagnation contributes to inefficient land use, evidenced by the reduction in population density in the directly affected area, which fell from 54 inhabitants/ha in 2000 to 40 inhabitants/ha in 2022. In contrast, UN-Habitat (2014) sets the urban densities of 150 inhabitants/ha as a goal for sustainable cities. This density also contrasts with the average found by Melchiorri *et al.* (2019) for Latin America and the Caribbean of 90 m<sup>2</sup>/inhabitant, while in the directly affected area this concentration reached 252 m<sup>2</sup>/inhabitant in 2022.

The data from the Sankey diagram indicate that urban expansion occurred mainly at the expense of the Mosaic of Uses class, but there was also conversion of Pasture areas and, to a lesser extent, Forest, which may indicate a conversion of peri-urban areas, such as farms, for urban purposes.

Although the direct loss of forest to urban areas was limited in hectares, its ecological relevance is accentuated as it may be remnants of primary vegetation of the Atlantic Forest — a biome recognized for its biodiversity and degree of threat (Ribeiro *et al.*, 2009) and the replacement of more mature forests with secondary vegetation can lead to the extinction of species that need better preserved and more primitive areas (Metzger *et al.*, 2009).

Similar studies show that large infrastructure projects, such as oil pipelines, highways, or industrial complexes, often result in the conversion of natural and productive areas into urban zones, especially when associated with land speculation and peripheral expansion (Aung; Fischer; Buchanan, 2020; Li *et al.*, 2021; Morshed *et al.*, 2024). COMPERJ is an emblematic example of

urbanization anchored in promises of economic development that did not materialize, generating a legacy of underutilized infrastructure, urban sprawl, and social expectations that were never met (Silva; Irazábal-Zurita, 2019; Lima, 2015).

Despite methodological advances, this study has important limitations. The spatial resolution of the images (30 m) may not capture smaller-scale occupations, such as informal settlements or irregular subdivisions (Kaya, 2007), so urban occupation may be underestimated. The frequency of demographic censuses (decennial) also limits the capture of annual dynamics or rapidly changing events. In addition, the use of the “Land Use Mosaic” class—which is heterogeneous by definition—makes it difficult to accurately interpret transitions between urban, agricultural, and peri-urban uses.

Nevertheless, the results highlight the potential of the integrated use of remote sensing and census data for multitemporal monitoring of territorial transformations induced by large-scale developments. The approach adopted can be replicated in other regions undergoing large-scale infrastructure projects, contributing to evidence-based urban and environmental planning (Wang; Krstikj; Koura, 2017). Future research can deepen the understanding of the effects of COMPERJ on sanitation, the environment, land concentration, or access to housing in the areas directly affected (Pont *et al.*, 2020; UN-Habitat, 2014).

#### 5. Conclusions

The integrated analysis of census data and remote sensing demonstrated the effectiveness of multitemporal approaches to investigating the spatial effects of large projects on territorial dynamics. In the case of COMPERJ, a spatial correlation was observed between the expectation of development induced by the project and the expansion of the urban class, especially between 2000 and 2010. Even after the project was halted, the urban area remained stable or grew, indicating low reversibility of the occupation process.

The processing of images from MapBiomas Collection 9 via Google Earth Engine allowed us to characterize relevant transitions in land use and land cover (LULC), with a predominance of conversions from the “Mosaic of Uses” class, but also involving losses of forest formations. The analysis reinforces that urbanization in industrial infrastructure contexts is highly dependent on exogenous economic flows and can result in dispersed occupation, with reduced urban density and permanent pressure on vegetation cover.

The methodology adopted, based on open data, automated flows, and graphical representation of transitions (Sankey diagram), proved to be adequate for spatial monitoring purposes applied to public policies and territorial planning. The case of CONLESTE highlights the need for better evaluations to be done before and after large projects, with attention to their territorial externalities, especially in regions with high socio-environmental sensitivity, such as the Atlantic Forest biome.

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**Appendix**

| Region               | 2000       | 2010       | 2022       |
|----------------------|------------|------------|------------|
| Rio de Janeiro (BRA) | 14.392.106 | 15.989.929 | 16.055.174 |
| Itaboraí             | 187.479,00 | 218.008,00 | 224.267,00 |
| Maricá               | 76.737,00  | 127.461    | 197.277    |
| São Gonçalo          | 891.119    | 999.728    | 896.744    |
| Tanguá               | 26.057     | 30.732     | 31.086     |
| Cachoeiras de Macacu | 48.543     | 54.273     | 56.943     |
| Guapimirim           | 37.952     | 51.483     | 51.696     |
| Magé                 | 205.830    | 227.322    | 228.127    |
| Niterói              | 459.451    | 487.562    | 481.749    |
| Rio Bonito           | 49.691     | 55.551     | 56.276     |
| Silva Jardim         | 21.265     | 21.349     | 21.352     |
| Casimiro de Abreu    | 22.152     | 35.347     | 46.110     |

Table 1. Number of inhabitants per region according to IBGE census data from 2000, 2010 and 2022.