

## Detecting urban change with open-source GIS programs: a case study in Guayaquil

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## Detecting Urban Change with Open-Source GIS programs: A Case Study in Guayaquil

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### Abstract

Urban sprawl constitutes a significant challenge to sustainable development, particularly in rapidly expanding urban environments. In the case of Guayaquil, in Ecuador, the construction of Perimetral Avenue in 1987 facilitated uncontrolled urban transformation. The absence of effective planning and oversight has led to the conversion of mangrove ecosystems into urban areas in specific sectors, with Isla Trinitaria notably experiencing the most substantial transformation, without yet having a clear strategy or methodology for responding to the problem. Within this framework, the objective of the study is to propose a methodology utilizing free software for optimizing resources in territorial planning. This investigation employed data from MapBiomass and the municipal urban cadastre; spatial information was integrated through free software platforms such as QGIS and PostgreSQL/PostGIS. One of the stages of the methodology included the vectorization of raster images, conducting spatial intersections with the cadastral data, and establishing a geographic database to enable SQL queries. The results indicated urban expansion from 2.1% in 1985 to full occupation in 2010, with a peak in construction activity in 1997. Furthermore, limitations such as low image resolution and data absence due to cloud cover were identified. This proposal aims to enhance sustainable urban planning by leveraging accessible tools, thereby contributing to effective territorial planning and informed decision-making in urban contexts.

### 1. Introduction

Urban growth is a natural and complex phenomenon, characteristic of societal evolution throughout history, serving as both an engine of economic development and a significant challenge to environmental sustainability and social equity (Seto et al., 2011). Demographic projections indicate that by 2050, about two-thirds of the world's population will reside in urban areas, intensifying pressure on natural resources, infrastructure, and access to basic services (Revi et al., 2020). This process of accelerated urbanization heightens the need to understand and effectively manage changes in land use and land cover (LULC) to ensure balanced territorial development (Gaur & Singh, 2023).

The LULC changes facilitate assessing various environmental, economic, and social impacts of urban expansion. This demonstrates that the unplanned growth of urban areas is typically correlated with the degradation of vegetation cover, fragmentation of ecosystems, and heightened vulnerability to natural disasters such as floods and landslides (Li et al., 2018; Weng, 2007). Within this framework, the monitoring of urban expansion at both spatial and temporal scales gains significance, not only for effective environmental management but also for the development of public policies directed at territorial planning (Chen et al., 2025).

The study of LULC is feasible through remote sensing, enabling multi-temporal analyses to identify changes in both urban and rural landscapes and evaluate expansion patterns (de Moraes Novo, 2010; Jensen & Epiphany, 2009; Zhou et al., 2018; Zhu & Woodcock, 2014). Moreover, using free software like QGIS (QGIS Development Team, 2024) and PostgreSQL (PostgreSQL, 2024) facilitates the efficient integration and analysis of spatial and non-spatial data, providing access to analytical tools that were previously available only to resource-rich institutions (Griffiths et al., 2010).

In different cities worldwide, like Bangkok, Thailand, and Sao Paulo, Brazil, the opening of new roads has enabled the settlement of peri-urban areas, fostering dispersed urbanization that obstructs service provision and undermines ecological connectivity (Angel, 2011). In contrast, another study (Emmanuel, 2015) examines how road development and expansion in Akure, Nigeria, affect traffic and socioeconomic growth, advocating for the expansion of roads, complementary infrastructure, and integrated urban planning to enhance settlements, residential areas, and services.

The lack of planning and rapid urban expansion in Ecuador has generated patterns of informal and fragmented growth, affecting not only environmental sustainability but also the quality of life for the inhabitants (Burneo et al., 2020; Peralta Arias & Higuera García, 2016; Velastegui-Montoya et al., 2022). Although studies

encourage the planning of new roads in medium-sized cities in the country, the problem of unplanned urban growth must already be addressed during execution (Angel, 2008). This causes new needs, such as basic services and access to roads, forcing the authorities to act immediately (Fernandes, 2011).

In the case of Guayaquil, the most populous city in Ecuador, which, in the year 2022, surpassed 2.5 million inhabitants and has an annual growth projection of 1.3% (INEC, 2022), its expansion has been characterized by intensity and, for the most part, disorderliness, encroaching upon parishes and towns adjacent to its urban perimeter (Mora-Araus et al., 2021). Creating new areas for intervention and poses a challenge in regions such as Trinitaria Island. This area is a clear example of unplanned urbanization, wherein the construction of peripheral roads has functioned as a catalyst for significant transformations in LULC. Despite endeavours to relocate a portion of the inhabitants to safer areas (Bonilla Mena et al., 2021; MIDUVI & MAATE, 2013), it continues to represent a problem that necessitates resolution.

In this context, the objective of this work is to propose a methodology that utilizes free software, specifically the application of QGIS (version 3.34.15) and PostgreSQL (version 17), for the identification and quantification of urban growth patterns in the southwestern region of Guayaquil and optimize resources in territorial planning. The employed methodology, along with the information and results presented, will be of significant interest to decision-makers in the execution of urban planning initiatives or the formulation of public policies.

## 2. Materials and Methods

### 2.1 Area of Interest (AOI)

Trinitaria Island is located southwest of Guayaquil [2.22 S, 79.91 W; 2.28 S, -79.94 W], the capital of Guayas, Ecuador (Figure 1). It is situated in an estuarine area influenced by branches of the Estero Salado. The island has a tropical savannah climate (Aw) according to the Köppen climate classification, characterized by consistently high temperatures throughout the year, typical of the south-central coastal area of Ecuador, and a monthly average of around 18 °C, with rainfall occurring in two distinct seasons: wet and dry (Peel et al., 2007).

In Guayaquil, the wet season runs from December to May, while the dry season lasts from June to November (INOCAR, 2007). Regarding temperature, it typically ranges between 25 and 28 °C, with accumulated precipitation varying from 800 to 2300 mm depending on the intensity of climatic events (INAMHI, 2024).

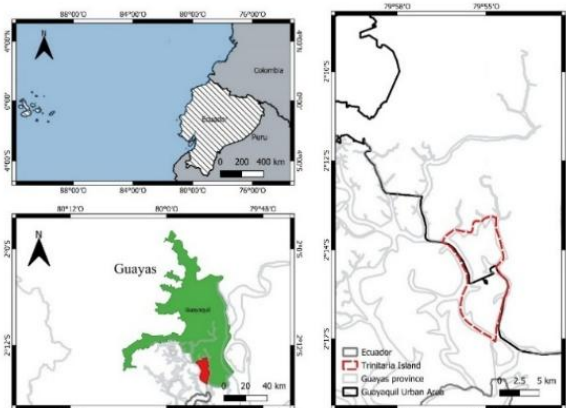


Figure 1. Location of Trinitaria Island, Guayaquil – Ecuador.

## 2.2 Data collection

### 2.2.1 Information from MapBiomass

The download of the annual LULC maps was conducted from the MapBiomass portal (MapBiomass, 2024b), which provides standardized geospatial data at a spatial resolution of 30 meters from 1985 to 2023. The direct download option was chosen to access the maps, replacing the desired year in the download link to obtain the raster with different classes of LULC in GeoTIFF format. Additionally, the portal allowed users to consult the description of each code and the methodology used in preparing the maps. Data from the years of interest (1985-2010) were uploaded to QGIS and delineated for the AOI. This process enabled the identification of the temporal changes in various classes of LULC, such as "mangrove," "urban areas," and "areas without vegetation."

### 2.2.2 Cadastral information

Through the Geoportal of the Municipality of Guayaquil (GAD Guayaquil, 2014), geographical files (shape of areas) were downloaded with information regarding the urban cadastre of the city. This information includes the location, dimensions, and boundaries, typically utilized for fiscal, legal, urban, or territorial planning purposes. However, the present undertaking was employed for geographical purposes. Upon obtaining the information, it was uploaded to QGIS and delineated for the AOI, which facilitated the updated spatial identification of the properties located on Trinitaria Island.

## 2.3 Data Processing

Once the LULC data (1985-2010) and the AOI cadastre data were obtained, a new field was created in the shapefile containing the "year of creation" of the property. This process was carried out in three stages (Figure 2).

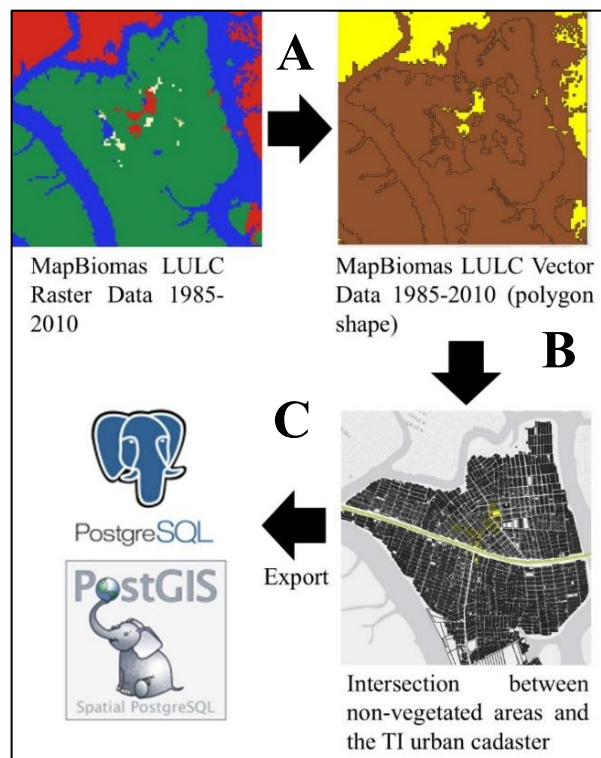


Figure 2. Diagram of the creation of the cadastre file with information on the year of creation. A) Information of

MapBiomias; B) Matching LULC data with Cadastral information; C) Data processing in PostgreSQL

Considering that the information from MapBiomias is presented in raster format, we undertook the process of vectorizing the images for the specified temporal range (1985-2010) to enable spatial intersection with the urban cadastre data. Upon vectorization of the image, we identified the attributes that indicated urban settlements, which, for the AOI, were categorized as "Other natural non-vegetated area" in accordance with the MapBiomias LULC class code (MapBiomias, 2024a).

The choice of QGIS was supported by its extensive set of geoprocessing tools, its capability to work with both raster and vector formats, and its compatibility with PostgreSQL/PostGIS for smooth spatial database integration. PostgreSQL/PostGIS was selected for its efficiency in managing large geospatial datasets, performing complex SQL queries, and enabling reproducible workflows for spatio-temporal analysis. Each step (vectorization, attribute filtering, and spatial intersection) was executed with clear criteria to ensure reproducibility and transparency, following best practices outlined in open-access geospatial analysis literature (Lovelace et al., 2019)

The spatial intersection of the urban cadastre's shape with the "Other natural non-vegetated area" class of LULC from MapBiomias for each analyzed year was conducted. This allowed for the identification and classification of properties based on their year of creation. After creating the file with information for 1985-2010, the updated cadastre's shape was exported to the previously established (empty) geographic database in PostgreSQL, integrated with PostGIS.

PostgreSQL is an open-source relational database management system that enables efficient handling of large amounts of data, offering tools for both spatial and non-spatial queries in SQL format (Souza et al., 2011; Stonebraker & Kemnitz, 1991). In addition to PostgreSQL, we utilized its PostGIS extension, which facilitates the connection and support for spatial and geographic data within the database.

### 2.4 Urban change detection consultations

In order to achieve the proposed objective and following the establishment of the geographic database and the implementation of structured SQL commands (see Appendix), a set of both spatial and non-spatial queries was executed to extract annual data on the number of constructed properties. This analytical stage is a cornerstone of the study, as it provides a detailed temporal breakdown of urban development patterns, thereby enabling an understanding of the spatial dynamics associated with land transformation. Using the interoperability between QGIS and PostgreSQL, four queries were conducted for the years 1985, 1990, 1997, and 2010. These years were deliberately selected to reflect distinct phases of urban expansion, aligned with key infrastructure developments. The resulting land use classifications facilitated the identification of significant spatial changes over time. This analysis provided an empirical basis to examine the extent to which the construction of peripheral avenues has acted as a catalyst for unplanned urban sprawl and informal settlement growth.

## 3. Results

### 3.1 Non-spatial queries

Upon executing the query in PostgreSQL, the data was acquired concerning the number of properties constructed annually, considering the information integrated from MapBiomias (Figure 3).

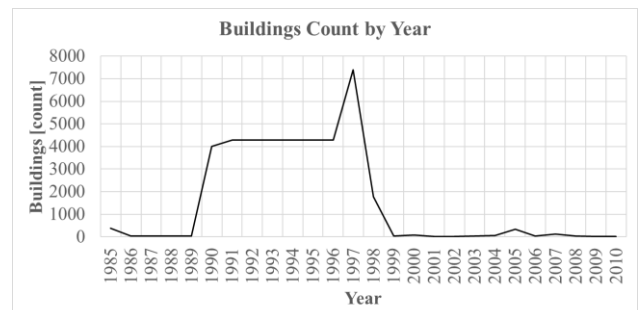


Figure 3. Time series of the number of constructions per year for the AOI.

### 3.2 Spatial queries

In 1985, 1990, 1997, and 2010, urban change detection was conducted within the QGIS environment to spatially demonstrate the alterations in LULC and illustrate the progressive encroachment of urbanization throughout the area designated by the AOI (Figure 4).

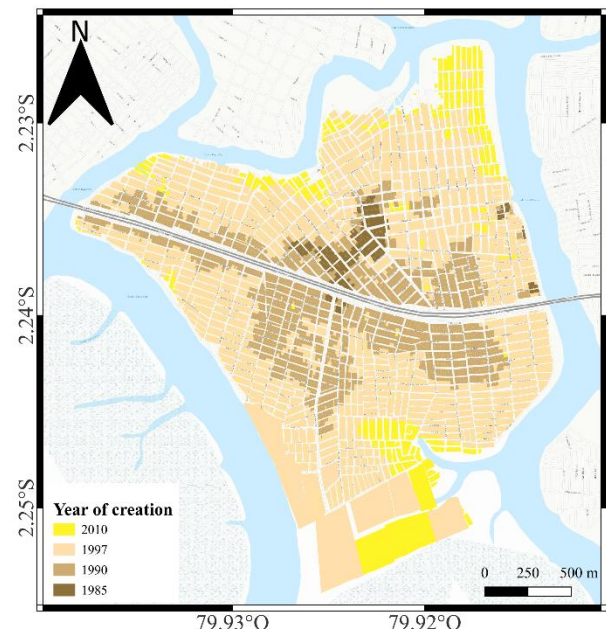


Figure 4. Different scenarios of urban growth within the AOI. The colour coding corresponds to the quantity of properties constructed during the specified years.

In 1985, an area of occupation of 74,473.1 m<sup>2</sup> was observed, corresponding to 2.1% of the total area, marking the starting point of the study. By 1990, the occupation area had increased to 752,087 m<sup>2</sup>, occupying 23.8% of the total area; by this point, the Perimetral Avenue was already in use, and the expansion was beginning to develop. The year 1997 is considered the peak of urban expansion in the AOI, with an occupation of 2,536,330.7 m<sup>2</sup>, representing 86.1% of the total area. Finally, for 2010, the

concluding date of our study, an occupation of 2,791,451.2 m<sup>2</sup> was recorded, representing 100% of the total area.

#### 4. Discussion

It was observed that there are specific years in which there is an increase in construction for the AOI; however, some aspects must be considered before drawing any conclusions. One of these aspects relates to the exclusive use of LULC information from MapBiomias. The absence of data in certain years, due to cloud cover issues in the equatorial regions, hinders the acquisition of satellite images, restricts the availability of optical data, and causes bias in the LULC classification (Asner, 2001). This problem is evident in the lack of LULC registrations for the AOI in the years 1987, 1988, 1989, 1992, 1993, 1994, 1995, and 1996. Here, the lack of variation in LULC changes does not correspond to a lack of alteration in the territory but rather to the inability to detect changes caused by cloud interference. This limitation not only creates temporal gaps but also risks underestimating the intensity of urban expansion during unseen periods, which can bias trend analyses and delay the identification of key intervention points in urban development policy.

The dataset's spatial resolution of 30 meters is inadequate for characterizing densely urbanized or small-sized regions, such as the AOI, which encompasses a total area of merely 10 km<sup>2</sup>. Analogous studies have documented this limitation (Zhu et al., 2012), advocating for the supplementation of optical data with Synthetic Aperture Radar (SAR) sensors to enhance the identification of urban structures in areas characterized by high density or recurrent cloud cover.

Urban expansion presents significant challenges when developed in an unplanned manner. In the case of the AOI, it demonstrates the impacts of road infrastructure construction on LULC changes over time. The methodology not only revealed the accelerated growth of the area but also highlighted the catalytic role of roads in this process, marking them as a driving factor behind urban expansion, as transportation infrastructure opens new urban frontiers, reduces travel time, and thereby encourages the occupation of previously undeveloped land (Angel, 2011). In the case of the AOI, a notable increase in the urbanized area was observed starting in the 1990s, coinciding with the implementation of road infrastructure.

This finding aligns with similar studies conducted in other countries, such as in Lop Buri, Thailand (Patarasuk & Binford, 2012), where a direct correlation has been recorded between road development and peri-urban expansion, or in the study conducted in Cameroon, where road construction has improved access to new areas, promoting human settlements and ecosystem degradation (Mertens & Lambin, 2000). In contrast, some cases, such as in Medellín, Colombia, demonstrate that coordinating road development with public transportation and land-use regulation can reduce uncontrolled sprawl. This comparison emphasizes the importance of governance context in determining whether infrastructure serves as a catalyst for sustainable or unsustainable growth (Patino & Duque, 2013).

Considering that the Perimetral Avenue in the AOI was inaugurated in 1987 (El Telégrafo, 2015) and the information obtained from Figure 3, the scenarios for the years 1985, 1990, 1997, and 2010 were analyzed for the respective spatial consultations. These years were selected for their relevance to the changes in LULC in the AOI; 1985 was identified as the starting point, reflecting an environment prior to the construction of the Perimetral Avenue and the subsequent urbanization that occurred

after it was built. The year 1990 corresponds to the first major expansion in the area surrounding Perimetral Ave., demonstrating the effect that road access has on changes in land use and land cover (Basu et al., 2023). In 1997, the largest number of built properties was identified (7389), marking the peak year for urban expansion, the lack of control and regulations in the area fortified rapid informal urban expansion in just seven years (Ebraheem et al., 2024), occupying almost the entire island. After this point, growth declined considerably, as the AOI had been almost entirely occupied. The year 2010 signifies the endpoint of the urbanization of Trinitaria Island, since urban growth consolidated from this date onward.

The integration of MapBiomias data with information from the urban properties of the AOI in a spatial database facilitated the quantification of urbanized areas and the identification of critical years in the transformation, such as the one recorded in 1997, when more than 116,000 m<sup>2</sup> were built. This provides solid evidence to assess the impact of infrastructure decisions, such as road openings, and to plan future urban projects more informedly.

Additionally, the study introduced a low-cost tool, both financially and in computational capacity, intended for municipal authorities and planning agencies. One of the primary obstacles to effective urban management in developing countries is the lack of reliable data (United Nations Department of Economic and Social Affairs, 2019). In this regard, Latin American cities with similar characteristics can adopt the proposed methodology, promoting a collaborative approach based on technical support for territorial planning.

It is important to highlight that the replicability of the methodology is one of its most significant contributions. Because the tools used are open source and the data is sourced from freely accessible platforms, this approach can be scaled and adapted to different urban contexts. This characteristic is particularly significant in Latin America, where unplanned urbanization remains a structural challenge that necessitates accessible and adaptable solutions (Salazar et al., 2021). However, despite its operational strengths, the methodology does not show significant innovation compared to the current state of the art in urban change detection. Incorporating advanced methodologies, such as machine learning algorithms (ML) for automated feature extraction (e.g., Random Forest, Support Vector Machine) and spatial metrics for measuring urban sprawl (e.g., Shannon's entropy, fractal dimension), would improve its analytical depth and contribution to the literature.

For future research, the inclusion of socioeconomic variables should be considered. Although the present study focused on physical and spatial variables, it has been shown that including data on poverty, access to services, and mobility enriches our understanding of urban expansion processes (Gómez-Baggethun & Barton, 2013; McPhearson et al., 2016). For example, informal urban expansion is often related to internal migration and a lack of access to formal housing, so a comprehensive view would allow for the design of better public policies.

Furthermore, the analysis could be enhanced by explicitly incorporating socioeconomic datasets, such as census data on poverty levels, household income, internal migration patterns, and access to basic services, into the spatial framework. These variables often play an important role in influencing urban growth patterns, as shown in Latin American studies contexts (Silva & Vergara-Perucich, 2021; United Nations Department of Economic and Social Affairs, 2019). Including such data would

help identify causal links between infrastructure development and settlement growth, thereby strengthening the reliability of policy recommendations.

## 5. Conclusions

Urban expansion within the AOI has been associated with road infrastructure development, particularly following the construction of Perimetral Avenue in 1987. The proposed methodology, which was informed by integrating open data from LULC through MapBiomias with local cadastral information, has enabled the identification and quantification of urban growth patterns in the southwestern region of Guayaquil. The utilization of free software solutions such as QGIS and PostgreSQL/PostGIS ensures the accessibility and replicability of this low-cost methodology for urban expansion in other mid-sized cities throughout Latin America, thereby contributing to the enhancement of more informed and sustainable territorial planning within complex urban environments. Nonetheless, certain limitations have been acknowledged, such as the spatial resolution of 30 meters provided by MapBiomias, which is inadequate for capturing details in densely urbanized areas, along with the lack of data in certain years attributable to persistent cloud cover. Future research is advised to incorporate SAR data alongside socioeconomic variables to enrich the analytical framework and to achieve a deeper understanding of the underlying factors influencing the processes of informal land occupation.

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## 7. Appendix

Query 1: Number of properties built per year (non-spatial).  
SELECT "Year\_Coverage",  
COUNT(\*) AS houses\_year  
FROM "Predios\_Urbanos\_Trinitaria"  
GROUP BY "Year\_Coverage"  
ORDER BY "Year\_Coverage" ASC;

Query 2: Construction areas (m<sup>2</sup>) per year (non-spatial).  
SELECT "Year\_Coverage",  
sum("area\_escr") AS area\_construida  
FROM "Predios\_Urbanos\_Trinitaria"  
GROUP BY "Year\_Coverage"  
ORDER BY "Year\_Coverage" ASC;

Query 3: Properties that were created before 1985 (included)  
Select\*  
from "Predios\_Urbanos\_Trinitaria"  
where "Year\_Coverage" <= 1985

Query 4: Properties that were created in 1990  
Select\*  
from "Predios\_Urbanos\_Trinitaria"  
where "Year\_Coverage" = 1990

Query 5: Properties that were created in 1997  
Select\*  
from "Predios\_Urbanos\_Trinitaria"  
where "Year\_Coverage" = 1997

Query 6: Properties that were created in 2010  
Select\*  
from "Predios\_Urbanos\_Trinitaria"  
where "Year\_Coverage" = 2010