Modeling the Impact of Bogotá's Metro Infrastructure on Residential Land Values: A Comprehensive Analysis of Socioeconomic, Geographic, and Physical Factors for Informed Sustainable Development

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Abstract

This study examines the potential impact of Bogotá's mass transit infrastructure, particularly the first two metro lines under development, on residential land values. Using the Coarsened Exact Matching (CEM) method and spatial regression models, the analysis focuses on residential blocks located within an 800-meter radius of the planned metro stations. The results show that proximity to the metro significantly increases land values during the early stages of project development. For the first metro line, an appreciation of approximately 11.7% was observed during the pre-construction phase (2019), followed by 8.8% during the construction phase (2023). A comparative approach was also applied to estimate the potential land value uplift for the second metro line, suggesting a projected increase of approximately 11.8% near its planned stations.

Keywords: Value Capture, Land Value, Land Use, Infrastructure, Urban Development, Transport Oriented Development

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List of Acronyms

BFML: Bogotá First Metro Line

BSML: Bogotá Second Metro Line

BRT: Bus Rapid Transit

CEM: Coarsened Exact Matching

DBOM: Design, Build, Operate, and Maintain

CAPEX: Capital Expenditure

OPEX: Operational Expenditure

CBD: Central Business District

UAECD: (Bogotá's) Special Administrative Unit of District Cadastre

IDECA: Spatial Data Infrastructure for Bogotá

OLS: Ordinary Least Squares

SES: Socioeconomic Strata

PH: Horizontal Property

ZHG: Homogeneous Geoeconomic Zone

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1. Introduction

The impact of public transport infrastructure on land values has been extensively documented and studied (Cervero & Dai, 2014; Currie, 2006; Byun & Jang, 2024; Transport for London & Greater London Authority, 2017). Accelerated urban growth and increasing vehicle congestion have raised the need for Mass Transit systems that improve accessibility and quality of life for citizens.

Public transport is a key pillar for the development and performance of cities, as it ensures access to a wide range of opportunities and services. It facilitates connectivity to jobs, educational institutions, and recreational spaces, which directly influences urban structure. This accessibility contributes not only to improving the quality of life of citizens but also to the cohesion of cities, allowing urban amenities, such as parks, libraries, and other essential services, to be within reach of a larger part of the population (Garcia-López & Gómez-Hernández, 2024).

In the context of urban development, accessibility refers to the extent to which land-use and transport systems enable individuals or groups to reach desired activities or destinations by means of one or several transport modes (Geurs & van Wee, 2004). Improving this accessibility through high-capacity public transport such as metro infrastructure tends to increase an area's attractiveness, stimulating land demand and, consequently, land values. In cities like Bogotá, where urban connectivity remains limited for many residents, this mechanism becomes particularly relevant for analyzing the spatial impacts of new metro infrastructure.

The integration between public transport and urban development must be done through coordinated planning, as this maximizes the return on infrastructure investments and improve transport efficiency (Zhang & Wang, 2013). In cities such as Portland (USA), the impact of public transport projects has been significant, improving accessibility to key infrastructure and reducing travel times and costs, resulting in more equitable and livable communities (Smith & Gihring, 2006). Similarly, studies in San Diego (USA) show how spaces designed around public transport, with a pedestrian focus, have not only increased property values but also created more integrated and accessible neighborhoods, improving the well-being of residents (Duncan, 2011). These projects not only boost urban development, but also foster an environment that promotes sustainable mobility and the general well-being of the population (Dubé, Rosiers, Thériault, & Dib, 2011).

This study examines the potential impact of the Bogotá Metro on residential land values and its evolution over time, focusing on the relationship between proximity to stations and land prices. The effect on land, excluding buildings, was specifically investigated to identify and measure how land values change as a function of proximity to the metro. For this analysis, a 800-metre catchment area around the stations was evaluated. In addition, other variables that could also influence residential land values were controlled for, ensuring that the results primarily reflect the effect of proximity to the Metro.

2. Metro line Projects in Bogotá

Iniciatives

The idea of establishing a metro system in Bogotá has been a constant feature in the city's urban planning for over half a century. Throughout the decades, various administrations have promoted studies and proposals aimed at materializing this project, reflecting the growing need for a mass transit solution capable of addressing the rapid demographic and urban expansion of Colombia's capital.

Finally, in 2016, under the administration of Mayor Enrique Peñalosa, the Bogotá Metro Company (Empresa Metro de Bogotá S.A., EMB) was created through Agreement 642 of the Bogotá City Council. The creation of EMB aimed to lead the planning, structuring, and execution of the metro project, that was contracted in 2019 with financial support of InterAmerican Development Bank, the Worl Bank ans the European Bank of Development,.

Bogota First Metro Line (BFML)

The Bogotá Metro project has been a long-standing aspiration of the city since the mid-20th century. However, it was only in recent years that it became consolidated as a public policy with technical, financial, and institutional support. The following timeline outlines the main recent milestones in the structuring process of the First Line of the Bogotá Metro (BFML), covering the period between 2014 and 2020. It highlights key studies, responsible entities, and government decisions that enabled progress from conceptual design to the start of construction. This chronology underscores the technical and multisectoral nature of the project, as well as the critical moments that defined its feasibility and implementation.

A timeline of the BFML's most important milestones is presented below:

Table 1: Timeline BFML

YEAR	EVENT	CARRIED OUT BY
2014	Advanced basic engineering study for an underground metro	Consorcio l1 (Idom, Euroestudios, Cano Jiménez)
2015	Value engineering study to assess the financial feasibility of alternatives	Sener Ingeniería and Sistemas Colombia s.a.s.
2015	Complementary studies: financial, legal, and operational analysis	- Sumatoria s.a.s. (financial) - opebsa s.a.s. (legal) - metro de medellín (operational)
2016	Alternative options review study to compare underground vs. Elevated metro	Systra (Under contract with FDN)
2016	Study on the location of the depot and workshop	Consultoría colombiana S.A. (CONCOL)
2017	Start of the technical, legal, and financial structuring for the tender process	FDN, Consorcio Metrobog (Systra, Ingetec)
2018	Launch of the international bidding process	Empresa Metro De Bogotá (EMB) con apoyo de la FDN
2019	Awarding of the contract	Emb, Gobierno Nacional, Consortium APCA Transmimetro
2020	Official start of construction	EMB, Consortium

Source: Own elaboration based on (EMB, 2017).

The BFML is an elevated corridor of 24 kilometers, starting in the southwestern part of the city (Portal de las Américas, in the Bosa district) and ending in the northeast, at the intersection of Calle 72 and Avenida Caracas. The entire route will be developed on an elevated viaduct.

The BFML starts at Portal Américas in Kennedy, ending at the intersection of Calle 72 and Avenida Caracas. The system will feature 16 stations, 10 of which will provide direct integration with TransMilenio. It will be developed under a DBOM scheme (Design, Build, Operate, and Maintain) through a 20-year concession contract awarded to Chinese Consortium Metro Línea 1 S.A.S.

In line with the structuring of the BFML Concession Contract, the total estimated CAPEX is projected at USD 4.3 billion, measured in constant USD 2017 prices. In parallel, the average annual OPEX is estimated at USD 90 million, covering recurring costs related to the operation, maintenance, and delivery of metro service throughout the duration of the contract. These figures were presented by the National Development Finance Agency (FDN) as part of the financial structuring process for the project.

Bogotá Second Metro Line (BSML)

The following timeline presents the main milestones that have marked the progress of the project since its inclusion in the 2020–2024 District Development Plan, through its technical and financial structuring, up to the current stages of the bidding process and the planned contract award in 2025. This chronology highlights the key moments and responsible entities that have driven the development of the Second Line of the Bogotá Metro.

Table 2: Timeline BSML

YEAR	EVENT	CARRIED OUT BY
2020	Inclusion of the Second Metro Line in the 2020–2024 Development Plan ("metro network")	Bogotá City Council / Bogotá Mayor's Office
2021	Comprehensive structuring of the BSML (technical, legal, and financial studies)	FDN, EGIS and Steer
2022	Approval of CONPES 4104 and signing of the co-financing agreement	DNP (National Planning Department), National Government, Bogotá Mayor's Office
2023	Launch of the international tender process: prequalification and publication of final bidding documents	EMB
2023	Multilateral loans approved by CAF (USD 255 million) and IDB (USD 415 million)	CAF and BID
2024	Extension of the tender timeline and postponement of contract award	EMB
2025	Award of the concession contract (Projected)	EMB

Source: Own elaboration based on DNP (2022) and Semana Editorial Team (2025)

According to official information from the Bogotá Metro Company (EMB), the BSML will have a total length of 15.5 kilometers and will connect with the BFML in the Chapinero district. The route will begin at Calle 72 with Carrera 10, moving westward across the city until reaching Avenida Ciudad de Cali, where it will turn north to follow that corridor. It will then connect with the Avenida Longitudinal de Occidente, continuing along Calle 145 until reaching the site of the yard and maintenance depot located in the Fontanar del Río area.

The line will feature 11 stations, of which 10 will be underground and one elevated. The full journey from the first station to the yard and maintenance depot is expected to take approximately 20 minutes. The project will enable a 65% expansion of the city's rail network, adding to the 23.9 km of the First Line. It is estimated that during its first year of operation, the BSML will help avoid the emission of approximately 87,000 tons of CO_2 and will generate an annual travel time savings of 46.3 million hours for public transport users.

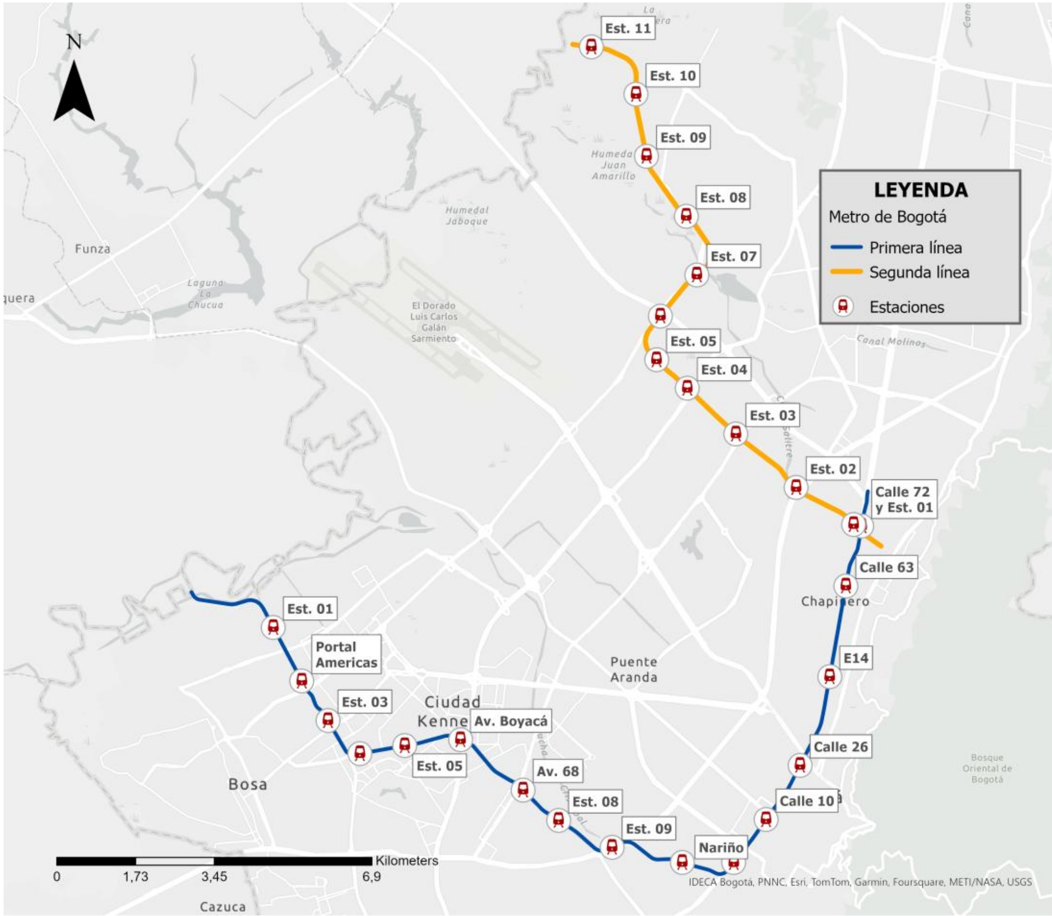
The analysis conducted by Unión Temporal Egis–Steer Metro de Bogotá (2021) estimates that the capital investment (CAPEX) required for the construction of the SLMB ranges between COP 11.7 and 12.1 trillion, depending on whether only essential or all land parcels are acquired. These figures have been adjusted to constant 2017 Colombian pesosexpressed in constant December 2020 Colombian pesos. Additionally, the average annual operating and maintenance cost

(OPEX) is projected at approximately COP 115.1 billion, equivalent to an operating cost ratio of around COP 40.8 thousand per train-kilometer, also in 2017 constant pesos.

Currently, the project is undergoing an International Public Bidding Process, and its construction will move forward in parallel with Line 1, marking a decisive step toward consolidating a more integrated, efficient, and sustainable mass transit system for Bogotá.

Below is a map of the Bogotá Metro system, showing the integration of the First and Second Lines:

Figure 1: System map of the first and second lines of the Bogotá Metro



Source: Own elaboration

3. State of the art: Mass transit systems and land value

Accessibility, defined as the extent to which land-use and transport systems enable people to reach activities or destinations (Geurs & van Wee, 2004), is a key mechanism through which mass-transit investments shape urban land markets. By reducing travel frictions and expanding the set of reachable opportunities, new or upgraded transit services increase the relative attractiveness of parcels located near stations, generating additional demand and, consequently, higher land and property values (Rodríguez & Targa, 2004; Thomas, 2018; Ünver Göçer, 2023). Transit-Oriented Development strategies build deliberately on this relationship: when station areas are designed with compact, mixed uses and high-quality pedestrian environments, accessibility gains are maximised and often capitalised into land markets. In Hong Kong, TOD-based Rail + Property projects were associated with substantial ridership gains and housing-price premiums of over 30% compared to non-integrated areas (Cervero & Murakami, 2009). This conceptual framework provides the foundation for the present literature review, which considers a range of value indicators to understand how accessibility improvements associated with Bogotá's forthcoming metro may influence urban value dynamics.

The relationship between mass transit systems and urban land value appreciation has been widely addressed in the literature. However, studies differ significantly in the type of variable used to represent such appreciation, ranging from land value, total property value, to cadastral value. This review focuses on the effects observed on commercial land value, understood as an estimate of the urban land market price per square meter, which reflects real estate market dynamics and expectations regarding location and development potential.

Throughout the literature, it is common to find studies that do not clearly distinguish between these three variables, or that use property values as a proxy for land value due to data availability limitations. For this reason, this review includes studies that, while measuring other forms of value, provide relevant evidence to understand the impacts of mass transit systems on land appreciation.

Given that the subject of this study is the impact of the Bogotá Metro, the literature review is structured in two key parts. First, it presents studies on comparable rail-based systems, including international literature and recent research on the Bogotá Metro project. Second, it includes a brief review of the effects of Bus Rapid Transit (BRT) systems, with a particular focus on TransMilenio, in order to contrast prior experiences in the city and provide contextual background for interpreting the results.

Metro Systems and Land Value

A comprehensive review by the Royal Institute of Chartered Surveyors (RICS) of over 150 studies in the US, UK, Europe, Japan and Asia concluded that mass transit systems tend to increase nearby land values, although the effects vary depending on the implementation of complementary policies that promote land use changes or discourage car use (Salon & Shewmake, 2011).

In the Asian context, it has been confirmed that land value decreases by approximately 1% for every 10% increase in distance from a public transport station, reinforcing the direct relationship between proximity to transport infrastructure and increased land values (Salon & Shewmake, 2011). A study conducted in Daejeon, South Korea also showed that commercial land values within a 500-metre radius of metro stations experienced a significant increase of approximately 2280 USD/m², underlining the benefits of the improved accessibility that the metro provides (Byun & Jang, 2024).

Nevertheless, not all mass transit systems have the same impact. In Medellín, for example, the Metroplús BRT system had a negative effect on housing prices (market value of residential properties), reducing them by 5.7%, while the Tramway generated a 4.4% increase in properties near its stations. These contrasting outcomes highlight how different transit modes can influence housing markets, depending on contextual factors such as urban form, perceived externalities, and the socioeconomic characteristics of surrounding areas (García-López & Gómez-Hernández, 2024).

Abiad et al. (2019) present an analysis of the MRT-3 project in Manila that illustrates how increases in land value vary depending on the phase of the project. According to the study, prior to the project's announcement in 1995, land price trends were similar across all areas. However, following the announcement, parcels located within one kilometer of MRT-3 stations experienced significantly higher appreciation compared to those more than two kilometers away. Specifically, residential land values increased by an additional USD 154 per square meter, while commercial land values rose by USD 545 per square meter in areas near the stations. As a result, the conservative estimate of the total land value uplift attributable to public investment in MRT-3 amounts to approximately USD 3.4 billion, nearly five times the system's construction cost of USD 655 million. Complementary analyses in the same document confirm that market responses vary across project stages, with land value effects becoming especially pronounced during the operational phase, when the infrastructure becomes fully functional and its benefits are realized by the city.

An empirical study assessing the impact of Bogotá's First Metro Line announcement on the housing market reveals a clear capitalization effect prior to the system's construction. Using administrative records from the Bogotá Urban Development Institute (IDU), complemented by web scraping techniques and spatial data, the authors examined how the October 2019 announcement affected property values in the surrounding areas. The findings indicate that residential sale prices began to rise following the announcement, with properties located within 1.5 kilometers of future metro stations experiencing price increases of 10.5% for flats and 6.5% for houses. These results highlight how market expectations tied to major transport investments can influence housing values well before infrastructure is physically delivered (Cárdenas, Gallego & Urrutia, 2023).

The study by Vergel-Tovar et al. (2025) examined the anticipation effects of the announcement of Bogotá's Metro Line 1 on the unit sale prices of new real estate projects, using these prices as a proxy for property value (including both land and construction components). The analysis covered the period between 2007 and 2023 and employed walking isochrones to delineate four treatment zones based on their proximity to the planned metro stations, along with a control zone outside the area of influence. The results show that, during the post-announcement period, unit prices increased by 6.8% in treatment zone 1, 7.4% in zone 2, and 6.7% in zone 3, while the control zone experienced a 5.9% increase. In contrast, treatment zone 4, recorded a lower increase of 4.6%. These figures reflect the variation in price trends across zones following the metro project's announcement.

In conclusion, the reviewed studies show that metro systems can generate measurable changes in land values even before construction begins, particularly through anticipation effects triggered by project announcements. While some of the cited studies rely on proxies such as property prices, their findings remain relevant for understanding how land markets respond to the expected benefits of new metro infrastructure.

BRT TransMilenio and Land Value

While this study focuses primarily on the effects of rail based transit systems, it is worth briefly examining the evidence on Bus Rapid Transit (BRT) systems, particularly due to their relevance in the context of Bogotá. Although BRT systems differ from metro systems in terms of passenger capacity, infrastructure permanence, and public perception, several studies have analyzed their potential to influence land values. These findings offer a valuable point of comparison and provide additional insight into how transit infrastructure, beyond rail, can shape urban land dynamics. In Bogotá, the implementation of the TransMilenio system has produced varied impacts, influenced by factors such as proximity to BRT corridors, neighborhood income levels, and land use conditions.

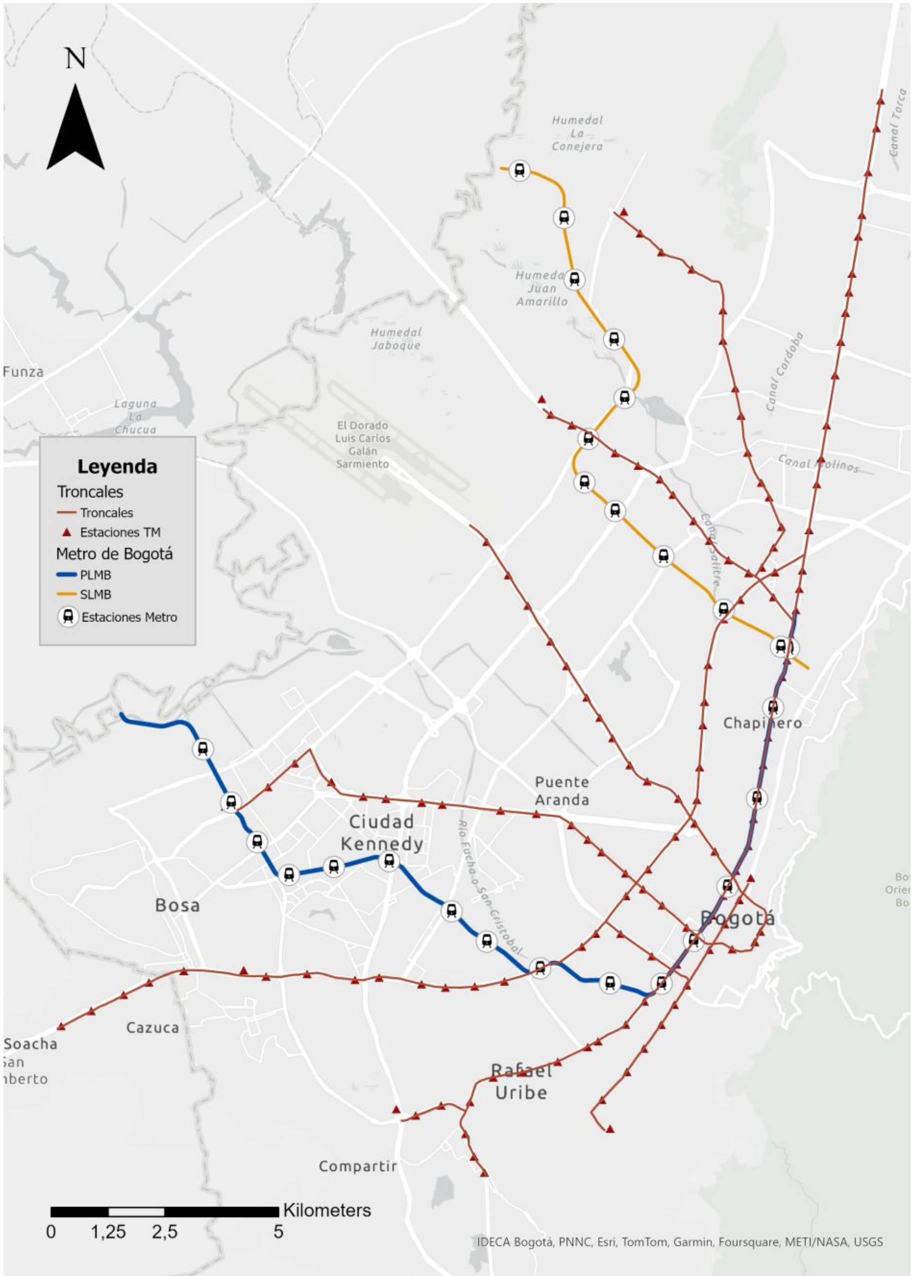
In Bogotá, (Guzmán, Enríquez, and Hessel, 2021) examined the impact of the TransMilenio BRT system on residential land values, using cadastral data and a Coarsened Exact Matching (CEM) approach. Their findings reveal heterogeneous effects depending on corridor location and socioeconomic context. For example, in the Caracas Sur/Carrera 10 corridor, residential blocks located within 200 meters of the BRT corridor exhibited a 7.7% higher average land value compared to matched controls. At a distance of 200 to 500 meters, the premium rose to 17.1%, suggesting a stronger effect slightly farther from the corridor. Positive effects were also found, though smaller in magnitude, in the NQS Sur and Calle 80 corridors. In contrast, in areas dominated by medium and high income households, particularly in the north of the city, proximity to the BRT corridor had either no effect or a negative impact on residential land values.

(Vergel-Tovar & Welch, 2019) conducted a longitudinal parcel-level analysis to evaluate the impact of Bogotá's first phase of the TransMilenio BRT system on cadaster appraisal values per square meter, using data from 2000 to 2013. Their findings indicate heterogeneous effects across land use types and distances from BRT stations. Commercial parcels showed an increase in built-up area and higher appraisal values over time, particularly within 100 meters of BRT stations. In contrast, residential parcels exhibited a decrease in both built-up area and cadaster values over time, although a higher concentration of development and value was observed between 200 and 500 meters from stations. These results highlight spatially differentiated effects of BRT infrastructure on cadaster-based land valuation dynamics in Bogotá.

In summary, the literature on BRT systems reveals the complexity of their relationship with land values, shaped by diverse institutional, spatial, and socioeconomic factors. Although this study focuses on rail-based transit, the evidence reviewed here offers a relevant point of comparison, enriching the broader understanding of how different forms of mass transit infrastructure interact with urban land dynamics.

The following figure illustrates the integrated TransMilenio and Metro system.

Figure 2: Metro and Transmilenio system



Source: Own elaboration

Although research on the relationship between mass transit systems and land values has expanded in recent years, there is still limited evidence on how these dynamics evolve during the early stages of project development—particularly between the announcement and the completion of construction. While anticipation effects have begun to receive attention, especially in recent analyses of Bogotá, the literature continues to lack a comprehensive understanding of how land markets respond over time and across different locations during these pre-operational phases.

This study aims to address that gap by analyzing spatial variations in commercial land values surrounding the Metro de Bogotá project, prior to the system's implementation.

4. Methodological approach

This paper seeks to estimate the potential effects of residential land value surplus that may occur in areas around the first and second metro lines in Bogotá. The dependent variable used in this study is the commercial land value – hereinafter referred to as land value – which corresponds to the reference value per square meter of land determined by Bogotá's Unidad Administrativa Especial de Catastro Distrital UAECD. This value is periodically updated based on the agency's core processes and reflects the city's ongoing urban development dynamics. The reference values result from an annual real estate market analysis conducted by UAECD, which identifies the commercial value trends of urban land throughout Bogotá. This process involves validating and refining data from property sale offers, transaction records, rental listings, and appraisal activities (both massive and targeted). Based on this analysis, Catastro delineates *Zonas Homogéneas Físicas y Geoeconómicas*, which group properties with similar physical and market characteristics. Each *Zona Homogénea Geoeconómica* (ZHG) is defined by evaluating economic investigation points within the physical zones to determine the prevailing market value of land.

The use of this variable is justified by the availability of annual data for different time periods, which allows for a consistent temporal analysis. Given that the UAECD updates the commercial land value each year based on observed market behavior, it is possible to track changes over time in a standardized manner. This temporal consistency is particularly relevant for the objectives of this study, which seeks to evaluate potential variations in land value in relation to the different stages of implementation of Bogotá's metro lines.

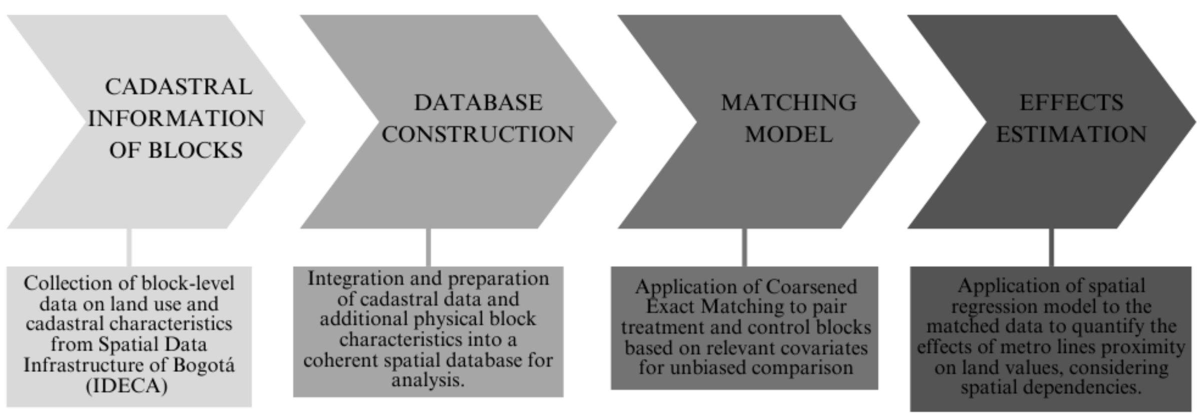
The selection of the analysis period is based on the specific milestones reached by each metro line. For BFML, the reference year is 2019, which corresponds to the period immediately following the signature of the contract. This milestone represented a definitive step toward the materialization of the project, generating credible expectations in the market before the initiation of physical works. Selecting this year allows the study to capture potential land value effects driven by the official confirmation and contractual commitment to the project. For BSML, the year 2023 was chosen as it marked a key moment in the project's planning phase, the launch of the international bidding process and release of final tender documents. The clear definition of the route and the formal progression of the procurement process likely shaped market expectations. Therefore, 2023 serves as an appropriate reference point to assess anticipatory changes in land value linked to the expected implementation of the project.

The methodology for estimating land value surplus in the area of influence is divided into two phases. In Phase 1, blocks located within 800 meters of the first two metro lines are identified to assess value changes from 2019, compared to similar blocks in the rest of the city. In Phase 2, blocks within 800 meters of the second metro line are identified and matched with those selected in the first phase. Using this data, a spatial regression of land values is conducted to estimate potential increases associated with the pre-construction phase in 2023. This methodology projects the potential impact of Line 2 on residential land value based on changes observed in Line 1.

In this analysis, it is crucial to distinguish between the sample and the subsample selected for the study. The initial sample includes all blocks located within 800 meters of the first metro line and those with a mostly residential land use. This sample provides the base of blocks on which to study variations in land value as a function of their proximity to the project. However, to minimize bias in the comparison between nearby and distant blocks, treatment and control groups, CEM is applied. This process produces a specific subsample, consisting only of blocks that meet the matching criteria, thus improving the covariate balance between the two groups. This ensures that the treatment and control blocks are comparable, allowing observed differences in land value to be attributed to proximity to metro corridors more accurately.

Figure 3 presents the methodological framework developed to assess the influence of metro lines proximity on land values in Bogotá. This comprehensive approach encompasses four distinct stages: collecting detailed cadastral data on blocks from the Spatial Data Infrastructure of Bogotá (IDECA); constructing a robust spatial database to integrate and organize this data; applying a matching model to rigorously pair treatment and control blocks based on relevant covariates; and estimating the effects using a spatial regression model to precisely quantify the impact of metro proximity on property values.

Figure 3: Methodological framework



Source: Own elaboration

Database Construction

The database used in this study was constructed by aggregating and processing information primarily at the block level. In Bogotá's cadastral system, spatial data is structured in a hierarchical manner: the largest unit is the block, which contains multiple cadastral lots or properties, and each lot can include one or more constructions. While some variables were already available at the block level, others were originally recorded at the lot or construction level and required appropriate aggregation to ensure consistency across the dataset. It is shown at the following table.

Table 3: Spatial Data Structure and Variable Aggregation Levels

Spatial unit	Description	Variables
Construction	The physical unit made of materials adhered to the land permanently.	- Num_Floors
Property	A legally identified property, which may or may not have constructions. Includes units like horizontal property, parcels, etc.	- Age - PH horizontal property (%) - Score
Lot	The minimum unit of land where one or more properties are located. It serves as the base unit for property data.	- Lots_Block (number of lots per block)
Block	The largest unit representing a portion of land, typically bounded by streets or geographic features, and consisting of one or more properties.	- Commercial land value (m^2) - Socioeconomic strata

Source: Own elaboration

The information used in this study comes from three main data sources, all covering the Bogotá Capital District. The "Estratificación Manzana Bogotá D.C." database, published by the Secretaría Distrital de Planeación, provided the socioeconomic strata by block. This variable was already available at the block level and was used directly in the analysis. The data was in shapefile format.

The "Mediana del Valor de Referencia de Terreno por Manzana" database, provided by the Unidad Administrativa Especial de Catastro Distrital (UAECD), offered the commercial land value per square meter. This value was already aggregated by block and used as is in the study. The data was in shapefile format.

Most of the remaining variables were derived from the "Mapa de Referencia del Distrito Capital" database, consolidated by the Infraestructura de Datos Espaciales para Bogotá (IDECA). This source provided several variables, including Num_Floors, Lots_Block Age, PH horizontal property (%), Score, and Res_Density. The data was stored in GeoDataBase format.

The dependent variable, commercial land value per square meter, was already aggregated at the block level. Similarly, socioeconomic strata data was readily available at the block level, sourced directly from Bogotá's Secretaría Distrital de Planeación, and did not require further processing.

The variable Lots_Block was calculated using GIS analysis to count the number of cadastral lots located within each block polygon. Initially, this data was available at the cadastral lot level, where each lot was individually recorded.

For Age, which originated at the cadastral property level, the median construction age was first determined for each cadastral lot. These median values were then averaged across all properties in a block to obtain the block-level figure. Similarly, PH horizontal property was derived by identifying properties under this regime and calculating the percentage of the total constructed area in the block that corresponded to PH units. The Score variable, representing construction quality, was also originally at the property level and was aggregated to the block by averaging. Res_Density was obtained by summing the total number of residential lots per block and dividing by one hectare, providing a measure of residential density standardized by area.

Finally, for Num_Floors, the information was originally available at the construction level. To aggregate it, the average number of floors per construction was first calculated at the cadastral lot level. Then, the maximum value among the properties within each block was assigned to represent the block-level value.

Additionally, the variables D800_L1, D800_L2, Dred_TM, and DIST_CBD were all calculated using GIS analysis. D800_L1 and D800_L2 are dummy variables that take the value of 1 if the block is within the influence zone of the first or second metro lines, respectively. Dred_TM measures the network distance from the centroid of the block to the nearest TransMilenio station. Finally, DIST_CBD represents the Euclidean distance between the centroid of the block and the economic center of the city, located at the intersection of Calle 72 and Carrera 7.

While the use of block level data provides a consistent and comparable spatial unit for the analysis, it also entails certain limitations that should be acknowledged. Several variables were originally available at more disaggregated levels (such as the construction or cadastral lot level) and required aggregation to ensure alignment with the dependent variable. This process may lead to a partial loss of intra-block variability and assumes a certain degree of spatial homogeneity within blocks. However, this level of aggregation is consistent with the spatial scale of most urban policy instruments and land use planning tools in Bogotá, and it allows for meaningful comparison across the city. The use of robust statistical techniques, such as Coarsened Exact Matching and weighted regressions, further supports the reliability of the results despite these structural constraints.

Identification of working subsamples

The estimation strategy for the effects on land values derived from the pre-construction phase of the BFML is based on the fact that proximity to the corridors generates surplus values for those residential blocks that have similar characteristics to those not close to the metro. A direct comparison based on the calculation of average land values between nearby and distant blocks from the corridor can lead to erroneous conclusions due to the heterogeneity of the blocks that is inherent to the development of the city.

To overcome bias problems in the estimation of land value effects, matching methods are used, from which a subsample can be generated to compare blocks under the notion of treatments and controls, in this case, those nearby versus those that are statistically comparable.

Within the family of matching methods, CEM (Coarsened Exact Matching) is used as a strategy to obtain a subsample that allows identifying city blocks that can be matched for estimating effects. CEM has the benefit of reducing the imbalance of covariates used in the identification process (Ripollone et al., 2020) compared to traditional methods like Propensity Score Matching.

The CEM algorithm consists of generating clusters, in this case of blocks, by creating categories of the covariates used in the identification process. If a cluster contains both treated and control blocks, it is considered eligible for inclusion in the subsample. Conversely, subgroups that contain only treated blocks or only control blocks will be considered unmatched. Once the sub-sample has been identified, CEM assigns a weighting to each block. Treated blocks receive a weight of one, while control blocks are weighted based on the proportion of treated and control blocks within each cluster, ensuring that matching groups are comparable in the analysis (Iacus, King & Porro, 2012, p8).

With this observation weighting structure, the weighted mean estimator of the variable of interest in the study can be calculated, which in this case is the commercial land value per m^2. From this, the mean differences between the treated group and the control group can be statistically verified to determine if there is a significant effect on land value in the first group compared to the second.

The estimation of the mean differences is obtained through a linear regression for the land value, conditioned on a dummy variable that identifies whether the blocks in the subsample are within the area of influence of the metro line, along with other control variables such as the maximum number of floors, distance to the economic center, number of lots, percentage of built area in horizontal property, building quality score, residential property density, and the average age of buildings.

5. Results

Subsample for Identifying Effects on Blocks within the Influence Zone of the First Metro Line

For the construction of this subsample, cadastral information was used on blocks located within 800 meters of the first metro line, as well as those with predominantly residential land use, defined as blocks where the sum of the built area in residential use categories exceeds 50%, according to the cadastre’s land use table. This information was obtained from the Spatial Data Infrastructure of Bogotá (IDECA).

For the matching process, treatment blocks are considered those located within the influence zone of the first metro line, and control blocks are those outside the influence zone. The covariates used to find matched blocks in both groups include the average maximum number of floors, the distance to the city's economic center, lots per block, and the percentage of residential built area associated with the horizontal property regime. Also included is the average building score, based on the qualitative evaluation of a set of variables that assess the type and condition of the construction and the quality of its attributes. Finally, the residential property density per hectare within the block is included, providing a measure of how densely populated the block is with residential properties, as well as the average age of the buildings.

Table 4 shows the descriptive statistics of the covariates in the working database for 32,030 blocks, of which 2,980 are located within the influence zone of the first metro line and 29,050 are control blocks.

Table 4: Descriptive statistics of covariates before matching of the First Metro Line

Variable	Description	Treated Mean	Control Mean	Standarized, Mean Difference
Num_Floors	Average maximum floors per block	2.78	2.68	0.11
Dist_CBD	Distance to city center	10083.99	11923.91	-0.55
Lots_Block	Number of lots per block	24.86	23.15	0.14
Age	Average building age	44.62	36.39	0.46
PH	Percentage of area under horizontal property	0.07	0.10	-0.17
Score	Average building score	36.40	33.37	0.44
Res_Density	Residential density (per ha)	1022.75	1010.76	0.00

Source: Own elaboration

After applying the CEM, a subsample of blocks is found for which the covariate statistics improve in their balance, reducing differences in characteristics between treated and control blocks. From this process, 2,413 blocks are in the treatment group and 7,308 blocks are in the control group as a result of the matching. The results of the process are shown in Table 5.

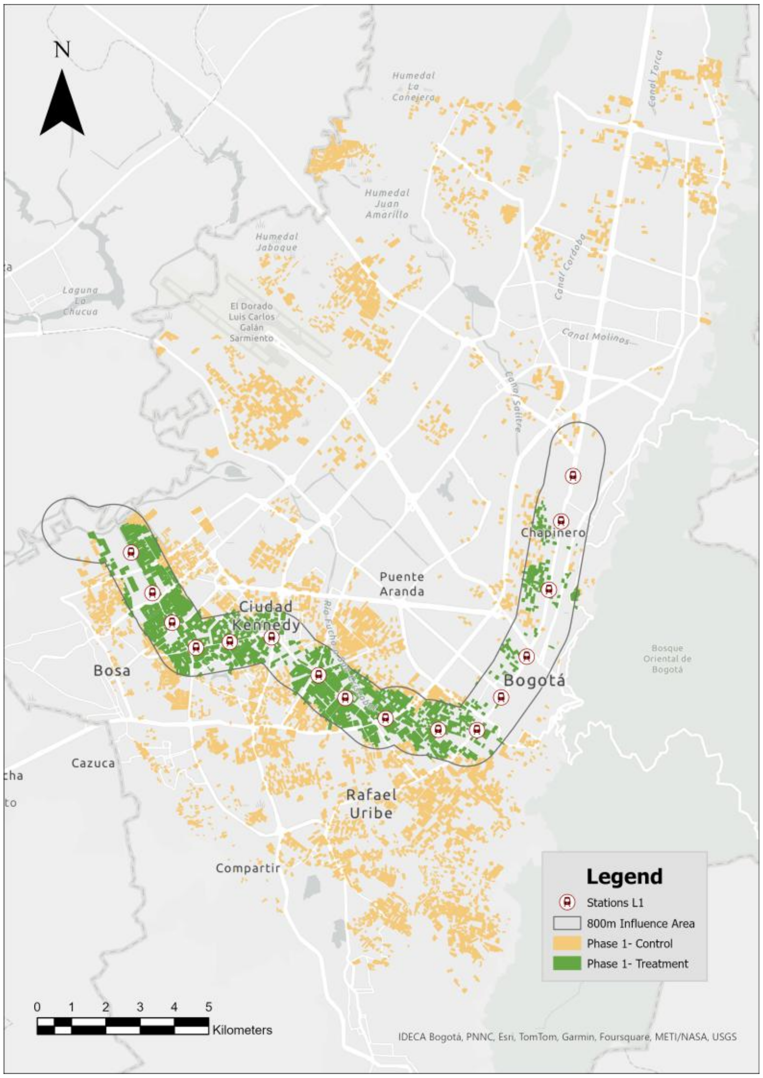
Table 5: Descriptive statistics of covariates after matching of the First Metro Line.

Variable	Description	Treated Mean	Control Mean	Standarized. Mean Difference
Num_Floors	Average maximum floors per block	2.67	2.62	0.06
Dist_CBD	Distance to city center	10725.78	10738.60	-0.00
Lots_Block	Number of lots per block	25.39	25.45	-0.01
Age	Average building age	42.72	42.65	0.00
PH	Percentage of area under horizontal property	0.04	0.04	0.01
Score	Average building score	35.19	34.91	0.04
Res_Density	Residential density (per ha)	433.45	335.44	0.01

Source: Own elaboration

Figure 4 illustrates the treatment and control groups used to estimate the change in land value for Bogotá's First Metro Line.

Figure 4: Treatment and Control Groups for Bogotá's First Metro Line



Source: Own elaboration

The comparison between Tables 4 and 5 shows the effect of the matching process on the balance of covariates between the treatment and control groups. In the first table, the initial differences in block characteristics before matching indicate that the blocks in the sample were distinct. The second table, which presents the results after applying CEM, shows a reduction in these differences, achieving greater similarity between the treated and control blocks. This conclusion is based on the reduction in the mean difference of each covariate, which demonstrates that the matching process has balanced the characteristics between the groups. As explained in the CEM section, this balance is essential to ensure that any observed effect can be attributed more precisely to the treatment, minimizing bias in comparisons.

Land Value Appreciation Effects in the Pre-Construction Phase of the First Metro Line

Once the subsample, composed of blocks within the 800-meter buffer of the first metro line and matched blocks outside this zone is identified, the next step is to determine the effects of proximity to the corridor of the first metro line by comparing these blocks. To analyze the effects of the metro on land value, the model also included average socioeconomic conditions of the population residing near metro stations and the corridor. Socioeconomic strata[1] (SES) was used as a proxy to represent the economic conditions of these areas' residents. The outcome variable is the logarithm of land value per m^2. The following regression model is used for estimating the effect:

$$\mathrm{lnVS_i} = 14.77 + 0.11 * \mathrm{D800_{L1_i}} - 0.00005 * \mathrm{Dred_{TM_i}} - 0.000002 * \mathrm{DIST_{CBD_i}} - 0.34 * \mathrm{Low}_i + 1.19 * \mathrm{Medium_i} - 0.0036 * \mathrm{Age_i} + 0.02 * \mathrm{PH}_i + \mathrm{e_i}$$

Where:

- $lnVS_i$: natural logarithm of the residential land value per square meter for block i
- $\mathrm{D800\_L1}_i$: dummy variable that takes the value of 1 if the block is within the influence zone
- $\mathrm{Dred\_TM}_i$: network distance from the centroid of the block to the nearest TransMilenio station
- $\mathrm{DIST\_CBD}_i$: Euclidean distance to the CBD
- Low_i: Lower socioeconomic strata
- Medium_i: Middle socioeconomic strata
- Age_i: Average age of the buildings
- PH_i: Percentage of built area associated with the horizontal property regime

Table 6 presents the results of estimating the effects on land value using an ordinary least squares (OLS) regression, with the weights obtained by CEM for each block in the subsample.

[1] In Colombia, socioeconomic strata are an official classification system used to categorize residential properties based on the physical and urban characteristics of the dwelling and its surroundings. This system, established by national regulations and implemented by local authorities, ranges from stratum 1 (the lowest) to stratum 6 (the highest), and is primarily used to allocate public subsidies and set differential rates for public services. For the purposes of this study, the strata were grouped into three broader categories: Low (strata 1 and 2), Medium (strata 3 and 4), and High (strata 5 and 6), in order to facilitate comparative analysis.

Table 6: Estimation of effects on land value of the First Metro Line 2019

Predictor	Description	Estimate	Std. Error	T Value	Pr(>T)
INTERCEPT	Constant in model	14.77	0.07	198.36	< 2e-16 ***
D800_L1	In influence zone of Line 1	0.11	0.01	12.41	< 2e-16 ***
DRED_TM	Distance to TransMilenio	-0.00005	0.000003	-15.89	< 2e-16 ***
DIST_CBD	Distance to city employment center	-0.00002	0.000002	-10.26	< 2e-16 ***
LOW	Lower socioeconomic strata	-0.34	0.07	-4.59	4.42e-06 ***
MEDIUM	Middle socioeconomic strata	1.19	0.07	1.63	0.10
AGE	Average building age	-0.0036	0.00032	-11.15	< 2e-16 ***
PH	% Horizontal property	0.02	0.02	0.73	0.46
ADJUSTED R-squared: 0.1607			F-statistic: 728.2 on 7 and 9713 DF		p-value: < 2.2e-16

Significance level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Source: Own elaboration

The results in Table 6 indicate that, on average, the blocks near the first metro line have a land value premium by 11.67% during the pre-construction phase of the first metro line.

Land Value Appreciation Effects in the Construction Phase of the First Metro Line

Applying the same methodological approach for the year 2023, it can be observed that the appreciation effect remains positive and statistically significant, now during the construction phase of the project. In this case, Table 7 shows that blocks located within 800 meters of the first metro line stations exhibit an average premium of 8.8%. This result indicates that, although the positive effect persists, it is 2.88 percentage points lower than the effect observed in 2019.

Table 7: Estimation of effects on land value of the First Metro Line 2023

Predictor	Description	Estimate	Std. Error	t value	Pr(>t)
(Intercept)	Constant in model	15.17	0.06	250.75	< 2E-16 ***
D800_L1	In influence zone of Line 1	0.08	0.01	11.68	< 2E-16 ***
Dred_TM	Distance to TransMilenio	-0.00005	0.000003	-18.24	< 2E-16 ***
DIST_CBD	Distance to city employment center	-0.00002	0.000002	-18.18	< 2E-16 ***
Low	Lower socioeconomic strata	-0.60	0.06	-10.05	4.42E-06 ***
Medium	Middle socioeconomic strata	-0.19	0.06	-3.27	0.0011
Age	Average building age	-0.0022	0.00025	-8.64	< 2E-16 ***
PH_Porcent	% Horizontal property	-0.0026	0.01	-0.19	0.85
Adjusted R-squared: 0.382			F-statistic: 1242 on 7 and 14043 DF		P-VALUE: < 2.2E-16

Notas: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Source: Own elaboration

Projected Land Value Appreciation in the Pre-Construction Phase of the BSML

This section presents the projected land value appreciation for blocks adjacent to the second line of the Bogotá metro. The objective is to estimate future land values based on the appreciation observed in blocks near the first metro line during its pre-construction phase, whose results are shown in the previous section. This approach allows for an analysis of potential land value increases during the current pre-construction phase of the second line

In this case, a database that includes the blocks that resulted from the matching of the first metro line, plus the blocks that are predominantly residential and located within 800 meters of the second metro line's catchment area. Thus, the 9,721 blocks from the initial matching process are supplemented by 2,466 blocks for which future land value premiums is projected due to their proximity to the second metro line.

A new matching process is conducted using this database, with treatment blocks being those near the second metro line while the control blocks being those previously used in the analysis of the first metro line. Control blocks from the first metro line analysis, which are not near the metro, are retained in the database to introduce a randomization component into the matching process.

For this matching process, the covariates included are the distance to the CBD, the number of lots per block, the percentage of built area used for residential purposes under horizontal property, the construction condition score, and the average age of the buildings. Tables 8 and 9 show the descriptive statistics before and after matching.

Table 8: Descriptive statistics of covariates before matching of the Second Metro Line

Variable	Description	Treated Mean	Control Mean	Standarized Mean Difference
Dist_CBD	Distance to city employment center	7803.44	10963.75	-1.03
Lots_Block	Number of lots per block	28.32	24.75	0.24
Age	Average age of buildings	40.88	41.43	-0.04
PH	% Area under horizontal property	0.07	0.03	0.15
Score	Average building score	36.69	33.93	0.54

Source: Own elaboration

Table 9: Descriptive statistics of covariates after matching of the Second Metro Line.

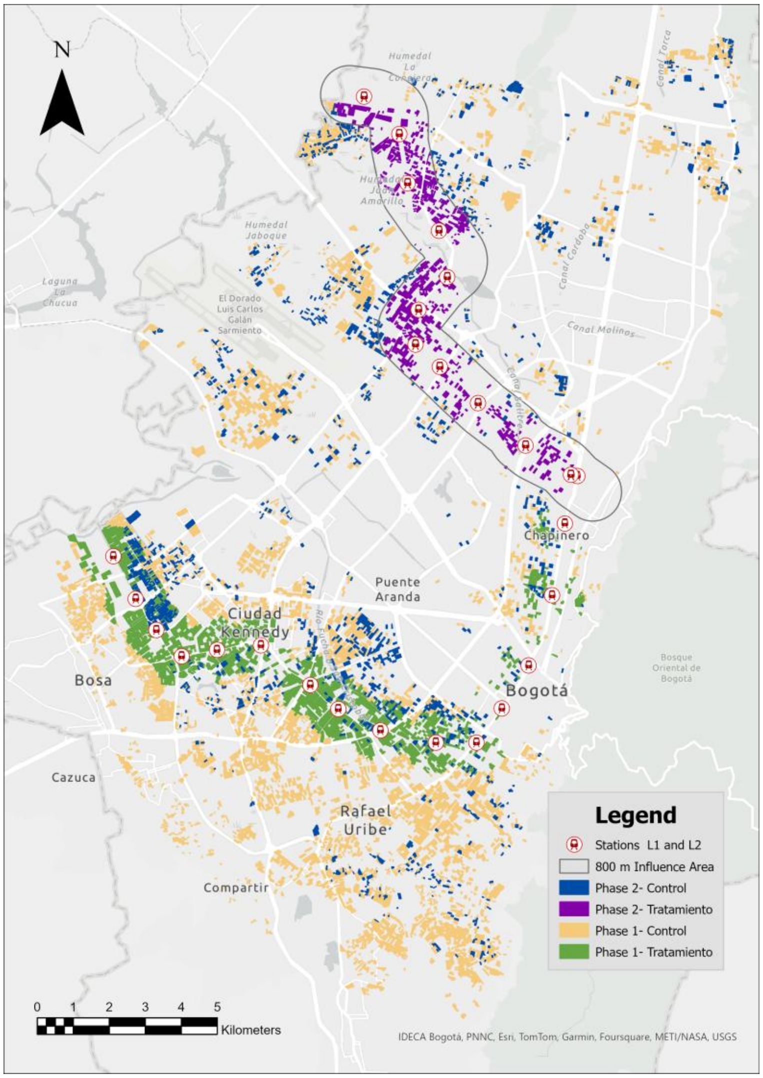
Variable	Description	Treated Mean	Control Mean	Standarized. Mean Difference
Dist_CBD	Distance to city employment center	8535.67	8596.20	-0.02
Lots_Block	Number of lots per block	25.90	25.89	0.0004
Age	Average age of buildings	40.92	41.12	-0.01
PH	% Area under horizontal property	0.03	0.03	-0.001
Score	Average building score	35.85	35.95	-0.02

Source: Own elaboration

After the matching process using the CEM algorithm, there are 2,850 blocks for the estimation exercise, of which 1,000 are located near the second metro line.

Figure 5 shows the treatment and control groups for blocks near the second metro line, identified through the matching process described earlier. Blocks within 800 meters of the second metro line form the treatment group, while other blocks serve as the control group.

Figure 5: Treatment and Control Groups for Bogotá's Second Metro Line



Source: Own elaboration

Using the data and weights generated by CEM, a regression model is estimated to obtain a linear prediction of the land value for the blocks of interest. The regression model is shown below:

$$\mathrm{lnVS_i}=14.41+0.11 * \mathrm{D800\_L2_i} - 0.00003\mathrm{DIST\_CBD_i}+0.02\mathrm{Num\_Floors_i}+0.23*\mathrm{Medium_i}+0.0008*\mathrm{Age_i} - 0.03\mathrm{PH_i}+\mathrm{e_i}$$

Where:

- $lnVS_i$: Natural logarithm of the residential land value per square meter for block i
- $\mathrm{D800\_L2}_i$: Dummy variable that takes the value of 1 if the block is within the influence zone
- $\mathrm{DIST\_CBD}_i$: Euclidean distance to the CBD
- $\mathrm{Num\_Floors}_i$: Average maximum number of floors in the buildings on the block

- Medium_i: Middle socioeconomic strata
- Age_i: Average age of the buildings
- PH_i: Percentage of built area associated with the horizontal property regime

Table 10 presents the results of the regression model. The expected impact of proximity to the second metro line is a positive increase in land value, indicating that, as with the first line, nearby blocks should also experience appreciation during the pre-construction phase of the second metro line project.

Table 10: Estimation of effects on land value of the Second Metro Line

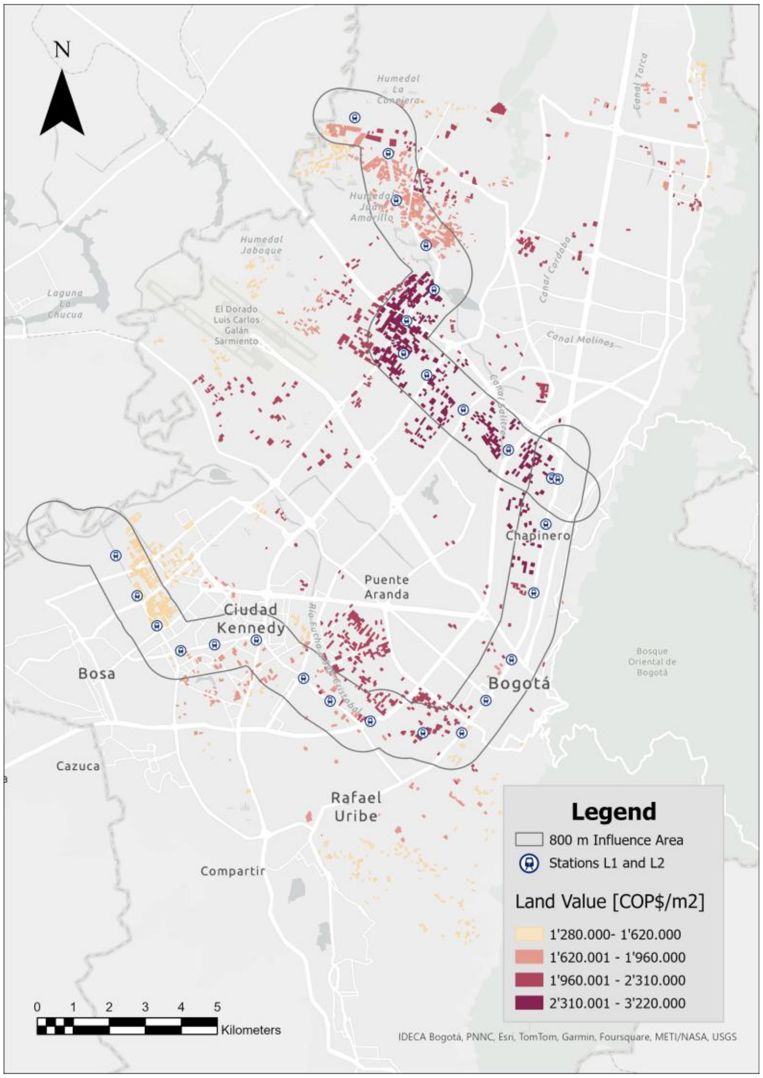
Predictor	Description	Estimate	Std. Error	T Value	Pr(>T)
INTERCEPT	Constant in model	14.41	0.04	385.80	< 2e-16 ***
D800_L2	In influence zone of Line 2	0.11	0.01	7.73	1.43e-14 ***
DIST_CBD	Distance to city employment center	-0.00003	0.000002	-11.59	< 2e-16 ***
NUM_FLOORS	Avg. max floors per block	0.0221	0.01	3.25	0.01 **
MEDIUM	Middle socioeconomic strata	0.2313	0.01	20.19	< 2e-16 ***
AGE	Avg. age of buildings	0.0008	0.0004	1.88	0.06
PH	% area under horizontal property	-0.0301	0.0303	-0.99	0.32
ADJUSTED R-SQUARED: 0.42			F-statistic: 338.6 on 6 and 2843 DF		p-value: < 2.2e-16

Significance level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Source: Own elaboration

The results in Table 10 show that the coefficient associated with the variable D800_L2_i, indicates that, on average, blocks near the second metro line appreciated by 11.75% during its pre-construction phase, even though second metro line has not yet been awarded. These results are illustrated in Figure 6.

Figure 6: Land Value Results



Source: Own elaboration

6. Conclusions

The methodology implemented allows for the isolation of the effect of the metro corridors on surrounding blocks by comparing land value changes between equivalent areas. The results confirm a positive land value difference of approximately 11.7% for Line 1 during the pre-construction phase (2019) and 8.8% during the construction phase (2023). For Line 2, the projected land value premium is approximately 11.8% during its announcement stage. These results suggest that land value effects may vary across different stages of project development.

This study shows that land value impact analysis can be performed at the earliest stages of an infrastructure project, such as pre-construction. This allows urban developers and planners to anticipate changes in the real estate market and adjust land use policies to accommodate future increases in in land and property demand.

The application of the CEM method in the evaluation of infrastructure projects is effective in minimizing biases in the results and ensuring more accurate comparisons between zones of influence and control areas. This methodology allows for more reliable estimates of the impact of projects on land values.

Given the results showing that metro lines generate land value uplift during both the pre-construction and construction phases, it becomes relevant to analyze how this increase could be captured through financial instruments. To address this, it is necessary to explore the instruments defined in the Plan de Ordenamiento Territorial and assess how they can be deployed according to project attributes, financing strategies, and the payment capacity of households within the project's area of influence.

Finally, in cities such as Bogotá, anticipating and monitoring land value impacts throughout different stages of major infrastructure projects represents a strategic advantage. This approach facilitates better management of urban development around future transport nodes, promoting more orderly and sustainable urban growth.

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