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Sustainable Asset Valuation of Parques del Río Norte in Medellín, Colombia

NBI REPORT

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The **Nature-Based Infrastructure (NBI) Global Resource Centre** aims to improve the track record of NBI to deliver infrastructure services and adapt to climate change while delivering other environmental, social, and economic benefits. We provide data, training, and customized valuations of NBI projects, based on the latest innovations in systems thinking and financial modelling.

The Centre is an initiative led by IISD, with the financial support of the Global Environment Facility (GEF) and the MAVA Foundation, in partnership with the United Nations Industrial Development Organization.

Sustainable Asset Valuation of Parques del Río Norte in Medellín, Colombia

March 2024

Ronja Bechauf, Marco Guzzetti, and Nathalia Niño

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This report is part of a wider collaboration between C40 Cities Finance Facility and IISD to support the project preparation phase of NBI projects in cities in Colombia and South Africa. C40 Cities Finance Facility and IISD are working together on integrated economic assessments of urban NBI projects to support implementation and showcase the value of nature for cities.

Author contributions

All authors are listed in alphabetical order. Marco Guzzetti carried out the spatial analysis and prepared the corresponding technical annex. Nathalia Niño developed the Excel model based on systems thinking and integrated cost-benefit analysis, coordinated communications with the C40 City Finance Facility and the City of Medellín, and led the drafting of the report. Ronja Bechauf provided support for various sections of the report.

Executive Summary

Colombia's second-largest city, Medellín, has rapidly developed in recent decades. Together with the consequences of climate change, Medellín is now facing the consequences of its rapid urban development. Formal and informal urban areas, including housing and commerce, have historically been located on the banks of both sides of the Medellín River, contributing to riverbank erosion and leaving the city with fewer green spaces for citizens. Climate impacts have aggravated the flood risks in these areas and further contributed to erosion.

The Parques del Río Norte project aims to address and mitigate these issues. It seeks to offer attractive green spaces for walking and cycling, which will, in turn, improve air and water quality and increase natural habitats for biodiversity in a densely populated city. The project will provide multiple benefits to the residents of Medellín, especially for the inhabitants of surrounding sectors (communes 2, 4, and 5), including important social benefits, by providing pleasant public spaces intended to support community cohesion and increase environmental awareness.

The city has a long-term vision for the development of a green park that stretches along the river through the urban areas of Medellín. At present, only a central area of the park, of 75,000 m^2, has been completed. Parques del Río Norte is the 300,000 m^2 extension of the park and is the subject of this analysis. The first phase covers 7 ha, of which 2.6 ha of development has secured funding and approval.

The project is being led by the Secretariat of Physical Infrastructure of Medellín and designed and built by the Urban Development Company, a company of the public conglomerate of the district in charge of the execution of the works. The C40 Cities Finance Facility is providing technical assistance in cooperation with the city for the general preparation of the project and future connections with potential funders.

This report presents the results of an integrated cost-benefit analysis (CBA) for which the multiple environmental, social, and economic benefits of the park are quantified. The benefits were identified through a review of the literature and project documents and a co-creation process with project stakeholders. This process identified the benefits listed in Table ES1, some of which feature as an avoided cost.

Table ES1. Avoided costs and added benefits of the park

Avoided costs	Added benefits
Avoided cost of carbon emissions	Labour income from construction and operation and maintenance (O&M) of Parques del Rio Norte
Avoided energy expenditure by heat island reduction	Revenue from park operations
Avoided cost of flood damage and reconstruction	Increased retail revenue
Avoided cost of air pollution	Increased property value
	Health benefits of physical activity

Source: Authors.

The integrated CBA shows the outcomes of the project over a 30-year period. The analysis uses results from spatially explicit models (with the Integrated Valuation of Ecosystem Services and Tradeoffs [InVEST]) and Excel-based models customized with best-practice valuation methodologies for each indicator.

The integrated CBA is presented in Table ES2.

Table ES2. Integrated CBA in COP and USD

	Discounted values in billions of COP[1]	Discounted values in billions of USD
Total costs	**2,984.50**	**710.60**
Construction	2,575.28	613.16
O&M	409.23	97.43
Total added benefits	**3,665.35**	**872.70**
Discretionary spending from employment creation	22.27	5.30
Revenue from park operations	76.87	18.30
Retail revenue	1,336.83	318.29
Increased property value	148.88	35.45
Health benefits of physical activity	2,080.50	495.36
Total avoided costs	**1,314.43**	**312.96**
Carbon emissions	2.15	0.51
Energy expenditure	0.07	0.02
Flood damage	1,312.08	312.40
Air pollution	0.13	0.03
Net profit	**1,995.27**	**475.06**
Benefit-to-cost ratio	**1.67**	**1.67**

Note: The values are cumulative over a 30-year period (2023-2050), discounted at 3.5%.[2]
Source: Authors.

[1] For this evaluation, billions are used according to the American system as 10e9 (1,000,000,000), which would correspond to a thousand million for Colombia.

[2] Original values and calculations were made in Colombian pesos (COP). Conversion to USD was done for illustrative purposes at a rate of COP 4,200.

Our review has revealed the following:

- Parques del Río Norte generates USD 1.67 in societal value for each dollar invested.
- The park effectively reduces the risk of flood: in the buffer area,[3] water retention increases by 57.68% and prevents flood damage to properties and infrastructure worth USD 312.4 billion over 30 years. The 300,000 m^2 park increases the green space per inhabitant (m^2/person) from 1.32 m^2 to 1.44 m^2 per person.[4]
- The park will improve habitat quality by 86.43% and increase carbon storage by 103.75% in the buffer area by 2053.
- The park will revitalize neighbourhoods near the riverbanks by increasing the value of buffer-zone properties by USD 35.45 billion (COP 148.88 billion) and boosting retail revenues by USD 318.29 billion (COP 1,336.83 billion).
- People living in the 2,683 properties around Parques del Río Norte will directly benefit from reduced temperatures and decreased expenditures in energy.
- The park is projected to attract approximately 44,994 visitors daily and an additional 4,659 cyclists using the dedicated bike paths and trails. This will result in health benefits for the community worth USD 495.36 billion (COP 2,080.50 billion).

These results can be used to present the nature-based infrastructure (NBI) use case for reducing the risk of flooding, heat stress, and pollution. They can also inform funding and financing strategies for subsequent phases of the park development.

Table ES3 presents how different stakeholders can use and leverage the results of the assessment.

[3] The buffer area is an additional bank of 250 m on each side of the corridor that is considered the area of direct impact of the Parques del Río Norte project (see example in Figure 10).

[4] Data used for the calculation: 1) total population of Medellín = 2,569,000 inhabitants; 2) public space before project execution = 3,391,080 m^2 (which translates into 1.32 m^2/inhabitant); 3) public space after the project execution = 3,691,080 m^2.

Table ES3. How stakeholders and decision-makers can use the results of this assessment

Stakeholders	Role in the project	How can the stakeholder use the results of the evaluation?
C40 Cities Finance Facility	Support and technical assistance for the Parques del Río Norte project in the technical and financial preparation of the project	C40 Cities Finance Facility can use the results of this assessment in Colombia to raise awareness about the importance of NBI for cities in other countries and regions. The results can be used to demonstrate the positive impacts NBI has on cities. The identification and monetization of benefits can serve as a basis for discussions on funding and financing strategies for the construction of the entire extension of Parques del Río Norte.
Secretariat of Physical Infrastructure (SIF)	Leader in the design and execution of Parques del Río Norte	SIF is leading the project in its initial stage and is in charge of supervising the activities developed by the Urban Development Company. SIF can use the results of this analysis to attract investors and extend the park to the entire northern zone, not just the area approved so far. In addition, the results can serve as a precedent to support similar projects that rely on nature to solve (infrastructure) problems in the city.
Urban Development Company	The company responsible for the design of Parques del Río Norte and the execution of the works	The Urban Development Company can use the results of this evaluation to inform decisions on the continuation of the construction of the park up to 300,000 m^2.
Donors and investors	Funding and financing for NBI initiatives	Investors and donors can use the results of this assessment to inform strategies for climate adaptation and mitigation funding and financing.
Civil society	Participates in planning and support for the appropriate use and maintenance of the park	Civil society organizations can use the results in support of NBI and nature-based solutions widely.
Municipal, regional, and national governments	Support the delivery and financing of NBI projects and scale these initiatives for other jurisdictions	Governments can use the results to estimate the impacts of parks for climate mitigation and adaptation—for instance, to show the benefits of green infrastructure in mitigating flood impacts. Local administrations can use the results of the analysis to advocate for national government departments to collaborate and fund more nature in cities (e.g., for health-related purposes).

Source: Authors.

Glossary

Discount: A financial process to determine the present value of a future cash value.

Indicator: Parameters of interest to one or more stakeholders that provide information on the development of key variables in the system over time and trends that develop under specific conditions (United Nations Environment Programme [UNEP], 2014).

Integrated Valuation of Ecosystem Services and Offsets (InVEST): "A set of models used to map and value nature's goods and services that sustain and satisfy human life. It helps explore how changes in ecosystems can lead to changes in flows of many different benefits to people" (Natural Capital Project, 2019).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used and the qualitative and quantitative tools for data collection and parameter estimation (UNEP, 2014)

Model transparency: The degree to which the structure and equations of the model are accessible and allow the behaviour of the model (i.e., the numerical results) to be directly related to the specific structural components of the model (UNEP, 2014)

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with observed behaviour in reality (i.e., national statistics, established databases) and whether the structure of the developed model (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net profits: The amount of monetary benefits accumulated across sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Scenarios: Expectations about possible future events used to analyze possible responses to these new and future developments. Consequently, scenario analysis is a speculative exercise in which various alternatives for future development are identified, explained, and analyzed for discussion on what can cause them and the consequences that these paths may have on our system (for example, a country or a company).

Simulation model: Models can be thought of as systemic maps in the sense that they are simplifications of reality that help reduce complexity and describe, at their core, how the system works. Simulation models are quantitative in nature and can be constructed using one or more methodologies (UNEP, 2014).

Acronyms and Abbreviations

BAU	business-as-usual
CBA	cost-benefit analysis
CFF	C40 Cities Finance Facility
CLD	causal loop diagram
EDU	Urban Development Company
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
LULC	land-use/land cover
O&M	operation and maintenance
NBI	nature-based infrastructure
$PM_{2.5}$	particulate matter (smaller than 2.5 micrometres)
SIF	Secretariat of Physical Infrastructure
SMA	Secretariat of Environment
SSP	Shared Socioeconomic Pathways

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1.0 Introduction

Medellín is grappling with the challenges that accompany its urbanization processes. This city is the second-largest in Colombia and is located in the Antioquia region. The Medellín River runs through the city, flowing from south to north. Historically, since the latter half of the 20th century, the river has been the axis that structures the city's road system and has been providing valuable ecosystem services to the local community.

Urban growth, aggravated by the impacts of climate change, has led to riverbank erosion, a decrease in available green spaces, water pollution, increased heat island effect, and flood risk, all of which affect the well-being of local communities. The issues also reinforce one another. For example, the reduction of green space and low permeability of the soils because of the encroachment and informal settlements are worsening the flood risks and damages.

Parques del Río Norte has been designed to address these interlinked issues. The park is an example of nature-based infrastructure (NBI) alongside the river. The Secretariat of Physical Infrastructure (SIF) of the City of Medellín is the city unit responsible for it and oversees the activities of the Urban Development Company (EDU), which is in charge of the design and construction of the first 70,000 m^2. The C40 Cities Finance Facility (CFF) supports the project with technical and financial feasibility studies. The International Institute for Sustainable Development and the NBI Global Resource Centre are providing an integrated cost-benefit analysis (CBA) as part of the C40 CFF's technical assistance.

The first stage of the Parques del Río Norte project consists of 26,312 m^2, which is expected to expand to 300,000 m^2 to cross the entire northern area of the city along the river. Specifically, the park will be located where the Palermo, Sinai, and La Frontera neighbourhoods are currently located, adjacent to the river on the left side bank if you look from north to south (see Figure 1). Of these neighbourhoods, La Frontera is the one with the highest flood risks, given its proximity to the river.

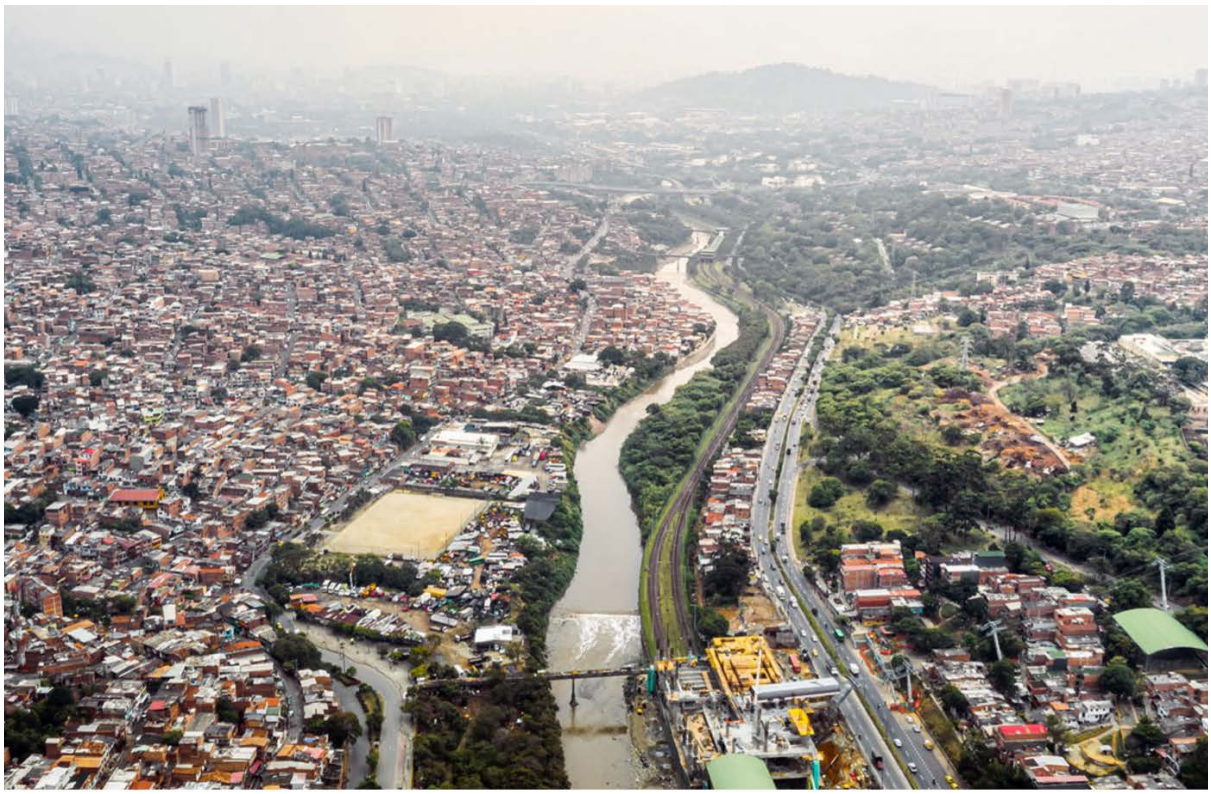
Approximately 1 million residents in communes 2, 4, and 5 will directly benefit from the 30-ha park. If the park expands along the entire river, including the part already built in the centre of the city (75,000 m^2), the benefits will reach a much larger population, including both those who live in areas near the park and those who cross the area regularly, such as public transport users (cable car or metro).

The park is expected to offer attractive green spaces for walking and cycling, improve air and water quality, reduce extreme heat, and increase natural habitats for biodiversity in the densely populated city. Parques del Río Norte also includes commercial spaces and public facilities for users of the park. This feature offers social and socio-economic benefits, such as revenue for small retail shops and community cohesion.

To value these benefits in a way that decision-makers can use for further planning and implementation, we use a combination of spatial analysis, systems thinking-based models, and integrated CBA. The combination of these tools generates evidence of the positive social, economic, and environmental outcomes of investing in green spaces.

We compare this NBI scenario with a baseline scenario in which the project is not implemented. Since the project is located along the banks of the Medellín River, a systemic evaluation will contribute to implementing NBI in the second and third phases and replicate it in the existing Master Plan along the entire river in the city, as well as in other cities around the world with similar characteristics.

Figure 1. Photo of the Medellín River in the northern part of the city, flowing from north to south



Source: EDU, 2023.

2.0 Methodology and Assumptions

Through a co-creation process, we developed a causal loop diagram (CLD) to show how the important parts of the system around the project interact with each other. Based on the diagram, we identified the key ecosystem services to quantify using a spatially explicit analysis. The CLD also informs the indicators of the quantitative model for the integrated CBA.

2.1 Causal Loop Diagram

The CLD for the Parques del Río Norte project (Figure 2) identifies the dynamics that have driven urban development around the Medellín River through reinforcing loops, as well as the side effects of this development on the environment, society, and the economy through balancing loops.

Reinforcing loops, marked with an "R," represent loops containing self-reinforcing dynamics that tend to grow stronger over time when triggered by a change. For example, loop R1 shows that as the urban population increases, so does the need for urban development. This development increases the attractiveness of the city, which increases the urban population further. Loop R2 represents the increase in urban development, leading to further urban sprawl around the river and increasing settlements and the retail sector, which increases the valorization of surrounding neighbourhoods, attracting investments from both the public and private sectors and increasing urban development in the city and urban sprawl around the river. This expansion occurs both formally and informally, depending on the neighbourhoods. Over time, these processes of expansion in the northern part of the river may also have been affected by displacement due to armed political conflict and rural poverty.

Balancing loops, denoted by the letter "B," seek to achieve a goal or equilibrium by balancing the forces of the system. In the case of Medellín, the side effects of urban development act as balancing forces, which at some point end up limiting development around the river. One of the side effects is the emergence of informal settlements, which present particular and differentiated dynamics from those that formal settlements may present, specifically in terms of investment. Loop B1 shows how informal settlements require more public investment (e.g., utility networks) and how this public investment, focused on regulating and reducing informal development and expansion, decreases informal settlements around the river. On the other hand, loop R3 explains how informal settlements can increase through private sector investment. Due to a lack of legal certainty and regulations, informal settlements limit private capital investment, which decreases overall investment; declining investment in the sector increases the expansion of informal settlements.

Regarding the secondary effects of urban expansion around the Medellín River, there are two drivers of declining quality in ecosystem services on the river: the discharge of wastewater into the river and its tributaries (B2) and the erosion of the riverbanks (B3). Both decrease the quality of ecosystem services, which decreases the attractiveness and appreciation of neighbourhoods around the river (for example, due to bad odours and biodiversity loss).

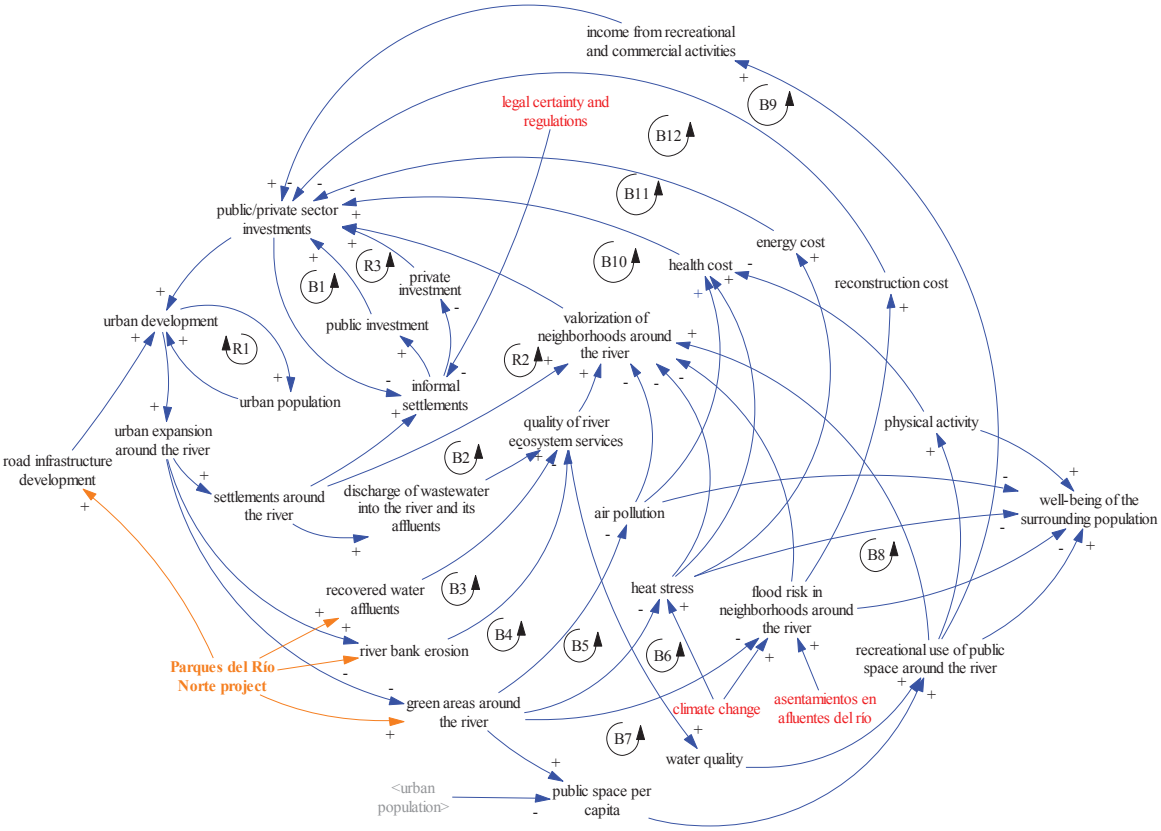
These elements negatively affect investment in these areas and, consequently, urban development around the river. One effect of a decrease in the quality of ecosystem services is a reduction in the water quality of the Medellín River (B8). This effect can lead to the river being perceived as dirty and generating a bad smell for the inhabitants and those who use the existing public areas, decreasing the recreational use of public space around the river. In this way, the valorization of the area is also reduced, which decreases investment and urban development, reducing urban expansion around the river.

With urban expansion around the river comes increased land occupation for settlements, which decreases the green areas around the river. This expansion increases air pollution (B4), as less carbon dioxide (CO_2) and particulate pollutants are captured; worsens the heat island effect (B5), as there are fewer trees to offer shade; increases the risk of neighbourhood flooding around the river (B6), as there is less rainwater retention; and leads to a decrease in green space per capita (B7). The reduction in the recreational use of public space around the river is also accompanied by a decrease in income from recreational and commercial activities (B9), which reduces investment in the sector and its development. Importantly, all these issues are worsened by several external factors (red variables in the CLD). One factor is climate change, which increases temperature and generates more variable precipitation. Higher temperatures, for instance, can increase the heat island effect in the area, while changes in precipitation can increase the risk of floods. The other external factor is the settlements along the effluent of the Medellín River, which affect the ability of the tributaries and their surroundings to retain rainwater, increasing the flow of water that reaches the river and the risk of flooding in the surrounding areas. All these side effects diminish the attractiveness of the neighbourhoods around the river and their valorization, consequently decreasing investment in the area and urban development around the river.

Urban sprawl along the Medellín River also incurs costs, in addition to reducing the valorization of the area. For example, both air pollution and an increase in the heat effect, along with a lack of physical activity among residents associated with the reduction of green public spaces (B10), can increase the associated health costs for the inhabitants of the surrounding areas. Energy is another associated cost (B11), which increases with the heat island effect, as surrounding buildings and houses potentially require increased use of fans. Finally, the risk of flooding generates reconstruction costs due to damage to infrastructure (B12). All of these additional costs diminish the investment potential of both the public and private sectors. On the other hand, prevention and reconstruction actions will require more investment from the public sector, which could reduce investment in other projects that could bring greater development opportunities to the neighbourhoods located around the river.

The Parques del Río Norte project (the orange variable in the CLD) has several positive effects on the dynamics described above. This project is projected to avoid many of the side effects of urban sprawl and support climate adaptation. Among the impacts of the project are the recovery of river tributaries, reduced erosion of the river banks, an increase in green areas around the river, and the restoration of nature. All of these impacts seek to improve the quality of ecosystem services and, therefore, the attractiveness of the neighbourhoods located around the river. In addition, air pollution and the heat island effect are expected to decrease, the risk of flooding will be lower, and public space around the river will increase.

Figure 2. A CLD depicting the main dynamics affecting urban development in Medellín in neighbourhoods near the river



Source: Authors.

2.2 Spatially Explicit Analysis

The spatially explicit analysis performed for this assessment is based on the set of Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) models. These models, developed by the Natural Capital Project, use land-use/land cover (LULC) maps as input and quantify a wide range of ecosystem services.[5]

For this assessment, we downloaded the land cover of the study area in 2019 from the Copernicus Global Land Service (n.d.) (Figure 3), showing the LULC business-as-usual (BAU) scenario. It should be noted that the Medellín River was added to the map from Geofabrik (n.d.). A second LULC map was created, this time with the northern part of a 30-ha park along the banks of the Medellín River, of which 60% (i.e., 18 ha) are green areas, as shown in Figure 4.

[5] For a description of InVEST models, see https://naturalcapitalproject.stanford.edu/software/invest

Figure 3. LULC BAU

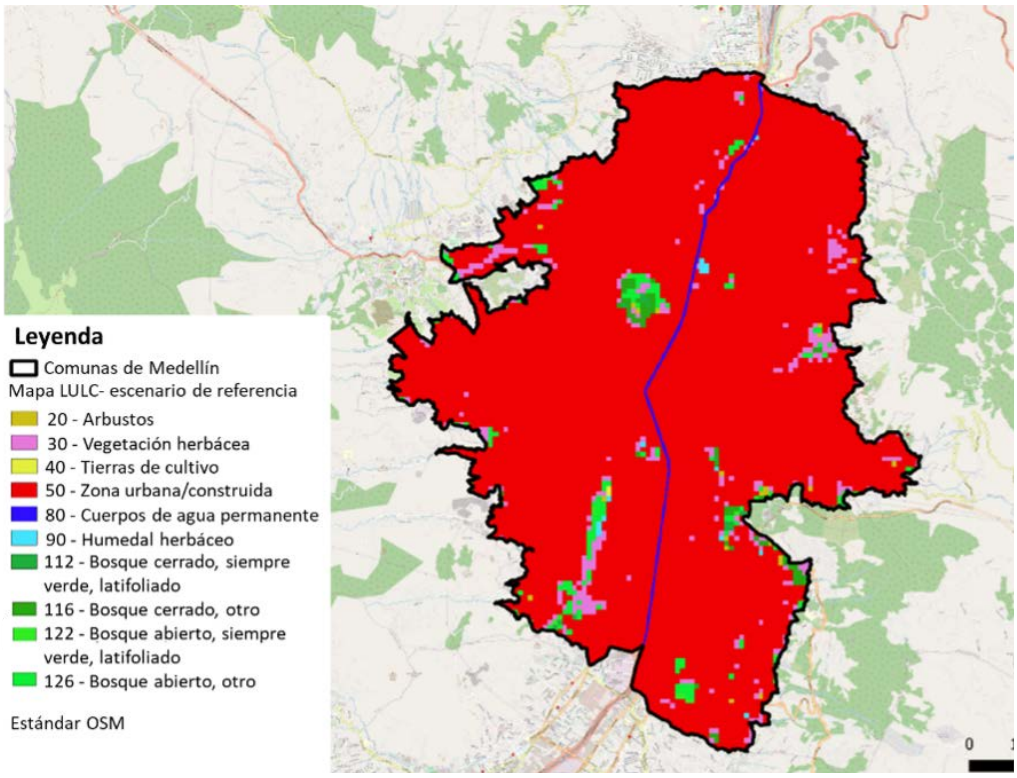
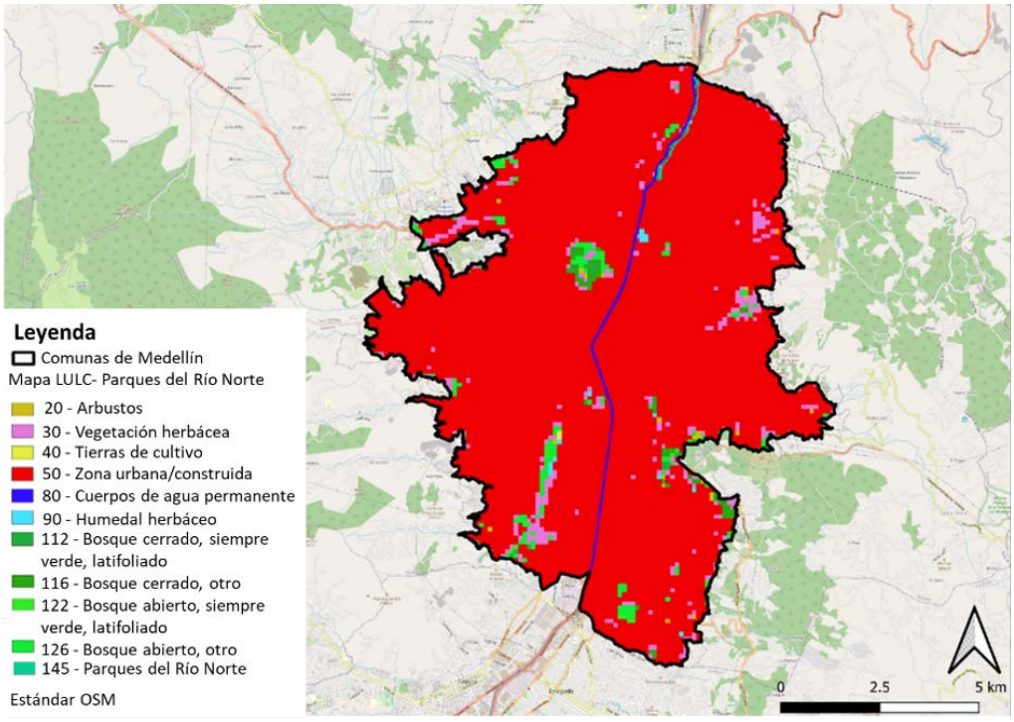


Figure 4. LULC Parques del Río Norte



2.3 Integrated CBA

A spreadsheet model (Excel) was developed for the evaluation of the required investment, avoided costs, and aggregate benefits related to project implementation. The approach used for the calculation of all model parameters is described in Table 1, and the indicators are listed below:

- Investment and costs
  - Construction
  - Operation and maintenance (O&M)
- Additional benefits
  - Discretionary spending from employment creation
  - Revenue from park operations
  - Retail revenue
  - Increased property value
  - Health benefits from physical activity
- Avoided costs
  - Carbon emissions
  - Energy expenditure
  - Flood damage
  - Air pollution

Table 1. Externalities quantification methodology for Parques del Río Norte

Indicator	Assumptions
Investment and costs	
Construction cost	The capital cost for the construction of the park is calculated based on the construction rate (1,000 m^2/year) and the construction cost per m^2. A plan for the construction of the park has been established up until 2026. The construction schedule is assumed and validated with the SIF team to 2027. The construction schedule is as follows to complete 300,000 m^2 (Alcaldía del Medellín, 2023). **Table 2.** Construction schedule Source: Alcaldía del Medellín, 2023.

Table 2. Construction schedule

Año	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Construction rate (1,000 m^2/year)	15	30	25	30	35	35	35	35	35	25

Indicator	Assumptions
	The cost of capital per m^2 is based on the total capital costs of the Mayor's Office of Medellín for Parques del Río's downtown area, which is already built (Alcaldía del Medellín, 2023). These costs include underground road development that would pass under the park. After dividing the total capital costs by the square metres mentioned, the cost per m^2 is COP 9,546,518. Capital costs for Parques del Río Norte include the following items: • Work contract (including underground) • Audit contract • Supervisory support contract • Silvicultural interventions • Acquisition of land • Technical, legal, and financial structuring • Studies and designs of the park • Relocation of electrical networks
Operation and maintenance	O&M costs for the park are based on the total area of the built park and the average expected maintenance costs per m^2 per year. O&M costs are based on annual O&M costs for Parques del Río Centro divided by the park area, which is 75,000 m^2. The O&M cost per m^2 is COP 96,533/year/m^2. O&M costs for Parques del Río Norte include the following items: • Underground maintenance • Maintenance of public space • Location maintenance • Substation maintenance • Forestry maintenance • Consumables • Appropriation activities and campaigns • Administrative costs • Staff for park management • Private security personnel
Added benefits	
Discretionary spending from employment creation	This indicator is based on the employment created by the project and the portion of income spent in the local economy. The total employment created by the park is multiplied by both the average annual salary in Medellín and the proportion of discretionary spending. For this assessment, the annual salary is COP 15,793,416/person/year (Indeed, 2023), and the discretionary spending in Medellín is 22.1%, based on Numbeo (2023). Construction displacement is a function of m^2 built and average employment per m^2 and results in 0.00373 jobs per m^2. The O&M employment factor (jobs per m^2) was estimated based on the average employment of the Parques del Río Centro area that is already in operation. The value corresponds to 0.00128 jobs per m^2 (Alcaldía del Medellín, 2023).

Indicator	Assumptions
Revenue from park operations	Revenue from the sale of commercial premises and parking fees is considered revenue resulting from the operation of the park. Rental income is based on the number of premises and the lease value of the premises. Revenue from parking fees is based on the number of visitors and the average parking fee per day. According to data received by the SIF (SIF, personal communication, 2023), the area is expected to have seven commercial premises within a 70,000-m^2 area of the park, as well as 180 parking spaces for cars and 60 parking spaces for motorcycles in the same area. These numbers can be used to extrapolate the potential for the entire 300,000-m^2 Parques del Río Norte. To monetize this externality, the rental value for commercial premises of 45 m^2 can be calculated at COP 3.9 million per month, a parking value for cars can bring COP 20,000/vehicle/day, and motorcycles can bring COP 10,000/motorcycle/day, based on data validated by the SIF (SIF, personal communication, 2023).
Retail revenue	In addition to the revenue generated within the park, shops in the vicinity of the park also benefit from visitors. Visitors will be encouraged to wander around the area, which leads to increased spending. Retail revenue is based on the number of visitors walking, average retail spending per year, and an increase in walkability spending of 42.2% (Rabl & Nazelle, 2012).
Increased property value	Property owners are supposed to benefit from the construction of North River Parks, as green spaces increase the value of the property. A total of 2,683 properties were considered according to the spatial analysis for the 300,000 m^2 of the park and an area of direct influence of 250 m on each side of the park. The number of buildings found within the buffer zone was estimated from the shapefiles of the buildings obtained from Geofabrik (n.d.). Property values are calculated based on the number of buildings mentioned, an average area of 100 m^2 per building, and a value per square metre of COP 4.5 million. The increase in this value is estimated by multiplying the value of the mentioned properties and an average increase in property value resulting from the establishment of green spaces of 15% (Centre for Green Mobility, 2015).
Health benefits of physical activity	The benefits of physical activity are calculated using the World Health Organization's [WHO's] Health Economic Assessment Tool (HEAT) methodology (WHO, 2017). The kilometres walked and cycled in the park are used to estimate the additional time spent being physically active. Increased physical activity translates into reduced mortality, which translates into economic value using the value of a statistical life (WHO, 2017). The value of statistical life in Colombia is COP 2.88 billion per person (Mardones & Riquelme, 2018). The effects of physical activity are calculated using the number of users in Parques del Río Norte. Users are divided into pedestrians and cyclists. According to information provided by the Mayor's Office of Medellín, the communes directly impacted are 2, 4, and 5, with a total of 1,074,319 inhabitants (Alcaldía del Medellín, 2023).

Indicator	Assumptions
	Additionally, a percentage of the users of the subway station called Acevedo are expected to use the park. The maximum number of users of this station per day to 2022 was 50,532 people. It is assumed that 4% of the daily users of Acevedo will use Parques del Río Norte, resulting in 2,021 people/day. In the same way, it is assumed that 4% of the total inhabitants of communes 2, 4 and 5 will be using the park infrastructure daily, which results in 42,973 people/day (C40 CFF, personal communication, 2023). Therefore, the total number of pedestrians per day, once the 300,000-m^2 section is built, is 44,994. As for cyclists, in 2021, an average of 9,318 bicycle trips were made per day in communes 2 and 4. It is assumed that 50% of these cyclists will pass through Parques del Río Norte when crossing the area instead of using the existing road infrastructure. This gives us a total number of cyclists per day of 4,659.
Avoided costs	
Carbon emissions	The calculation of the avoided costs of carbon emissions is based on the social cost of carbon and the carbon storage results from the InVEST carbon model. The total amount of carbon stored is converted into CO_2 sequestered by the park, which is multiplied by an average value per kg of CO_2 sequestered. The value per kg of CO_2 captured is equivalent to the social cost of carbon. This value is COP 139.50/kg of CO_2 (Nordhaus, 2017).
Energy expenditure	The green space introduced by the park reduces the average urban temperature in its proximity. It is supposed to be a 250-m shock absorber. The drop in temperature reduces the total electricity consumption of the surrounding buildings proportionally to the temperature reduction. Energy consumption per building (family home) per month is 157 MWh/month (Unidad de Planeación Minero Energética, 2019). The average cost per kWh in Colombia is COP 287.71 (Vélez-Robledo, 2022).
Flood damage	The installation of the park increases urban water retention capacity. It serves as a buffer that absorbs some of the stormwater, reducing runoff and related flood risk. Flood risk reduction is estimated using spatial models. This reduction is used to calculate reductions in flood damage resulting from rainfall and river growth. Avoided damages are based on the reduction of affected buildings and the average cost of repairs per affected home or building. The reduction in the number of affected buildings in the buffer is given by the spatial model (2,683 buildings) multiplied by the complement of the percentage increase in runoff retention (100%-57.68%=42.32%). The result of this value is multiplied by the flood frequency per year (assumed in two events per year) and finally multiplied by the unit cost of repairing property damage, which is COP 30 million according to values estimated by the Economic Commission for Latin America and the Caribbean (2012).

Indicator	Assumptions
Air pollution	Planting trees in the park will lead to a higher amount of captured particulate matter ($PM_{2.5}$)[6] emissions compared to the baseline. The reduction in $PM_{2.5}$ emissions is estimated based on the number of mature trees (4-year-old trees) and the average capture of $PM_{2.5}$ per tree. The resulting reduction in $PM_{2.5}$ emissions and an average health cost per kg of pollutants are used to estimate the avoided costs of air pollution. According to data provided by the Mayor's Office of Medellín, the additional trees per m^2 have a value of 0.007 (Alcaldía del Medellín, 2023). This calculation is derived from data provided on the number of existing trees (645) in a study area of 70,000 m^2 and the number of trees to be cut down and replaced (274). This results in 487 new trees. The capture of $PM_{2.5}$ per tree per year is 9.5 grams. Finally, the health cost per kg of $PM_{2.5}$ is COP 550,582.92 (CE Delft et al., 2011; Zhang et al., 2021).

Source: Authors.

Our study does not include a detailed analysis of the tributary streams of the Medellín River involved in the Parques del Río Norte project. The present study focuses solely on the aforementioned buffer zone. For more specific results on the tributaries of the river and their effects on flooding and soil permeability, a detailed study of these tributaries is required.

Additionally, the results of this study are presented under the assumption that Parques del Río Norte guarantees a certain volume of pedestrians, cyclists, and general users of the park.

2.4 Scenarios

The results of the simulation are compared to a scenario in which no park is built. Figure 5 shows the current situation, and Figure 6 represents the simulation of the construction of Parques del Río Norte.

Figure 5. Current situation of Medellín along the river, looking from south to north

Source: EDU, 2023.

[6] Particulate matter measuring equal to or less than 2.5 μm in diameter.

Figure 6. Rendering of Medellín along the river after the implementation of Parques del Río Norte, including Parques del Río Centro, looking from south to north

Source: EDU, 2023.

2.5 Climate Data and Scenarios

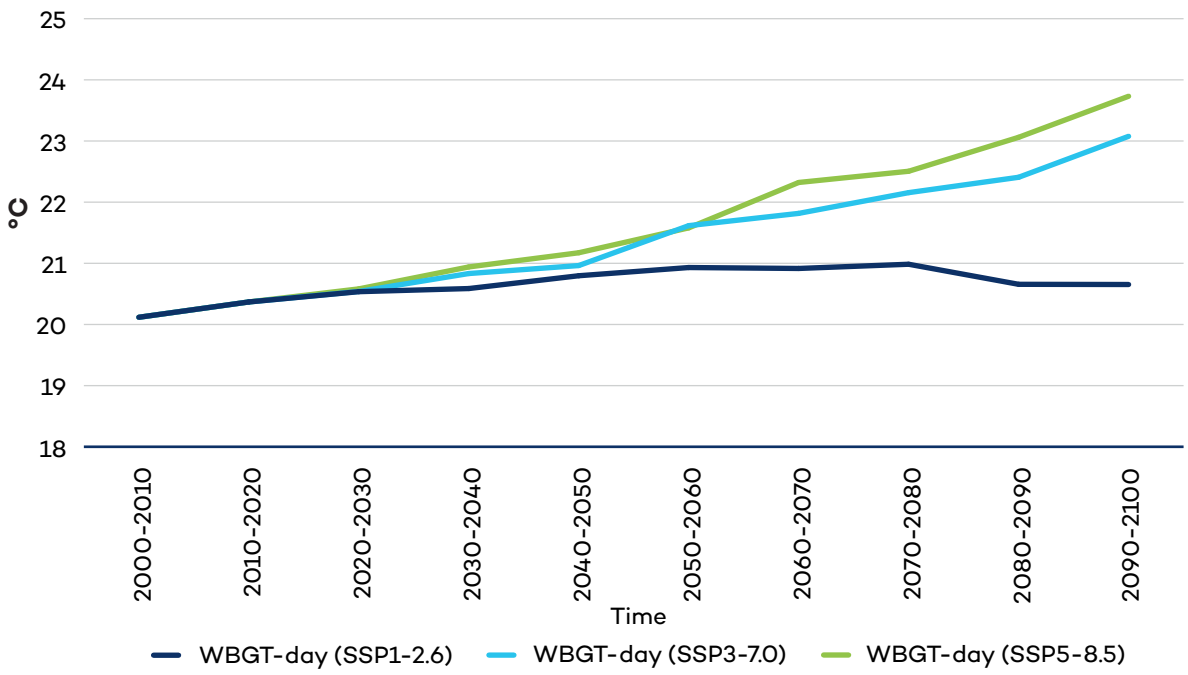
The climate data considered in this analysis are based on Shared Socioeconomic Pathway (SSP) scenarios. SSPs define different baselines that could occur based on various underlying factors, such as population, technological, and economic growth, which can lead to different future greenhouse gas emissions and warming outcomes (Carbon Brief, 2018). SSPs are based on diverse narratives that describe broad socio-economic trends that can shape future societies. Specifically, we consider the following SSPs, as described by Meinshausen et al. (2020):

- SSP 1–2.6, or the "2°C scenario," roughly corresponds to the Representative Concentration Pathway 2.6 scenario, where global temperatures are expected to increase by 2°C by 2100.
- SSP 3–7.0 is a medium-high baseline scenario.
- SSP 5–8.5 corresponds to a high-reference scenario in which fossil fuels remain in high use throughout the 21st century.

Figure 7 shows the average monthly temperature (°C) in Medellín from 2000 to 2100 in the three different SSP scenarios. The trends are similar in the three SSP scenarios up to 2050, after which they fork. In SSP 1–2.6, the monthly temperature remains constant over the decades between 2050 and 2100. In the SSP 3–7.0 scenario, the average monthly temperature increases by about 2°C compared to 2050, or 3°C compared to 2000, while in the SSP 5–8.5 scenario, temperatures increase by almost 1°C compared to the SSP 3–7.0 scenario. The SSP 5–8.5 scenario projects the largest temperature increase, followed by the SSP 3–7.0 scenario.

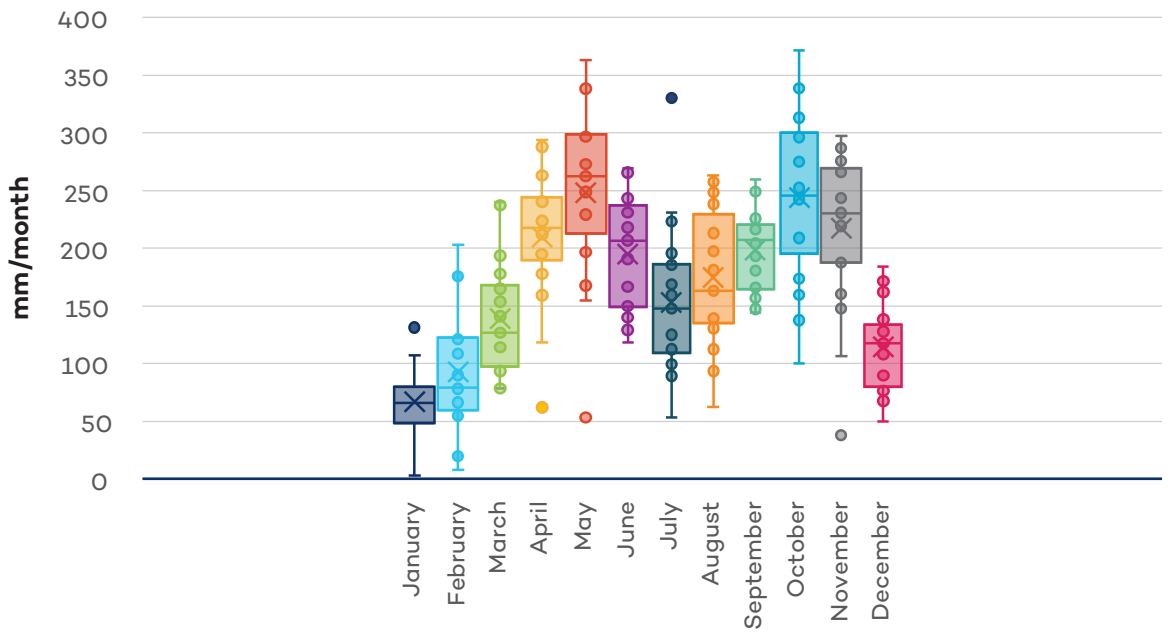
Figure 8 shows the average precipitation (mm/month) in Medellín for the period 2000–2020, while Figure 9 shows the same variables, but for the period 2040–2060 under scenario SSP 5–8.5. The results suggest that from 2000 to 2020, most months received an equal amount of rainfall, with January and December being the main exceptions. This trend is not expected to change in the estimated average precipitation for the period 2040–2060. It can be argued that the problem of flooding, exacerbated by unsustainable urban planning, is already present and will not change in the future. Therefore, increasing resilience through the expansion of green urban areas along the Medellín River is already relevant and important today, not only in the future.

Figure 7. Average monthly temperature in Medellín (2000–2100)



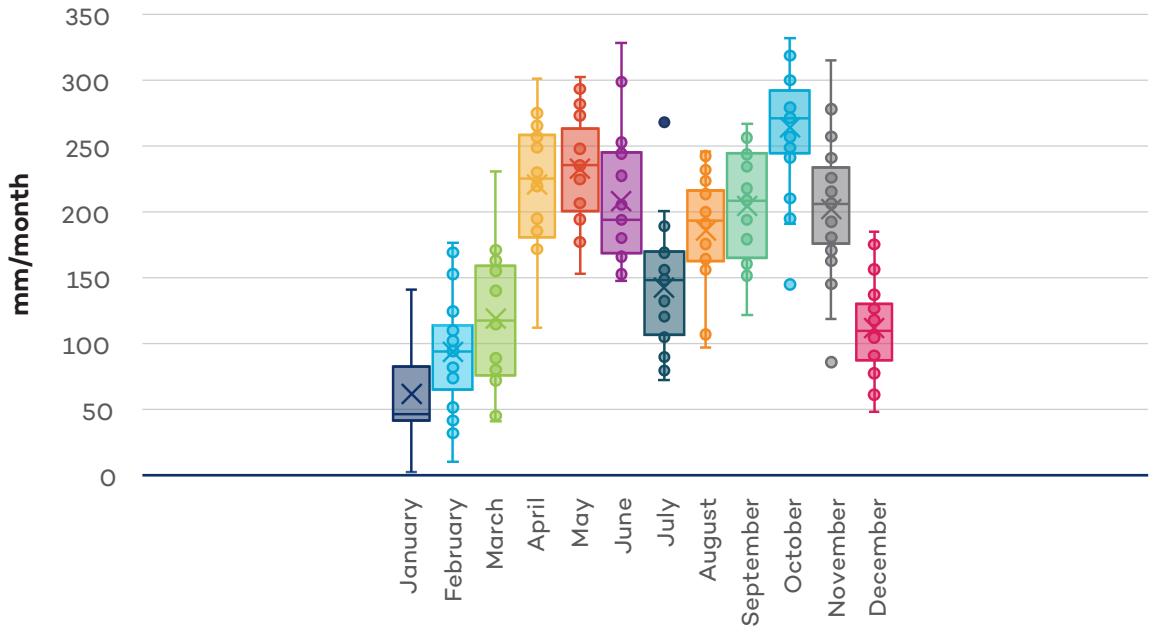
Source: Copernicus, 2023.

Figure 8. Average rainfall in Medellín (2000–2020)



Source: Copernicus, 2023.

Figure 9. Average rainfall in Medellín (2040–2060)



Source: Copernicus, 2023.

3.0 Results

3.1 Highlights

Investment in Parques del Río Norte is not only socially and environmentally beneficial but also economically attractive. According to the economic analysis, for every Colombian peso invested in the Parques del Río Norte project, a return of COP 1.67 is expected. All values presented in the results section are discounted at an annual rate of 3.5% (social discount rate; see Lowe, 2008).

One of the key benefits of the park project is its ability to effectively reduce flood and erosion risks around the Medellín River. By increasing water retention by 57.68% in the buffer area, the project helps prevent flood damage to buildings, infrastructure, which is worth USD 312.40 billion (COP 1,312.08 billion).

In addition to reducing flood risk, the project also has a significant impact on the availability of green spaces in the densely populated city. The project increases the area of green space per inhabitant from 1.32 m^2 to 1.44 m^2, improving habitat quality in the buffer area by 86.43% and increasing carbon storage by 103.75% in the same area.

The park is expected to revitalize neighbourhoods near the riverbanks by increasing property values by USD 35.45 billion (COP 148.88 billion) and increasing retail revenues by USD 318.29 billion (COP 1,336.83 billion). In addition, people living in 2,683 buildings around the new park will directly benefit from the temperature reduction by decreasing energy expenditure by USD 0.02 billion (COP 0.07 billion), decreasing air pollution by avoiding USD 0.03 billion (COP 0.13 billion) in health costs, and reducing by USD 0.51 billion (COP 2.15 billion) carbon emissions through tree planting. In addition, the park will create attractive walking and cycling routes, generating physical activity benefits worth USD 495.36 billion (COP 2,080.50 billion) and new spaces that unite communities and foster environmental awareness.

Overall, the park project offers a number of economic, environmental, and social benefits, making it a very attractive investment for both the public and private sectors. By choosing to invest in NBI solutions like the park project, cities can work toward sustainable development while improving the quality of life for their citizens.

3.2 Integrated Cost-Benefit Analysis

The results of the integrated CBA are presented in Table 3. The analysis shows investment, additional benefits, avoided costs, and total net benefits, both discounted and undiscounted, for the period from 2023 to 2053 (30 years). The results show that the project is financially viable, generating COP 2.38 benefits for each Colombian peso (COP) invested and net benefits of COP 5,156.53 billion in undiscounted values.

When the values are discounted, the result is a cost-benefit ratio of 1.67, generating net profits of COP 1,995.27 billion (USD 475.06 billion).

Table 3. Integrated CBA (values are cumulative between 2023 and 2053)

	Values without discount in billions of COP[7]	Discounted values in billions of COP (3.5%)	Discounted values in billions of USD[8]
Total costs	**3,730.52**	**2,984.50**	**710.60**
Construction	3,001.21	2,575.28	613.16
O&M	729.31	409.23	97.43
Total added benefits	**6,545.74**	**3,665.35**	**872.70**
Discretionary spending from employment creation	37.66	22.27	5.30
Revenue from park operations	136.99	76.87	18.30
Retail revenue	2,442.48	1,336.83	318.29
Increased property value	181.10	148.88	35.45
Health benefits of physical activity	3,747.50	2,080.50	495.36
Total avoided costs	**2,341.31**	**1,314.43**	**312.96**
Carbon emissions	2.59	2.15	0.51
Energy expenditure	0.12	0.07	0.02
Flood damage	2,338.35	1,312.08	312.40
Air pollution	0.24	0.13	0.03
Net profit	**5,156.53**	**1,995.27**	**475.06**
Benefit-to-cost ratio	**2.38**	**1.67**	**1.67**

Source: Authors.

[7] For this evaluation, billions are used according to the American system as 10e9 (1,000,000,000), which would correspond to a thousand million for Colombia.

[8] The exchange rate used is 4,200 COP/USD.

As for the costs of the project, the capital costs for the construction of Parques del Río Norte amount to USD 613.16 billion (COP 2,575.28 billion) for the 30 ha of the park. The cumulative O&M costs for 30 years of operation, progressively, considering the costs until it is fully built, are USD 97.43 billion (COP 409.23 billion).

The implementation of the project brings added benefits valued at USD 872.70 billion (COP 3,665.35 billion). Most of these benefits come from physical activity, which is valued at USD 495.36 billion (COP 2,080.50 billion), generated by approximately 44,994 pedestrians and 4,656 cyclists. Retail revenues have a cumulative discounted value of USD 318.29 billion (COP 1,336.83 billion) as a result of increased spending in and around the park due to the increased number of pedestrians and cyclists in the area. The property value of the area around the park is expected to increase by 15%, corresponding to cumulative benefits of USD 35.45 billion (COP 148.88 billion).

Two benefits that are generated directly from the construction and operation of the park are (i) the generation of income from employment and (ii) income from commercial premises and parking spaces within the park. The discretionary spending derived from the employment creation and labour income connected to the construction and operation of the park amounts to USD 5.30 billion (COP 22.27 billion) by 2053. In the case of revenues from commercial stores and parking lots, the cumulative benefit amounts to USD 18.30 billion (COP 76.87 billion) by 2053.

The spatial analysis for Parques del Río Norte provides information on indicators such as carbon storage, habitat quality, runoff retention, and average temperature.

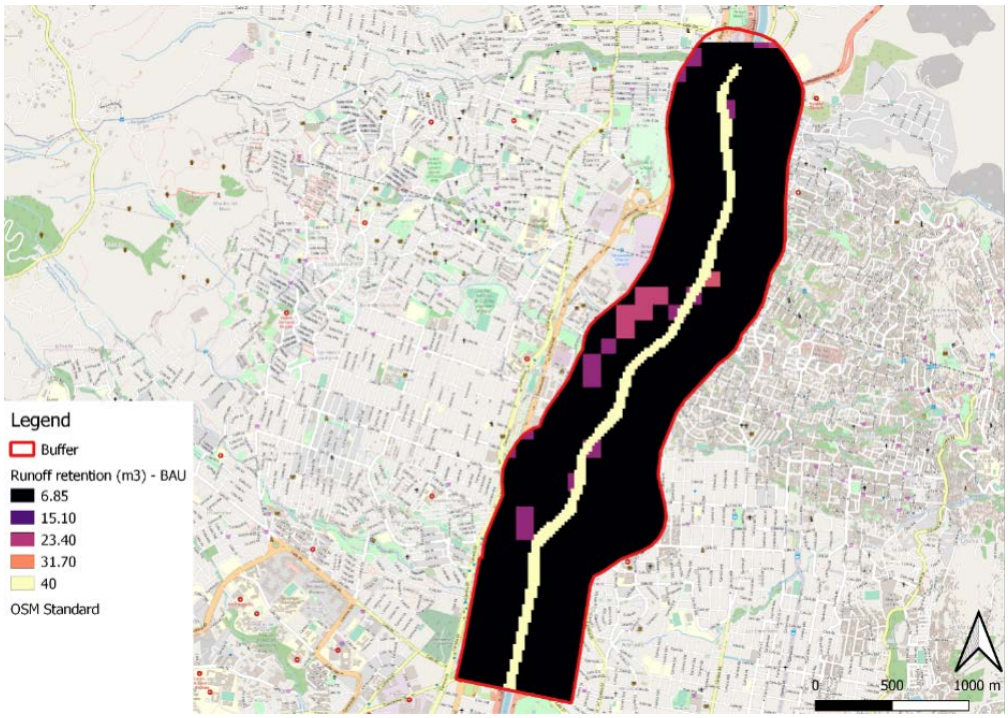
Table 4. Summary of the results of the spatial analysis in the buffer zone

LULC scenario	Carbon storage (tonnes)	Average habitat quality	Runoff retention (m^3)	Average temperature value (°C), reference air temperature 30.5°C
Baseline	1,343	0.018	95,948	34.565
Parques del Río Norte (30 ha)	2,737	0.033	151,293	34.446
Difference	103.75%	86.43%	57.68%	-0.34%

Source: Authors.

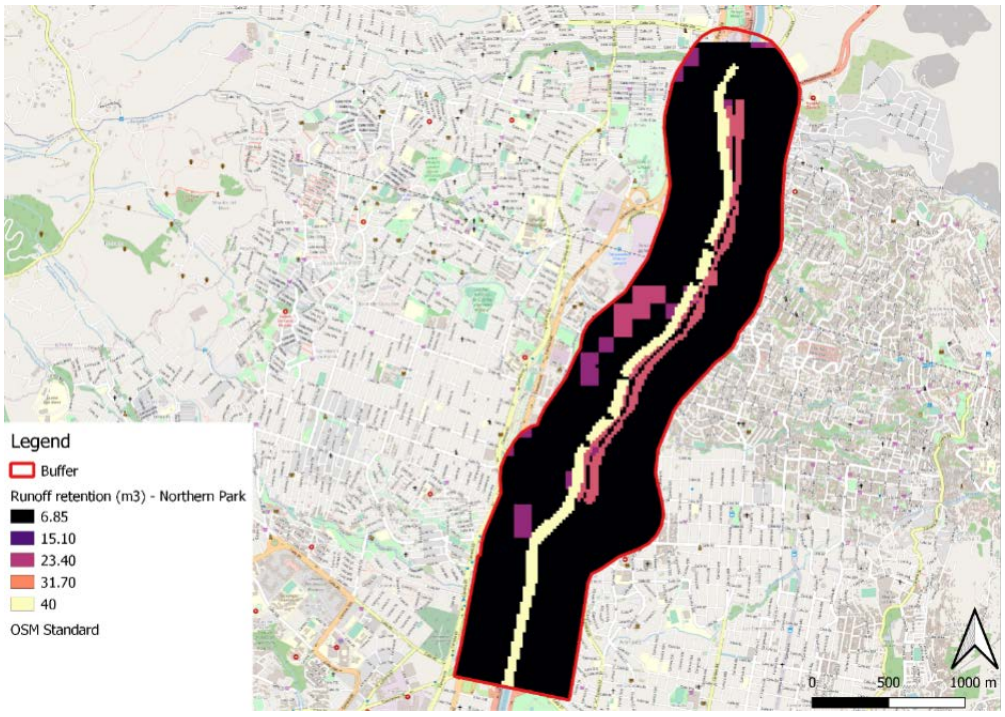
The largest avoided cost arises from avoided flood damage, with a cumulative value of USD 312.40 billion (COP 1,312.08 billion). This avoided cost is the result of an increase in runoff retention of 57.68% after project implementation in the buffer zone (see Figure 10 and Figure 11).

Figure 10. Runoff retention values (m^3) before project implementation – Buffer area



Source: Authors.

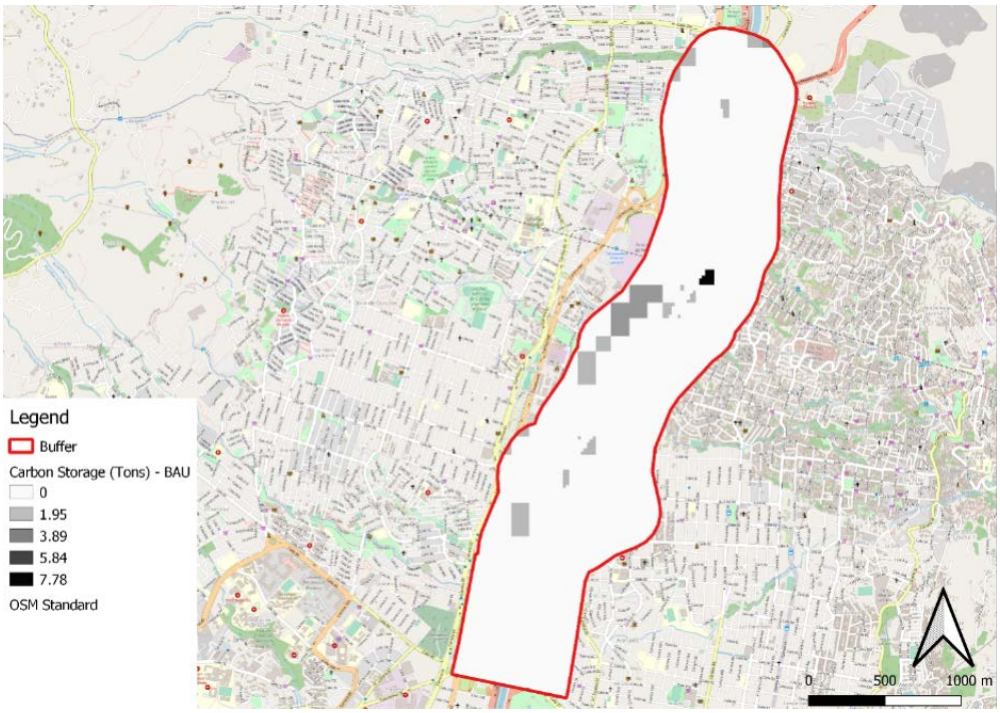
Figure 11. Runoff retention values (m3) after project implementation – Buffer area



Source: Authors.

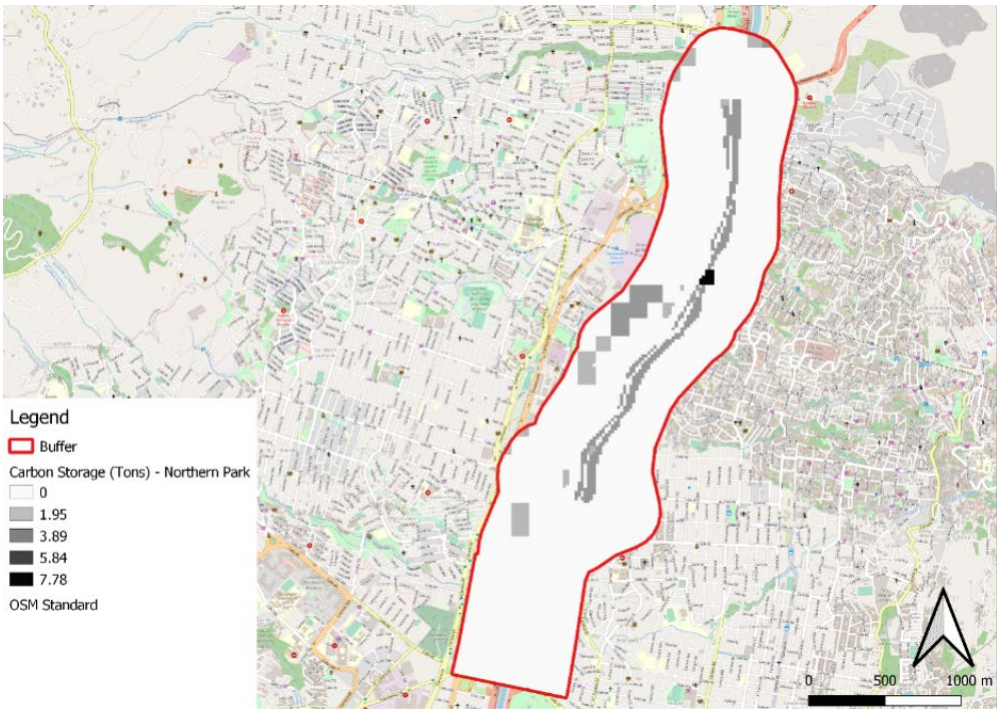
The avoided cost of emissions results in USD 0.51 billion (COP 2.15 billion) due to an increase in carbon storage of 103.75% (see Figure 12 and Figure 13).

Figure 12. Carbon model results before project implementation – Buffer area



Source: Authors.

Figure 13. Carbon model results after project implementation – Buffer area

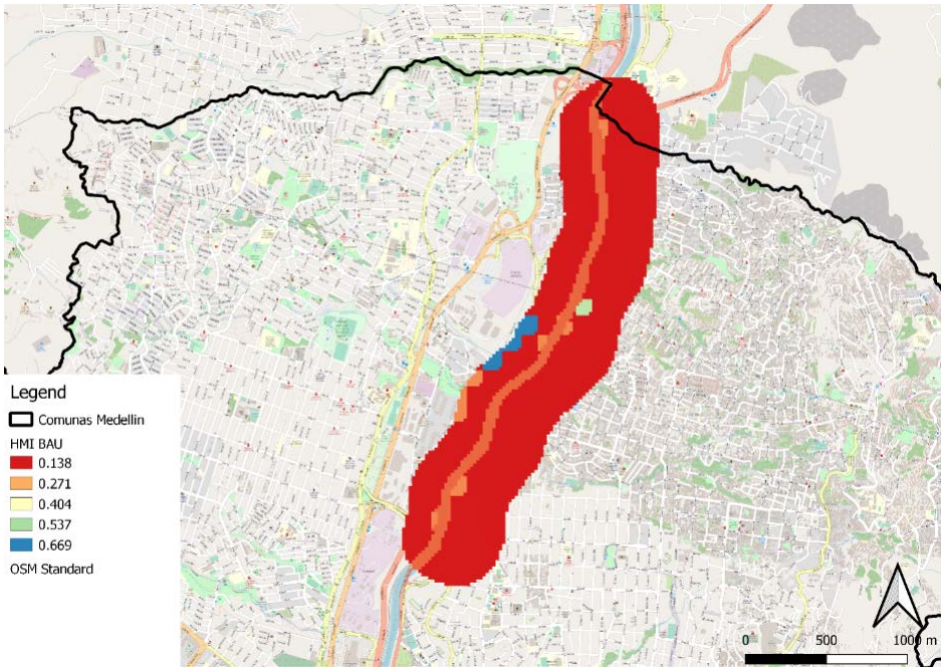


Source: Authors.

Reduced $PM_{2.5}$ pollution results in an avoided health cost of USD 0.03 billion (COP 0.13 billion). This value depends mainly on the number of trees that are planted throughout the park and their contributions to air purification.

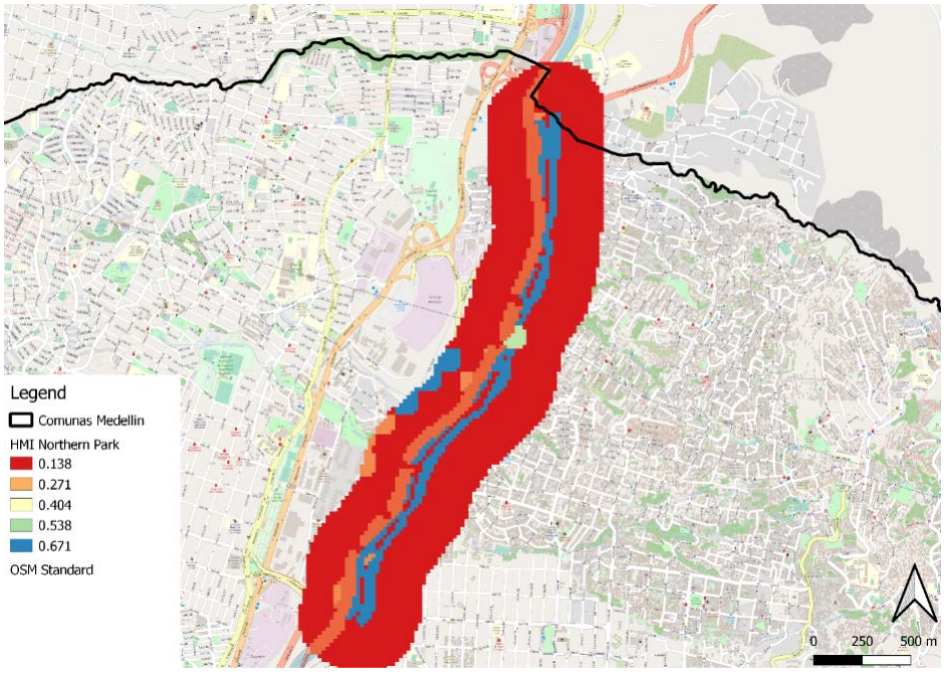
The 0.34% decrease in the heat mitigation index (see Figure 14 and Figure 15) results in avoided energy costs of USD 0.02 billion (COP 0.07 billion). It is important to clarify that the average temperature is calculated within a 250-m buffer area of the park and with a reference air temperature of 30.5°C.

Figure 14. Heat mitigation index prior to project implementation – Buffer area



Source: Authors.

Figure 15. Heat mitigation index after project implementation – Buffer area



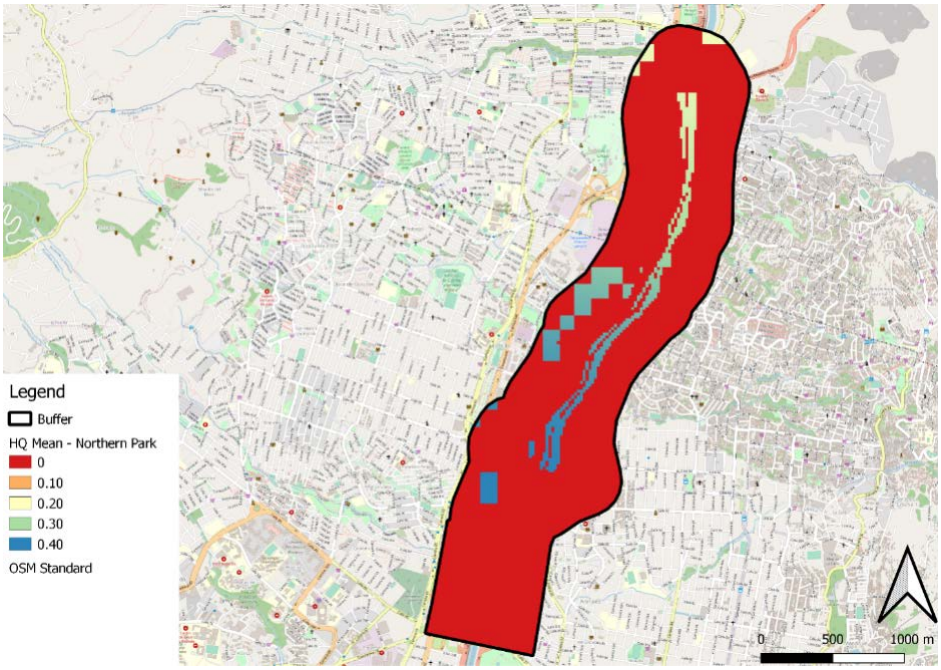
Source: Authors.

Finally, the quality of the habitat in the buffer zone will improve by 86.43% after the implementation of Parques del Río Norte (see Figure 16 and Figure 17). This means that there is an increase in biodiversity in the area, which indicates that there will be an extension of the habitat and vegetation types in the landscape.

Figure 16. Habitat quality scores before project implementation – Buffer Area

Source: Authors.

Figure 17. Habitat quality scores after project implementation – Buffer area



Source: Authors.

4.0 Conclusions and Recommendations

Our analysis demonstrates that Parques del Río Norte is an economically viable investment that carries a wide range of social, environmental, and economic benefits. Over a period of 30 years, the modelling shows that it will generate USD 1.67 in benefits for every USD invested.

To avoid flood damage that negatively impacts human health and surrounding communities, Medellín should invest in NBI along the banks of the Medellín River.

The park's implementation is crucial for reducing flooding and its adverse impacts on residents and the environment. By acting as a buffer between the river and surrounding areas, the park reduces impervious surfaces along the riverbanks. Green spaces' ability to absorb excess runoff allows them to function as natural sponges. Opting for the park as a flood mitigation strategy proves to be more sustainable and economically viable than traditional grey infrastructure, such as maintaining sewage and water management systems and river dredging.

By investing in Parques del Río Norte, Medellín could serve as a powerful example of the potential of NBI to combat urbanization challenges in densely populated and rapidly expanding cities.

The park's potential to benefit the community while mitigating many of the city's urbanization and environmental problems provides valuable insights for future planning and financing strategies. It shows that cities facing similar challenges can enhance resilience to floods and heat islands while improving the quality of life for residents by embracing NBI and green parks.

Continuous maintenance is crucial to ensuring that the park delivers its full benefits.

Routine maintenance will be indispensable to ensure that the park functions optimally and reduces floods and erosion. This maintenance is particularly critical in the first few years of the project, as trees and plants within the park mature. In addition, many co-benefits of Parques del Río Norte, such as the health benefits from cycling and increased retail revenues, depend on keeping the green space attractive and safe. The continuous maintenance of the park brings direct benefits to the local communities by creating job opportunities, fostering economic growth, and contributing to the well-being of residents.

Ensuring Medellín can continue to face climate change challenges will require more than just investing in parks and NBI.

Scaling up natural infrastructure can help Medellín to address flooding and improve the quality of life for residents. Nevertheless, additional measures, such as flood-proofing critical infrastructure and urban planning that avoids construction in flood-prone areas, are essential to ensuring safe and sustainable living conditions.

The results of the integrated valuation clearly support the use of NBI as a strategy for addressing flood risks, heat stress, and pollution in the city of Medellín. These findings are critical to presenting a compelling case for implementing NBI and informing the financing strategies necessary to carry out projects of this nature. Parques del Río Norte is presented as a comprehensive solution that provides long-term benefits in various aspects of urban life and is a valuable investment for the well-being and sustainable development of the city.

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Appendix A. Nature-Based Solutions or Nature-Based Infrastructure?

The International Union for Conservation of Nature (IUCN) defines nature-based solutions (NbS) as "actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature" (Cohen-Shacham et al., 2016).

Nature-based infrastructure (NBI) is a subset of NbS with a focus on nature-provided infrastructure services. The NBI Global Resource Center considers the concept of NBI to include the following:

- natural ecosystems or functional landscapes that can be conserved, rehabilitated and maintained to enhance capacities and reduce the need for grey infrastructure and
- hybrid infrastructure that combines engineered and nature-based solutions.

The proposed interventions in Medellín were evaluated as NBI—that is, we consider that Parques del Río Norte is an investment in infrastructure that seeks to address problems related to flooding, river erosion, air pollution, and urban heat as an alternative to exclusively gray infrastructure. It should be recalled that many organizations, including C40 CFF, the World Wildlife Fund, the Global Infrastructure Basel Foundation, and the European Investment Bank, refer to these projects as NbS.

NATURE-BASED INFRASTRUCTURE
GLOBAL RESOURCE CENTRE