NATURE-BASED INFRASTRUCTURE
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Climate-Resilient Infrastructure for Urban Flood Risk Management in San Salvador de Jujuy, Argentina

AN ECONOMIC VALUATION OF ALVARADO CANAL CONDITIONING AND READAPTATION

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.

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Climate-Resilient Infrastructure for Urban Flood Risk Management in San Salvador de Jujuy, Argentina

June 2024

Written by Marco Guzzetti, Nathalia Niño, and Ronja Bechauf

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Author contributions

All authors are listed in alphabetical order. Marco Guzzetti carried out the climate data analysis and prepared the corresponding section of the report. Nathalia Niño developed the Excel model based on systems thinking and integrated cost-benefit analysis, coordinated communications with the World Bank, and led the drafting of the report. Ronja Bechauf provided support for various sections of the report.

Executive Summary

Context

San Salvador de Jujuy, located in northwest Argentina—specifically the San Pedrito neighbourhood—experiences recurrent flooding due to insufficient stormwater infrastructure exacerbated by heavy rainfall events associated with climate change. The Alvarado Canal, the primary drainage channel in San Pedrito, is in a deteriorated state and obstructed by solid waste, amplifying flooding challenges and posing health hazards to residents. The absence of essential services in informal settlements, coupled with the canal's impacts on mobility and limited green spaces, adversely affects the residents' overall well-being.

In response to these issues, the Municipality of Jujuy is collaborating with government agencies and the World Bank to implement an integrated project focused on the conditioning and readaptation of the Alvarado Canal. The main objective of the project is to mitigate flooding while maximizing other benefits in terms of improved safety and mobility, create green spaces, and enhance infrastructure for canal maintenance and waste management. Through reconstructing the canal, upgrading stormwater infrastructure, increasing green areas, and enhancing urban amenities, the project seeks to enhance the quality of life of close to 26,000 residents in San Pedrito.

Methodology

The Nature-Based Infrastructure (NBI) Global Resource Centre, in collaboration with the World Bank, the National Ministry of Public Works, and the Municipality of Jujuy, conducted a comprehensive assessment comparing the economic performance of three alternative approaches dealing with the flooding issues in the city: (i) a grey infrastructure scenario, (ii) a hybrid scenario, and (iii) a green scenario. All three scenarios are designed to achieve the same level of flood risk reduction. However, the grey scenario only focuses on the reconditioning of the Alvarado Canal through a concrete-lined canal, while the hybrid and green scenarios involve a more integrated approach, incorporating different nature-based elements.

This assessment uses systems thinking and cost-benefit analysis (CBA) to value the economic, social, and environmental added benefits and avoided costs of the project. Some of the added benefits or avoided costs can be defined as externalities, and others are defined as direct impacts. An examination of the externalities allows us to estimate the economic (i.e., societal) and financial value of the project. The CBA indicators (see Table ES1) were identified through a co-creation process that involved project stakeholders coupled with a comprehensive review of relevant literature and project documents.

Table ES1. Added benefits and avoided costs included in the assessment

Added benefits	Avoided costs
Income creation from construction employment	Flood damages
Income creation from operation and maintenance jobs	Carbon sequestration
Non-motorized transport use	Street maintenance
Improved livability [1]	

Source: Authors.

Several limitations related to the methodology and data availability should be considered when interpreting and analyzing the results presented in this report. These limitations include a reliance on secondary data, as opposed to performing primary data collection, which introduces uncertainty in cost-benefit calculations. Related to this, climate scenarios were analyzed but not explicitly taken into account in the modelling work. In other words, future climate trends have been reviewed and considered in the interpretation of results, but the climate impacts assessed with the model are derived from an existing publication that estimates average annual climate impacts over time. Finally, the formulation of scenarios was impacted by limited local data. Certain interventions could not be analyzed in detail, and potential local benefits, including increased physical and recreational activity, from the planned nature-based solutions were excluded due to a lack of data.

Results

The integrated CBA shows the outcomes of the project over a 30-year period. The analysis uses results from Excel-based models customized with best-practice valuation methodologies for each indicator. The integrated CBA is presented in Table ES2. It is worth noting that the three scenarios consist of different types of interventions; on the other hand, the ambition related to flood mitigation is identical across investments. As a result, the outcomes of the CBA can be compared directly but with the caveat that these are different typologies of investment that may cover different goals (e.g., the hybrid scenario includes the construction of non-motorized transport infrastructure and street lighting that are not found in the grey scenario, which focuses entirely on flood mitigation). Overall, results show that a more integrated package of interventions results in a better return on investment in the long term.

[1] The improved livability in the context of this assessment refers to the increase in property value resulting from the introduction of new green areas in the green and hybrid scenarios. Additional factors affect livability in urban areas; on the other hand, the main driver of livability impacted by the interventions analyzed in this study is the addition of green spaces.

Table ES2. Integrated CBA (in USD million)

	Grey scenario		Hybrid scenario		Green scenario	
	Discount rate 4%	**Discount rate 6%**	**Discount rate 4%**	**Discount rate 6%**	**Discount rate 4%**	**Discount rate 6%**
Investment and costs	**8.64**	**8.15**	**19.17**	**17.90**	**24.87**	**23.00**
Construction	6.94	6.83	14.45	14.23	17.66	17.39
Operation and maintenance (O&M)	1.70	1.32	4.72	3.68	7.22	5.62
Added benefits	**1.10**	**1.07**	**17.96**	**16.76**	**20.36**	**19.10**
Income creation from construction employment	1.03	1.01	1.03	1.01	1.03	1.01
Income creation from O&M employment	0.08	0.06	0.34	0.26	0.48	0.37
Non-motorized transport use	-	-	0.61	0.47	-	-
Improved livability	-	-	15.98	15.02	18.85	17.72
Avoided costs	**6.17**	**4.80**	**6.22**	**4.85**	**6.23**	**4.85**
Flood damage	6.16	4.79	6.16	4.79	6.16	4.79
Carbon sequestration	-	-	0.06	0.04	0.07	0.05
Street maintenance	0.011	0.008	0.011	0.008	0.011	0.008
Net benefit	**(1.38)**	**(2.29)**	**5.00**	**3.70**	**1.71**	**0.94**
Benefit-to-cost ratio (BCR)	**0.84**	**0.72**	**1.26**	**1.21**	**1.07**	**1.04**
Internal rate of return (IRR)	2.00%	2.00%	15.04%	15.04%	8.82%	8.82%

Note: The values are cumulative over 30 years, discounted at 4% and 6% for each scenario.
Source: Authors' modelling.

The main results of the analysis can be summarized as follows:

- The Canal Alvarado project is economically viable under the green and hybrid scenarios, with the hybrid scenario outperforming the green scenario in terms of returns, net benefit, and IRR.
- All scenarios effectively reduce flood damages; however, only the hybrid and green scenarios generate social and environmental benefits and reduce carbon emissions.
- The main benefits of the hybrid infrastructure are improved livability and avoided flood damages, which present the highest values among externalities. Further, the hybrid scenario provides additional social benefits for San Pedrito neighbourhood residents, specifically related to urban mobility.
- Despite requiring a lower total investment, the grey scenario is less desirable, with a BCR of less than 1, negative net benefits, and the lowest IRR.
- Sensitivity analysis indicates using a 4% discount rate does not change the insights generated by the model and the integrated CBA.

This study emphasizes the importance of conducting integrated CBAs early in NBI infrastructure projects. This approach facilitates economic viability evaluation, stakeholder engagement, and an assessment of impacts across social, economic, and environmental indicators. The following conclusions and recommendations have been drawn from the economic analysis and stakeholder consultations carried out for this project:

- The economic valuation of the Alvarado Canal exemplifies the multiple benefits and multistakeholder nature of NBI.
- Integrated infrastructure projects may necessitate higher initial investments but offer long-term social, economic, and environmental benefits.
- Hybrid measures prove cost-effective, particularly in urban settings, leveraging the strengths of grey and green infrastructure.
- Climate change uncertainties play an important role in NBI cost-benefit analyses.
- Stakeholder participation is vital throughout the project identification process to ensure reliable data collection and long-term engagement.
- Ex-post evaluation is recommended for projects incorporating green elements to analyze the impacts and added values of NBI.
- Proper communication of the study results is critical to inform local authorities and experts, resulting in better integration of green and grey infrastructures.
- This case study contributes to understanding the need for resilient infrastructure and the optimal balance of green and grey infrastructure in Argentinian cities and urban settings globally.

The results of this NBI assessment can serve as a valuable tool for stakeholders to make informed decisions, promote sustainable development in the urban setting, and enhance resilience to environmental challenges. Table ES3 shows how different stakeholders can use and leverage the results of the assessment.

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

Stakeholders	Role in projects	How can the stakeholder use the evaluation results?
World Bank	Support, monitoring and evaluation, and technical assistance to the Alvarado Canal project	Results can help scale the discussion on the role of NBI in urban settings as a means to manage the increasing flood risk in Argentina. The workshops and results obtained can also contribute to building a stronger case for resilient infrastructure and identifying the optimum balance of green and grey infrastructure in Argentina (and other countries).
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	Participation in planning and support for the appropriate use of the infrastructure	Civil society organizations can use the results in support of NBI to realize the many co-benefits emerging in green and hybrid scenarios. Additionally, strong local stakeholder engagement can increase ownership of the project and support the long-term maintenance of public spaces.
Municipal, regional, and national governments	Support the delivery and financing of NBI projects and scale these initiatives to other jurisdictions.	Governments can use the results to assess the financial and economic viability of the investment and evaluate the impacts of nature-based and hybrid infrastructure for the selected intervention. Local and national administrations can use the results of the analysis and information on the added value of green and hybrid interventions to support proper decisions on the types of interventions available.

Source: Authors.

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Glossary

Discounting: A finance process to determine the present value of a future cash value.

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

Internal rate of return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST): "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the 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 qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to 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 behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Nature-based infrastructure (NBI): A subset of nature-based solutions with a focus on nature-provided infrastructure services. The NBI Global Resource Center defines NBI as natural ecosystems or functional landscapes that can be conserved, rehabilitated, and maintained to enhance capacities and reduce the need for grey infrastructure, as well as hybrid infrastructure that combines engineered and nature-based solutions (Nature-Based Infrastructure Global Resource Centre, 2023).

Nature-based solutions (NbS): The International Union for Conservation of Nature defines 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).

Net benefit: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of an investment compared to the baseline, as reported by the intervention scenario.

Net present value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

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

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

1.0 Introduction

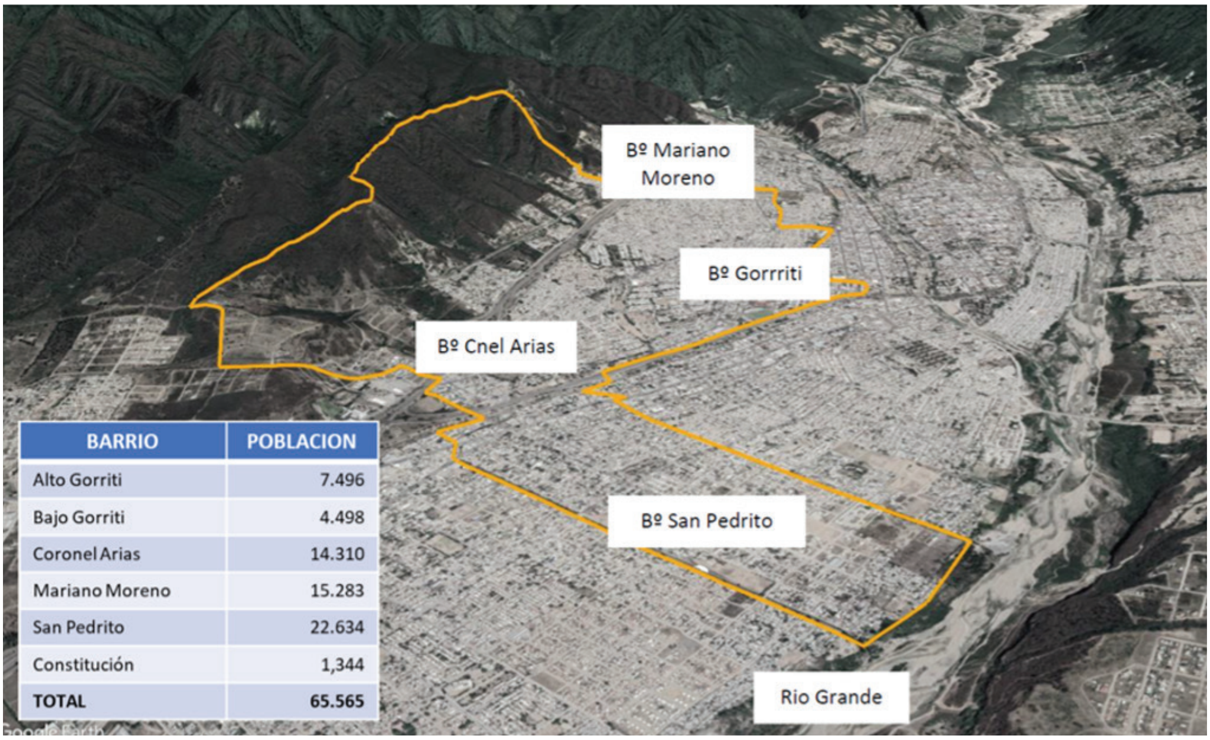
San Salvador de Jujuy, located in northwest Argentina, faces a significant challenge from frequent flooding, particularly in the San Pedrito neighbourhood (see Figure 1). Insufficient stormwater infrastructure has left the city vulnerable to the impacts of climate change, such as increasingly heavy rainfall events (El Dia, 2022; La Nacion, 2018).

The main drainage channel in San Pedrito, the Alvarado Canal, is in poor condition and has become clogged with solid waste, exacerbating the flooding problem. At the same time, residents in San Pedrito's informal settlements lack access to essential services, such as sewage and clean drinking water. Stagnant water in the canal poses health risks to the residents, especially through waterborne diseases and mosquitos. Currently, the Alvarado Canal cuts straight through the San Pedrito neighbourhood, hindering residents' mobility and access to services. People in the area also experience a lack of green spaces for recreation and community activities, further affecting the quality of life.

The Municipality of Jujuy, in collaboration with the provincial and national ministries of infrastructure and with support from the World Bank, is preparing an integrated project focused on the Alvarado Canal axis to enhance the quality of life for residents in the San Pedrito neighbourhood. The project aims to (i) reduce flood risk around the San Pedrito neighbourhood (where the canal is located); (ii) increase safety and mobility from one side of the canal to the other, and by doing so, guarantee access to community facilities and basic services and promoting sustainable mobility; (iii) increase green spaces for relaxation, social activities, and recreational opportunities, as well as for the reduction of extreme heat; and (iv) develop supporting infrastructure to improve canal maintenance and solid waste management.

To achieve these goals, the project includes rebuilding and revitalizing the deteriorated Alvarado Canal, upgrading stormwater infrastructure such as drains and gutters, and increasing the presence of green spaces through tree planting in plazas, parks, and green corridors. Approximately 26,000 people in the San Pedrito neighbourhood are expected to benefit from this project, directly or indirectly.

Figure 1. The Alvarado Canal watershed with data about the neighbourhood's population from 2010



BARRIO	POBLACION
Alto Gorriti	7.496
Bajo Gorriti	4.498
Coronel Arias	14.310
Mariano Moreno	15.283
San Pedrito	22.634
Constitución	1,344
TOTAL	65.565

Source: Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

The Nature-Based Infrastructure (NBI) Global Resource Centre, in collaboration with the National Ministry of Public Works, the Municipality of Jujuy, and the World Bank, has conducted a comprehensive assessment of the societal outcomes associated with the planned NBI for stormwater drainage in Jujuy. We analyzed three scenarios for the project: (i) a grey scenario, which provides a solution using traditional grey infrastructure; (ii) a green scenario, which uses NBI; and (iii) a hybrid scenario, which combines both NBI and grey infrastructure. From a flood management perspective, the interventions are expected to reduce flood risk at the same level. We have used an integrated approach using systems thinking and cost-benefit analysis (CBA) to inform the estimate of the required investments, added benefits, and avoided costs that each scenario can generate.

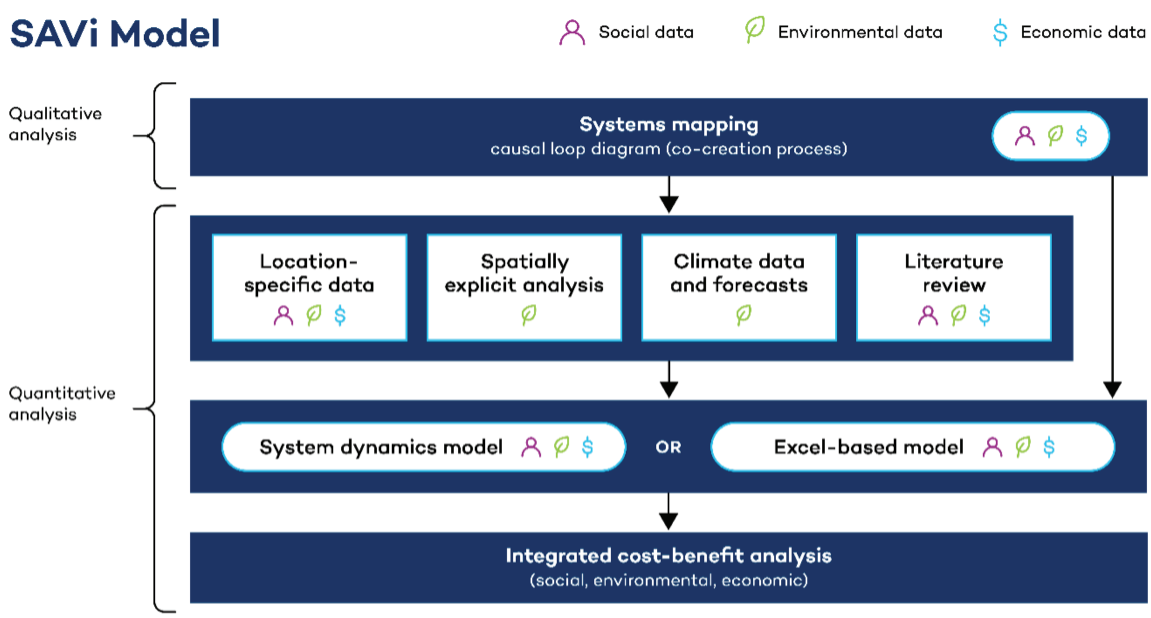
This integrated valuation aims to provide local policy-makers and communities with the necessary tools to make well-informed decisions regarding climate resilience and infrastructure development. By evaluating the economic viability and the impacts of nature-based and hybrid infrastructure, the assessment will make the case for the use of nature for managing urban flood risk. It will also provide useful information that will facilitate the integration of green and grey infrastructures in technical designs when feasible, promoting a more effective and balanced approach. Furthermore, the valuation will contribute to establishing a track record for NBI and support its broader adoption and upscaling throughout Argentina. It will be relevant to conduct an ex-post evaluation of the infrastructure implemented to confirm or contrast the findings of this assessment with the real outcomes.

2.0 Methodology and Assumptions

The analysis was carried out using a multiple-method approach. The work started with the creation of a system map using a participatory approach. Past climate data were analyzed and complemented by a literature review of observed impacts, as well as forecasts of future climate trends. Scenarios and the quantification of climate impacts in the Excel-based model are based on literature (i.e., a simplified approach using local data was adopted). On the other hand, the interpretation of results considers future trends under different climate scenarios and an estimate of the probability of occurrence and magnitude of extreme weather events. The following sections provide details on the methods and models used to carry out this Sustainable Asset Valuation (SAVi) assessment.

SAVi is an assessment methodology that provides policy-makers and investors with a comprehensive life-cycle analysis of infrastructure projects that considers often overlooked impacts. Combining systems thinking and project finance modelling, SAVi captures the full costs, including environmental, social, economic, and governance risks. It calculates the monetary value of externalities, offering a nuanced evaluation. This holistic approach enables investment decisions to align with regional development priorities, climate change adaptation, and the United Nations Sustainable Development Goals, ensuring a financially sound and sustainable outcome.

Figure 2. The SAVi methodology combines qualitative and quantitative tools to develop an integrated cost-benefit analysis of NBI projects



Source: IISD.

2.1 Importance of Systems Thinking

The SAVi approach relies on systems thinking. This holistic methodology considers the intricate connections among various factors within a system and forms the first step of the SAVi methodology (see Figure 2). By employing this approach, our study explores how different indicators and variables within the system interact. It delves into the complex relationships and interdependencies among key indicators across social, economic, and environmental dynamics. Understanding these interconnections provides a more nuanced perspective, enabling us to identify the fundamental drivers and dynamics influencing the livelihoods of local communities.

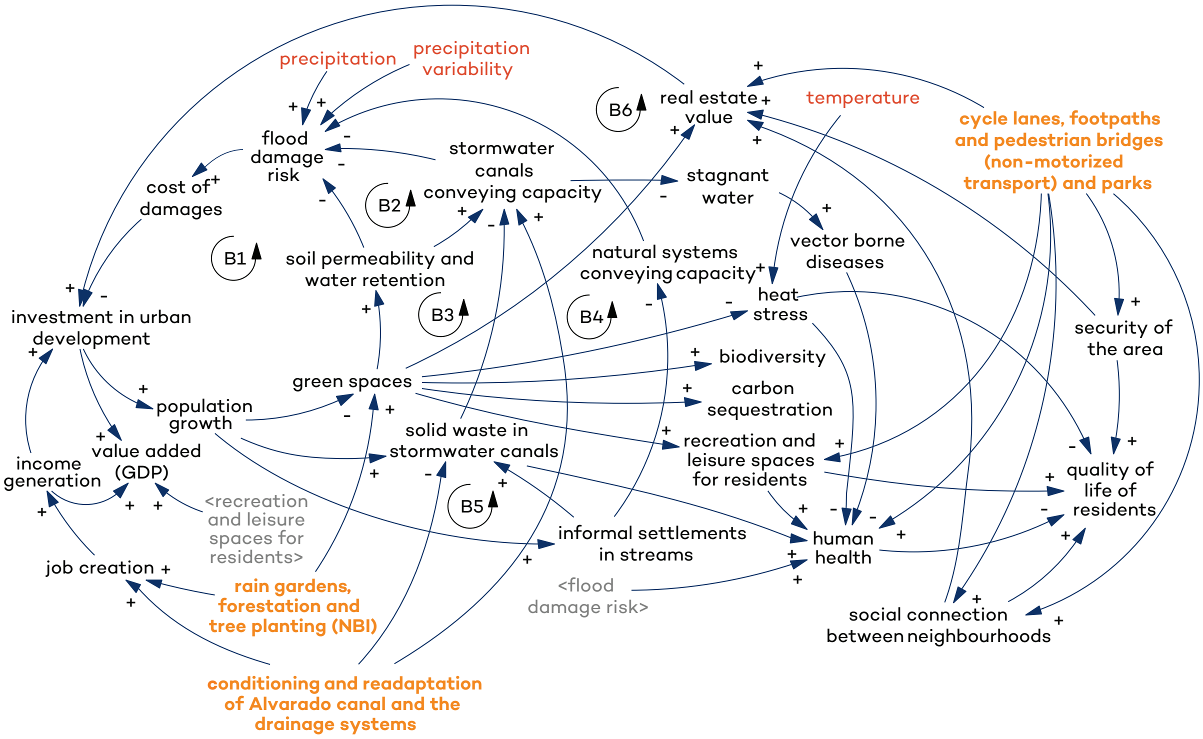
Systems thinking also helps to identify policy entry points—specific areas or aspects within the system where interventions or policies can yield the greatest impact. A systemic understanding allows for a strategic approach to policy formulation by revealing leverage points and areas where interventions can be most effective. Policy-makers, armed with knowledge about these entry points, can prioritize and target their efforts, thereby maximizing the efficiency and effectiveness of policy interventions.

In summary, by applying systems thinking, our study achieves several key objectives: gaining a comprehensive understanding of the problem, recognizing the interconnectedness of key indicators, uncovering key drivers and dynamics, and discerning the most impactful policy entry points.

2.2 Causal Loop Diagram

San Salvador de Jujuy is the most populated city in Jujuy province, with 336,000 people in 2023. The population has been growing rapidly, and, in some places, urban infrastructure has not been adapted sufficiently to provide the required public services and develop the required hydraulic infrastructure to discharge or absorb stormwater and maintain an acceptable flood risk level. And climate change increases the challenges related to flood risks. The causal loop diagram (CLD) prepared for this assessment (Figure 3) reflects the main dynamics present in the neighbourhoods that surround the Alvarado Canal.

Figure 3. CLD of the NBI assessment for Alvarado Canal



Source: Authors' modelling.

One of the side effects of population growth in the area has been a decrease in green spaces due to land being taken for settlements, as explained in loop B1. The reduction in green spaces reduces soil permeability and water retention, thereby increasing the risk of flooding. A higher risk of flooding increases the likelihood and resulting costs of flood damage. This risk also reduces the potential for investment in urban development, resulting in a potential decrease in budget due to the higher cost of flood damages or from decreasing interest in investing in infrastructure if that infrastructure is regularly damaged. The decrease in urban development investment in the area can decrease the attractiveness of living in that area, and the decrease in the attractiveness will potentially reduce population growth in the area, which explains balancing loop B1. Also, as seen in loop B2, the decrease in soil permeability—and hence water retention of the soil—will put extra pressure on the stormwater systems, given that less water is retained by the soil, increasing flood risk and the cost of flood damage. Population growth also leads to increased generation of solid waste, which is occasionally dumped into stormwater canals in certain neighbourhoods, including in informal settlements, due to the lack of waste management infrastructure. This practice further elevates the risk of flood damage, as presented in loops B3 and B5, because canals are obstructed by solid waste. The use of stormwater canals for dumping solid waste can also lead to an increase in waterborne diseases, increasing health risks.

The risk of flooding is also affected by the diminished capacity of natural systems to convey stormwater when informal settlements are situated in stream areas, as shown in loop B4. This diminished capacity is due to encroachment, which reduces the amount of biomass and green spaces and increases bank erosion. The final loop, B6, illustrates how a decrease in green spaces results in a decline in real estate value (more space for settlements is added, but the lack of infrastructure, risk of floods, and lack of green spaces reduce the value of housing in the area). Consequently, this decrease in value reduces investment in urban development, both private and public (as mentioned above), and may result in a permanent problematic situation, with reduced population growth in the medium and longer terms.

All the loops in the CLD mentioned above are balancing loops denoted by the letter "B." Balancing loops are feedback loops that aim to achieve a goal or equilibrium by balancing the forces within the system. In the case of San Salvador de Jujuy, the side effects of population growth act as balancing forces, ultimately limiting the extent of future population growth, decreasing real estate value and overall development of the urban area.

Certain external factors, represented by variables in red, can further amplify the impacts of specific dynamics within the system. For example, extreme changes in precipitation volume and variability contribute to an increased risk of flooding. Additionally, rising temperatures associated with climate change can lead to heat stress, negatively affecting the quality of life for residents.

To address these challenges, certain actions have been identified in the CLD exercise for the Alvarado Canal in San Salvador de Jujuy. The actions, presented in orange in the CLD, represent specific components of the scenarios assessed. The first action involves the conditioning and readaptation of the Alvarado Canal and the corresponding drainage systems. This action will mitigate problems associated with flood risk and solid waste. The second action includes NBI, such as rain gardens, reforestation, and tree planting, which will contribute to increasing green spaces and hence reduce the flood risk. The third action entails the implementation of cycle lanes, footpaths, pedestrian bridges, and parks, which not only provide recreational and leisure spaces for residents but also promote physical activity by using non-motorized transport. This action also fosters social connections between neighbourhoods and enhances security in the area (if the infrastructure comes with street lighting and it is maintained in good condition).

In addition to the benefits mentioned, the investments analyzed will generate local employment opportunities. The increase in recreation and leisure space for residents can also generate added economic value since it incentivizes consumption.

Ultimately, the goal of these investments is to improve the quality of life for the city's residents. This output indicator is directly or indirectly influenced by various factors, including heat stress, recreation and leisure spaces, human health, social connections between neighbourhoods, security, and flood risk.

By implementing these investments and addressing the underlying dynamics contributing to flood risk, San Salvador de Jujuy can strive for a more sustainable and resilient urban environment that supports the well-being and quality of life of its residents.

2.3 Scenarios

The analysis in this study compares three different scenarios for the Alvarado Canal project:

Grey scenario: This scenario is designed to achieve the same level of flood risk reduction as the other scenarios using grey infrastructure and can be considered as traditional infrastructure. This scenario is limited to the reconditioning of the Alvarado Canal as a concrete-lined canal with an approximately 7-m trapezoidal base and 1H:1V slopes, together with secondary storm drainage systems.

Hybrid scenario: This scenario is designed to achieve the same level of flood risk reduction as the other scenarios using both green and grey infrastructure. It consists of the same concrete-lined channel and secondary storm drainage system included in the grey scenario (a 7-m trapezoidal base and 1H:1V slopes) combined with a series of NBI interventions: rain gardens, permeable pavements, and approximately 103 ha of reforestation in an upper sub-basin, tree planting in a 288-ha upper sub-basin, and a linear park along the canal that includes pedestrian and cycle lines.

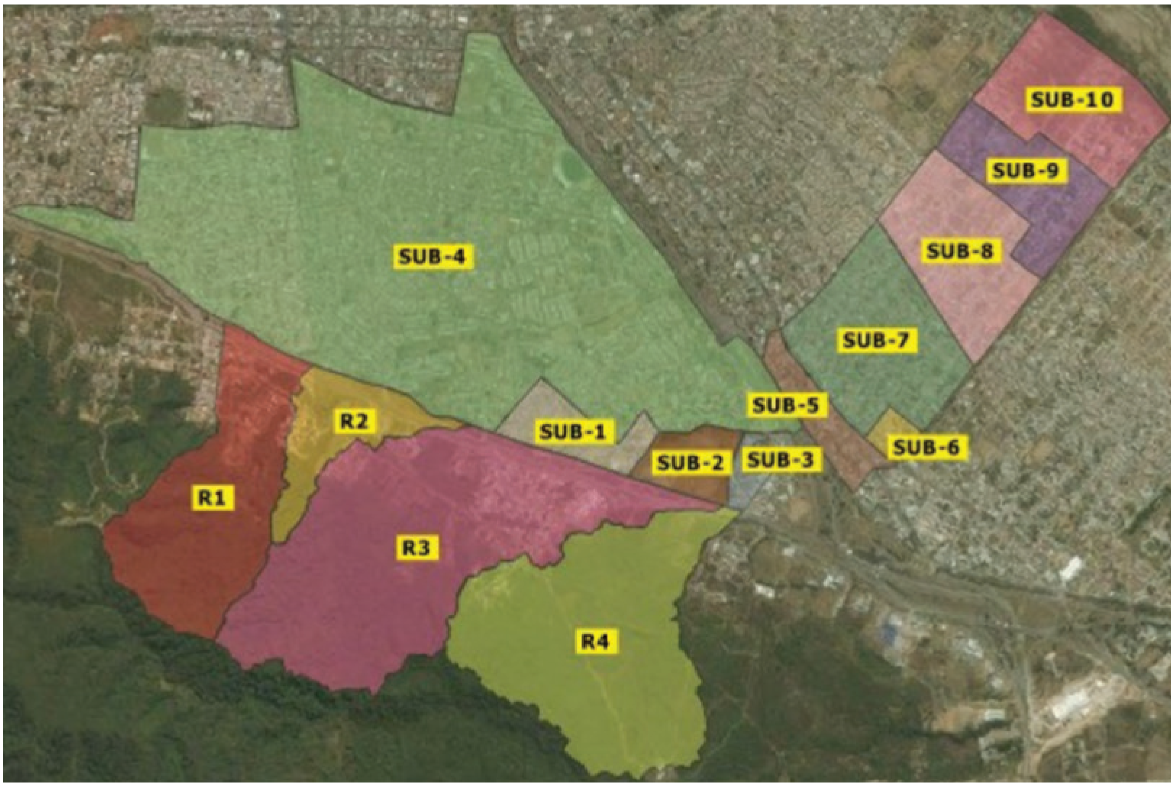
For the hybrid scenario, the rain gardens, permeable pavements, and reforestation will be implemented in sub-basins SUB-7, SUB-8, and SUB-9, and the tree planting will be focused in the SUB-4 sub-basin (see Figure 4).

Green scenario: This scenario is designed to achieve the same level of flood risk reduction as the other scenarios using green infrastructure, which involves natural vegetative infrastructure. It consists of a larger grass-lined canal (12-m trapezoidal base and 2H:1V slopes), a storm drainage system to conduct runoff to the canal, rain gardens, permeable pavements, tree planting in several sub-basins with an area of around 586 ha, and three additional recreation spaces with runoff retention at the exit of three sub-basins.

It should be noted that the linear park included in the hybrid scenario is eliminated here due to the inclusion of a wider green canal; however, green public spaces are added in two available plots along the canal and an existing park is upgraded.

For the green scenario, the rain gardens, permeable pavements, and tree planting will be implemented in sub-basins R-1, R-3, SUB-2, SUB-3, SUB-4, SUB-7, SUB-8, and SUB-9, and recreation spaces with runoff retention will be focused at the exit of sub-basins SUB-4, SUB-8, and SUB-9 (see Figure 4).

Figure 4. Sub-basins feeding the Alvarado Canal



Source: Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

2.4 Integrated CBA

A spreadsheet model (Excel) was developed to estimate 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
    - Income creation from construction employment
    - Income creation from O&M employment
    - Non-motorized transport use
    - Improved livability
- Avoided costs
    - Flood damages
    - Carbon sequestration
    - Street maintenance

Externalities Quantification Method

INVESTMENT AND COSTS

Indicator: Construction cost

Assumptions

The total construction cost for each scenario is calculated based on the specific interventions considered. Given that the hybrid scenario is the one previously considered and budgeted by the government, it was used as the starting point to estimate the cost of the grey and green scenarios. Specifically, the total construction cost of the hybrid scenario is USD 14,930,122; for the grey scenario, the total construction cost is USD 7,168,187; and for the green scenario, the total construction cost is USD 18,247,048.[2] The construction costs are accounted for at market prices.

The timetable for the reconstruction and rehabilitation of the Alvarado Canal was assumed to be 30 months (2.5 years) for all the scenarios,[3] using the hybrid scenario as the reference. Based on the construction period and the total construction costs, the results of the annual undiscounted investment in construction for the different scenarios are listed in Table 1.

Table 1. The annual undiscounted investment in construction for the different scenarios

Scenario	2024	2025	2026
Hybrid	5,972,049	5,972,049	2,986,024
Grey	2,867,275	2,867,275	1,433,637
Green	7,298,819	7,298,819	3,649,410

Source: Authors' modelling.

Indicator: O&M costs

Assumptions

The total O&M cost is estimated in the model as a share per year of the total construction cost. Starting with the hybrid scenario and using information made available by the government, the O&M cost for the hybrid scenario is set at 2% per year, 1.5% for the grey scenario, and 2.5% for the green scenario,[4] given that green interventions typically require higher average maintenance costs. This cost applies only after all the interventions are built, after the first 2.5 years of the simulation.

2 Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

3 Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

4 Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

During 2024 and 2025, the O&M cost is zero. In 2026, the O&M cost per respective scenario is 50% of the annual cost, as the infrastructure is available to be used only half of the year. From 2027 until the end of the simulation (2054), the O&M per year is 100% of the annual cost calculated.

ADDED BENEFITS

Indicator: Income creation from construction jobs

Assumptions

This indicator is based on the construction jobs created by the project and the portion of income spent in the local economy. The total construction employment per scenario is multiplied by the average annual salary in Argentina and by the share of the income that is considered discretionary spending.

The total construction employment is estimated at 205 people per year for all scenarios based on the O&M jobs, as there was no data available for the construction jobs. For the calibration of the construction jobs, it was considered that the share of income created from O&M employment out of the total O&M cost was 7.14%. This share was validated with local economists from Ministerio de Obras Públicas. Based on that share, the number of construction jobs was manually calibrated to generate a share as similar as possible, which in this case was 7.12% for 205 jobs per year.

To calculate the annual salary per person in Argentina, we multiplied a monthly salary in 2023 of USD 645 (Wage Centre, 2023) by 12 months, which results in an annual salary of USD 7,740.

The share of discretionary spending in Argentina is the sum of the shares of expenses in restaurants (15.4%), sports and leisure (5.4%), and clothing and shoes (6.0%), which amounts to 26.8% (Numbeo, 2023).

Indicator: Income creation from O&M jobs

Assumptions

This indicator is based on the O&M employment created by the project and the portion of income spent in the local economy. The total O&M employment per scenario is multiplied by the average annual salary in Argentina and by the share of the income that is considered discretionary spending.

The total O&M employment is estimated as the hours of work per year required for O&M divided by the hours per year that a person can work. For instance, for the hybrid scenario, the total hours of work per year required are 20,547, and the hours of work per person per year are 2,000 (8 hours/day/person multiplied by 250 labour days/year in Argentina).[5]

[5] Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

To obtain the annual salary per person in Argentina we multiplied the monthly salary in 2023 of USD 645 (Wage Centre, 2023) by 12 months, which resulted in an annual salary of USD 7,740.

The share of discretionary spending in Argentina is the sum of the shares of expenses in restaurants (15.4%), sports and leisure (5.4%), and clothing and shoes (6.0%), which is 26.8% (Numbeo, 2023).

Indicator: Non-motorized transport use

Assumptions

To estimate the benefits of non-motorized transport use, resulting in an increase in physical activity, the model uses the total amount of people impacted by the project, which is the total population of the San Pedrito neighbourhood—25,961 people (Municipalidad de San Salvador de Jujuy, 2022). Of that total, the share of the population impacted will be users of the park, which was established as 4%, or 1,038 people per day.[6] As the goal is to account only for the new non-motorized transport use—as some park users will represent a transfer from other parks, such as the Xibi Xibi linear park—the users of the park are narrowed down to new users by applying a conservative share of 20%. This calculation results in 207 new park users per day.

From the total number of new park users, there is a distinction between pedestrians and cyclists, as the infrastructure allows for both types of non-motorized transport. Hence, the modelling team assumes that most of the users will be pedestrians, with 80% participation, and the rest will be cyclists, with 20% participation. This results in 166 pedestrians/day and 41 cyclists/day.

To calculate the total benefits from non-motorized transport use, the economic benefits from both walking and cycling are added. To estimate the economic benefits of walking, the model multiplies the total annual walking distance from new users by a monetary benefit from walking of USD 0.41 per km (Gössling et al., 2019). Similarly, to estimate the economic benefits of cycling, the model multiplies the total annual cycling distance from new users by a monetary benefit from cycling of USD 0.20 per km (Gössling et al., 2019). The monetary benefits from walking and cycling used in this assessment include the private cost of walking and cycling in relation to the following items (Gössling et al., 2019):

- Vehicle operation
- Travel time
- Health benefits
- Prolonged life
- Accidents
- Perceived safety and discomfort

[6] Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

The annual walking distance is calculated by multiplying the (i) pedestrians per day; (ii) 260 days of sun per year (World Weather & Climate Information, 2023); (iii) the travel frequency, which is assumed to be two trips/person/day; and (iv) the travel distance per trip, which is assumed as 1 km/trip. The annual cycling distance is calculated by multiplying (i) the number of cyclists per day; (ii) 260 days of sun per year (World Weather & Climate Information, 2023); (iii) the travel frequency, which is assumed to be two trips/person/day; and (iv) the travel distance per trip, which is assumed to be 1.5 km/trip. The travel distance per trip is estimated based on the maximum distance of the park, which is 1.8 km.

Indicator: Improved livability

Assumptions

The total value of improved livability is calculated as the multiplication of three factors. The first factor is the total direct beneficiaries from the project, the second is the property value per inhabitant in the area, and the third is the percentage of property value increase because of the green spaces that the project will bring, depending on the scenario. This increase in property value is applied to the model only after the project is finished.

The total direct beneficiaries are calculated based on the total population of the San Pedrito and Coronel Arias neighbourhoods, which is 25,961 and 16,414 people, respectively (Municipalidad de San Salvador de Jujuy, 2022) (see Table 2), and a share of that population that directly benefits from the project due to proximity, estimated as 67% for San Pedrito in the hybrid scenario, 60% of San Pedrito and 30% of Coronel Arias in the green scenario, and 0% for the grey scenario. The beneficiaries are calculated based on their location, which concerns the improvements and assumes homogeneous spatial distribution. For instance, the San Pedrito neighbourhood has the Alvarado Canal as its axis and is 1.5 km wide. Assuming that the beneficiaries of the park and the urban improvement will be no more than 500 m on both sides of the canal, the benefiting area is equivalent to 67% of the neighbourhood area.

Table 2 shows the projected population of the San Pedrito and Coronel Arias neighbourhoods. It was calculated by applying a 1.15% annual increase to the baseline census of 2010 to 2022 (Municipalidad de San Salvador de Jujuy, 2022).

Table 2. Projected population[7] San Pedrito and Coronel Arias neighbourhoods

	San Pedrito	Coronel Arias
2010	22,634	14,310
2022	25,961	16,414

Source: Based on data provided by World Bank.

[7] Estimate by the World Bank team based on data from the Dirección Provincial de Estadística y Censos Provincia de Jujuy and the Dirección General de Estadística y Censos de la Ciudad de Buenos Aires.

The property value per inhabitant is estimated to be USD 20,987 per person (Municipalidad de San Salvador de Jujuy, 2022). Finally, the percentage of additional property value estimated for this project is 5%. This percentage was estimated by the World Bank based on various studies (CH2M Hill, 2019; Kozak et al., 2022; World Bank, 2009, 2016; Zoloa, 2015).

AVOIDED COSTS

Indicator: Flood damage

Assumptions

The total avoided cost of flood damage is estimated based on the properties impacted by the project, the inhabitants per property, and the cost due to flood damage per person per year.

The project benefits 972 properties; on average, 3.87 people live on each property, resulting in 3,760 total beneficiaries (Municipalidad de San Salvador de Jujuy, 2022).

The avoided cost due to flood damages is estimated at USD 103.50 per person in hedonic prices for a mean type of residence, based on values from the San Pedrito neighbourhood (Municipalidad de San Salvador de Jujuy, 2022).

For this externality, the total avoided cost for damages is assumed to be the same per year across all the scenarios, as the scenarios are designed to avoid the same level of flood damages using different types of infrastructure.

Indicator: Carbon sequestration

Assumptions

The value of carbon sequestration is calculated as the total carbon sequestration from green spaces per year multiplied by the carbon dioxide (CO_2) shadow price, also accounting for an increase in the shadow price each year. The CO_2 shadow price of USD 50/tonne of CO_2 is chosen based on the range provided in the guidance note from the World Bank (2017). The annual increase in the CO_2 shadow price is 2.25% per year (World Bank, 2017).

Total carbon sequestration from green spaces is the sum of the carbon sequestration from trees and the carbon sequestration from grass, which varies among the scenarios. For instance, in the hybrid scenario, 1,280 trees are planted, while 1,651 are planted in the green scenario. For both scenarios, 70,920 m^2 of grass area is considered.[8] On the other hand, in the grey scenario, the number of trees and grass areas is zero.

To calculate the carbon equation from trees, the model multiplies the number of trees planted by a carbon sequestration factor, which is 0.03 tonnes of CO_2/3 trees/year (Ecotree, 2023).

To calculate the carbon sequestration from grass, the model multiplies the total grass area by the carbon sequestration factor for grass, which is 1,000 pounds of C/acre/year (The Lawn Institute, 2023). The result of the carbon capture is later multiplied by the conversion factor from C to CO_2: 13.46 tonnes CO_2/tonne C.

[8] Based on data provided by the Ministerio de Obras Públicas de Argentina & Municipalidad de San Salvador de Jujuy (2023).

Indicator: Street maintenance

Assumptions

For the avoided cost of street maintenance, the model uses a reference to the preliminary economic analysis of Alvarado Canal, which establishes that the project will avoid USD 665/year (Municipalidad de San Salvador de Jujuy, 2022) in the cost of unpaved street maintenance in San Pedrito neighbourhood due to flood events. This value is used for all scenarios, as they are designed to avoid the same level of flood damage.

SUMMARY

The valuation methods that have been used for each of the CBA indicators are summarized in Table 3. These methods encompass a variety of approaches tailored to assess different aspects of the project's impact.

Table 3. CBA indicators and the valuation methods used in the assessment

CBA indicators	Valuation methods
Construction costs	Market prices
O&M costs	Market prices
Income creation from construction jobs	Market prices
Income creation from O&M jobs	Market prices
Benefits from non-motorized transport use	Value transfer
Improved livability	Hedonic prices using property value
Avoided costs of flood damages (housing flood mitigation)	Avoided damages
Avoided costs of street maintenance (Street flood mitigation)	Avoided damages
Cost of carbon sequestration	Shadow price for carbon

Source: Authors' analysis.

2.5 Limitations and the Interpretation of Results

The methodology and data used in this study present some limitations, and although the results have been estimated conservatively, the findings should be taken with caution:

- In the absence of primary data, some calculations in the CBA rely on secondary data from different contexts or global estimations, adding a significant level of uncertainty to the study results.
- Climate impacts were included in the analysis based on the analysis of local climate data that provides information on the average impact of climate change over time (see Appendix C). Climate scenario modelling, considering month-by-month climate variability obtained from future climate scenarios, was not applied in this economic analysis due to the limited availability of studies that provide details on the past impacts of extreme weather events and the lack of literature that analyzes future risks on infrastructure performance (i.e., we have information on extreme events from climate scenarios but lack information on the extent to which these will impact local infrastructure). However, climate change forecasts for San Salvador de Jujuy and the region are included in Appendix C and show that the frequency and intensity of flood and heat-wave risk are projected to increase within the project time frame (30 years).
- The design of the scenarios included in the CBA was influenced by the limited availability of local data and time restrictions, resulting in three interventions that are comparable but not substantiated by the same level of detail in relation to the cost-efficiency of the NBS for flood risk reduction.
- Our study does not consider interventions such as (i) landfilling and environmental sanitation of the *huaico*,[9] (ii) property regularization of the Alberdi settlement, and (iii) expansion of the Alberdi settlement's potable water and sewer networks. This implies that neither the construction and O&M costs nor the added benefits and avoided costs of the above-mentioned interventions are considered in the analysis.
- The study omits some of the potential benefits generated by NBI, such as (i) heat stress mitigation, (ii) benefits from an increase in physical activity that is not related to mobility, and (iii) cultural and biodiversity ecosystem services, as there was not sufficient certainty on the impacts of the interventions or insufficient data to quantify these values.

[9] *Huaico*, also known as *huayco*, is an Andean term to describe an event with mudslides accompanied by flash flooding, generally caused by large amounts of rainfall.

3.0 Results

The results of the integrated CBA are presented in Table 4. These results include investment and costs, added benefits, avoided costs, and total net benefit, discounted using two different rates (6%, the current central bank interest rate, and 4%, the forecasted value in the medium to longer term) for the period from 2024 to 2054 (30 years). Undiscounted results can be found in Annex A.

Table 4. Integrated CBA cumulative results between 2024 and 2054 (in USD million)

	Grey scenario		Hybrid scenario		Green scenario	
	Discount rate 4%	**Discount rate 6%**	**Discount rate 4%**	**Discount rate 6%**	**Discount rate 4%**	**Discount rate 6%**
Investment and costs	**8.64**	**8.15**	**19.17**	**17.90**	**24.87**	**23.00**
Construction	6.94	6.83	14.45	14.23	17.66	17.39
O&M)	1.70	1.32	4.72	3.68	7.22	5.62
Added benefits	**1.10**	**1.07**	**17.96**	**16.76**	**20.36**	**19.10**
Income creation from construction employment	1.03	1.01	1.03	1.01	1.03	1.01
Income creation from O&M employment	0.08	0.06	0.34	0.26	0.48	0.37
Non-motorized transport use	-	-	0.61	0.47	-	-
Improved livability	-	-	15.98	15.02	18.85	17.72
Avoided costs	**6.17**	**4.80**	**6.22**	**4.85**	**6.23**	**4.85**
Flood damage	6.16	4.79	6.16	4.79	6.16	4.79
Carbon sequestration	-	-	0.06	0.04	0.07	0.05
Street maintenance	0.011	0.008	0.011	0.008	0.011	0.008
Net benefit	**(1.38)**	**(2.29)**	**5.00**	**3.70**	**1.71**	**0.94**
Benefit-to-cost ratio (BCR)	**0.84**	**0.72**	**1.26**	**1.21**	**1.07**	**1.04**
Internal rate of return (IRR)	2.00%	2.00%	15.04%	15.04%	8.82%	8.82%

Source: Authors' modelling.

The results show that the Alvarado Canal project is economically viable under the hybrid and green scenarios but not under the grey scenario. When discounted at 4%, the hybrid scenario generates USD 1.26 in benefits for each USD 1 invested and a net benefit of USD 5 million in a 30-year period. When discounted at a 6% rate, the BCR declines from 1.26 to 1.21, and the net benefit falls to USD 3.70 million. The IRR of the hybrid scenario is 15.04%. For the green scenario, when discounted at a 4% rate, there is a return of USD 1.26 per every USD invested and a net benefit of USD 1.71 million. When discounted at a 6% rate, the hybrid scenario generates USD 1.04 in benefits for each USD invested and USD 0.94 million. The IRR of the hybrid scenario is 8.82%. This shows that both the green and hybrid scenarios are economically viable, but hybrid interventions perform better, primarily via cost savings on the side of investments.

The grey scenario shows a BCR of 0.84 and 0.72 with 4% and 6% discounting, respectively. Instead of a net benefit, losses emerge in the range of USD 1.38 million (4% discounting) to USD 2.29 million (6% discounting). For this scenario, the IRR is 2.00%. This shows that a solution that excludes NBI is not economically viable in this context.

The stronger economic performance of the hybrid scenario can be explained by its comparatively lower cost and, simultaneously, by its competitive performance on added benefits and avoided costs. On the other hand, the underperformance of the grey scenario is explained by the smaller amount of avoided costs and added benefits generated. Finally, the green scenario generates the highest amount of added benefits and avoided costs but also requires the highest amount of investment.

To explore these dynamics in more detail, results show that, in relation to the investment required, the green scenario is estimated to require USD 24.87 million (4% discounting) and USD 23 million (6% discounting). The hybrid scenario, in comparison, requires USD 19.17 million (4% discounting) and USD 17.90 million (6% discounting). These values are higher than the investment required for the grey scenario—USD 8.64 million and USD 8.15 million, respectively, for 4% and 6% discounting.

An estimate of the added benefits explains the overall performance of the three scenarios. The implementation of the Alvarado Canal project in the 4% discounting scenario is forecasted to generate added benefits between 2024 and 2054 valued at USD 20.36 million (green scenario), USD 17.96 million (hybrid scenario), and USD 1.11 million (grey scenario), respectively. The results of added benefits in the hybrid and green scenarios are similar, making the hybrid scenario the best performer as a result of the lower investment required between these two scenarios. On the other hand, the added benefits of the grey scenario are much lower, even smaller than the investment required. The main difference emerges from the impact on improved livability, driven by the presence of green spaces, which are missing in the grey scenario.

In relation to the avoided costs, all scenarios result in equal avoided flood damage costs (e.g., USD 6.16 million at a 4% discount rate) and avoided street maintenance costs (e.g., USD 0.011 million at a 4% discount rate). Additionally, only the hybrid and green scenarios result in reduced carbon emissions (via carbon sequestration), as they incorporate NBI. The green scenario avoids a value of USD 0.07 million in carbon emissions when discounted at a 4% rate and USD 0.05 million when discounted at a 6% rate. The hybrid scenario avoids USD 0.06 million in carbon emissions when discounted at a 4% rate and USD 0.04 million when discounted at a 6% rate.

To provide more detail on the impacts and respective indicators considered, the CBA of the hybrid and green scenario includes (i) avoided flood damage, (ii) the cost of carbon sequestration, and (iii) the avoided cost of street maintenance. Among the added benefits, these scenarios include (i) income creation, (ii) improved livability, and, in the case of the hybrid scenario, (iii) benefits from non-motorized transport use. The grey scenario does not include the economic valuation of carbon emissions, as it does not result in higher carbon sequestration and does not consider benefits from non-motorized transport use and improved livability.

Overall, it is estimated that the largest benefits, across all the indicators considered, are improved livability and avoided flood damages. These benefits are shared across a variety of local stakeholders (e.g., population, businesses, and the municipality). On the avoided costs, all scenarios result in equal flood damages and street maintenance avoided costs, but the green and hybrid scenarios also generate substantial social and environmental benefits (e.g., improved urban mobility and a reduction of emissions), as well as indirect economic benefits (e.g., improved livability).

4.0 Conclusions and Recommendations

This study reinforces the idea that the creation of an integrated, systemic CBA at the preliminary development phase should be a key part of NBI projects. This assessment allows us to quantify and evaluate the economic viability of different investment options, engage stakeholders, and evaluate multidimensional impacts across social, economic, and environmental indicators. The following conclusions and recommendations have been drawn from the economic analysis and stakeholder consultations carried out for this project:

- The economic valuation of the conditioning and readaptation of the Alvarado Canal is a clear example of how NBI can offer **multiple benefits for a variety of beneficiaries**. Benefits generated in the form of improved livability, sustainable mobility, or climate regulation are a critical part of their value proposition. This implies that, to accurately reflect the full value of these projects, both risk reduction and all relevant societal benefits and costs should be considered in the economic assessment.
- As shown in the Alvarado Canal CBA, **integrated infrastructure projects with multiple objective approaches** (e.g., flood reduction, improved livability and mobility, climate regulation, etc.) could require higher initial investments in some cases[10] (we estimated lower costs in other locations for different NBI investments). However, these higher costs also come with the potential to generate higher social, economic, and environmental benefits in the long term.
- The results of the CBA also demonstrate how **hybrid measures can be cost-effective** options, especially in urban-heavy populated settings, capitalizing on the strengths of grey infrastructure (immediate effectiveness, alignment with technical knowledge of local experts, smaller size, etc.) and green infrastructure (adaptability, aesthetics, provision of co-benefits, etc.) while minimizing their respective weaknesses. The inclusion of additional co-benefits that could not be assessed in this study (e.g., the reduction of the heat island effect) would further increase the economic viability of NBI. More work should be done to expand the analysis, with more effort dedicated to data collection.
- Uncertainties driven by climate change play an important role in the assessment of the benefits and costs of infrastructure (e.g., in relation to the forecasted number and strength of extreme events) and should be analyzed explicitly. The application of climate scenario modelling to an NBI CBA would support the calculations of impacts over time, adding value to **flexible green and hybrid solutions** that can be implemented in steps, gradually and efficiently adapting to future climate change development.

[10] Our previous work on a variety of NBI assessments point to the lower cost of NBI as compared to grey infrastructure (see: https://nbi.iisd.org/report/investment-in-nature-based-infratsructure/). On the other hand, differences emerge depending on the type of infrastructure service to be provided and the co-benefits generated by nature.

- **Stakeholder participation** throughout the project identification process is fundamental and should involve both local communities and expert consultation. As NBI benefits are often context-specific, it is critical to consult and engage stakeholders to identify the relevant benefits of the project and ensure reliable data collection and long-term engagement. A good application of available global- and national-level data tools and sources, in combination with primary data from local consultations, can improve the quality of the results and/or the efficiency of the process, reducing the costs and time associated with these types of studies.
- If the implemented project eventually includes some of the suggested green elements, it is recommended to **conduct an ex-post evaluation** using the same methodology to analyze discrepancies and/or confirm results, helping to increase our understanding of the impacts and added values of NBI. This will increase our knowledge base on the effectiveness of NBI investments and contribute to analyses performed for several other projects in the future.
- This case study can contribute to building a stronger case for resilient and integrated infrastructure and identifying the optimum balance of green and grey infrastructure in Argentinean cities, as well as similar urban settings around the world. Communicating the results of this study to local authorities and project developers will help raise awareness of the importance of NBI and can support their integration into future project designs.

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Appendix A. Nature-Based Solutions and Nature-Based Infrastructure

The International Union for Conservation of Nature 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 Centre 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.
- Hybrid infrastructure that combines NbS and engineered solutions.

The proposed hybrid and green scenario interventions for Alvarado Canal's conditioning and readaptation were evaluated as NBI—that is, we consider that the infrastructure seeks to address problems related to urban flooding as an alternative to exclusively grey infrastructure. It should be noted that many organizations, including the World Bank,[11] the World Wildlife Fund, the Global Infrastructure Basel Foundation, and the European Investment Bank, refer to these projects as NbS.

[11] See, for instance, https://www.worldbank.org/en/news/feature/2019/03/21/green-and-gray and https://openknowledge.worldbank.org/entities/publication/c33e226c-2fbb-5e11-8c21-7b711ecbc725

Appendix B. Cost-Benefit Analysis With Undiscounted Values

Table B1. Cost-benefit analysis with undiscounted values (in USD million)

	Grey scenario	Hybrid scenario	Green scenario
Investment and costs	**10.23**	**23.44**	**31.25**
Construction	7.17	14.93	18.25
Operation and maintenance (O&M)	3.06	8.51	13.00
Added benefits	**1.20**	**20.97**	**23.35**
Income creation from construction employment	1.06	1.06	1.06
Income creation from O&M jobs	0.14	0.61	0.86
Non-motorized transport use	-	1.14	-
Increased property value	-	18.16	21.43
Avoided costs	**11.11**	**11.22**	**11.24**
Flood damage	11.09	11.09	11.09
Carbon sequestration	-	0.11	0.13
Street maintenance	0.02	0.02	0.02
Net benefit	**2.08**	**8.75**	**3.34**
Benefit-to-cost	1.20	1.37	1.11
Internal rate of return	2.00%	15.04%	8.82%

Source: Authors' modelling.

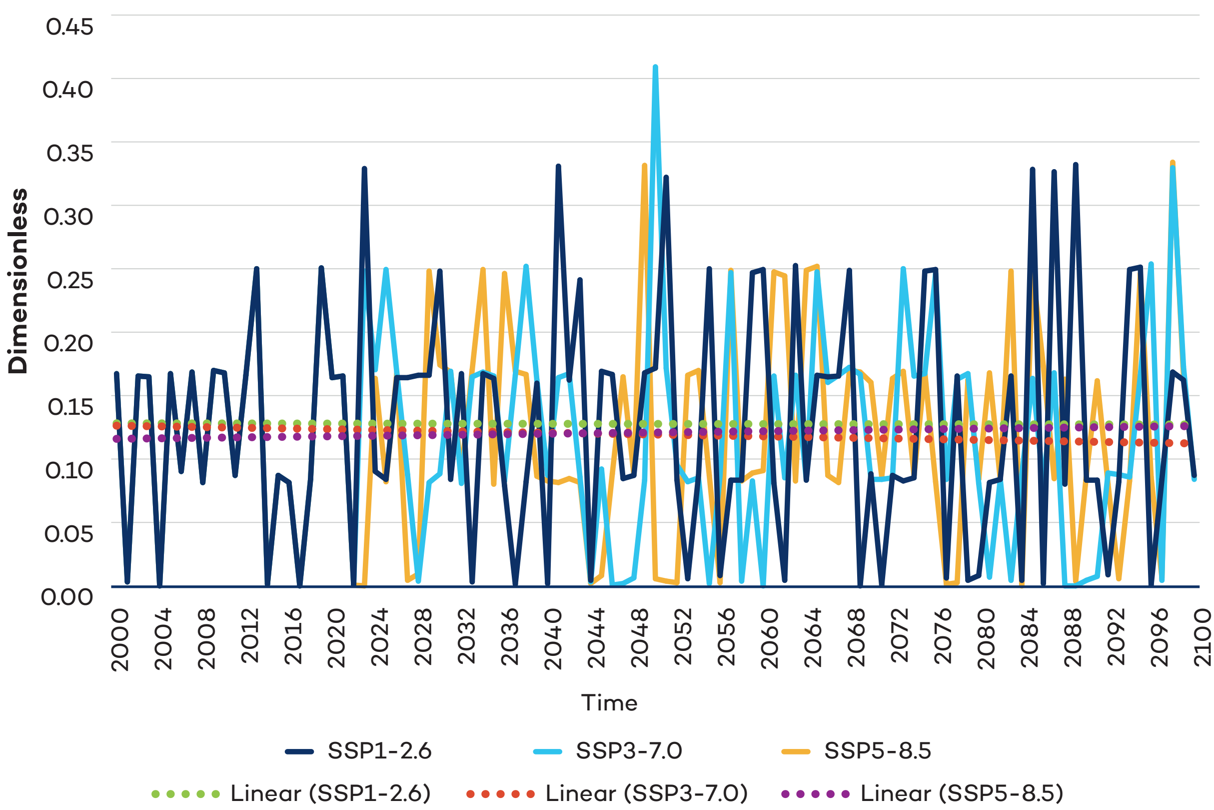
Appendix C. Climate Data Analysis

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

- SSP1-2.6, or the "2°C scenario," approximately corresponds to the RCP2.6 scenario, where global temperatures are expected to increase by 2°C by 2100.
- SSP3-7.0 is a medium-high reference scenario.
- SSP5-8.5 corresponds to a high reference scenario in a high-fossil-fuel-use world throughout the 21st century.

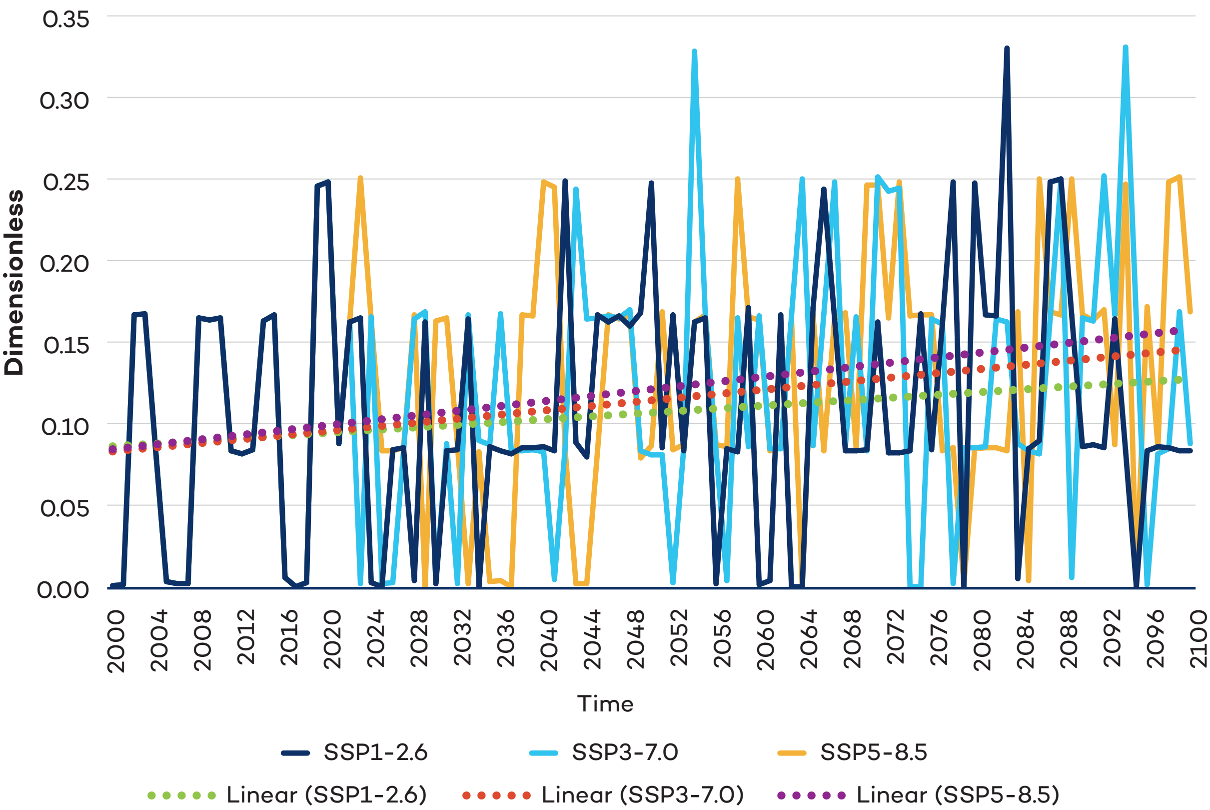
Figure C1 shows the extreme dry percentile from 2000 to 2100 under different SSP scenarios. Climate data suggest that the extreme dry percentile will remain constant under all climate scenarios. Figure C2 shows the extreme wet percentile from 2000 to 2100 under the same SSP scenarios. Here, all future climate scenarios show an increase in wet conditions. This result suggests that wetter weather will be more common. Therefore, it is possible that the frequency and intensity of flood risk will increase in the study area.

Figure C1. Extreme dry percentile (Jujuy)



Source: Authors' modelling.

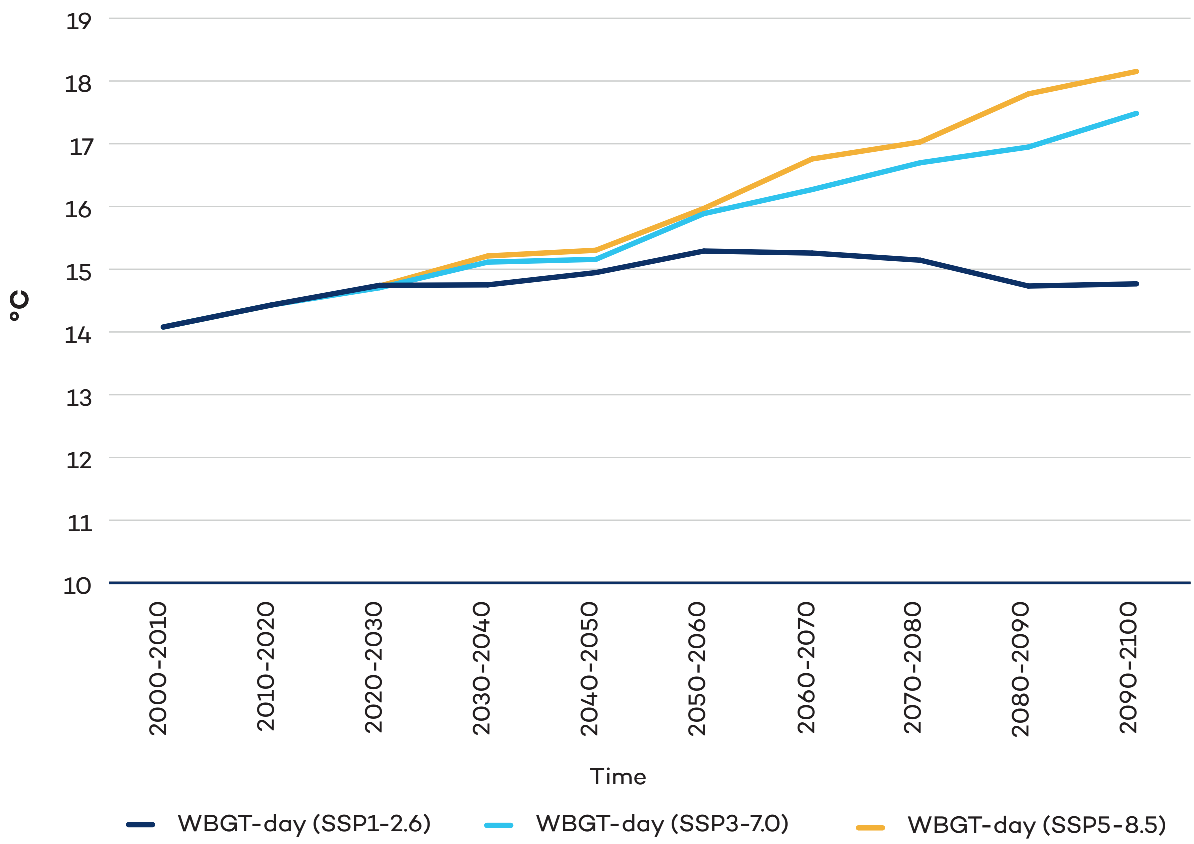
Figure C2. Extreme wet percentile (Jujuy)



Source: Authors' modelling.

Figure C3 shows the average monthly temperature (°C) in the study area from 2000 to 2100 under the three different SSP scenarios. The trends are similar under all three SSP scenarios until 2050, after which they bifurcate. In SSP1-2.6, the monthly temperature remains constant throughout the decades between 2050 and 2100. In the SSP3-7.0 and SSP5-8.5 scenarios, the average monthly temperature increases by roughly 2.5°C compared to 2050 or 3.5°C compared to 2000. The increase in temperature after 2050 may increase the frequency and intensity of heat waves, threatening human health.

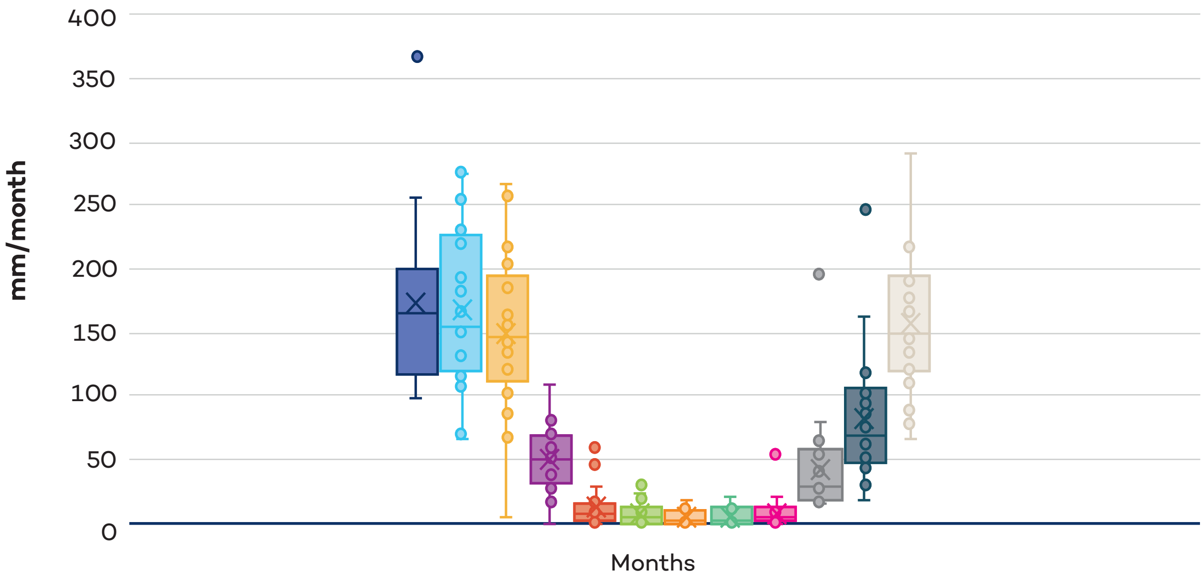
Figure C3. Average monthly temperature (Jujuy)



Source: Authors' modelling.

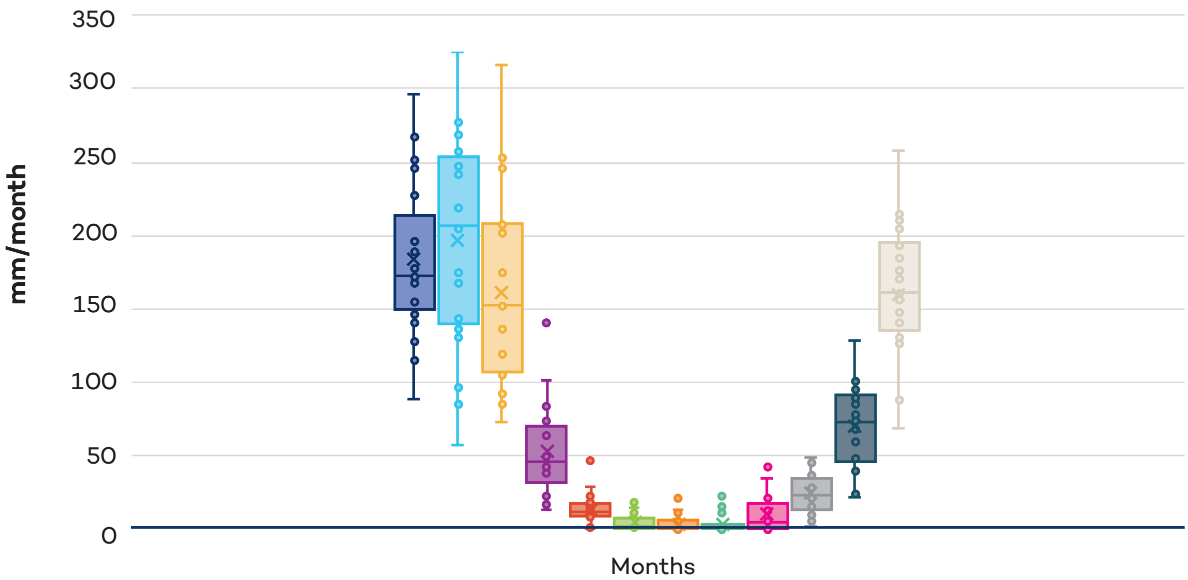
Figure C4 shows a box plot of the average precipitation (mm/month) in the study area for the period 2000 to 2020 under the SSP5-8.5 scenario, while Figure C5 shows the same variables but for the period 2040 to 2060. The results suggest that the maximum values of precipitation estimated for the period 2040 to 2060 during the first 3 months of the year are forecasted to increase. This means that precipitation patterns are expected to change in the future, potentially leading to wetter conditions.

Figure C4. Average precipitation (2000–2020)



Authors' modelling.

Figure C5. Average precipitation (2040–2060)



Authors' modelling.

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