

Analysis of urban solutions to flood risk in Santa Ana, Asunción, Paraguay

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Abstract: Informal urban settlements represent a structural problem in Paraguay. They house about 20% of Asunción's population and are constantly threatened by urban flooding caused by the river regime and precipitations. The following article is a summary of the authors' thesis work on the case of Santa Ana, a neighborhood located on a flood area of Asunción. The country's Ministry of Public Works offered two possible solutions to tackle floods, namely polders and hydraulic filling, which resulted incomprehensible to the residents of the area. This research work is intended to provide an analysis of both proposed solutions to flood risks as a contribution to decision making for those who live in informal urban settlements, spreading the advantages and disadvantages of these proposals. Providing a design solution is beyond the scope of this work. At the time of this research (2023), the population was about 7,344 inhabitants. The overall situation of the neighborhood was analyzed to determine the possible impacts of both solutions. Pros and cons were systematized. It presents a full picture of the associated impacts, risks and benefits, and highlights the necessity of communicating this information to local people so they can make well-considered choices.

Key words: South waterland; urban flooding; polder; hydraulic filling; urban risks

1 Introduction

This review article focuses on the solutions put forward by the government for settlements located on the floodplain of the Paraguay River. One key initiative is the *Master Plan for the Asunción Coastal Strip*, which sets out a range of interventions to mitigate flooding in the wetlands along the river. The plan aims to integrate these areas into Asunción's urban planning framework. Accordingly, various proposals have been raised to relocate, resettle or provide compensation for vulnerable families living in these zones (Pesci, n.d.). At present, the coastal promenade is still under construction, and no targeted plans have been finalized for each affected neighbourhood.

The Santa Ana neighbourhood in Asunción was selected as a case study, given the urgency to decide on the urban flood mitigation technique to adopt. The Ministry of Public Works is currently reviewing urban design proposals submitted by South Korea's KOICA (Korea International Cooperation Agency, 2021).

This area of the city experiences periods of flooding of varying magnitude. Due to the river's natural behavior, during periods of low water, an area of available land is created. Its proximity to the city center and the availability of land make these areas attractive to families who cannot access the formal urban land market. These families settle informally and are affected by river floods, rain, and other inundations.

Two technical solutions proposed by the government, namely polders and hydraulic filling, were selected for analysis (Pesci, n.d.). The two schemes will bring different impacts on the neighbourhood's urban design. Local residents — not

only those in Santa Ana but also inhabitants of all flood-prone neighbourhoods across the city — need to understand these differences to make informed decisions.

These neighbourhoods are referred to as "bañados", and they are located to the north and south of downtown Asunción (Figure 1).

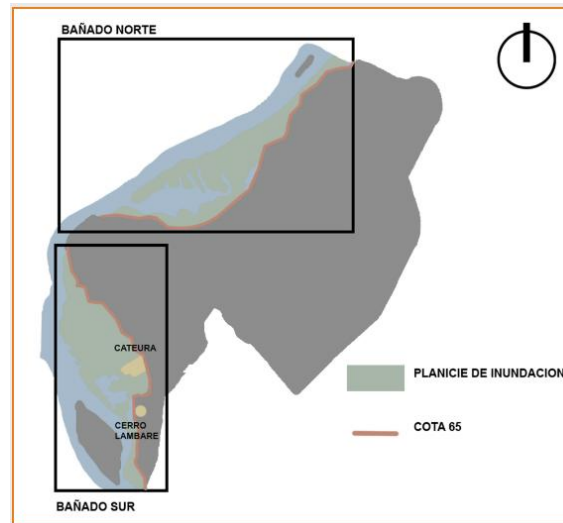


Figure 1. Location of the North and South wetlands of the city of Asunción with respect to the Paraguay River
Source: Prepared by the author based on data from the Cadastre of the City of Asunción (Municipality of the City of Asunción, n.d.).

2 The problem of informal occupation

In Asunción, the proliferation of settlements in high-risk areas is increasing (Galeano Monti & Rojas, 2017). These settlements are located in riverside areas, where low-income families are especially vulnerable to flooding caused by rising river levels and heavy rains that disrupt their daily lives. As a result, they are forced to relocate to higher ground in the city, losing their belongings, jobs, their children's schooling, and access to public transportation. They are also exposed to economic and health problems, as well as cyclical stress (Figure 2).



Figure 2. Historical floods in the Bañado Sur area of Asunción. Recorded maximum flood levels of the Paraguay River and their impact on the Bañado Sur area of Asunción.

Source: Prepared by the authors based on data from Major Floods in Paraguay (Rojas, 2016).

The economic losses are substantial for both the families and the state, which must assist them by relocating them to temporary sites until the causes of the disaster are resolved. This is compounded by the degradation of the natural environment of the area.

To avoid recurring this expense every year, the Paraguayan State proposed the "Asunción Coastal Strip Project", whose objectives include solving the aforementioned problems. The Ministry of Public Works and Social Welfare was responsible for studying technical alternatives to mitigate the impacts of floods on the wetlands, and proposed hydraulic filling and/or polder solutions (Palazon, Granada de Geam, Duarte & Spiridonoff, 2008). These solutions have advantages and disadvantages that were analyzed and systematized to help residents of the neighborhood understand the trade-offs of each measure, so that every decision is made with full knowledge of what is lost and gained with each option. To achieve this goal, it was necessary to understand different aspects of the Santa Ana neighborhood—including social, environmental, and urban dimensions—and then compare them against both technical proposals to present the pros and cons to residents. This analysis method could be useful for the Santa Ana neighborhood and other areas of the South Wetland, as the "South Wetland Coastal Strip Project" is currently being implemented. Furthermore, it could serve as a model for other similar risk situations.

3 Background

3.1 Master plan for the coastal strip of Asunción, Paraguay

It encompasses the riverine territory of the municipality of Asunción, especially the approximately 16 km of coastline between Puerto Botánico and Cerro Lambaré (Mendez Vail, n.d.). This area is where the most significant problems of flood-prone low-lying areas are concentrated.

Its proposal and structure are divided into three levels: coast-river, coast-coast, and coast-city (Environmental Studies and Projects Consulting, 2017). Within these levels are various strategies. At the first level (coast-river), there are projects such as the coastal promenade, a major road axis connecting the city center and its periphery, and flood defenses, where the coastal promenade's route creates a natural and/or artificial embankment that serves this purpose and is complemented by hydraulic filling and polders.

The second level (coast-coast) encompasses the area subject to periodic flooding (Environmental Studies and Projects Consulting, 2017), where human settlements were identified as the biggest problem. It focuses on implementing socio-environmental improvements for the residents and their surroundings, allowing most of them to remain in their current location after their habitat has been consolidated.

The third level (coast-city) works with the reconversion of large facilities (Consulting for Studies and Projects of the Environment, 2017), the reduction of negative impacts on the formal city and the improvement of employment for the flooded population.

The project has several key aspects, including relocation, resettlement, or compensation for families; productive development; mitigating the negative impacts of disrupted employment strategies and the rising cost of living; strengthening community organizations and networks; providing support to vulnerable groups; and promoting social and human capital, community health, and education. It also includes training and strengthening community networks and organizations, and contributing to increased income for families resettled in the Coastal Strip to ensure their sustainability and improve their quality of life (Mendez Vail, n.d.).

3.2 Master plan for the southern wetland and detailed plan for the coastal area – KOICA

In the context of frequent flooding, precarious settlements, rapid urbanization and a new city linked to the coastal avenue, a project was developed in Bañado Sur that complies with the higher plans and solves the urban, economic, social

and environmental problem.

The project is based on filling the site in order to level it to the safe elevation (level 64) to prevent future flooding.

The project objectives include minimizing flood impacts, developing parks, addressing housing issues for low-income groups, restructuring urban spatial layout for sustainability, and building an eco-city aligned with Paraguay's National Development Plan (KOICA, 2021).

3.3 Executive project for the southern riverside avenue

The Southern Riverside Avenue stretches 7.51 kilometres, running along the banks of the Paraguay River within the Southern Wetland area of Asunción. Additionally, it includes a 2.55-kilometre service road alongside the shore of Yrupe Lagoon, which eventually rejoins the main Riverside Avenue. (Consortio del Sur & MOPC, 2021)

Regarding hydrological and hydraulic studies, cross passages crossing the avenue between the river and the wetland, drainage systems for the roadbed and public areas along the avenue, as well as urban drainage facilities at the junctions between the avenue and urban streets were designed. (Consortio del Sur and MOPC, 2021)

To this end, the hydrological characteristics of all watersheds impacting the project were analyzed, ensuring their runoff can be diverted without causing adverse effects on the avenue.

The project will streamline traffic entering and exiting Asunción, and provide infrastructure throughout the Southern Wetland to improve its severely deteriorated current conditions. In addition, it includes riverbank protection works to prevent recurring floods in the area and improve the living standards of local residents.

3.4 The wetlands of Asunción

These wetlands are distributed in similar areas across the city and therefore share comparable features.

They were formed by informal settlements established by residents, largely resulting from rural-to-urban migration. This is driven by the rapid decline of living conditions for local people. Unable to afford land in the formal real estate market with high land prices, these communities occupy urban fringe areas. Most residents possess few assets and have great difficulty obtaining conventional loans. (Imas, 1993).

Another factor preventing these areas from being formally integrated into urban expansion and turning them into zones accommodating informal settlements of disadvantaged groups lies in their environmental conditions. Primarily, frequent flooding occurs here because the land lies within the floodplain of the Paraguay River (Figure 2). These territories boast high environmental value, featuring rivers, ravines, ditches and streams, as well as wetlands. A typical example is San Miguel Bank, which is occupied by the so-called Northern Wetland.

In terms of socio-economic conditions and structural poverty in the wetlands, official statistics show that households in these areas record the highest rates of Unmet Basic Needs (UBN) across indicators including housing quality, sanitation services, access to education and livelihood capacity. (National Institute of Statistics, 2023)

High population density, coupled with the lack of basic services such as sewerage and waste collection, leads to environmental degradation in these inhabited areas. (Figure 3)



Figure 3. Population growth in Bañado Sur.

Population growth in the Bañado Sur area is evident, comparing a satellite image from 2003 with one from 2023, emphasizing the Santa Ana neighborhood. Source: Prepared by the author based on satellite images from Google Earth Pro (Google, n.d.).

For many residents in these communities, recycling municipal solid waste serves as a source of income, as they sell recyclables to enterprises for use as raw materials. A large share of the local population also takes on casual jobs in the city centre, border areas and along the river (Imas, 1993). For this reason, residents are reluctant to leave these flood-prone zones. The areas lie close to their workplaces, and relocation would mean extra daily commuting costs, which they can barely afford on their low incomes. In terms of education, residents here have lower educational attainment, and the illiteracy rate is higher than in other urban districts (Imas, 1993).

The high cost of living in flood-free areas of the city is another reason why local residents choose to stay in flood-prone settlements. Compared with downtown neighborhoods, these areas have easier access to low-cost markets and shops. The river also serves as a source of food. In addition, healthcare, water supply and transportation services are more affordable here (Imas, 1993). Furthermore, residents have deep roots and strong emotional attachment to their living areas. These informal settlements also face accessibility issues, caused by natural factors such as terrain, as well as social problems including public insecurity. This creates social division between informal communities and formal urban areas, and further exacerbates the marginalization of the region.

3.5 The Santa Ana neighborhood

In terms of topography, the area features low to moderate terrain, sloping down towards the Paraguay River. A vast marshy plain lies alongside the river. The neighborhood can be divided into two parts: the higher ground, which is largely inhabited; and the lower area, where informal settlements are sparsely distributed.

Santa Ana District features a grid-like urban layout in its higher-lying area with standard planning. However, the layout is broken at multiple spots by terrain and physical barriers, forming dead ends. Near the river, the regular grid pattern fades away, giving way to an organic street network with irregular roads and shabbier housing. The study area is a

typical residential district with around 1,632 dwellings (Basili Yoriki & Delgado Serafini, 2023). This scale is reflected in residents' use of public spaces — for instance, sidewalks serve as venues for social contact and gatherings. This district-scale form is shaped by its urban structure: low-rise buildings, uniformly wide streets and standard public facilities. These features foster ongoing interaction between residents and their social, physical and spatial surroundings.

There are two types of housing. The first are solid-structured dwellings located closer to the formal urban area. The second are single-storey houses in low-lying zones, built haphazardly from flimsy, short-lived materials such as wooden planks and metal sheets. Most of these homes lack access to basic urban utilities.

In terms of population density, the district had a total population of 7,344 at the time of the survey, covering an area of approximately 165 hectares (Basili Yoriki & Delgado Serafini, 2023). Population density is higher in the upper part of the district and gradually decreases towards the Paraguay River.

As for road conditions, most streets here are paved with cobblestones or have become dirt roads due to vehicle traffic. No major infrastructure projects have been carried out over the past five years. Combined with the irregular road layout across parts of the district, local mobility is greatly hampered.

As for public transportation, it is almost nonexistent and in poor condition. Residents must walk more than five blocks to reach a bus stop, even though the minimum distance between stops is 200 meters and the maximum is 400 meters.

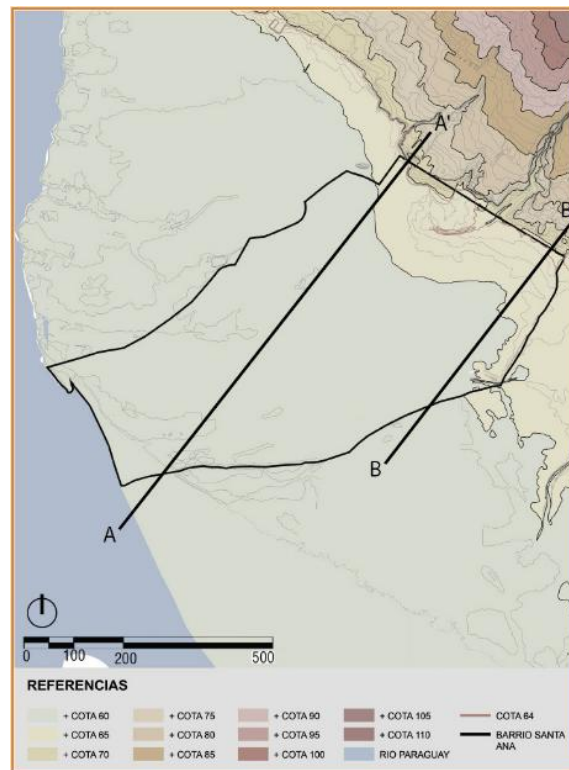


Figure 4. Topographic map of the Bañado Sur of Asunción
Elevation levels of the studied district

Source: Author's own compilation based on data from the Cadastre Office of Asunción (Municipality of Asunción, n.d.).

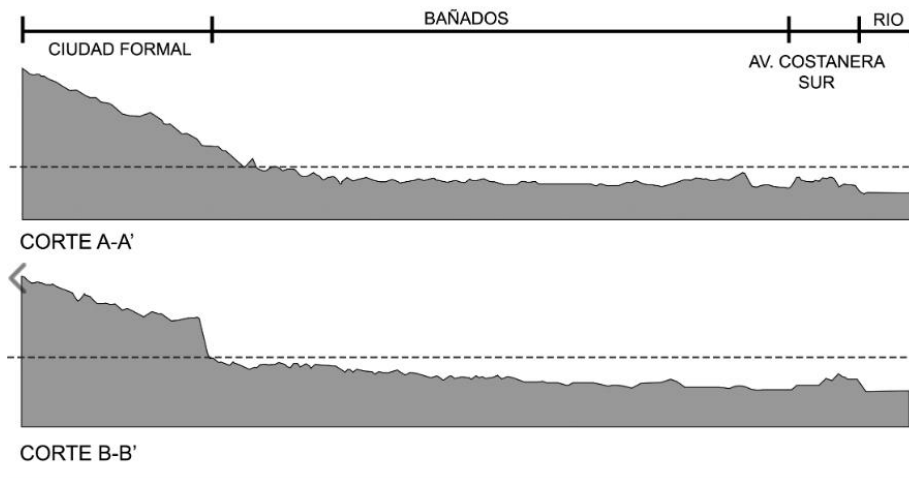


Figure 5. Topographic profile at two points in the Santa Ana neighborhood, located in Figure 4.

Source: Prepared by the author based on Google Earth Pro data (Google, n.d.).



Figure 6. Plan of filled and empty areas in the Bañado Sur of Asunción

Location of buildings within the Santa Ana neighborhood. The high density is evident near the formal city, which gradually decreases towards the Paraguay River.

Source: Prepared by the author based on data from the Cadastre of the City of Asunción (Municipality of the City of Asunción, n.d.).

4 Possible urban solutions

To select the most suitable technique for a given site, various multidisciplinary analyses must be conducted, including Environmental Impact Assessment (EIA), Cost-Benefit Analysis (CBA), risk analysis and public consultation (USAID, 2012). These analyses are not covered in this final-year dissertation, which only presents a schematic overview of technical solutions for polders and hydraulic filling, compiled solely for local residents' reference.

4.1 Polder

The polder technique solution consists of a barrier or dike, made with fill material, which may or may not be material extracted from the riverbed, that prevents the passage of water to the protected area (López Bosio, n.d.a.:1–9) (Figure 7)

The polder technique applied to the wetlands of Asunción would have advantages and disadvantages analyzed according to the data collected (Table 1).

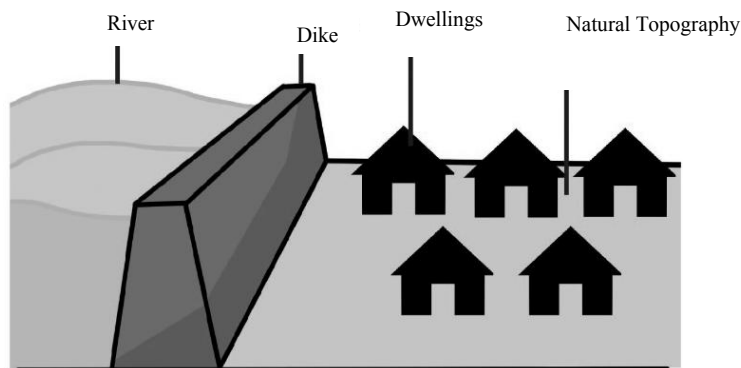


Figure 7. Polder Technique.

Schematic graphic of the polder technique applied to the Santa Ana neighborhood.

Source: Author's own elaboration.

Table 1. Advantages and disadvantages of applying the polder technique

Advantages	Disadvantages
Residents can remain in their homes. Preserves the existing community organization.	Confines residents within an enclosed area. Urban improvement of the neighborhood is hindered, as the area is not vacated.
Creates a habitable space protected from floods. Preserves the natural soils within the enclosure.	River visibility is lost, as the area is at a lower elevation than the protective dike. Risk of river water infiltrating the enclosure beneath the dike's base level. Requires a treatment plant to receive wastewater, which must then be pumped and discharged into the river. Requires an efficient pumping system for rainwater and a permanent monitoring/control entity. Pumping system failure can cause more severe flooding. A dike breach would have catastrophic consequences. Risk of collapse of riverbanks and/or slopes.

Source: Prepared by the author based on data compiled from López Bosio, n.d.a

4.2 Hydraulic filling

This process extracts mainly sandy materials from the riverbed using a pump-equipped dredger. The materials are then transported hydraulically to the designated filling area (López Bosio, n.d.: 1–6) (Figure 8). Based on the collected data, this paper analyzes the advantages and disadvantages of the hydraulic filling technique adopted in the study area (Table 2).

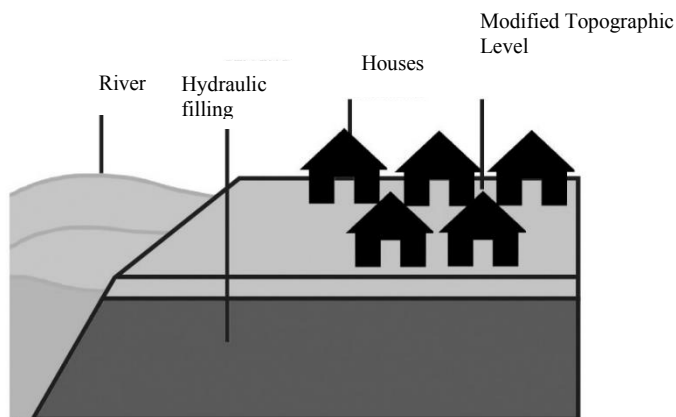


Figure 8. Hydraulic filling technique

Schematic diagram of the hydraulic filling technique applied in the Santa Ana neighborhood. Source: Author's own elaboration based on data compiled from "Hydraulic filling as an alternative for the Bañado Norte de Asunción. Case study: Refugio neighborhood, Asunción" (López Bosio, n.d.a.).

Table 2. Advantages and disadvantages of the application of the hydraulic filling technique

Advantages	Disadvantages
Relocates families to new, sanitized land.	Requires residents to move until filling works are completed, which affects construction timelines. Loss of existing community organization.
Organizes the territory, improving land use efficiency. Consolidates, improves, and equips existing neighborhoods and housing in the border zone, within non-flood-prone areas	Construction takes longer due to the large amount of earthworks involved. Territorial reorganization could affect the current community structure.
Integrates the floodplain into the city and the city with the river. Increases property values and enables the formalization of the area.	Residents could be exposed to the risk of real estate speculation.
Generates employment due to the large scale of the works, including housing construction and access infrastructure, among others. The neighborhood's proximity to the Paraguay River facilitates soil extraction for filling works. Facilitates the implementation of sanitary sewer, stormwater drainage, and potable water systems	High cost due to the large-scale nature of the project.
Would significantly reduce government spending related to floods.	Requires an entity to regulate urban planning, among other aspects.

Source: Author's own work based on collected data regarding hydraulic filling as an alternative for the Bañado Norte de Asunción. Case study: Refugio neighborhood, Asunción (López Bosio, n.d.b.).

5 Analysis of the impact of both solutions applied in the Santa Ana neighborhood

The impacts are compared according to the aspects analyzed: social, environmental and urban, as well as other general criteria (Table 3).

5.1 Social aspect

Among the most important factors are the attachment to the site and the community, as well as the proximity to the city center.

If the polder solution is adopted, residents will not have to leave the neighborhood during construction, which helps preserve the existing community and maintain residents' daily routines. On the downside, residents of the Santa Ana neighborhood will be separated from those in formal urban areas. Besides, the neighborhood cannot be fully integrated into the city as its original terrain remains unchanged.

For the hydraulic filling solution, residents will have to move away from the site for a long time during construction and be resettled elsewhere. As a result, they will lose existing community bonds and be separated from relatives and friends. Children will need to transfer schools, while local shop owners will be forced to close their businesses and lose their livelihoods. Those who work near the neighborhood may also be relocated to distant areas.

This relocation, in the case of implementing the hydraulic filling solution, is a key point that must be taken into account to achieve the evacuation of the neighborhood during the construction time of the project.

5.2 Environmental aspect

This site is environmentally significant for the city due to its wetland features, watercourses, and strategic location on the banks of the Paraguay River. It supports rich biodiversity and serves as a stopover for migratory birds. In the case of the polder, the most severe impacts would affect groundwater. Increased recharge reduces the depth of the water table, making the area far wetter than usual and disrupting the environmental balance (Auge, 2016). This issue is compounded by

untreated domestic wastewater discharges, which pollute the water bodies. A rising water table also renders pit latrines unusable, complicating waste disposal. The polder technique preserves the site's natural soil and vegetation. Thanks to its faster construction process, local fauna can repopulate the area more quickly. By contrast, hydraulic filling requires clearing woody vegetation from the site; covering the land with fill material would result in the loss of native plant life. In terms of topography, a polder would retain the existing elevation difference between the urban area and the wetlands, along with the associated social implications. Hydraulic filling, however, would eliminate the ravine as a physical barrier, creating a continuous urban fabric and enabling unobstructed access from the city to the river. Regarding the local hydrological network, both approaches allow surface watercourses to be retained in their open-air state. For the polder, retaining walls must be built around these channels to ensure their discharge into the river. For hydraulic filling, the watercourses can be preserved without the need for retaining walls or pumping systems.

5.3 Urban aspect

Both solutions would alter land use and urban facilities. Once the area is made flood-proof, existing land uses will be enhanced and new functions will emerge. Under the hydraulic filling scheme, new neighbourhoods will be developed with sanitation works, urban development and full public amenities, consolidating and upgrading residential buildings in the fringe areas (López Bosio, n.d.a). After the area is evacuated and reclamation works completed, the entire district will be available for new urban planning implementation. In the case of the polder option, designing a new urban fabric would prove difficult, yet the existing urban layout will likewise undergo changes.

Regarding the local road network, hydraulic filling would deliver improved road infrastructure as entirely new streets can be designed from scratch. By contrast, the polder approach would make it difficult — though not impossible — to upgrade existing roads in terms of width and pavement conditions.

Changes to the urban fabric and road network would impact public transport. Under the polder scheme, buses would be able to serve the neighbourhood free from flood risks, provided the pavement is repaired, as it is currently in poor condition. With hydraulic filling, public transport accessibility would be greatly enhanced, ensuring full supply coverage across the entire neighbourhood.

As for alternative mobility solutions, they would be easier to implement under the hydraulic filling scheme, thanks to the gentler terrain.

If hydraulic filling is carried out, residential buildings will undergo major changes. Most dwellings will be evacuated and demolished prior to land filling. In contrast, once relocated to a new flood-free neighbourhood, these homes will no longer be makeshift housing. Under the polder scheme, residential buildings will remain largely unchanged.

In terms of urban utilities, the hydraulic filling scheme allows for straightforward installation, as terrain gradients, pipeline slopes and the water table will not pose any issues. By contrast, urban utilities in a polder area will be adversely affected by the site's water table and gradients, requiring multiple pumping systems to ensure proper operation.

Table 3 provides a general summary comparing the analysed variables of the two alternatives, with scores assigned based on their respective advantages and disadvantages.

It should also be noted that the impacts of either solution depend on the specific site where it will be implemented. For each area to be developed, a prior site-specific multidisciplinary analysis must be conducted, as varying local features will lead to different impacts and risks.

Table 3. General analysis comparing the polder and hydraulic filling

General Comparative Table			
Criteria	Impact	Solutions	
		Polder	Hydraulic Filling
Social Aspect	Permanence on site	P	N
	Improvement in physical conditions	I+	P
	Preservation of the existing community	P	N
	Preservation of jobs	P	N
	Continuity of schooling	P	N
Environmental Aspect	Social integration with the formal city	I+	P
	Biodiversity conservation	N	N
	Impact on watercourses	N	P
	Impact on the site's microclimate	N	P
	Pollution from human waste	N	P
Urban Aspect	Impact on soils and topography	P	N
	Sanitation of the area	N	P
	Fluidity of the urban fabric	I+	P
	Neighbourhood-city-river connection	I+	P
	Urban development of the area	I+	P
	Improvement in housing quality	N	P
	Possibility of new urban planning	N	P
	Improvement of the road network	I+	P
	Accessibility to public transport	I+	P
	Implementation of alternative mobility	N	P
Other Aspects	Implementation of urban utilities	N	P
	Consolidation of housing and the neighbourhood	I+	P
	Risk in case of operational shutdown	N	P
	Implementation cost	P	N
	Maintenance requirements	N	P
	Construction process duration	P	N
	Risk of collapse	N	P
	Risk of water infiltration	N	P
	Solution to flood risk	I+	P
	Accessibility to raw materials required for implementation	N	P
	Job creation during construction	I+	P
	Increase in property values in the area	I+	P
	Reduction in flood-related expenses for the State	P	P
Score by compliance:		P: 8 – N: 14 I+: 11 – I-: 0	P: 25 – N: 8 I+: 0 – I-: 0

P: Positive impact, I+: Moderate positive impact, I-: Moderate negative impact, N: Negative impact.

Source: Author's own elaboration.

6 Final comments

Urban flooding and informal settlements are serious problems affecting the entire city across multiple dimensions. As architecture professionals, we have a duty to get involved and offer insights from our expertise. It should be noted that this issue is closely related to urban planning and all associated architectural works.

Furthermore, involving the community in decision-making is a key factor when selecting the urban solution to be implemented. This ensures decisions are made rationally and thoughtfully, taking into account the views of local residents, who are the most affected group. It is also recognized that engaging residents and the general public will boost public acceptance, thereby streamlining logistics and construction work. Since public participation must be based on adequate understanding, this graduation thesis concludes with a set of explanatory posters distributed to the local community.

Today, many cities in Latin America face this problem, so this work, and perhaps more specifically this methodology, can serve as examples and be applied in such places.

Professionals from various fields are invited to continue studying urban flooding, as well as issues related to the relationship between citizens and the environment, in order to contribute to building better cities.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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Note:

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