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Original Article

Analysis of Informal Settlements in Risk Areas: Perspective of Sustainable and Resilient City

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Abstract *- Starting in the new century and between the time of transition from the sucre to the dollar in Ecuador (1999), a boom was generated in terms of the growth of informal settlements, especially in the Northeast and Northwest areas of Guayaquil because the land was much cheaper and in relationship without any legal owner, generating internal and external problems around risk in the territory. Therefore, by choosing the Coop, we want to demonstrate how urban environmental analysis can generate objective solutions for risk reduction in informal settlements. Sergio Toral Stage 1 as a case study. Among the methods used, the ethnographic and hermeneutical research design stands out for the development of strategies that protect these guidelines. The methodology is based on a qualitative and quantitative approach in relation to risk in the territory. In conclusion, it is obtained that the strategy generates a risk mitigation percentage of 52%, which meets the urban green index regulations, and that, through ODS guidelines, it would generate a risk reduction of 90% with the established actions.*

Keywords *- Territorial risk, Sustainability, Informal settlements, Resilience.*

1. Introduction

This study analyzes the phenomenon of the growth of informal human settlements in the city of Guayaquil, Ecuador, and how these have caused significant changes in the territorial structure, shaping a current risk for territories that converge with natural spaces or, in turn, have been part of a process of abrupt urban consolidation. The risk is measured through the vulnerability of the territory [1], having a significant focus on the impact on popular communities, which in the urban area will be called informal human settlements. This name is based on the initial concept that a human settlement is itinerant and seeks to stabilize remotely, thus becoming an unplanned aspect within the territory, which makes it informal. Current publications defend the knowledge of human settlements and their potential for local development; in resident studies, experiences based on the population of Santiago de Chile [2] and its transformations towards a planned settlement system are shared, applying ECLAC guidelines for the development of resilient communities.

These initial guidelines propose how the territory should be treated so as not to significantly affect it and alter both internal and external conditions, preventing what is known as territorial risk due to urban load within the natural environment. Taking local experiences such as those established in Guayaquil, Cuenca and Loja, cities in Ecuador as a reference, this work focuses on urban and strategic planning experiences considering risk reduction and its sustainable management, as analyzed in Santiago de Chile in the commune of Salinas de Cahuil [2] and in Chibunga in the commune of San Luis [3], having as binding objectives the identification of the most exposed systems, such as drinking water, sewage, electrical grid and utility poles, in the face of the urban occupation of informal human settlements.

These two study references aim to develop a planned territory that follows a less risky and agreed typology by evaluating the diversity in land use and its characteristics of protection and mitigation against vulnerability, in the case of emerging communities [4]. However, the contribution of the case study analyzed lies in the role played by territorial analysis and citizen participation in the face of the dynamics of territorial expansion [5] as a determinant of risk, which provides an interpretation of the planning process by reading the city according to its growth, the properties of the soil and the environment, as a community management oriented towards the sustainability of the territory [6].

This article begins by describing the theoretical and environmental public policy context from which the concept of sustainable communities emerges, particularly in relation to

SDG 11 (Sustainable Cities and Communities). Subsequently, the Sergio Toral Cooperative is described, analyzing its urban, social, and territorial-environmental structure, and, based on this, how human settlements have influenced the territory. The third part presents and interprets the results, highlighting two aspects: first, the risk variables and indicators, and second (and more relevant), the development of solutions based on strategies and guidelines in line with community decision-making [7].

Finally, the discussion suggests that the morphological and functional characteristics of the Cooperative should improve their relationship with the territorial-environmental structure indicator, allowing for a planned configuration of the territory based on objective and area-specific interventions.

Indeed, this scientific article proposes solutions from the diagnostic and identification phase, applying the six pillars of resilience to the biophysical environment to structure an urban analysis and synthesis based on applicable strategies to address problems seen in informal settlements, proposing a guide of recommendations and urban strategies to improve the conditioning of informal settlements and reduce natural and artificial/man-made risks in the territory.

2. Materials and Methods

2.1. Informal Human Settlements: Characteristics and Challenges in the Face of Territorial Risk

Informal human settlements represent a particular form of urbanization that arises from the inability of formal planning systems to respond to the housing demands of populations in conditions of socioeconomic vulnerability.

Informal settlements are residential areas where inhabitants lack secure tenure over the land or homes they inhabit, ranging from illegal occupation to informal rental housing [8]. They are characterized by the absence of basic services, adequate infrastructure, and legal recognition by the competent authorities.

These territories are characterized by self-construction processes that reflect their inhabitants' technical and organizational capacities, progressive densification that responds to specific demographic and economic dynamics, and the development of intense social networks that constitute the basis of community organization. Self-construction refers not only to the construction of housing, but also to the construction of community infrastructure, public spaces, and service systems that respond to specific needs identified by the inhabitants themselves.

Rapid urbanization has largely outpaced municipalities' capacity to provide land with public services and accommodate the influx of newcomers, generating housing shortages that are expressed in both quantitative and qualitative terms. However, these territories also constitute spaces of social and economic innovation, where alternative forms of community organization and territorial management emerge, demonstrating the capacity of communities to generate creative solutions to complex urban problems.

Informal settlements present specific physical characteristics, including irregular urban layouts, high housing densities, construction of varying quality, and deficient or nonexistent public service systems [8]. These physical characteristics are articulated with specific territorial dynamics linked to the consumption of water and land, and the unbalanced consideration of occupation versus preservation generates a territory deeply framed by the attention to services and damage to the natural and progressive development of the ecosystem.

The challenges faced by these settlements include vulnerability to natural disasters, limited connectivity with the formal city, accelerated consumption of the natural environment, and a limited focus on resource preservation [9].

In prospecting, the city of Guayaquil since the 21st century has grown vertiginously in the Northwest area, displacing 25% of the current population of Guayaquil (989,222 people), establishing a high number of new Pre-cooperatives and Cooperatives that have been preying on the urban green area of Guayaquil which, according to data from the INEC in 2022, the urban green index stood at 2.36 m2 per inhabitant. [10]; well below that recommended by the WHO (9 m2 per inhabitant). Based on the previous data, it is considered that the informal human settlements of Guayaquil are considered part of the problem by not considering basic criteria of sustainability or urban resilience for their continuous development.

These settlements, often referred to as "slums" or "invasions," are characterized by a lack of formal planning and inadequate access to essential services such as water, sanitation, electricity, and healthcare [11]. Each settlement presents its own characteristics of irregularity and illegality, which may derive from its typical location on the outskirts of the city and in areas less conducive to formal development, such as low-lying areas prone to flooding or mountainous areas prone to landslides. These risks interrelate in complex ways, generating long-term cycles of informality that make the territory unsustainable and diminish the degree of resilience of communities to territorial risks.

2.2. Urban Resilience

The precise assessment of urban resilience has been a paradigmatic process in urban planning, given that its concrete structure is not fully understood. Therefore, based on systems thinking and the Sustainable Development Goals (SDGs) theoretical perspectives, resilience has been interpreted as a dimension of urban planning distributed across six pillars or

foundations that define what a resilient community should look like [12].

Drawing on two urban frameworks, such as the case studies of Xi'an, China [13] and Honorarios in the Solomon Islands [14], positive community responses have been generated regarding communities located in potentially at-risk areas, and how, thanks to planning, territorial solutions have been provided based on a dynamic design of sustainable and resilient action plans, which, as a starting point, seek territorial adaptation and a local productive system that aligns territorial potential for local and environmental development.

For the configuration of a territory that generates a dynamic of preservation and use of natural resources, such as how the community of Honoira in the Solomon Islands managed to integrate the use of green and blue infrastructure for biotic irrigation systems and water circulation for livestock consumption.

The case of the Xi'an community offers a perspective on how transportation is a cohesive element within the territory and how it must entail a formal relationship with the natural environment, proposing multimodal transportation that respects waterways and generating a proposal that provides a territorial experience within the community, thus becoming an ally of urban resilience.

The basis of these solutions is centered on key concepts, also referred to as pillars of sustainability by the authors [13, 14], which emphasize citizen participation as a means of action, adaptation as a means of resilience, project economics as a means of development, infrastructure provision as an alternative means, ecological management as an environmental means, and urban diversity as a means of land use. These pillars have been categorized as means for the development of communities in risky areas, thereby reducing their intrinsic and exogenous vulnerabilities.

2.3. Study Context

The territorial structure of informal human settlements in Northwest Guayaquil, as already mentioned, is categorized by generating risk zones and natural predation; therefore, a sample was taken from one of the largest and most densely populated informal human settlements in the city of Guayaquil, such as the Sergio Toral Cooperative [6, 15], considered a high-risk zone for flooding and devastated by its truncated mixed topography where these two natural phenomena occur almost simultaneously, leading to increasing territorial vulnerability.

The territory has developed in four stages, with aggressive urban development taking over the entire area until 2024, thus consolidating a gray area that has destroyed much of the territory's vegetation cover and natural habitats.

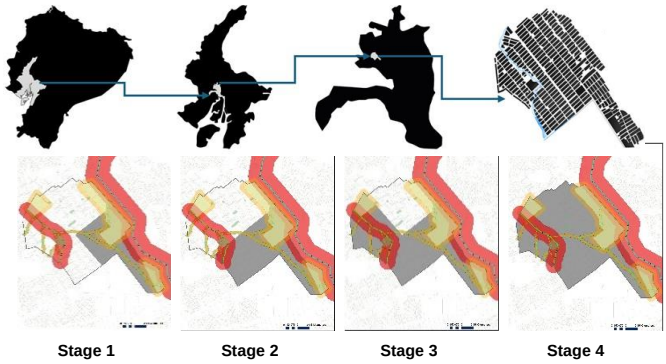

Fig. 1 Study context and growth of the gray spot

3. Methodology

The study is based on a mixed-method, qualitative and quantitative approach that incorporates socio-spatial sizing techniques into the territorial risk-based planning process by applying a historical compilation analysis of the evolution of the territory and its coverage. This initial qualitative approach is based on community experiences through an ethnographic analysis of community growth and their risk perceptions. The study was carried out in three stages, conducted between May 2023 and July 2024, a period of on-site study with the Sergio Toral Cooperative Stage 1. The first stage began with a digital ethnography of the growth model to identify urban areas with a high presence of housing and a shortage of green areas. As a territorial element of interest, the spectrum of natural resource presence and human settlements was also analyzed.

Table 1. Actors interviewed by the profile

Interviewee profiles	Number of participants
President Barrial	1
Historical leader*	1
Historic Neighbors**	5
Non-historical neighbors***	5
Merchants	2
Homeowners	1
Room landlords	2
House landlords	2
Neighbors outside the neighborhood	2
University representative	1
Neighborhood students	8
Total number of participants per profile	30****

* These are residents who were part of the initial leadership of the neighborhood's social organizations.
** These are residents who arrived during the first days after the occupation began.
*** These are residents who arrived in the neighborhood years after the occupation, so they are not familiar with the details of this process.
**** The number of participants per profile is greater than the number of people per gender, since some interviewees fit two profiles. For example, a landlord and a long-time resident.

The second stage of the project consisted of a semi-structured sampling of individuals and focus groups from each of the Sergio Toral stages, conducted jointly with students from the sector, the Universidad Estatal de Milagro, and Universidad de Guayaquil, with the participation of key stakeholders based on their profile within the sector (see Table 1). This population stratum was selected because it is a fundamental part of the urban structure of the Sergio Toral Cooperative as active stakeholders.

The study focused on the neighborhood and then progressed to the experience of each independent urban process at the neighborhood level, thus measuring the risk generated by each informal human sub-settlement (settlement stages).

Data processing was linked to a qualitative-quantitative study and was systematically conducted using the Multivariate Choice Analysis (TOPSIS) method to analyze the types of risk (floods, erosion, landslides, fires, and insecurity) in tables and percentage graphs [16]. The processed data set was triangulated and synthesized using the TOPSIS method, generating meaning around the phenomenon under study (risk and mitigation).

4. Results and Discussion

4.1. Virtual Ethnography

From the analysis of the site, a partial understanding of the territory was obtained for the construction of a virtual ethnographic that shows the location of areas with a high residential presence where urban green areas and protected zones have been occupied (see Figure 2).

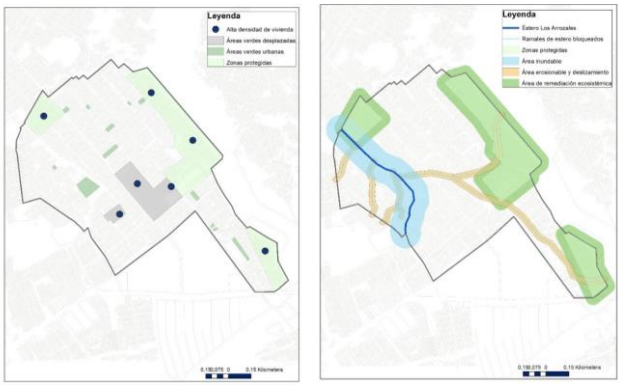

Fig. 2 Virtual ethnography of urban settlements and natural areas

These graphic data show that the growth of urban gray stains has led to the destruction of protected areas and urban green spaces, which, since the beginning of settlement, have deteriorated the territory and generated risk clusters, evident in the risk areas of influence of urban virtual ethnography. Data attributed to census data [15] have resulted in the deterioration of more than 30% of all homes due to flooding and landslides caused by erosion in their areas of influence (see Figure 3).

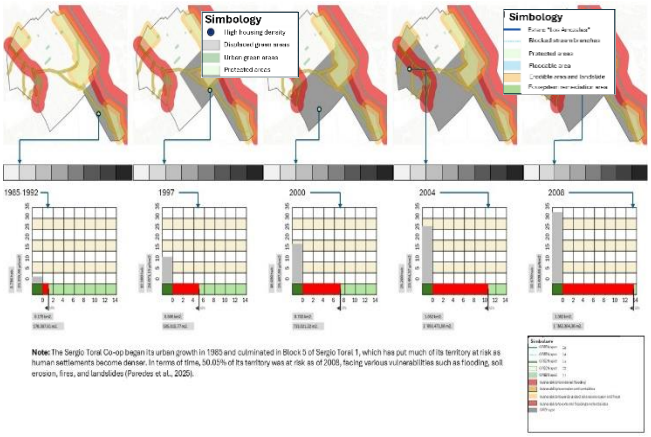

Fig. 3 Virtual ethnography of Sergio Toral's growth timeline vs. vulnerability/risk

4.2. Risk and the Process of Vulnerability of Territory

According to some residents of the Sergio Toral 1 Coop, specifically on the banks of the "Los Arrozales" estuary, his home has been exposed to constant risks, such as landslides, which have required rebuilding of the foundations of his house on more than two occasions.

He has also lost electrical appliances and other belongings due to flooding during the harsh winters. This has led to a relatively high degree of vulnerability for his home, as he suspects this will not be the last time.

Situations like several residences' experiences in the community suggest that this is a widespread process of vulnerability in the territory as human settlements grow and the land becomes increasingly vulnerable.

Therefore, based on these experiences, a structured timeline was created based on historical data from the territory and interviews with residents to determine three types of urban sprawl: gray sprawl as a human settlement; green sprawl as a green space and aquatic areas; and red spot as vulnerability zones in the territory which will meet different levels of the vulnerability scale determined by the number of accidents, adverse effects on homes and total loss of the same.

To determine the colors, the areas were subdivided into green patch categories (green resources) such as: Urban green areas (patch c1); protected areas (patch c2); "Los Arrozales" estuary (patch c3); estuary branches (patch c4); and CONELEC Canal (patch c5).

The red patch category (vulnerabilities) was divided into: Internal flood vulnerability (patch c1); Erosion and landslide vulnerability (patch c2); Protected areas vulnerability - erosion and fires (patch c3); and External flood and landslide vulnerability (patch c4). The gray patch was determined by the expansive growth of housing/human settlements.

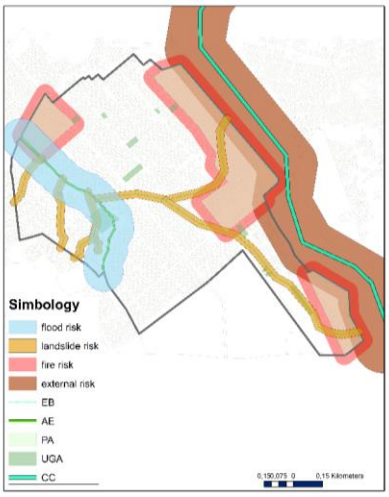

Fig. 4 Risk and vulnerability on the territory.

4.3. Stakeholders Participation

Within the methodological process, an essential aspect was the management of community participation, structuring workshops with the community for the development of urban planning boards. A method of selecting the participating population, which included neighborhood presidents, neighbors, leaders, and social actors such as merchants, landlords, and students (see Table 1), was designed with them. This consisted of diagnosing and generating solutions in the community.

From this workshop, diagrams were developed that correlated the deficiencies of the land perceived by the site's owners and residents through intervention points. The planning board shows both perspectives (problems and solutions in the territory), which can be independent or combined.

From this solution/problem location diagram, the critical points in the territory were connected to obtain a traditional planning diagram. From this, a base model for decision-making regarding the location of each intervention could be extracted using a geometric model (see Figure 5).

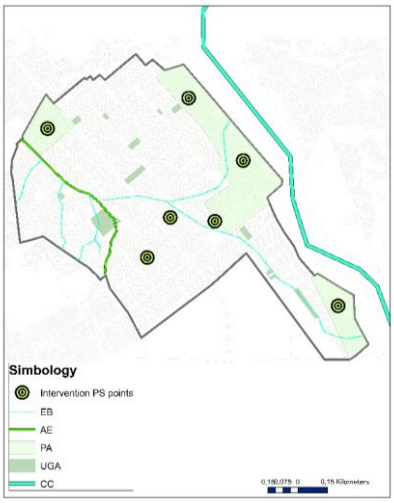

Fig. 5 Intervention points selected by the boards of planning

4.4. TOPSIS Multivariate Synthesis

This synthesis evaluated the six pillars of resilience previously analyzed qualitatively. It now analyzes them from their multivariate relationship with environmental, social, and economic risks, organized in tables with percentage graphs that define the total percentage of risk and vulnerability with their mitigation percentages according to the risk types in the territory (see Table 3). This allows a single result to determine the total risk reduction and mitigation in the territory.

TOPSIS was applied to determine which development best meets the risk reduction and mitigation needs. Stakeholder assessment surveys (see Table 2) were initially administered, obtaining a score for each development evaluated on the six criteria (pillars of resilience).

Table 2. Score each risk based on the respondents' criteria.

Alternatives\ Criteria	Adaptation			Citizen participation			Project economics			Infrastructure provision			Ecological management			Urban diversity		
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
Risk - flood	9	3	5	9	9	9	3	9	5	7	5	5	9	9	7	9	1	5
Risk - erosion	9	3	1	7	9	3	5	9	5	3	0	3	7	5	5	9	3	9
Risk - slip	1	9	9	3	7	5	5	9	5	9	9	7	9	1	5	3	0	3
Risk - fires	7	9	3	5	9	9	7	9	9	9	9	9	1	5	3	9	9	5
Risk-insecurity	5	3	0	0	0	9	0	9	5	9	9	1	5	7	7	9	3	3

Continuing with the TOPSIS Hierarchy process, formulas (1) and (2) were applied, with which the normalized matrix was obtained, which is weighted with the weight of each criterion and based on this, the ideal positive (A+) and negative (A-) solutions of each criterion can be calculated, applying formulas (3) and (4) respectively (See Table 3). That is, determining the ideal and anti-ideal alternatives.

Table 3. Negative and positive ideal solutions of each criterion

Adaptation	Adaptation			Citizen participation			Project economics			Infrastructure provision			Ecological management			Urban diversity		
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
A+	0,062	0,053	0,173	0,159	0,1 36	0,073	0,236	0,061	0,063	0,076	0,088	0,053	0,051	0,088	0,053	0,06	0,088	0,053
A-	0,05	0,025	0	0	0	0,021	0	0,061	0,057	0,025	0	0,018	0,061	0,01	0,018	0,025	0	0,022

Formulas (5) and (6) were applied, obtaining the distance of each supplier alternative to the positive and negative ideal, and finally calculating the similarity index (7).

Table 4. Distance to the ideal solution and similarity index.

	Si+	Si-	Ci	%	Ranking
Risk - flood	0,03	0,29	0,9	90%	1
Risk - erosion	0,18	0,16	0,42	42%	4
Risk - slip	0,21	0,2	0,52	52%	2
Risk - fires	0,2	0,16	0,45	45%	3
Risk - insecurity	0,18	0,15	0,4	40%	5

The ranking of alternatives was obtained, with the most viable option being to solve the flood risk to reduce the risk based on the criterion of citizen participation and risk mitigation according to the landslide risk criterion through the provision of infrastructure, given that it had the highest similarity index (See Table 4).

This solution can generate the viability of projects within the territory by geometrically aligning each of the intervention points as risk buffer corridors, on its two flood fronts, such as the "Los Arrozales" Estuary and the CELEC Canal.

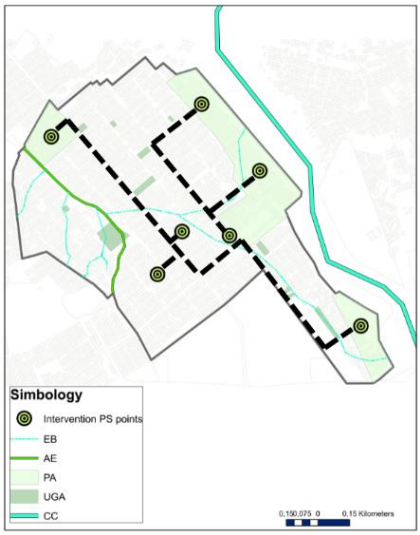

Fig. 6 Intervention points and their connectivity in the territory as a lower-risk solution

4.5. From Risk to Territorial Sustainability

The results indicate that the territory faces important environmental challenges that affect both the natural environment and the quality of life of its inhabitants. The implementation of strategies based on urban resilience fundamentally fulfills the role of the community in risk mitigation. This participatory role of the community has been evidenced in the scientific literature as successful solutions that offer a viable path towards a more balanced and sustainable development, as mentioned in the studies of the communities of Xi'an, China [13] and Honorarios in the Solomon Islands [14], where risk management is presented in a framework of active citizen participation to reduce vulnerabilities and improve environmental quality in situ [17, 18].

It is proposed that risk is territorial conditioning that houses several components, such as the impact they generate and their tangible vulnerability, which in question generates a comprehensive vision of how the geolocation factor of housing, urban green spaces, recreational spaces, and the provision of equipment and infrastructure put the quality of life of users at risk. The risk is a constant transmission factor that cannot be addressed with a linear strategy but must move from a dynamism to a resilience index that is activated as urban development warrants it; therefore, taking this background, a debate is generated around the viability of the solutions proposed in the results that denote that the intervention of areas prone to flooding generates a chain effect of how the territory can generate sustainability through the resilience of vegetation as an element of protection and water discharge, being raised as a development of green infrastructure [13].

The site's current resilience conditions do not provide the expected tangibility or near-future vision, but priority actions could address at least 80% of the vulnerabilities and address the spatial correlation between risks. This has been proposed in community planning boards as a means of citizen participation. To a certain extent, this method contributes to the generation of ideas and preventive activities from an empirical user perspective. However, technical and professional adjustments are required to achieve a sustainable environment that addresses possible local development paths.

Among the suggested points, it is mentioned how the focus on ecological space holds the potential to foster

socioeconomic activities and restructure the territory by creating green and public spaces. The Sergio Toral Cooperative's effective transition from risk to sustainability is based on addressing the stages in different ways, since the territorial conditions surrounding its topography divide risk into two prevalent types of vulnerability: flooding in the west of the property and gradual flooding in the east and north.

5. Conclusion

In conclusion, the strategy of implementing vegetative infrastructure as a flood protection barrier and ground support generates a 90% risk reduction, increasing the urban green index by 6 m² per inhabitant. These new green areas will serve as recreational green spaces that support the socioeconomic conditions of the population and generate proposals for the territorial reorganization of the protected subtropical and dry forest areas in the study sector. Territorial adaptation through vegetation cover was a collaborative effort with the community, conducting a broad sample study that supported decision-making for the urban resilience strategy [19]. This strategy was evaluated through a risk assessment that helped correlate experience with the assessment obtained from the territories.

This synthesis evaluated the six pillars of resilience, which were analyzed using a qualitative methodological approach. It is now analyzed from their multivariate relationship with environmental, social, and economic risks, organized in tables with percentage graphs that define the total percentage of risk and vulnerability, with their mitigation percentages according to the types of risk in the territory. This results in the most viable solution to flood risk based on citizen participation and community action around estuary systems, which in turn reduces landslides through increased infrastructure provision.

The methodology generated a synthesis of relevant results distributed across several phases that enabled development, contributing to site analysis, diagnosis, and prioritization [20, 21]. The preparation phase lays the foundation for the project, establishing clear objectives, forming a capable team, and assigning specific responsibilities. This preliminary step not only facilitates coordination among the various actors and stakeholders but also lays the groundwork for comprehensive data collection and a preliminary review of the environmental and social conditions in this intervention area. The resilience pillars strategy contributed to the visualization of the specificities of the territory, using the axiom of cause and effect. This approach, through the urban planning board, could be considered in perspective with the active participation of the community and, in effect, informed the decision-making method through data feedback to triangulate and obtain a linear solution criterion.

The relationship between the territory and the urban consolidation process must be measured by adapting the conditions of new housing developments while protecting natural ecosystems. In this case, the preservation of the estuary and green areas provides protection for the internal coastal profile [22, 23]. This contributes to the remediation of the territory, thus avoiding the serious effects of flooding and landslides due to erosion that occurs on the banks of estuaries. Maintaining the conditions of protected areas must be integrated into the conceptualization of new public spaces, taking advantage of air quality, improving the population's health, and actively interacting with urban green spaces.

For future research, it is recommended that neighborhood structure be analyzed to establish a direct reference scale for obtaining proposals from tactical urban planning, thereby establishing a more varied framework of solutions through specific and strategic interventions that function as a cohesive body for risk reduction.

Conflicts of Interest

This section is compulsory. A competing interest exists when professional judgment concerning the validity of research is influenced by a secondary interest, such as financial gain. We require that our authors reveal any possible conflict of interest in their submitted manuscripts. If there is no conflict of interest, authors should state that “The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.”

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