Environmental Protection Areas as a Strategy to Increase Flood Protection in Metropolitan Regions: A Case Study in Maricá, Rio de Janeiro, Brazil

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Abstract. In peripheral countries, the lack of adequate urban planning associated with natural dynamics intensifies the existing vulnerabilities of the environment, causing physical and material losses. Therefore, this research aims to discuss the potential use of Environmental Protection Areas as a tool to drive urban growth with a low-impact development, helping to mitigate urban floods and bringing nature into the city landscape. The municipality of Maricá, located in the metropolitan region of Rio de Janeiro, Brazil, is taken as a case study. The method proposed to drive the regional environmental planning and management can be described as a three-stage method coupled with the adapted SWOT Matrix, following: the diagnosis, the prognosis, and the action plan. This process points to the definition of a Hydrological Interest Area that would allow not only the restoration of local vegetation and a better interaction of the population with the watercourses, but also the recovery of areas that have been gradually impacted by the urban expansion. The method presented in this research allows its application in different urban contexts, once it has the objective of recognizing the strengths, weaknesses, opportunities, and threats to allow the elaboration of sustainable actions and guidelines.

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1 Introduction

In megacities, the rapid expansion of urban areas and the associated land-cover changes are capable to drastically increase the surface runoff, creating challenges such as urban flooding [1]. In this sense, when peripheral countries are taken into account, the lack of adequate urban planning associated with the nature dynamics intensifies the existing vulnerabilities of the environment, resulting in physical and material losses. Additionally, the culture of the real estate market focused on the production for the more affluent classes tends to increasingly expand urban areas, contributing to the loss of urban green spaces and the irregular occupation of hazardous areas. Due to the weakness of policies designed to protect regions of environmental and hydrological interest, there is a gradual loss of areas that could execute social and ecological functions.

Cities must be planned from the perspective of preserving spaces for the river [2], ensuring a better connection between green areas. In fact, when planning urban growth, it is always important to cope urban needs with environmental supporting capacity. Therefore, this research contends that the concept of Environmental Protection Areas is a powerful tool capable of containing the advances of urbanization towards nature, bringing multiple co-benefits to the population, such as flood mitigation, air quality improvement, and biodiversity increase. This comprehension is directly associated with the concept of Nature-based Solutions (NbS), defined by “solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience"[3]. The NbS concept encompasses interventions that bring various natural features and processes into cities and landscapes [4]. Moreover, when understanding natural restrictions, urban operation costs tend to be lower.

In Brazil, amongst the nearly 5.000 existing municipalities, only a few present a conurbation condition that hinders the formulation of strategies aimed at preserving the natural environment. The municipality of Maricá, for example, although located in the metropolitan region of Rio de Janeiro, is plenty of urban and rural green spaces, contrasting to other cities in its surroundings. Hence, this research aims to discuss the development of a system of territory planning to the municipality of Maricá, based on the use of Environmental Protection Areas as a tool to drive low-impact urban growth, mitigating urban floods and bringing nature into the city life. Although inspired by the Maricá setup, the presented method can guide sustainable urban planning of other new urban developing areas in metropolitan regions facing processes of rapid expansion, preserving the urban green spaces for the next decades and avoiding negative impacts of flooding events.

2 Method

The proposed method for guiding territory planning can be described in three stages. In the first stage, the Diagnosis of the territory is highlighted as an indispensable tool for understanding the interaction between the natural and the urban space. Aspects such as the urban open space system definition, hydrology, topography, and urban drainage of the municipality of Maricá were evaluated using Geographic Information System (GIS) and on-site information. The flood occurrences in the urban spaces were evaluated through MODCEL, a mathematical hydrodynamic quasi-2D model [5]. This stage intends to identify strengths and weaknesses of the territory, including natural and urban features.

The following stage comprises the Prognosis elaboration, responsible for estimating the population growth and predicting the effects of urbanization in non-occupied areas (specially highlighting how unplanned and spontaneous growth can be damaging to future results in terms of urban sustainability). Here, it is important to understand how different challenges and future scenarios can pose threats and opportunities to the city. This stage

allows the design of strategies to guide future occupation, reducing negative impacts on the hydrological cycle and restoring its conditions closer to the natural behaviour. It allows the creation of potential scenarios that can simulate the demand for stormwater management and urban drainage services, considering worse, average, and better conditions of growth. This step was also supported by the evaluation of the current legislation, and by the Municipal Master Plan [6], which establish guidelines for the land use and occupation.

Finally, the third phase aims to propose an Environmental Protection Area to preserve the most relevant regions from the point of view of maintaining the hydrological processes and preserving urban drainage from being stressed, guaranteeing ecological connections for environmental quality. These landscapes can add hydrological and hydraulic functions to structures, as well as provide a multifunctional urban equipment [7]. The Environmental Protection Area is also able to contribute to increasing resilience to urban floods and reducing the effects generated by inundations, mostly with the application of procedures that reduce the associated socioeconomic losses. Considering its main objective, which focuses on harmonizing the built environment needs with the natural stormwater cycle, this particular Environmental Protection Area is named as Hydrological Interest Area – HIA.

The phases of diagnosis and prognosis were supported by the use of adapted SWOT Matrix concepts, a tool that can help to define the strengths, weaknesses, opportunities, and threats of the considered process [8]. This way, this tool is adapted to territory planning by assuming that strengths and weaknesses correspond to attributes related to the current situation, supporting the diagnosis. On the other hand, the opportunities and threats are considered as future possibilities given by the legal, institutional, physical and socioeconomic framework, allowing the planning of actions that can increase the strengths using the positive opportunities and reduce the weakness by facing and avoiding the threats; therefore, supporting the prognosis. By the attentive reading of SWOT and evaluation of the measures necessary to mitigate weaknesses, enhance strengths, prevent threats, and guarantee opportunities, it is possible to directly list the objectives to be achieved with planning. Figure 1 shows the flowchart of the method used in this research.

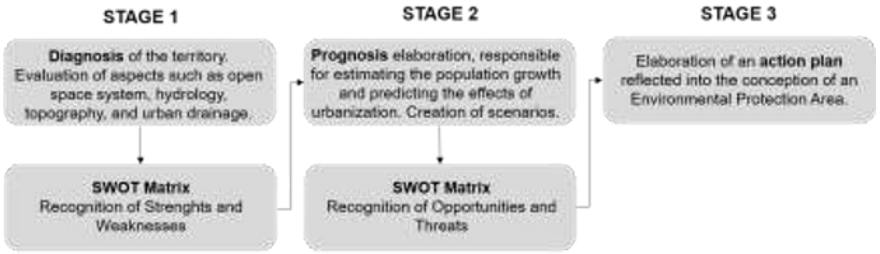

Fig. 1. Flowchart of the method used in this research.

3 Case Study: Bambu River Watershed, Maricá Municipality

Maricá municipality is located on the eastern side of the Rio de Janeiro Metropolitan Region, Brazil, as illustrated in Figure 2. Its territory covers approximately 362 km², which borders the municipalities of Niterói, São Gonçalo, Itaboraí, Rio Bonito, Tanguá, and Saquarema. The Brazilian Institute of Geography and Statistics estimates a total population of 174.442 living in the municipality [9]. In general, Maricá has a low population density. Therefore, only 19,85% of the territory is characterized as an urban area, while the rest is mainly composed of massifs and urban green spaces.

Maricá is composed of a lagoon complex that covers about 347 km² and is entirely located within the municipal boundaries. The watershed includes rivers, wetlands, and the lagoon ecosystem, with a surface area that corresponds to approximately 11% of the total

municipality [6]. Besides, it is highlighted that the local topography has a great influence on flood formation, impacting the surface runoff, the infiltration capacity, and the time of concentration of the watersheds. Considering that Maricá's urban development resulted in an actual situation with the predominance of floodplain areas occupation, the region presents challenges in stormwater management. Besides, the reduction of the original vegetation, and the occupancy of riverbanks accentuate the difficulties of flood protection.

According to the literature review, factors such as geomorphology, hydrography, soil type, proximity with the highways and with the surrounding municipalities are considered the main drivers for the occupation and urban expansion in Maricá [6]. Historically, the plain areas between the massifs and the water bodies were destined to farming. Later, they were subdivided into smaller portions of land to become part of the urban landscape. Nowadays, a lack of pattern in the design and dimensioning of allotments is observed due to the informal and discontinued process of subdivision of the land, in addition to the self-construction initiatives. Although the municipality has a large contingent of vacant lots, there is a tendency for new developments, mainly influenced by the improvements on streets and roads, external demand from real estate agents, and the agrarian character of a portion of the territory. Thus, the urban growth in the coming decades is expected to lead to unsustainable sprawl and the consequent increase of land consumption and soil sealing are highlighted as a concern directly related to urban floods, affecting urban drainage aspects.

The Bambu River Watershed, in the western zone of the municipality, was selected to illustrate this research. This is one of the most populous watersheds in the region.

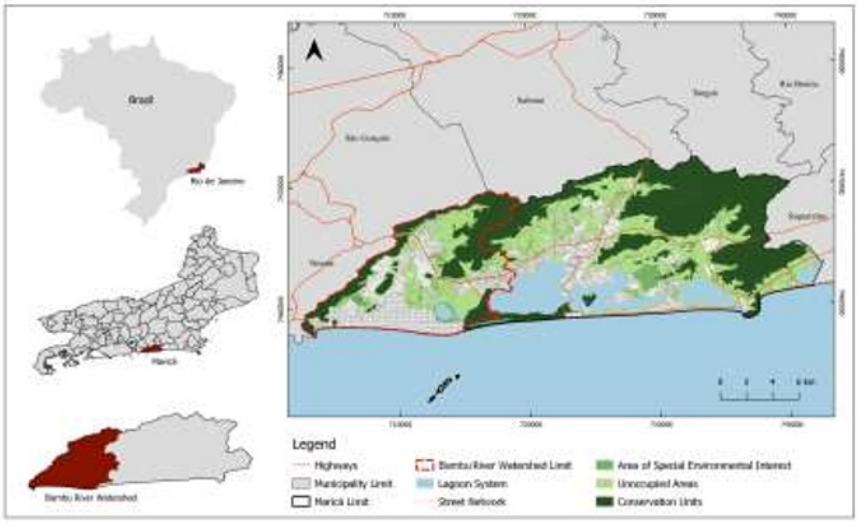

Fig. 2. Geographic location of the Maricá and of the Bambu River Watershed.

4 Results

The following topics present the three stages that lead to the conception of the Environmental Protection Area as a strategy for mitigating floods in the municipality.

4.1 Stage 1: Diagnosis

The Bambu River Watershed has approximately 104.0 km² of area, being responsible for the largest drainage contribution to the Maricá's lagoon complex. The natural landscape is mainly represented by a green belt of mountains and hills covered by natural forests that

compose the Conservation Units that already exist in the municipality, as well as by the smaller scale lagoons. The urban landscape, however, occupies 37% of the territory with a single-family residential pattern, being one of the most densely populated in the municipality. The topography analysis indicates an extensive area of coastal lowlands, where most of the elevations adjacent to the lagoon complex are close to sea level, creating challenges related to stormwater management. Moreover, the absence of rigorous municipal regulation for riverbanks preservation contributes to environmental degradation.

Besides, there has been an increase in the value of urban land and existing buildings, due to recent investments that have been made by the public authorities in this territory, including the review of the Municipal Master Plan [6] and works to improve urban infrastructure. In addition, there is an expectation of part of the population regarding such improvements and the possible impacts on quality of life, tourist attraction, and on the development of local economy. A critical problem identified is the absolutely low collection and treatment of sewage in the municipality, since only a very small portion of the territory is served by sanitary sewage network. The operation of the system fall on individual (and usually nonproper) solutions. In this sense, it is reported that many buildings make clandestine sewage connections in the storm drainage network or release untreated effluent directly into water courses and lagoons.

As a consequence of the urban growth, the Lagoa Brava can be exemplified as one of the main lagoons that have faced a constant degradation process, since it no longer presents its original configuration. Previously, the Lagoa Brava had an expressive water surface that disappeared because of the fluvial system degradation on the last decades. The area of approximately 5 km² became a target for the construction of new real estate developments.

According to the Diagnosis, strengths and weaknesses of the municipality were found. The strengths identified in the Bambu River Watershed shows that the permeability of roads and sidewalks is still largely preserved in the territory, which allows the exploitation of Nature-based Solutions associated with the urban drainage system. The residual open spaces formed by the urban network are favourable to the implementation of multifunctional projects, while the riverine areas can act as temporary reservoirs associated to multifunctional fluvial parks. In addition, the large number of unoccupied lots enables the growth of the municipality without the need to expand even more the urban perimeter. The territory has a good green tissue that allows the consolidation of a Blue-Green Infrastructure system connecting the protected natural areas of the hills with the lagoon system, spreading throughout the built environment, in a capillary green net.

On the other side, the geomorphological configuration of the watershed represents a weakness that contributes to floods in the flatter areas. Concurrently, the lack of environmental management does not constrain the urban growth towards riverbanks and natural floodable areas, generating risks to the population and to the local ecosystems. Besides, although there is a large supply of urban green spaces in the territory, they tend to become the target of real estate speculation. The lack of social equipment, such as public squares, was also perceived as a weakness.

4.2 Stage 2: Prognosis

The main objective of the Prognosis was to estimate the population growth of the municipality in a 10-year horizon (2023-2033), which is the official urban planning horizon in Brazil. Based on the projections of the Brazilian Institute of Geography and Statistics [9], it was considered the order of magnitude of 22,000 new residents for the Bambu River Watershed, which could correspond to 55,57% of the total municipality growth. The obtained quantity indicated that at least 6km² would be necessary to allocate the population,

considering a scenario where new lots would be created, in the business-as-usual procedure in Maricá, representing a typical urban sprawl development.

The study included the identification of vacant allotments in the watershed, to predict the spots with the highest possibilities of occupation in the next decade. These data were crossed with the average income of the inhabitants, offering directions about the tendency of occupation in the municipality. It was estimated that populations with greater purchasing power would occupy the central-east region of the watershed. On the other hand, densely populated areas, mainly composed of irregular housing, tend to occupy regions that already have the same characteristics, as well as the urban fringes. To determine the areas under tensions and threats of urban expansion, we considered the pattern of the municipality of Maricá for creating new subdivisions and occupation by contiguity. The areas susceptible to urban expansion are much larger than the area that would actually need to be occupied to meet the population estimate of 22,000 inhabitants for the next decade.

Subsequently, three scenarios of urban development were created to investigate the densification possibilities of the territory, as illustrated in Figure 3. In the Tendency Scenario (as usual), it was simulated the absence of management regarding the process of urban expansion and densification of the urban area, causing more damages to the natural spaces. The Official Scenario aims to discuss the future application of the macro-zoning proposed in the Municipal Master Plan [6], which provides more restrictive guidelines and creates new Environmental Protection Areas. Finally, the Optimistic Scenario illustrates the desirable conditions for occupation and preservation of the territory of Maricá within a 10-year horizon, through the establishment of guidelines that aim at a systemic planning.

Fig. 3. Scenarios of urban sprawl created for Maricá municipality.

According to the Prognosis, opportunities and threats of the municipality were identified. The opportunities for the Bambu River Watershed are primarily the creation of an integrative Environmental Protection Area with the aim of preserving the functions of the hydrological cycle, taking advantage of the presence of important elements of natural landscape and producing a connected green fabric. Reservoirs to detain and store floods can be implemented mainly upstream of the watershed, while other measures of sustainable water management can also contribute to the requalification of the built environment.

Factors such as the demographic growth, encouraged by the high migratory flow, which can endanger the natural environment due to the disorderly occupation of sensitive areas, were considered as the main threats. Moreover, the urban sprawl over urban transition areas threatens the existing Conservation Units, while the lack of adequate infrastructure causes the release of untreated sewage into the urban drainage system or directly into water courses. The summary of the SWOT Matrix can be seen in Figure 4.

STRENGHTS	***WEAKNESSES***
- Permeability. - Large number of unoccupied lots. - Residual open spaces formed by the urban network. - Good green tissue over the territory.	- Geomorphological configuration. - Lack of environmental management. - Real estate speculation. - Lack of social equipment, such as squares.
OPPORTUNITIES	***THREATS***
- Requalification of the built environment. - Reservoirs to detain and store floods at upstream. - Creation of an Environmental Protection Area	- Urban sprawl over urban transition areas. - Lack of adequate infrastructure. - Demographic growth, encouraged by the high migratory flow.

Fig. 4. SWOT Matrix of the Maricá municipality.

4.3 Stage 3: Action Plan

The proposed Environmental Protection Area (Figure 5) was defined by the inclusion of regions defined by the Municipal Master Plan [6], such as the Rural and Urban Transition Macrozones, as well as Environmental Conservation Units and Areas of Special Environmental Interest. In this regard, the Environmental Protection Area will not be composed only of areas with a nature protection character, but also of a system that allows rural and urban activities to be carried out, as long as they are accompanied by a specific and proper management plan that guarantees the preservation of its environmental functions and quality, focusing primordially on the water cycle conservation. Considering the need to maintain pervious areas inside the lots and also the non-occupation of areas susceptible to flood risks, the public authorities should be responsible for evaluating the activities allowed in the Environmental Protection Area, named as Hydrological Interest Area (HIA).

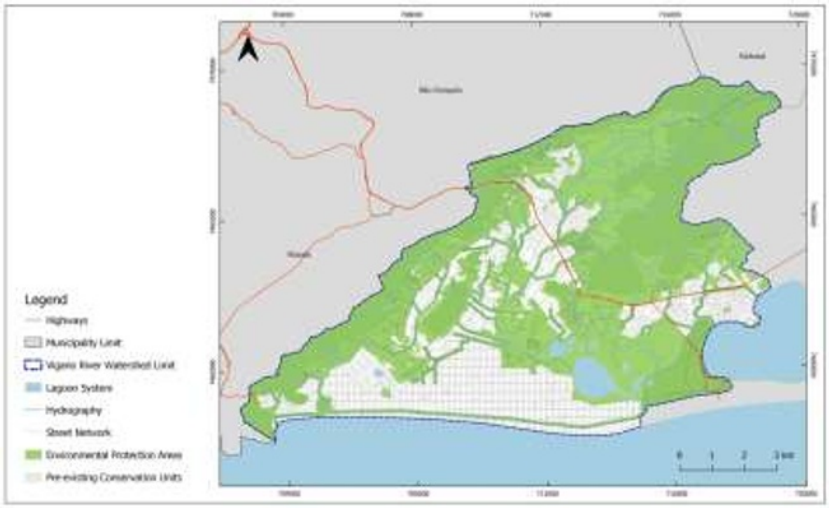

Fig. 5. The conception of an Environmental Protection Area for the Bambu River Watershed.

The HIA contemplates the preservation of flood-prone lands, which should be prioritized for the creation of multifunctional spaces with storage capacity. Furthermore, general urban green spaces may be associated with this sustainable system, such as the squares that can offer social and drainage functions. They can be explored with a view to connectivity between fragments of open spaces in this territory and enhance the recreational use of water. Finally, the conception was based on the optimistic scenario, which foresees that the occupation of inactive subdivisions and the possible expansion into new areas will

occur in a guided manner, so that new developments maintain portions of pervious and vegetated areas inside the lots, favouring the infiltration and recharge processes of the water tables. Rivers or lakes will be used as a priority to discharge the micro-drainage networks according to their flow capacity, while the riverbanks must be protected and reforested.

5 Conclusion

This research aimed to present a method for development of a planning system to target environmental issues related to urban floods and quality green spaces, initially thinking in the municipality of Maricá, a territory composed by large protected natural areas that ensure the conservation of the hydrological cycle in upstream area of the watersheds. The proposed approach can be used in other similar situations where urban developing is in its initial stages, but threatened by possible fast urban growth.

In the Bambu River Watershed, due to the recent uncontrolled urban growth in lowland regions, a significant portion of the territory is currently affected by floods. However, the diagnosis step helped to identify large urban green spaces capable of retarding and storing the water flows, allowing the conception of an Environmental Protection Area with multiple functions. This possibility would allow not only the restoration of local vegetation and the better interaction of the population with the watercourses, but also the recovery of areas that have been gradually impacted by the urban expansion, such as Lagoa Brava. Besides, it is highlighted that the occupation of the Environmental Protection Area would be allowed as long as it is conditioned to the guidelines that prioritize sustainable drainage solutions. Waterways should be preserved, and urban parks associated with stormwater storage facilities could be designed on strategic points of the watershed.

Although applied to the context of Maricá, we consider that the three-stage methodology coupled with the adapted SWOT Matrix, presented in this research, can be applied in different urban contexts, since it has the objective of recognizing the strengths, weaknesses, opportunities, and threats to subside consistent planning actions. Thus, in metropolitan regions that present a tendency for urban sprawl and massive densification, adequate environmental management and the creation of areas of hydrological interest must be seen as goals for creating more sustainable and resilient cities, avoiding the loss of the remaining green areas and their possible offer of ecological services.

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