



METHODOLOGY FOR THE SELECTION OF URBAN DRAINAGE MICRO BASINS FOR MICRO-RESERVOIR IMPLANTATION: A CASE STUDY OF THE TIJUCA BASIN, RJ

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ABSTRACT

More densely urbanized areas are increasingly suffering from flood and flood-related problems due to the lack of capacity of existing drainage systems. Currently, several project alternatives have been presented as unconventional urban drainage measures with the objective of reducing the impacts of surface runoff in urbanized areas, such as the implementation of delay and upstream retention systems, as well as the sharing of responsibility between public and private actors. The present work aims to define specific criteria for the selection of urban drainage basins, which present a greater feasibility of implementing microreservoirs for the abstraction and storage of rainwater in lots distributed in a given region. The methodology consists of the analysis of two distinct areas in Grande Tijuca, Rio de Janeiro, RJ, a region historically strongly affected by urban floods. The selection and hierarchization of drainage basins with the greatest potential for micro-reservoir implantation was performed according to the following criteria: (1) existence of large areas of waterproofing, especially coverings and roofs; (2) reduced efficiency/operational capacity of existing local microdrainage systems; (3) lack of external basins and/or backwater of the receiving body; (4) the potential of the use of stored rainwater. According to established criteria, it is feasible to define priority areas for the implementation of upstream damping by means of microreservoirs in the lots, increasing the possible benefits of using this technique. Future work is recommended to deepen the feasibility studies, with hydrological and hydraulic modeling of the basins and respective drainage systems.

Keywords: Urban drainage; Microreservoirs in particular areas; Upstream retention; Flow peak damping.



1. INTRODUCTION

Urban drainage studies are mainly due to the expansion of urbanization and population densities coupled with the increasing impermeability and lack of planning and control of urban land use (Canholi, 2005). The city of Rio de Janeiro, RJ has observed precipitation events with more frequent floods, especially in the decades of 2000 and 2010, and the Tijuca region was one of the most affected (Castro Corrêa *et al.*, 2017). In the conventional hygienist view, the concept that prioritizes the rapid withdrawal of the downstream deflation predominates, from the use of a system of rain gutters decharacterized by storage conditions. In this way, in some cases, it was verified that simply adopting solutions of this type, such as the rectification and channeling of rivers and the reduction of roughness and the increase of the hydraulic section of the pipes, reduce the concentration time of the basin, with effects on the overlapping of downstream flood spikes, among other hydrological parameters (Tucci *et al.*, 1995).

Based on the concept of damping, based on a successful experience in the city of São Paulo (Canholi, 2005), the Grande Tijuca Flood Control Program (PCEGT, acronym in Portuguese) was started in the city of Rio de Janeiro, under the coordination of the Rio Águas Foundation, with the implementation of four flood damping reservoirs in the Tijuca basin and surrounding areas of an overflow tunnel from the Joana river to the Guanabara Bay (Rio Águas Foundation, 2010). The execution of this program, based on the execution of flood control works in Grande Tijuca, is mainly due to the overloading of the macro drainage system in the Mangue basin, especially the Joana, Trapicheiros and Maracanã rivers (Canholi et Graciosa, 2011).

On the other hand, it can be seen that the problems of greater complexity and scale that currently affect urban drainage cannot be remedied by the adoption of localized initiatives and interventions of a structural nature, as well as the recent experience of these reservoirs. Despite the improvement in the situation, verified in recent years since the implementation of this program and confirmed by the local population itself, the new system, although not fully implemented, was not sufficiently capable of preventing the great flood that occurred in the region in March 2016.

Within a broader perspective, in order to obtain greater effectiveness in coping with and solving these problems, a set of alternatives must be considered, in a holistic perspective capable of encompassing a range of interventions, both corrective and management and planning. Santos (2016) argues that in many countries it is necessary to promote more sustainable drainage measures, also to ensure the sustainability of their water supply systems and to restore the hydrological cycle in the basin itself.

Compared to the large damping reservoirs downstream of the basin, retention/damping solutions upstream of the basin occupy fewer areas, as well as having a reduced cost and decentralizing the operation and maintenance of the systems along the agenda of public administrations and management bodies. These techniques and devices, such as the catchment, infiltration, damping, and retention of the run-offs at source, are already widespread in developed countries such as the USA, Canada and Japan (Canholi, 2005). Green roofs, catchment, and infiltration and/or use of roof water, winding streets, more permeable paving, holding basins and entry section bottlenecks are other examples of the application of this concept (Tucci *et al.*, 1995b).

Another issue that needs to be addressed relates to more recent concepts of sharing responsibility for drainage: in some US cities, new ventures are not licensed or accepted unless they demonstrate the adoption of measures that will impede the increase in the downstream of the sites where they will be installed. In this light, the city of Porto Alegre presented an innovative measure in this sense, only allowing new ventures to generate a maximum increase in flood deflation after its implantation in the respective drainage basin (Porto Alegre, 2014).

The implementation of these concepts applied in Brazilian legislation is still in an incipient form, since only four of the 5,570 municipalities in the country make compulsory the adoption of rainwater accumulation and retention reservoirs for new projects with waterproof areas greater than 500 m². The municipality of Rio de Janeiro addresses the issue in Decree No. 23.940/2004, and the municipalities of São Paulo, Niterói and Nova Iguaçu in Laws 41,814/2002, 2,630/2009 and 4,092/2011, respectively. In addition, the state of São Paulo also applied this obligation when establishing Law no. 12.526/2007. According to Table 1, a summary of the cited legislation can be found.

Specifically in Rio de Janeiro, there are distinct examples of individual and localized initiatives, such as the rainwater harvesting system of the Fernando Rodrigues da Silveira Institute of Application (CAp/UERJ, acronym in Portuguese) (Guimarães, 2016). Located in the Rio Comprido neighborhood, the CAp/UERJ has a reservoir with a capacity of 2,460 liters, used to characterize rainwater at different storage points, with a proposal to use water in less noble activities, such as garden irrigation and cleaning (Souza *et al.*, 2017). In the northern region of the municipality of Rio de Janeiro, the Ari Barroso Park, located in the Penha neighborhood, also has a buried reservoir 3.0 meters wide, 3.0 meters long and 1.2 meters deep, whose contribution area is the roof of the Arena Dicro, with approximately 500 m². The calculations verify that the existing reservoir, with a total volume of 10.8 m³, is sized according to the presented methodologies (Alvarez, 2017).



Following this philosophy, the remodeling project of Praça do Alto in Teresópolis, where the main fair of the city takes place, provides for the implantation of a rainwater system/reservoir for damping and later use in toilets, irrigation and cleaning/wash according to the local demands. The use of damping microreservoirs is not only limited to the state of Rio de Janeiro and Brazil, but is also used in other states such as São Paulo, Federal District, Rio Grande do Sul, Santa Catarina, Espírito Santo, and Paraná. Their employment is already widespread abroad, coupled with the reuse of water, such as in Australia. According to the Australian Bureau of Statistics (2013), more than a third (34%) of households use rainwater collection tanks

installed. Swinburne University of Technology has built two underground reservoirs on its 295 m³ combined Melbourne Campus, Australia, aiming at capturing rainwater from the roofs of certain buildings and using them for irrigation (Imteaz *et al.*, 2009).

The research project started in 2017, made possible through a partnership between technicians from the Department of Sanitary Engineering of UERJ and the Rio Águas Foundation, with the objective of studying solutions to the recurrent and localized drainage problems faced by many regions in the municipality of Rio de Janeiro, from the use of unconventional techniques, such as retention

Chart 1. Aspects and characteristics of legislation pertinent to the use of microreservoirs in Brazil

Location	Law/Decree	Main features	Observations
Rio de Janeiro, RJ	23.940/ 2004	Required for projects with waterproofed area greater than 500 m ² ; Reservoir capacity: 1	Uncovered locations for parking or guarding of vehicles for commercial purposes should have 30% of their area covered with draining floor or with a naturally permeable area.
Niterói, RJ	2.630/ 2009	Required for buildings with water consumption greater than or equal to 20m ³ per day;	Wastewater collection and reuse system in public and private buildings.
Nova Iguaçu, RJ	4.092/ 2011	Required for projects with waterproofed area greater than 500 m ² ; It should delay the arrival of rainwater in the drainage system in two hours	The municipality may create tax incentives for the installation of holding tanks
São Paulo, SP	41.814/ 2002	Required for projects with waterproofed area greater than 500 m ² ; Reservoir capacity: 2	Parking spaces on existing, future and authorized land must have 30% of the area covered with draining floor or with a naturally permeable area.
State of São Paulo	12.526/ 2007	Required for projects with waterproofed area greater than 500 m ² ; Reservoir capacity:	In the case of parking lots and similar, 30% of the total occupied area must be covered with draining floor or reserved as a naturally permeable area.
Porto Alegre, RS	18.611/2014	For land with an area of less than 100 ha, the required reservoir volume should be determined by the equation: $V = 4.25 A_i$, where v is the volume per unit area of land in m ³ /hectare and A_i is the waterproof area of the land in%. The reservoir volume required for areas greater than 100 ha should be determined through a specific hydrological study, with a project precipitation with probability of occurrence of 10% in any year (TR = 10 years).	The area to be computed in the calculation can be reduced, if there is any: Permeable floor application - reduce by 50% the area that uses these floors; Disconnection of roof rails for permeable surfaces with drainage - reduce drained roof area by 40%; Disconnection of roof rails for permeable surfaces without drainage - reduce drained roof area by 80%; Application of infiltration trenches - reduce by 80% the areas drained to the trenches.
Curitiba, PR	293/2006	Obligatory for the licensing of all constructions, there is provision for the implantation of a rainwater harvesting mechanism in the roofs of buildings.	-

Source: The authors themselves (2018)

¹ V: Reservoir volume (m³); k: coefficient of abatement (dimensionless) [corresponding to 0,15]; A_i: Waterproofing area (m²); h: rain height (m) [corresponding to 0,06 m in Planning Areas 1, 2 and 4 and to 0.07m in the Planning Areas 3 and 5].

² V: Reservoir volume (m³); A_i: waterproofed area (m²); IP: rainfall index (m/h)(acronym in Portuguese) [corresponding to 0,06 m/h]; t: rain duration time (h) [corresponding to 1 hour].



and damping at the origin through structures such as microreservoirs.

Considering the increasing importance of applying these techniques to improve urban drainage, including the existence of municipal legislation that encourages its use in RJ, the present work has as its general objective to deepen the knowledge on damping from the use of microreservoirs in private areas.

The following specific objectives were listed: (1) evaluate and propose a methodology for analyzing the potential and feasibility of using this technique, including the possibility of reuse of water collected; (2) to hierarchize the urban drainage basins of selected areas in the Tijuca basin, according to the proposed methodology; and (3) to identify, in the selected areas, examples/cases of buildings that present desirable and appropriate conditions for the implementation of rainwater storage systems in lots.

2. METHODOLOGY

Based on bibliographical research, technical and scientific articles, in addition to consultations with competent bodies, such as the Rio-Águas Foundation, general data on the state of the art of the use of retention devices at source were first collected, especially regarding the methodology/damping technique micro reservoirs. Subsequently, with the support of Rio-Águas technicians, with the experience acquired in the operation and management of these systems in the city of Rio de Janeiro, the process of defining the area to be adopted as a case study was developed, and the Tijuca basin was chosen.

2.1 The study area

Among other aspects, the Tijuca basin was adopted as a study area because it encompasses an extensive area with formal occupation and consolidated urbanization and because it presents many drainage problems, with frequent occurrences of floods, partly because of the saturation of some of their microdrainage systems/networks.

In sequence, data on the study area (Tijuca) were then collected for characterization and contextualization, identifying the existence of flood points due to the insufficiency of the local microdrainage system, among other aspects.

A previous survey of critical points was also carried out, with a breakdown of the areas covered by the main flood spots in the area of interest. In choosing the areas to be evaluated, these sites were avoided because spots, backwaters and other situations of this nature may interfere in the de-

velopment and results of the study. This may occur because inadequate drainage may be happening not because of specific micro-drain network failures, but because of other factors, such as the drowning of its drainage in the macro drainage and the flow of outflow from other adjacent sub-basins.

Data on the boundaries of the basins, sub-basins, projects and registers of the respective micro-drainage networks were obtained from the Rio-Águas Foundation's cadaster sector, which was also consulted regarding the indication of microdrainage systems that are more saturated and/or where there is a greater need for relocation.

In addition to Rio-Águas Foundation data, field information was also used, including consultations with technicians in the municipality, such as: a) the existence/location of more critical drainage areas; b) places where there is extravasation of excess flows from one basin to the adjacent one, due to the loss of rainwater retention capacity in the catchment basin and the efficiency of the conventional system in the drainage network in the basin of origin; and c) sites that suffer greater influence from backwaters of the respective recipient bodies.

Figure 1 illustrates the Tijuca region/neighborhood, including two of its main water bodies, the Joana River and the Maracanã River. Due to the large size of the adopted region, two specific areas to be evaluated were defined as Area 1 and Area 2.

These two areas present characteristics that indicate good potential for the development of studies regarding the adoption of damping devices and the consequent improvement of local drainage conditions. Among these characteristics can be mentioned the existence/occurrence of: (1) high waterproofing, (2) chronic microdrainage problems, observed in practice, even for less intense rains; and (3) good availability of rainfall data and cadaster/design of local storm water networks and galleries.

Area 1 is located further downstream of the basin (Tijuca) in relation to Area 2, and it is located between the Joana and Maracanã rivers. On the other hand, Area 2 drains to Rio Joana. (Figure 2)

While Area 2 has an occupation comprised of building groupings, such as building condominiums, where access roads predominate, Area 1 is predominantly composed of lots and buildings served by roads of the public road network.

Considering that it represents more comprehensively the studied universe (Tijuca Basin) and the reality of this region, Area 1 was then adopted for detailed and specific analysis



Figure 1. Location/situation of the area prioritized for the study (Tijuca), including its main water bodies: Joana and Maracanã rivers. Rio de Janeiro Brazil, 2018

Source: adapted from Google Earth (2018).

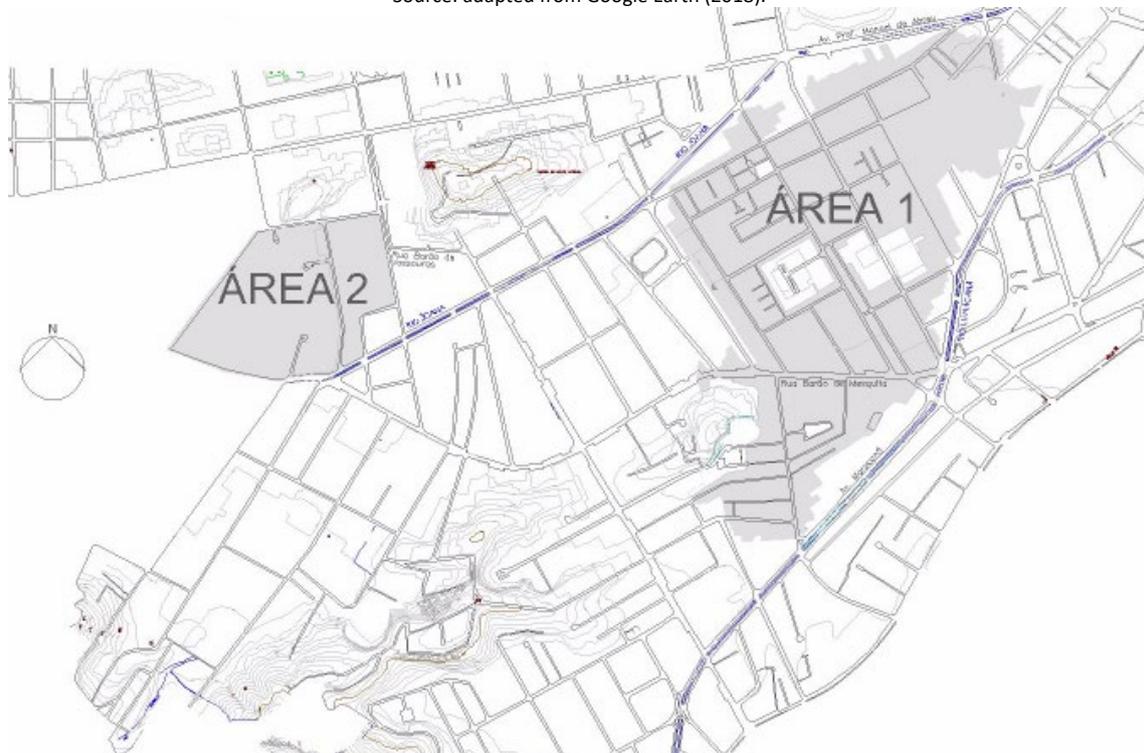


Figure 2. Location of Areas 1 and 2 in the Tijuca region. Rio de Janeiro, Brazil, 2018

Source: The authors themselves (2018)



of micro-basins and respective micro-drainage systems. The limits of these micro-basins were defined based on topographic criteria, grid of the streets and the situation of the networks and available rainwater galleries.

This area was subdivided into the sub-basins A, B, C, D, E, F, E and G to better analyze the characteristics that may justify the use of microreservoirs (Figure 3).

For the determination and ranking of those that will be modeled as a priority, a methodology was developed in which some specific aspects are evaluated that indicate whether or not there is a greater aptitude/viability regarding the adoption of the damping technique using the micro-reservoirs. To guide the prior analysis ten desirable boundary

conditions/characteristics were listed. They are detailed and justified as follows:

1. The micro basin should not receive contribution from external basin run-offs, in order to minimize the influence of external flows that may distort the results and make damping insignificant;
2. Have an area of less than 3 km², in order to allow the use of the Rational Method and the simplification of calculations and later hydrological and hydraulic modeling;
3. It should be provided with a registry of the existing drainage system, which makes it possible to evaluate

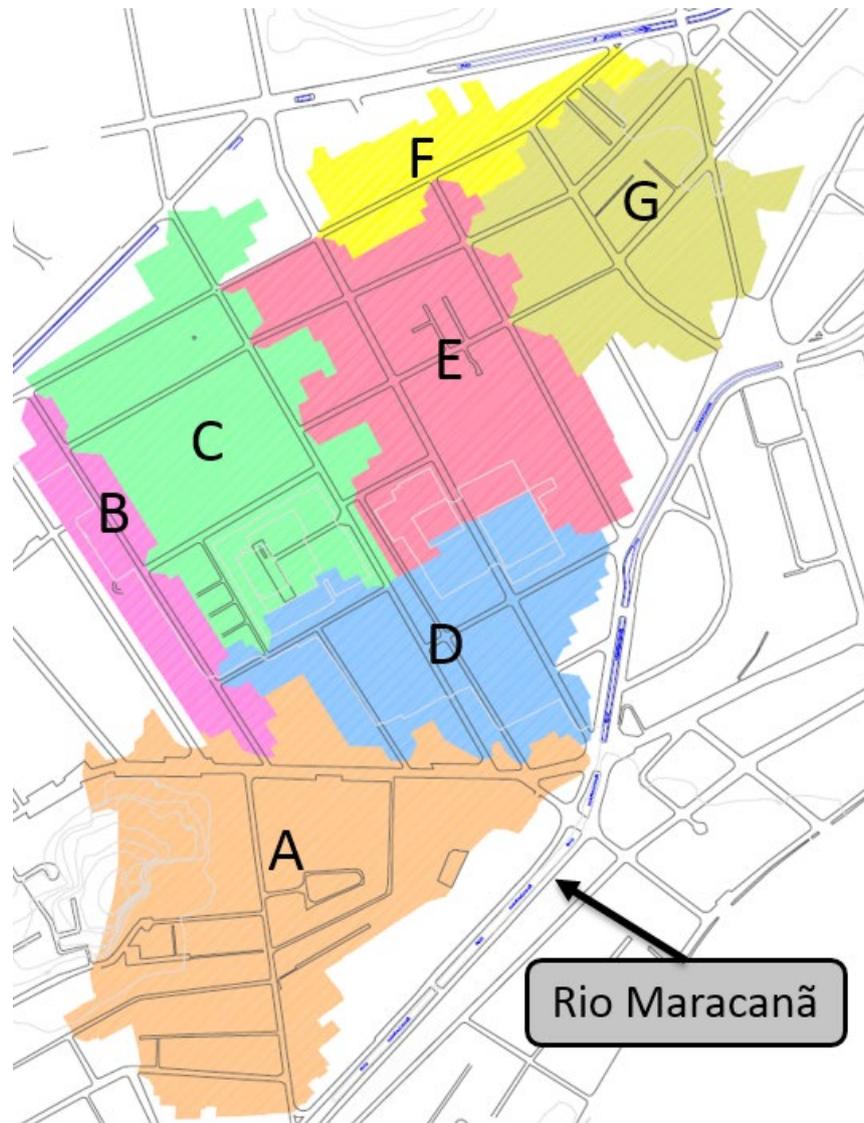


Figure 3. Division of the sub-basins of Area 1. Tijuca Region, Rio de Janeiro, Brazil, 2018

Source: The authors themselves (2018)

Legend: Maracanã river



the hydraulic performance of the galleries in the pre and post-implantation scenarios of damping systems (micro-reservoirs);

4. The existing system should not be functioning properly in the occurrence of more frequent rains, such as those referring to recurrence periods of less than two years. It is evident that in these cases there is a greater interest of the public power in providing an emergency solution to the problem, increasing the viability of the use of lots inside damping systems, which could eliminate or postpone the need to relocate/increase the capacity of the conventional system (galleries);
5. The points of extravasation and/or flooding identified should not be due to the influx of external flows to the watershed and/or to be influenced or caused by macro-drainage backwater phenomena and the receiving water bodies of the drainage systems of the micro-drainage systems under analysis. This aspect aims to prevent the existence of external factors and influences that could disrupt or invalidate the results of the pre- and post-implantation modeling of lots inside damping systems;
6. The area under analysis must have the largest number of micro-reservoir already deployed, making possible an analysis of the functioning and the implantation of damping systems or micro-reservoir for retention in the origin;
7. Contain a greater number of lots with areas equal to or greater than 500 m², which increases the need and feasibility for the implantation of micro-reservoir, from the requirements of the pertinent legislation.
8. Have larger areas of roofs in the lots (built area) and that preponderate in relation to the total area. This aspect increases the feasibility of implantation of damping systems or micro-reservoir in the origin, by the greater capacity of interception and collection of meteoric waters;
9. To have larger individual areas of roofs, which increases the technical and economic feasibility of installing damping systems or micro-reservoirs at the origin, by reducing the required number of these devices to the same damping/storage volume;
10. Have more condominiums or groupings of buildings with floors intended for the garage and green areas. This aspect increases the interest and/or viability of the implantation of damping systems or micro-reser-

voirs in the origin, with a view also to the reuse of the stored water.

For the presence of each criterion a point was assigned; in the event of its absence, it was attributed 0. In the end, the sum of points obtained for each system/micro basin was calculated, with subsequent hierarchization, adopting the same weight or importance for all evaluated aspects.

For purposes of comparison, a column for Area 2, which was assessed as a whole, was added. Then, the sub-basin(s)/ subsystem(s) with the highest score in the overall sum were selected to be the object of a more specific analysis.

For these cases, the different types of areas of lots, covers, roofs and paving, which were confirmed by visual analysis through Google Earth, were identified and quantified with the aid of a tool of the software used (AutoCAD).

Next, the cases of buildings with conditions more prone to the implementation of microreservoirs for reuse purposes were identified in these sub-basins with the aid of the Google Earth Street View tool. For this, it was verified the existence of the elements considered desirable for reuse, among which: large green and common areas; availability of free areas for the construction of reservoirs or cisterns; high number of parking spaces; large areas of covers and roofs; location in an area with a history of water supply problems by the public system; and subjection to the payment of sewage tariff.

3. RESULTS

According to Table 1, it is possible to verify that the drainage micro basins of Area 1 present more indicative characteristics of greater viability regarding the use of microreservoirs in the lots and particular areas.

According to the results, the sub-basins C and E of Area 1 are those with the greatest potential for the development of rainwater harvesting and storage systems. Scoring on all established criteria, these areas meet in a more comprehensive way the desirable characteristics for the feasibility of the use of microreservoirs, in order to reduce rainfall and to take advantage of the stored volumes. It was also verified that Area 2, as a whole, presented a good score.

Based on this previous selection, the sub-basin C of Area 1 was selected for a more specific analysis, distinguishing the types of occupation/paving that make up the basin: street and sidewalk areas, internal streets, and lots. The area of the lots was segregated into a roof area and non-built area, according to Figure 4.



Table 1. Punctuation of the criteria used to determine the greater feasibility of adopting microreservoirs in the micro-basins of Areas 1 and 2. Tijuca Region, Rio de Janeiro, Brazil, 2018

Criteria	Area 1							Area 2
	A	B	C	D	E	F	G	
Does not receive contribution from external basin run-offs	1	1	1	1	1	0	1	1
It has an area smaller than 3 km ²	1	1	1	1	1	1	1	1
It is provided with the existing drainage system register	1	1	1	1	1	1	1	0
The existing system does not function properly in the occurrence of frequent rains, with recurrence periods of less than two years	0	0	1	1	1	0	1	1
The points of extravasation and/or flooding identified are not due to the influence of backwater of macro drainage phenomena and to the water bodies receiving the drainage of these microdrainage systems	0	1	1	0	1	0	1	1
It has the largest number of reservoirs already implanted	1	1	1	1	1	1	1	1
It contains the roof area of the lots (built) greater than a minimum of 40% (*) in relation to the total area	0	0	1	0	1	0	0	1
It has bigger individual roof areas	0	0	1	0	1	0	0	1
It has more condominiums of buildings with more pavements destined to the garage and green areas	0	0	1	0	1	0	0	1
Contains more number of lots with areas equal to or greater than 500 m ²	No information							
Total	4	5	9	5	9	3	6	8

Source: The authors themselves (2018)

Notes: (*) - Value initially arbitrated that will be better measured with the continuity of the research project

The quantification of the areas of the typologies identified is presented in Table 2.

Table 2. Detail of the areas that make up the sub-basin C of Area 1. Tijuca Region, Rio de Janeiro, Brazil, 2018

Typology	Area (ha)	Area (%)
Streets and sidewalk	2,64	22%
Internal streets	0,22	2%
Lots	9,33	77%
Roof area of lots	6,47	53%
Non-built area of lots	2,86	23%
Total area	12,18	100%

Source: The authors themselves (2018)

It can be observed that the roof areas represent approximately 55% of its total area (and 70% of its area subdivided in lots), demonstrating a high degree of waterproofing and great capacity of interception/capture of meteoric water in the roofs. These aspects confirm the choice of this microbasin as a good potential for the implantation of microreservoirs.

Several cases of buildings that have appropriate conditions for the implementation of rainwater storage systems in the lots were also identified in sub-basin C (Area 1). The

building located at Rua dos Artistas (Figure 5) is an example of a building that meets the criteria of selection, having a lot with an area of more than 500 m², a large individual roof area (more than 40% of the total area), besides of pavements for the garage and extensive green area/coexistence, therefore, more prone to use (reuse) of stored water.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the present study, based on a case study from the city of Rio de Janeiro, more specifically from a well-waterproofed and consolidated urban region such as Tijuca, it can be deduced that:

- (1) Among the criteria that enhance the feasibility of damping through rainwater retention in particular areas, can be highlighted: a) the existence of a high available area of roof coverings (preferably with larger surfaces in a smaller number of lots); b) the non-contribution of external basins to the study area/sub-basin; c) saturation of existing drainage systems; and d) the existence of demand for reuse of stored water;
- (2) The proposed methodology for microbasin hierarchization made it possible to establish priorities in relation to the evaluation and selection of areas for



Figure 4. Component areas of the sub-basin C of Area 1. Tijuca Region f, Rio de Janeiro, Brazil, 2018
Source: The authors themselves (2018)



Figure 5. Building located at Rua dos Artistas of the sub-basin C of Area 1. Tijuca Region, Rio de Janeiro, Brazil, 2018
Source: Street View (2018).

the implantation of the technique of lots inside micro-reservoirs, with the objective of damping flood peaks and, secondly, reusing stored rainwater;

- (3) From the analysis of one of the areas classified as priority (sub-basin C), it was possible to identify the existence of several examples of buildings possessing desirable characteristics for the use of damping systems at the origin, according to the criteria defined in the methodology adopted.

As recommendations for the continuity of the research, it is considered of great importance the deepening of hydrological and hydrodynamic studies, in order to simulate the scenarios with and without the implantation of damping reservoirs. The development of the studies will also allow the detailing, rectification and/or ratification of some premises adopted, such as the minimum percentage of roof area in relation to the total area of the lot.

Among the contour conditions adopted, some may be considered more important than others according to the proposed objective. Thus, in future studies, it is interesting



to refine the methodology with regard to the weights assigned to the selection criteria, in order to provide a better hierarchy of the basins/systems to be evaluated.

Considering the existence of buildings that already have microreservoirs in compliance with municipal legislation, it is worth noting that it is necessary to carry out a survey of the cadaster of these constructions and the accomplishment of modeling in order to allow the evaluation of its operation, giving support for improving the application of this technology.

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