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# Environmental Analysis of Springs in Urban Areas–A Methodological Proposal

Milton Pavezzi Netto, Gustavo D'Almeida Scarpinella, and Ricardo Siloto da Silva

***Abstract*****—**The springs located in urban areas are the outpouring of surface water, which can serve as water supply, effluent receptors and important local macro-drainage elements. With unplanned occupation, non-compliance with environmental legislation and the importance of these water bodies, it is vital to analyze the springs within urban areas, considering the Brazilian forest code. This paper submits an analysis and discussion methodology proposal of environmental compliance functions of urban springs, by means of G.I.S. - Geographic Information System analysis - and *in situ* analysis. The case study included two springs which exhibit a history of occupation along its length, with different degrees of impact. The proposed method is effective and easy to apply, representing a powerful tool for analyzing the environmental conditions of springs in urban areas.

***Keywords***—Springs, urban area, Brazilian forest code.

## I. Introduction

STREAMS have always played a central role in the development of cities. They are also landscape elements that are highly vulnerable to a number of hydrological, morphological and ecological modifications intensified by urbanization processes. Of these modifications, [1] emphasizes the basin's impermeability, the structural changes in the river channel, the disposal of rainwater and sewage laden with sediments, nutrients and other contaminants, and the loss of native biota and habitats.

Similar to the threats to these water bodies, the riparian ecosystems are also threatened by local changes imposed by urbanization. These ecosystems can be described as those occurring at the interface between the lotic systems [rivers and streams] and uplands, exhibiting specific pedological, hydrologic and vegetative characteristics. [2] also indicates that the ecological processes of the riparian ecosystems have high habitat heterogeneity and high diversity. Within the landscape ecology context, the areas that encompass these ecosystems, as well as the streams, have the potential to act as linear connection elements within a fragment-corridor-matrix model [3].

Among the legal strategies to protect streams, springs and riparian ecosystems, there is the demarcation of conservation areas or low impact management. In the customary terminology, the terms "riparian management zone", "riparian forested buffer strip", "stream buffer zone" and "protected stream corridor" are highlighted [4]. In Brazil, the correlated protection term is the permanent preservation area (PPA), legally established in 1965 by the Forest Code and restructured by provisional measures in 1989 and 2001. In 2012 a new version of the Forest Code was enacted, which delimits the current criteria for implementing the PPAs. According to the law, these areas are demarcated by measures that vary according to the characteristics of the water body. For springs, the PPAs must have a of 50 meter radius of protection from the water flow point [5].

For streams, the areas must be delineated at the edge of the regular channel by measures that vary depending on the width of the river channel, starting from 30 meters for small streams (of up to 10 meters wide), up to 500 meters for large rivers (greater than 600 meters wide).

The PPAs management principle is the total preservation or restoration of natural conditions. Legally, these areas can only undergo interventions in the case of public utility or social interest, however only through an evaluation by the responsible environmental agencies, in order to minimize the negative ecological effects.

However, despite this protection system, the springs located in urban areas undergo environmental impacts, namely housing (e.g., impermeability of recharge areas, local topography changes), planning strategies that disregard their ecological importance (e.g., due to spatial restriction by roads and diffuse pollution), and urban population lots that are unaware of their environmental value (e.g., solid waste disposal). In order to reverse these impacts and contribute toward improving the environmental protection mechanisms of springs in urbanized territory, this paper proposes, as an assistance tool for environmental management, an expeditious analysis method for potential environmental impacts of PPAs at urban valley bottoms. The method was applied to two springs that have different characteristics of urban human intervention, and analyzed from an effective data collection perspective and representativeness of the variables listed.

## II. Methodology

The proposed method is under development by PAVEZZI-NETTO, M. and SILVA, RS within the scope of a Postgraduate research program in Urban Engineering, São Carlos Federal University (UFSCar).

This is an assessment of the potentiality of the APPs of urban springs and streams to consistently comply with various environmental functions in order to ensure the well-being of human populations, as legally determined by the Brazilian Forest Code (Federal Law No. 12.651/2012).

The theoretical basis of the method related the ecological functionality study of the riparian zones, and their importance in preserving the environmental quality of water bodies and

Milton Pavezzi Netto is with the Universidade Federal de São Carlos, São Carlos, CEP 13565905 BRASIL (e-mail: netpvz@yahoo.com.br).

Gustavo D'Almeida Scarpinella is with the Universidade Federal de São Carlos, São Carlos, CEP 13565905 BRASIL (gscarpinella@gmail.com).

Ricardo Siloto da Silva is with the Universidade Federal de São Carlos, São Carlos, CEP 13565905 BRASIL (corresponding author to provide phone: 55-16-33066582; fax 55-16-3351-8262; e-mail: rss@ufscar.br).

stream biodiversity. Other methods were studied to consolidate the practical aspects, developed for quality analysis of riparian zones and urban water resources, emphasizing the Quality Riparian Index [6] and the Urban River Survey [7].

The method addresses variables related to permeability, human intervention and vegetable strata composition, which can contribute to compliance with the following environmental functions: preservation of water resources, preservation of aquatic and floristic biodiversity, assistance in gene flow aquatic fauna and flora, landscape preservation and soil protection in terms of erodibility.

To analyze the springs, these are divided into four quadrants, considering a radius perimeter of 50 meters, and starting from the initial discharge point, as legally determined by the Brazilian Forest Code.

The data collection process in the sections consists of two stages: aerial imagery analysis using Geographical Information System (GIS), and subsequent *in situ* verifications, with photographic records and notes on the peculiarities of each quadrant analyzed.

Based on aerial images and annotations of each section, a field form is filled out for each fraction, to obtain the following data:

- Area percentage:

A - Of impervious areas;

B - Of permeable areas;

C - Of vegetal cover considering only the herbaceous layer;

D - Of vegetal cover considering only shrub-tree strata;

There is a gradation in the items described above due to delimitation, in GIS environment, in which the one applying the form must select whether this percentage is of up to 5% (representing the score of 0 points), from 6 to 25% (1 point), from 26 to 50% (2), from 51 to 75% (3), from 76 to 95% (4), and higher than 96% (5 points).

E - State of vegetal cover regeneration in shrub and tree strata, provided that:

- The vegetal cover of the strata has an occurrence of 5% or less in the permeable areas (representing the score of 0 points);

- Absence of forest formation and distance between individuals greater than 3 meters (1 point);

- Absence of forest formation and distance among individuals less than 3 meters (2 points);

- Formation of secondary forest, at pioneer or initial regeneration stage (3 points);

- Formation of secondary forest at middle or advanced regeneration stage (4 points);

- Formation of primary forest with no human intervention (5 points);

With the completed form and respective values, a template-form is used, where the characteristics are stratified by score and each score has a color that represents its potential to comply with its environmental functions.

The preservation aspects of the water resources, aquatic biodiversity and aquatic fauna gene flow are evaluated by the sum of factors B, C and D. Its score ranges from 0 to 15 points, going from critical condition to ideal condition in 5 strata values. For the preservation functions of vegetal biodiversity, landscape and gene flow flora assistance, the sum of factors B, C, D and E is considered. This score ranges from 0 to 20 points and the evaluative conditions are identical to the previous one. For the soil preservation function factors A, C, D and E must be added up, which can represent a summation of 0 to 20, and the evaluation condition similar to the previous ones. Table I shows the five evaluative strata of potential compliance with environmental functions, as well as the score of each environmental function:

TABLE I
EVALUATION OF THE ENVIRONMENTAL FUNCTIONS OF PPAS OF SPRINGS

| Environmental Functions | Evaluation Method | Evaluation | Potential compliance of function |
|---|---|---|---|
| Preservation of water resources Preservation of aquatic biodiversity Gene flow assistance of aquatic fauna | B+C+D | 15 | Ideal conditions |
| | | 12 to 14 | High potential |
| | | 6 to 11 | Medium potential |
| | | 1 to 5 | Low potential |
| | | 0 | Critical condition |
| Vegetal biodiversity preservation Landscape preservation Gene flow assistance of aquatic fauna | B+C+D+E | 20 | Ideal conditions |
| | | 15 a 19 | High potential |
| | | 7 a 14 | Medium potential |
| | | 1 a 6 | Low potential |
| | | 0 | Critical conditions |
| Soil protection (erodibility) | A+C+D+E | 20 | Ideal conditions |
| | | 14 to19 | High potential |
| | | 7 to 13 | Medium potential |
| | | 1 to 6 | Low potential |
| | | 0 | Critical conditions |

The final result is a ranking that indicates the level of compliance with environmental functions in each section and indicates which are the positive and negative factors involved in their social adaptation.

## III. Characterization of the Study Area

Two urban springs located in the municipality of São Carlos (SP/Brazil) were used in the case study. São Carlos was founded in 1857 and through an orthogonal urban model structure (as several cities in the world), it outlined the layout of some streets on the banks of the main streams, disregarding the biological issues resulting from such impact and its rainwater drainage role. The development of land subdivisions in the mid 1940s followed no cited orthogonal guideline or road continuity. Thus, many river stretches were channeled, as well as several springs hidden in drainage boxes [8]. The springs studied in this article are inserted in the sub-basins of Tijuco Preto and Medeiros (Fig. 1).

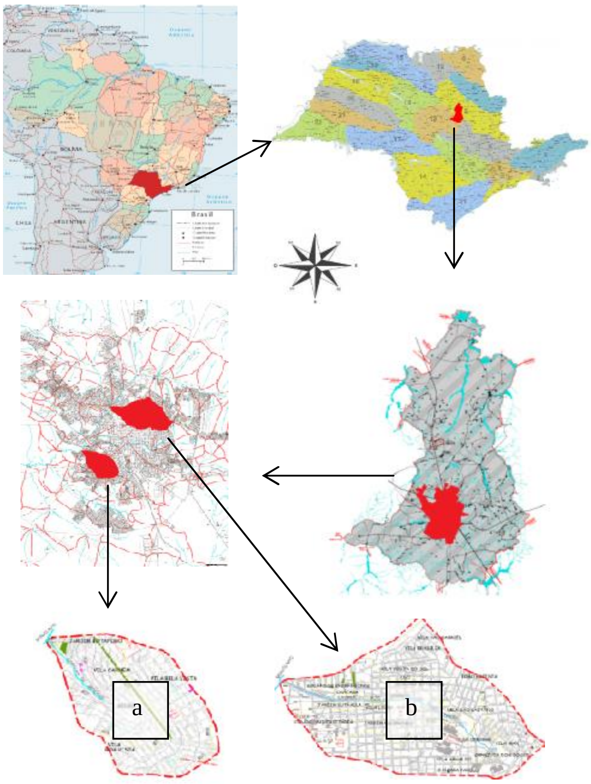


Fig. 1 Representation of sub-basins located in the urban area of São Carlos (SP/Brazil) – a: Medeiros Sub-basin; b: Tijuco Preto Sub-basin (No scale defined)

### A. Tijuco Preto Sub-basin

The spring of the Tijuco Preto stream is at an altitude of 846 meters, under the coordinates 203175.16 E/7563233.03 S (UTM SAD 69, Zone 23S). From the source to the mouth, the stream has a length of approximately 2.900 meters and flows into the Ribeirão do Monjolinho, the main water body of the city of São Carlos (Fig. 2).

Fig. 2 Sub-basin of the Tijuco Preto stream (No scale defined)

Along its length, this stream currently has human intervention of 5 bridges (for the passage of motor vehicles), 2 pedestrian bridges, 2 access roundabouts to other roads (located over the river), a culverted area of approximately 800 meters and concrete channeling of the embankments and river mouth up to approximately 900 meters upstream.

Historically, the regularized occupation of its surroundings began in the 1940s, especially developing in the 1980s and 90s in its intermediate extension. The coverage of the region near the mouth still presents permeable sections, unoccupied by lots.

In 2000, the City was cited for building side roads in the PPA area of some streams within the city without the proper environmental licensing. Among them, the Tijuco Preto stream. Acknowledging the problem that had been created, the city developed a daylighting and restoration project of the river along its initial stretch (after its source) additionally creating a linear park [9].

Fig. 3 indicates the stretch selected for analysis, corresponding to the PPA of the source, and the division of quadrants that were used.


Fig. 3 Quadrants used for the analysis of the PPA of the spring of the Tijuco Preto stream (No scale defined)

### B. Medeiros Sub-basin

The Medeiros stream, from its source to its mouth has an approximate length of 1.400 meters and also flows into the Monjolinho stream, about 3.000 meters downstream of the mouth of the Tijuco Preto stream. Its source is at an altitude of 816m, under the coordinates 200062.09E /7560789.29S (UTM SAD 69, Zone 23S).

In 1982, the Parque do Bicão (Praça Veraldo Sbampato) was implemented around the source of the Medeiros stream, a linear park with an area of approximately 4.2 ha [10]. This park is for physical activities, with sports courts, outdoor gym equipment, walking paths and a lake, originated from damming the Medeiros stream (Fig. 4).

Fig. 4 Sub-basin of the Medeiros stream (No scale defined)

The PPA of the Medeiros stream has a higher homogeneity in terms of tree cover and less human interventions in the river channel, compared to the PPA of the Tijuco Preto stream.

Fig. 5 indicates the passage selected for analysis, corresponding to the PPA of the source, and the division of quadrants that were used.


Fig. 5 Quadrants used for the analysis of the PPA in the Medeiros spring (No scale defined)

## IV. Results and Discussion

[8] Reports that the damage done to the springs and water bodies are the outcome of not only deforestation, but also the impermeability, modifications, occupation of floodplains and receiving excess rainfall (which was infiltrated before). Added to this the disposal of solid waste, inert or not, that can alter the conditions around the river and the water bodies.

The nominal preservation actions, in the case of the two springs studied, shows the government's concern by acknowledging the importance of water resources and the provision of a protection zone, even if insufficient, according to what the law determines.

### *A. Tijuco Preto Source*

The source of Tijuco Preto represents most of its revegetated PPA, due to environmental qualification actions undertaken by the Municipality since 2000. As urban structures within the PPA, a stretch of paved marginal road was taken into account, exhibited in quadrants 1 and 4, and a parcel of lots in quadrant 1. Because of the high vegetative cover rate, there were no low qualifications in any of the environmental functions group. However, *in situ* verification showed that that the herbaceous vegetal cover, unverified in the GIS environment, was incipient in stretch 01. This finding, when combined with the impermeability condition imposed by the presence of the lot parcels, resulted in this stretch being classified as average for all functions. Table II shows the qualification of the quadrants for certain functions in the method.

TABLE II
Potential Compliance of Environmental Function in the PPA of the Tijuco Preto Source

| **Functions** | **Quadrant** | **Ranking** | **Potential environmental function compliance** |
|---|---|---|---|
| Preservation of Water Resources<br>Preservation of aquatic biodiversity<br>Gene flow assistance of aquatic fauna | 1 | 10 | Medium |
| | 2 | 14 | High |
| | 3 | 13 | High |
| | 4 | 12 | High |
| Preservation of vegetal biodiversity<br>Landscape preservation<br>Gene flow assistance of flora | 1 | 12 | Medium |
| | 2 | 18 | High |
| | 3 | 17 | High |
| | 4 | 18 | High |
| Soil protection (erodibility) | 1 | 12 | Medium |
| | 2 | 14 | Medium |
| | 3 | 14 | Medium |
| | 4 | 14 | Medium |

Although the classification evidences high compliance potential, some negative conditions were verified *in situ*. Inert and non-inert solid waste disposal was found in quadrants 1 and 3, the presence of invasive species was detected in all quadrants, underlining leucaena *(Leucaena sp)* and guinea grass *(Panium maxinum).* The spring is also partially silted, probably due to the soil movement processes in the higher areas during the construction in the lots closer to quadrants 1, 3 and 4. Quadrants 2 and 4 had the best qualifications, set apart from the others due to the presence of well diversified vegetation cover. Based on these assessments, as intervention measures for this PPA the suggestions are: the reduction and control of invasive species in all quadrants, the growth of vegetation in quadrants 1 and 3, and changing the residents' perception regarding these quadrants through campaigns and environmental education initiatives for the residents in these surroundings.

### *B. Medeiros Source*

Created to preserve the Medeiros source, Parque do Bicão presents high socio-environmental potential proposal, as it incorporates the spring and the first stretch of the stream into an area dedicated to physical and cultural activities. Although the proposal has significant potential in terms of environmental education, the park does not receive much maintenance and the human interventions near the source interfere with its main biological role.

Quadrants 1 and 4 have most of its part inserted within the boundaries of the park. Although in terms of vegetation cover they are favorably represented, these quadrants are characterized by having most of the human interventions necessary to operate the park. Some of these interventions are low stone-walls, cement stairs and benches in quadrant 1, sidewalks, low-walls and highly impermeable outdoor gym in quadrant 4, and boundary fences of the Park, and a concrete channel to drain the source flow in both stretches. These quadrants have high potential compliance function in terms of preserving the water resources and aquatic fauna, with the aggravating condition, the first that should be modified, being the concrete channeling of the initial stretch of the stream shortly after the source.

Quadrants 2 and 3, in turn, have a portion of their extensions in the area outside the park with paved structures and buildings predominating. Although not fully vegetated, these quadrants showed high potential compliance function of water resources and aquatic fauna preservation. Also due to the fact they have impermeable parcels and high vegetal cover in the permeable plots, they were classified as low erosion potential and high soil protection rate. This condition was also not achieved in sections 1 and 4 due to the presence of exposed soil parcels (low coverage by herbaceous (low coverage by herbaceous strata). Table III illustrates the qualification of the quadrants for the specific functions in the method.

TABLE III
POTENTIAL COMPLIANCE OF ENVIRONMENTAL FUNCTIONS IN THE PPA OF THE TIJUCO PRETO SOURCE

| Functions | Quadrant | Ranking | Potential compliance of environmental function | |
|---|---|---|---|---|
| Preservation of Water Resources<br>Preservation of aquatic biodiversity<br>Gene flow assistance of aquatic fauna | 1 | 14 | High | |
| | 2 | 10 | Medium | |
| | 3 | 13 | High | |
| | 4 | 14 | High | |
| Preservation of vegetal biodiversity<br>Landscape preservation<br>Gene flow assistance of flora | 1 | 16 | High | |
| | 2 | 14 | Medium | |
| | 3 | 14 | Medium | |
| | 4 | 14 | Medium | |
| Soil protection (erodibility) | 1 | 13 | Medium | |
| | 2 | 15 | High | |
| | 3 | 13 | High | |
| | 4 | 15 | Medium | |

No negative conditions were verified for waste disposal or misuse of the area. It is likely that the main cause for the absence of such adversity is the adaptation form of the area, consolidated as a recreational space, with high circulation of people. The following are indicated as management recommendations: increase the vegetation cover in all strata in quadrants 1 and 3, and replace the channel in the initial stretch of the stream with a low impact containment structure, similar to the one used in the Tijuco Preto stream.

## V. CONCLUSION

Although there is a great demand for private occupation in urban spaces, a set of environmental planning strategies is possible and necessary in order to achieve full compliance conditions with the biological functions of water bodies in their ecosystem and landscape areas.

Therefore and within this context, support tools for decision making in urban areas are relevant for the feasibility of greater control of these specific areas, as well as awareness by government and society.

The method used was expeditious, efficient and inexpensive, considered suitable to support urban policy decisions that need to be taken within a short period of time.

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