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Analysis of the Conservation Status of Urban Springs in Brazil: a case of study in São Carlos/SP

Análise do Estado de Conservação de Nascentes Urbanas no Brasil: um estudo de caso em São Carlos/SP

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Abstract

Springs play an important role in maintaining the hydrological cycle, thus spring management is essential for improving the population's quality of life. In this sense, this research aimed to analyze the conservation status of three springs in the watersheds of Mineirinho and Paraíso streams located in the city of São Carlos/SP, Brazil, in order to understand the possible causes of their conditions. We applied the Integrated Assessment and Monitoring Protocol for Springs of Water Streams (PANÁgua), whose structure is summarized in three stages: field assessment, bibliographic research, and analysis using Geographic Information Systems (GIS). We identified that the three springs in both studied watersheds are in a poor conservation status. There is evidence that most impacts present in all three springs are related to intense anthropic actions that resulted in a lack of natural vegetation, the presence of strong erosion processes, irregular dumping of sewage, and pluvial water runoff. Furthermore, the disposal of various solid residues in the Permanent Preservation Areas (PPA) of the studied springs was also observed. The results show the need to prioritize environmental management actions in urbanized watersheds, as well as expand research on the status of watersheds in Brazil.

Keywords: Water resources management; Permanent preservation area; Watershed

Resumo

As nascentes têm um papel importante na manutenção do ciclo hidrológico, portanto, o manejo das nascentes é essencial para a melhoria da qualidade de vida da população. Nesse sentido, esta pesquisa teve como objetivo analisar o estado de conservação de três nascentes nas microbacias dos córregos Mineirinho e Paraíso localizadas na cidade de São Carlos/SP, Brasil, a fim de compreender as possíveis causas de suas condições. Nós aplicamos o Protocolo Integrado de Avaliação e Monitoramento de Nascentes de Córregos (PANÁgua), cuja estrutura se resume em três etapas: levantamento de campo, pesquisa bibliográfica e análise por meio de Sistemas de Informações Geográficas (SIG). Nós identificamos que as três nascentes em ambas as microbacias estudadas estão em mau estado de conservação. Há evidências de que a maioria dos impactos presentes nas três nascentes estão relacionados a intensas ações antrópicas que resultaram na falta de vegetação natural, presença de fortes processos erosivos, despejos irregulares de esgoto, e escoamento de águas pluviais. Além disso, também foi observada a disposição de diversos resíduos sólidos nas Áreas de Preservação Permanente (PPA) das nascentes estudadas. Os resultados mostram a necessidade de priorizar as ações de gestão ambiental em bacias hidrográficas urbanizadas, bem como ampliar pesquisas sobre a situação das bacias hidrográficas no Brasil.

Palavras-chave: Gestão de recursos hídricos; Área de preservação permanente; Bacia hidrográfica

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1 Introduction

The tropics comport an extensive part of the terrestrial biological diversity and are crucial for the maintenance of life on Earth, guarding more than 78% of the world's species (Barlow et al. 2018). Only in Brazil, which is the nation with the largest volume of freshwater on the planet, 15% of all plant and animal species exist in Brazilian territory (Barlow et al. 2018; Mello et al. 2020). As the technological, scientific, and economic evolution has been taking place, exploitation of natural resources progresses gradually (Gadotti 2010), generating socio-cultural, economic, and environmental disparities that have become part of the Brazilian reality, highlighting the importance and need for the sustainable use of natural resources. Thus, in urbanized areas, oil and water contamination are recurrent due to their exposure, the high amount of untreated domestic and industrial effluents, overexploitation, climate change, among others (Bezerra et al. 2018; Guerrero et al. 2018).

Environmental problems related to water resources are reflections of human actions in spring ecosystems, defined as areas on the Earth's surface that are influenced by the exposure and/or flow of groundwater (Stevens et al. 2021). Anthropic impacts decrease the quantity and quality of water, negatively affecting the population and several ecosystems through not sustainable practices (Tarpani & Brandão 2009; Cantonati et al. 2020). At the municipal level, this reality is not different. Population growth in small cities in the State of São Paulo was guided by the accelerated and disordered development process that occupied and used land inappropriately (Costa et al. 2012; Costa et al. 2013). One of the main consequences of this inordinate growth is the suppression of springs, which affects water quality, its use by living beings and the correct functioning of the hydrological cycle (Roberti, Gomes & Bittencourt 2008; Conti, Hanai & Menezes 2014).

Springs are extremely important for the maintenance of the environmental services offered by water, as well as the hydrological process, as it is responsible for the connection between groundwater and surface water, forming river channels in addition to protecting and conserving the most diverse species of fauna and flora (Felippe & Magalhães Junior 2009; Rosso Pinto 2019). Therefore, the management of watersheds and the preservation of springs are necessary to improve the quality of life of the population (CBRN 2009). Despite their worldwide importance and abundance, groundwater dependent ecosystems are one of the most threatened environments and are often scientifically neglected, which results in serious harm to their ecosystems and can even lead to their disappearance (Springer & Stevens 2008; Glazier 2014).

Given the above, the present research aimed to identify, analyze, and compare the conservation status of three springs in the watersheds of Mineirinho and Paraíso streams, which are located in the city of São Carlos/SP, Brazil, in order to understand the possible causes of their environmental degradation. Here, we chose to apply the Protocol for Integrated Assessment and Monitoring of Springs of Courses of Water (PANÁgua), developed by Rosso Pinto (2019). This protocol is a useful tool that determines the conservation status of stream springs, summarizing and presenting their environmental conditions. Developed through scientific research and by a validation process involving researchers, specialists, and users of the tool, PANÁgua comprises different application stages and evaluation categories that combine a series of parameters and indicators, allowing an integrated assessment and monitoring of the environmental conditions of springs and their surrounding areas.

2 Methodology

2.1 Study Area

We analyzed, in June of 2019, three out of four springs distributed in two watersheds located in São Carlos/SP (Figure 1), namely: Watershed of Mineirinho and Paraíso streams, which are inserted in the Water Resource Management Unit 13 (UGRHI 13) of Tietê-Jacaré (Dornelles 2006). The fourth spring (red dot, Figure 1) was not analyzed due to difficult access. Spring's areas are occupied mostly by residences, a shopping mall, a university campus, sugarcane crops, pastures, and land without vegetation cover (Pontremolez 2013). The watersheds are at an average altitude of 856 meters (IBGE 2018) and the city's population is approximately 249,415 inhabitants, with a population density of 195.15 inhabitants/km² (IBGE 2018). The climate is characterized by two seasons, with a dry season from April to August, and a wet season from September to March. The minimum average temperature is 16 °C and the maximum is 26.7 °C (INMET 2019).

2.2 Protocol for Integrated Assessment and Monitoring of Springs of Courses of Water (PANÁgua)

To assess the current status of the springs, we applied the Protocol for Integrated Assessment and Monitoring of Springs of Courses of Water (PANÁgua), developed by Rosso Pinto (2019). We visit both watersheds in the daytime to visually characterize the environmental condition in the field, as required by the used protocol. The protocol was chosen due to its recent elaboration, its parameters and indicators that allow an integrated and holistic analysis of the environmental conditions of springs and their respective surrounding areas. The protocol parameters were evaluated using the ordinal scale adapted from Likert (1932) (Table 1), as provided by the PANÁgua.

The protocol is based on three stages, due to the need to analyze different scales going from local assessment to watershed scale analysis. The three stages are, respectively: (i) Evaluation of environmental conditions in the field, (ii) Research on conservation and recovery actions developed, and (iii) Evaluation of environmental conditions using Geographic Information Systems (GIS).

The first stage of the protocol consists of an evaluation of environmental conditions in the field. This is done through the analysis of three categories: spring interferences, physical integrity of the soil, and characteristics of land use and occupation around the source. In this phase, due to the difficulty of accessing the springs, we adapted the protocol in relation to the criterion "qualitative monitoring". Adjustments can be necessary for the application of these instruments since features of water bodies can change according to climate, topography, geology, and vegetation (Guimarães, Rodrigues & Malafaia 2017).

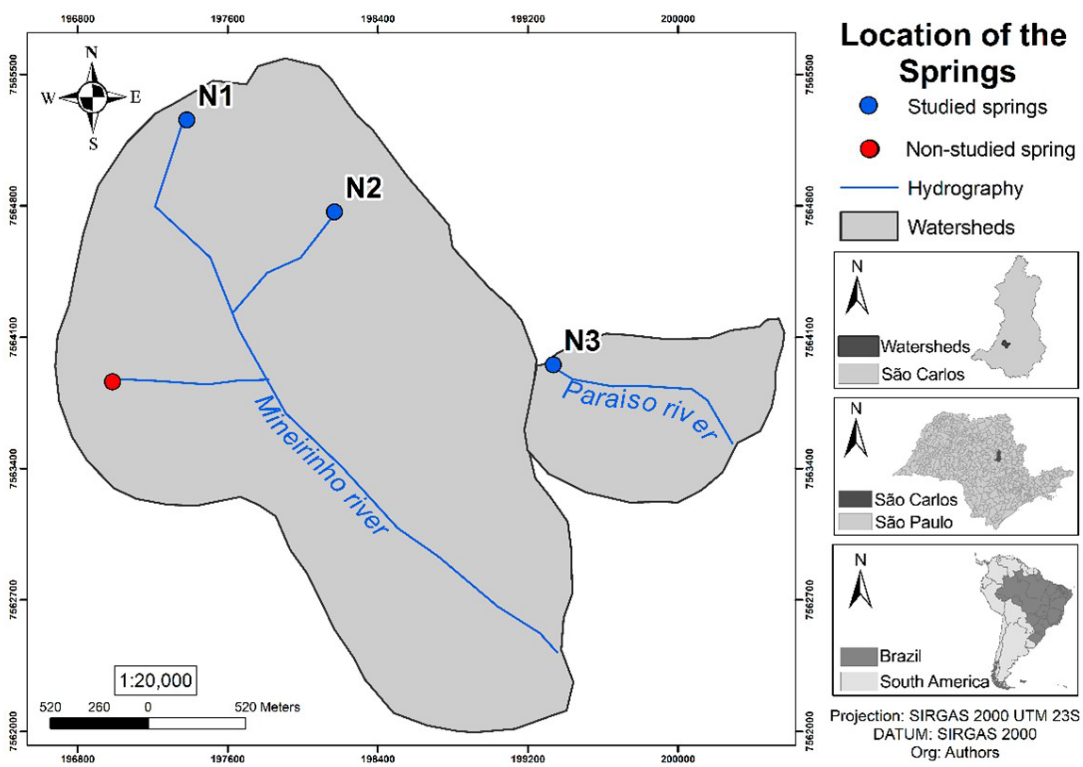

Figure 1 Location map of the studied watersheds and springs. Blue dots represent the studied springs. N1 and N2 belong to the Mineirinho watershed, and N3 belongs to the Paraíso watershed. The red dot represents the non-studied spring in the Mineirinho watershed.

Table 1 Scale of evaluation of the parameters. Adapted from Likert (1932).

Scoring	Qualitative Concept
4 to 5	Excellent
3 to 4	Good
2 to 3	Regular
1 to 2	Bad

For the second stage, 'research on conservation and recovery actions developed', we used observation in the field, bibliographic research on platforms for articles, reports, dissertations, theses; and bibliographic research using the Integrated Water Resource Management System of the State of São Paulo (SigRH) and the Master Plan of São Carlos. We collected data related to the development of projects, programs, plans, and actions for the conservation and/or recovery of the springs, following the protocol parameters. To optimize the search, we used the keywords: springs, spring suppressions, spring recoveries, and spring monitoring. Since all analyzed springs belong to the Tietê-Jacaré Water Resources Management Unit (UGRHI 13), we used the same calculation and grades for all springs in this stage.

Lastly, the third stage 'evaluation of environmental conditions using Geographic Information Systems (GIS)' combines two categories: the existence of natural vegetation around the spring, and characteristics of land use and occupation around the spring. These categories consider parameters and indicators which require analyzes of areas larger than the interface area, defined as the area consisting of the 50-meter width continuous to the PPA (Permanent Preservation Areas, according to Brazilian law), as specified by Rosso Pinto 2019. Thus, the area of 1-kilometer buffer around the spring was applied for this stage using GIS, as established by the protocol, which was based on Fumagalli et al. (2017). For this phase, it was necessary to obtain and process spatial data, such as water network, identification of the springs, and the 1-kilometer buffer for mapping the land use and occupation classes. The mapping of land use and occupation classes was elaborated using supervised classification, and the tools "Segment Mean Shift" and "Maximum Likelihood Classification". We used LANDSAT 8-OLI satellite images, with a 30m spatial resolution, a 12-bit radiometric resolution, and the mapping has a scale of 1:20,000. These images were acquired through the Earth Explore data platform. The following classes were identified: urban area, pasture, silviculture, free area, and agriculture. As a result, we obtained shapefiles of the surrounding areas and the area in hectares was calculated for each class. This process generated the final map of land use and occupation, allowing the evaluation of the parameters. Further details about the specifications of the PANÁgua can be found in Rosso Pinto (2019).

In each of the three stages described above there are specific parameters and indicators that allow the collection of information necessary for the application of the protocol, and each stage results in a grade according to the adapted Likert (1932) scale. For stages 1 and 3 of the protocol, grades for each stream were obtained using Equations 1 and 2 shown below, where 'Sci' is the sum of the result of the categories, 'P' is the weight of each parameter, 'n' is the score given to each parameter, 'Pci' is the weight of each category and 'Se' is the total sum for each stage.

$$Sci = \Sigma(P.n) \, . \, Pci \tag{1}$$

$$Se = \Sigma Sci \tag{2}$$

Furthermore, the final grade, characterized as the overall conservation status of the springs, was calculated through the integration and weighting of the results of the previous three stages following Equation 3, where 'Sn' is the final result for each spring, 'Se' is the total sum for each stage; and 'Pe' is the weight of each stage.

$$Sn = \Sigma(Se \, . \, Pe) \tag{3}$$

3 Results

The results are organized to comparatively present the conservation status of the springs in each stage of PANÁgua in the two studied watersheds. Detailed tables regarding information for each stage and spring can be found in the Supplementary Material. The values for each spring regarding the 1st stage of the protocol were obtained using Equations 1 and 2, resulting in the lowest classification according to the Likert (1932) scale, as shown in Table 2 below.

Results for the second stage are depicted in Table 3, with all springs classified as 'regular', according to the Likert (1932) scale. As the basins of the Mineirinho and Paraíso streams belong to the UGRHI 13, the plan of this UGRHI was used for all three springs in the second stage. We identified some actions for the conservation and recovery of springs from the UGRHI 13, for instance: elaboration of environmental awareness activities about the importance of sustainable use and conservation of water resources, identification of PPAs of springs, projects aiming the restoration of springs and riparian forests (UGRHI 13 basin plan), database of the basins and watersheds of UGRHI 13 containing information regarding the PPA of rivers and springs, the establishment of different criteria to define priority areas for forest restoration projects, and elaboration of maps for identification and characterization of springs (Forest Restoration Master Plan). Additionally, we found articles with the common aim of evaluating the environmental quality of water resources in the studied watersheds (Tarpani & Brandão 2009; Silva et al. 2014; Silva et al. 2016; Tanajura & Leite 2017).

Table 2 Results of the 1st stage of PANÁgua.

Spring	Watershed	Qualitative Concept
N1	Mineirinho stream	1.586
N2	Mineirinho stream	1.456
N3	Paraíso stream	1.931

Table 3 Results of the 2nd stage of PANÁgua.

Parameters	Scores
Evidence of the development of the PPAs reforestation projects	1
Establishment of programs or actions aimed at the conservation and / or recovery of springs in the plan of the hydrographic basin to which it contributes	5
Establishment of programs or actions aimed at monitoring the quality of spring water at the level of the hydrographic basin to which it contributes	1
Development of inspection actions by the responsible entities, in compliance with Brazilian Law 12.727 of 2012 (Forest Code) in relation to the PPA of the hydrographic basin to which the assessed spring contributes	1
Establishment of programs or actions for environmental awareness about the conservation of springs in the watershed plan to which it contributes or in other documents related to the management of water resources and watershed planning	5
Development of training projects for rural producers on edaphic, vegetative and mechanical good practices (e.g. organic fertilization, forest restoration, contour crops, permanent vegetation strands, rotated grazing, construction of terraces, among others)	1
Existence and/or permanence of cultural traditions that promote the springs conservation (e.g. intentions of respect, admiration and care, recognition of importance, sustainable use)	1
Result	2.14

For the third stage, the map of use and occupation of the spring's surrounding area (1 km buffer) can be found in Figures 2 (for N1 and N2 springs) and 3 (for N3 spring). There is a predominance of urban areas in the N1 spring (57.88%), followed by agriculture (26.64%) and natural vegetation (13.78%). At the N2 spring, the urban area also predominates (75.6%), followed by natural vegetation (16.41%) and free areas (3.81%). For spring N3, there is a predominance of urbanization (84.41%), followed by free areas (8%) and natural vegetation (7.59%) in the buffer.

The result of the 3rd stage for springs N1, N2 and N3 is shown in Table 4, with all springs classified as 'bad', according to the Likert (1932).

3.1 Conservation Status of the Springs

The final conservation status of the springs was obtained through the integration and weighting of the results of the previous stages, using Equation 3. Results for each spring are depicted in Table 5 below. All springs received the overall classification as 'bad'. Based on the results, we elaborated a thematic map containing information about the environmental conditions of the springs in the watersheds of Paraíso and Mineirinho streams (Figure 4).

4 Discussion

By applying the Integrated Assessment and Monitoring Protocol for Springs of Water Streams (PANÁgua) (Rosso Pinto 2019), we found evidence that springs of the watersheds of Mineirinho and Paraíso streams are in a poor conservational status, which can alter the availability of water as well as its quality, with impacts that might reverberate beyond the local area.

Spring N1 (Figure 5A) is the main source of the Mineirinho stream and is located close to a public square which is frequently used by the local population, even though there are signs indicating the existence of the PPA. Although this proximity to the community can become a positive aspect of their awareness, several impacts observed might point in the opposite direction, as supported by the grades attributed for the spring in the first stage. Exclusively in this spring (N1), due to its easy access, it was possible to perform the microbiological analysis of E. Coli and total coliforms using the COLIPAPER microbiological kit method (e.g. Loiola & Costa Sobrinho 2020). The result expressed in CFU/100 mL is between 93 and 96 Total Coliforms (violet to blue dots; pink to red) and 58 and 60 E. Coli (violet to blue dots), for a single sample.

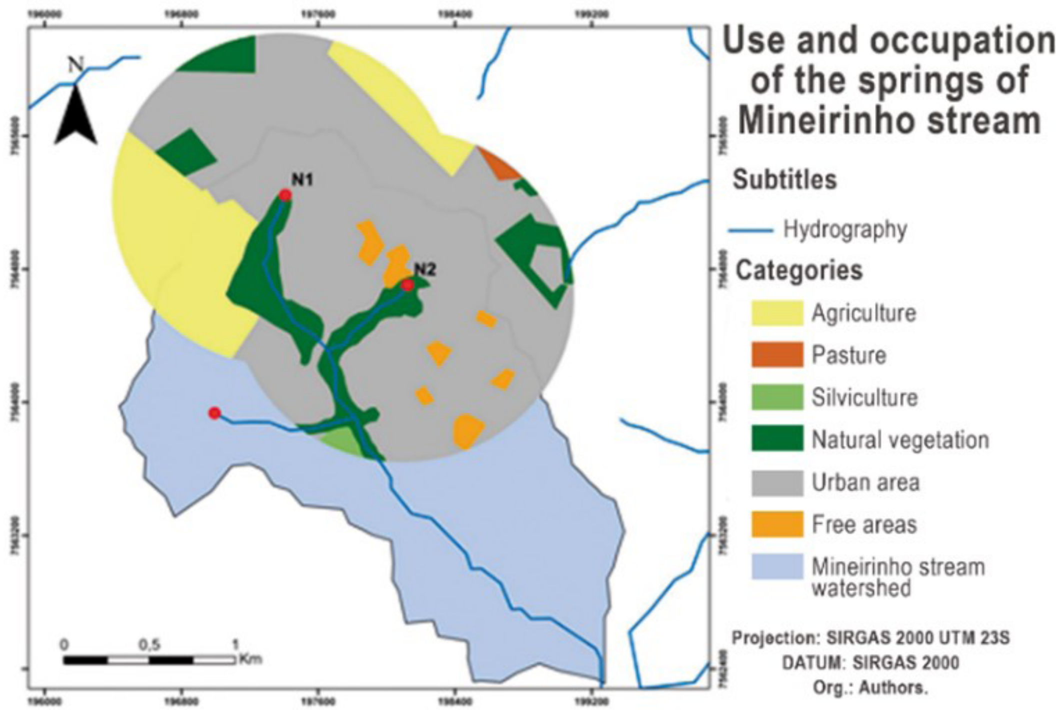

Figure 2 Map of use and occupation of the N1 and N2 springs of Mineirinho stream watershed.

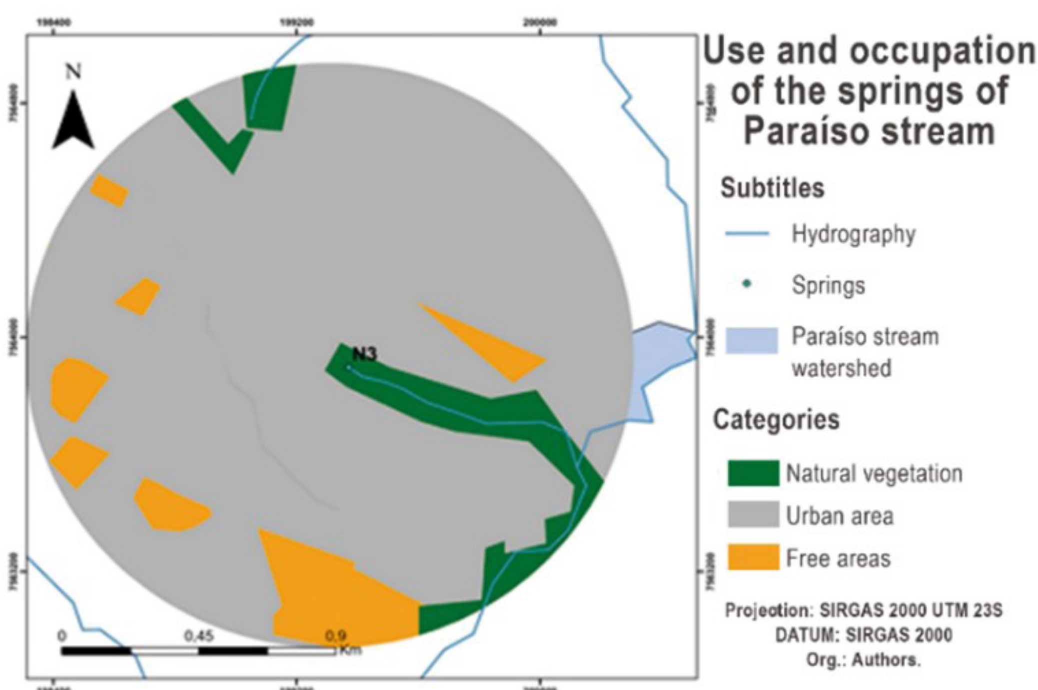

Figure 3 Map of the use and occupation of the N3 spring of Paraíso stream watershed.

Table 4 Results of the 3rd stage of PANÁgua.

Spring	Watershed	Qualitative Concept
N1	Mineirinho stream	1.36
N2	Mineirinho stream	2.08
N3	Paraíso stream	1.72

Table 5 Overall results for the springs N1, N2 and N3.

Spring	Watershed	Qualitative Concept
N1	Mineirinho stream	1.584
N2	Mineirinho stream	1.680
N3	Paraíso stream	1.899

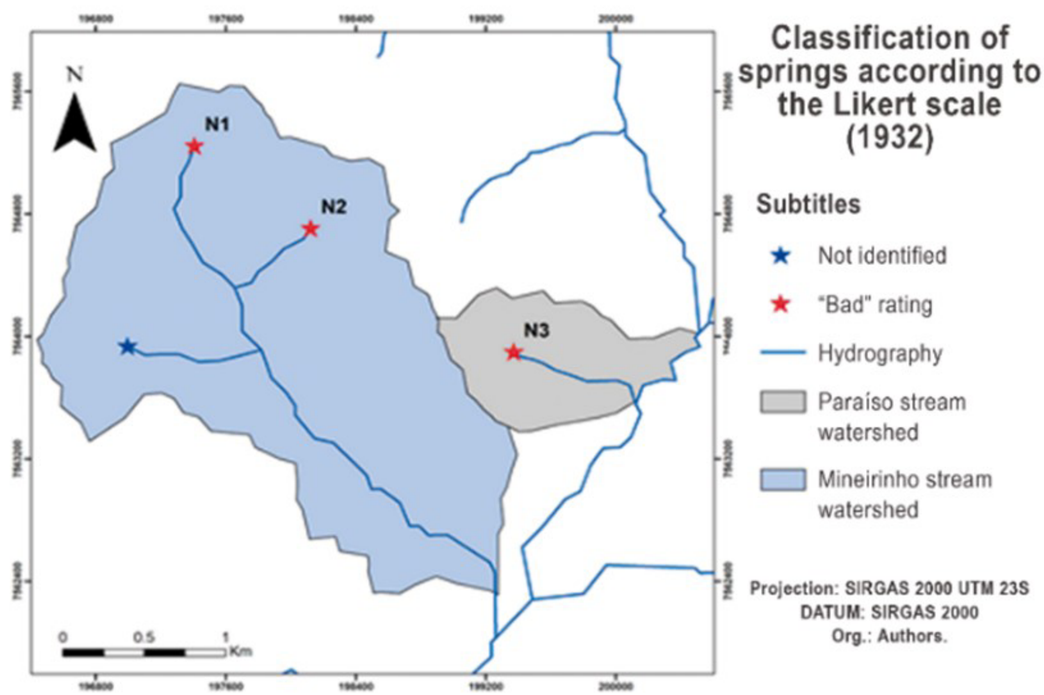

Figure 4 Classification of the springs of the watersheds of the Mineirinho and Paraíso streams. N1 and N2 belong to the Mineirinho watershed, and N3 belongs to the Paraíso watershed. Red stars represent springs classified with the "bad" rating. Blue star represents the non-studied spring.

The high concentration of fecal and total coliforms at the spring location of the Mineirinho stream indicates that there are other pathogenic organisms that offer risk to public health equal or bigger than the coliforms. The predominance of a high number of total coliforms is justified by this category to assemble a large number of bacteria that are not only present in the digestive tract of mammals, but also in the soil (Costa et al. 2012).

However, Reche, Pittol & Fiuza (2010) stated that the contamination of irrigation water with thermotolerant coliforms is not necessarily related to the presence of human or animal feces, since the genera Klebsiella, Citrobacter, Enterobacter, and Aeromonas are not exclusive to human or animal feces but are generally present in unpolluted waters. Moreover, observations in the field pointed to the presence and release of sewage and pluvial water runoff as the impacts that most degrade the spring's location (Rosso Pinto 2019). This was identified due to the characteristic odor of the water, its color, and the result of the microbiological analysis. Solid waste predominates in the landscape in contrast with little natural vegetation, leaving the spring area exposed and prone to erosion, as previously observed by Jacob (2010). Consequently, the integrity of the soil was found to be critical, with the spring located in a strong erosion gully, as well as evidence of earthmoving by machinery and the presence of animals such as dogs and horses within the PPA area. Regarding the characteristics of land use and occupation around the spring, including its PPA and interface area, there was a strong degradation of natural vegetation with a predominance of exotic species. The proximity of this area to the local urban occupation may be the result of an unplanned occupation that often leads to an environmental imbalance (Conti, Hanai & Menezes 2014).

Similarly, spring N2 (Figure 5B), where the Santa Fé stream originates (Jacob 2010), is in a critical condition, with several impacts such as constant discharge of contaminated effluents and sewage, solid waste left by the population, construction waste, car parking, and animal husbandry. Beyond that, spring N2 was found buried due to silting, representing an intense erosion in the site. Human activities have been found to lead to drying up of springs and reducing regular flow regimes in Nepal, which could similarly happen in other regions (Chapagain, Ghimire & Shrestha 2019; Ghimire, Chapagain & Shrestha 2019). There is also strong soil compaction both in the PPA area and in the interface area, with no presence of natural vegetation. The use and occupation of the surroundings has a predominance of urban areas, contributing to the degradation of the spring, which does not have any form of protection or isolation (e.g. absence of information signs).

Figure 5 Condition of the springs of Mineirinho (N1 and N2) and Paraíso (N3) streams: A. Erosion in the spring N1 (Jacob 2010); B. Erosion gullet in the spring N2 PPA; C. Solid wastes in the spring N3.

Finally, spring N3 (Figure 5C), where the Paraíso stream is born, has several interferences at the spring location, with emphasis on the presence of solid waste and discharge of sewage, easily identified by the pipes present upstream of the stream and by its characteristic smell. Erosive processes in the PPA and its interface area are very worrying, since it allows rainwater to be drained, contaminating the spring and destabilizing the soil, which may result in possible accidents at the site due to the considerable flow of people. The transit of animals was also evident, such as dogs and cats. Natural vegetation in the PPA, nonetheless, is reasonable, but with a predominance of exotic species. However, there is a building in the interface area and the vegetation is scarce due to urbanization. Furthermore, the predominant land use and occupation class is the urban area, which indicates a certain degree of anthropogenic activities at the spring location. The easy access to the PPA area and the interface area allows the population to use the site, which is done in a poorly manner probably due to the lack of environmental awareness evidenced by the existence of solid waste distributed on the site and by the burning practices observed in the field. Regardless of the importance of this spring to the studied area, little to no studies characterizing the spring condition were found.

The result of the second stage, investigated as one for all springs, demonstrates that there are actions for the conservation and/or recovery of the studied springs, but it was not possible to identify its implementation. To verify this, interviews with the local community should be conducted to understand if the actions to preserve and recovery were implemented and if they were effective.

Although spring N2 was found buried, the lowest grade of conservation status according to the protocol was for spring N1. In addition, it was necessary to adapt the first stage of the protocol due to difficulty in assessing the spring area. However, there is no clear information described in the protocol regarding how to adapt the instrument. This raises the question of how these assessment tools should be used to support decision-making processes on water resources management and watershed planning. Indeed, an integrated analysis such as the one provided by the PANÁgua considers a variety of different parameters with distinct weights for the final calculation, supporting the holistic interpretation of the environmental status of springs. It is unquestionable the use of these instruments to support processes of assessment, monitoring, conservation, and management of spring areas (Guimarães, Rodrigues & Malafaia 2017). However, it is necessary to look beyond the value given by the tool for the definition of priorities and strategies for recovery, mitigation and or conservation of springs.

5 Conclusions

For all springs (N1, N2 and N3), the state of conservation was classified as ‘bad’ according to the scale used. The evaluation of the springs allowed the identification of the most critical impacts that affect them, such as pluvial water runoff, release of sewage, and improper disposal of solid waste. These and other impacts considerably affect the native vegetation and the physical integrity of the soil, also contributing to the destabilization of the hydrological cycle at the site. Furthermore, there is evidence that these impacts in the studied springs are the result of intense urbanization in the PPA and interface areas. Thus, the springs suffer strong anthropic pressure, putting their natural resources at risk, including the availability of water in the watersheds, a subject of great relevance for the city in question. The status of the springs may be a consequence of the strong urbanization and the inappropriate use of the areas next to the springs, which is evidenced by the environmental degradation. The observed impacts might be the outcome of the lack of understanding and environmental awareness regarding the importance of water resources for the maintenance of life.

For the conditions of the springs in the watersheds of Paraíso and Mineirinho streams, the PANÁgua proved to be an easy, precise, and effective tool, mainly because it makes use of several indicators and parameters, allowing the analysis of different conditions of springs. However, some adaptations were necessary due to the difficulty in accessing the spring areas. Nevertheless, the results indicate the need to prioritize environmental management actions in the watersheds of Mineirinho and Paraíso streams, aiming to improve environmental conditions and provide the best conservation strategy of the springs.

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Author contributions

Giovanna Collyer: conceptualization; formal analysis; validation; writing – original draft; writing – review and editing**. Maurício José Rosso Pinto:** methodology; validation; funding acquisition; writing – review and editing. **Elvineide Máximo Alves da Silva:** conceptualization; writing – original draft. **José Marrugo-Negrete:** writing – review and editing. **Frederico Yuri Hanai:** conceptualization; validation; writing – review and editing; supervision.

Conflict of interest

The authors declare no potential conflict of interest.

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