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Analysis of water quality in springs in different types of land use using the soil-cement method

Análise da qualidade da água de nascente em diferentes tipos de uso do solo após recuperação pelo método solo-cimento

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Abstract: For a long time, spring water was considered pure and clean due to the natural filtration that occurs during the infiltration and movement of spring water through deep and shallow aquifers. However, due to the increase in anthropogenic activities, spring water has shown contamination problems. Various methods for spring recovery are found in the literature, especially in rural areas where spring water is used to supply the population. In the southeast region of the state of Paraná, Brazil, farmers have been applying the soil-cement method to improve the quality of spring water. However, there are few studies on the efficiency of this method. The objective of this article is to evaluate whether there has been an improvement in water quality after three years of using the soil-cement method in springs located in different types of land use (pasture, faxinal, forest, agriculture, and urban). Water samples were collected before the recovery, one year after, and three years after the recovery. At the end of the research, we observed an improvement in water quality, with areas with grazing animals showing the best recovery indices. Some parameters indicated significant improvement, such as E. coli, total coliforms, and turbidity.

Keywords: Recovery; Springs; Water quality.

Resumo: Durante muito tempo, a água das nascentes foi considerada pura e limpa, devido à filtragem natural que ocorre durante a infiltração e movimentação da água de nascente através de aquíferos profundos e rasos. Mas, devido ao aumento das atividades antrópicas, a água das nascentes tem apresentado problemas de contaminação. Na literatura são encontrados diversos métodos de recuperação de nascentes, principalmente em áreas rurais onde a água das nascentes é utilizada para o abastecimento da população. Na região Sudeste do estado do Paraná- Brasil, os agricultores têm aplicado o método solo-cimento para melhoria da qualidade da água das nascentes. No entanto há poucos estudos sobre a eficiência deste método. O objetivo deste artigo é avaliar se houve melhoria na qualidade da água após três anos da utilização do método de solo-cimento em nascente localizadas em diferentes tipos de uso do solo (pastagem, faxinal, floresta, agricultura e urbano). Foram coletadas amostras de água, antes da recuperação, um ano após e três anos após a recuperação. Ao término da pesquisa observamos que houve melhoria na qualidade da água e as áreas com animais pastando, indicaram os melhores índices de recuperação. Alguns parâmetros indicaram melhoria significativa como *E. cole*, coliformes totais e turbidez.

Palavras-chave: Recuperação; Nascentes; Qualidade da água.

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1. Introduction

Water is a natural resource available in various forms in nature; however, its quality can change due to natural and anthropogenic processes occurring in the environment. Among the anthropogenic actions that affect water quality are: industrial activity waste (TOMASZEWSKA et al., 2020), agriculture (CHAKRABORTY et al., 2016), grazing animals (Wen et al., 2017), the impact of urbanization (ESTRADA-RIVERA et al., 2022), environmental degradation due to mining (BARRAL et al., 2021), emerging pollutants (ARMAN et al., 2021), among others. Therefore, all these sources of pollution have led to a water crisis, which has social, economic, and environmental origins (ELLIS and RIVETT, 2007; VOROSMARTY et al., 2010).

Data from the United Nations (UN) indicates that 2.2 billion people worldwide lack access to safe drinking water. In developing countries, this issue is responsible for 80% of diseases and deaths. During the 20th century, water consumption increased sixfold relative to the growth of the global population. Currently, 26 countries face chronic water scarcity, and it is projected that by 2025, this problem will affect 52 countries and 3.5 billion people (KUMMU et al., 2016).

In recent decades, numerous researchers have employed various models to enhance the accuracy of water quality predictions. These models can be categorized into two primary types: conventional models and artificial intelligence (AI)-based models (RAJAEE et al., 2020). Further research endeavors aim to determine pollution levels in rivers and lakes by identifying the pollution sources (ALTENBURGER et al., 2019). It is noteworthy that the majority of water quality projects are conducted in rivers and lakes.

Research on the improvement of water quality in springs is nascent. However, there are a range of studies proposing methods for spring recovery: restoration and implementation of vegetation in spring areas (WINSA and BERGSTEN, 1994; CASTRO RIBEIRO et al., 2012); construction of vegetation buffers around streams and springs (BOURGEOIS et al., 2016); and maintenance of the riparian zone (XIANG et al., 2016).

Among these various techniques for the restoration of rivers and springs, there is a method widely used on small rural properties in southern Brazil known as the soil-cement method, which involves isolating the spring (SOARES et al., 2021). However, little is known about its efficiency in improving water quality.

Given this context, this research aimed to evaluate the efficiency of the soil-cement method used for spring recovery. This study sought to answer several questions, such as: a) Is the soil-cement method efficient in improving water quality? b) Do the types of land use around the spring affect water quality even with the spring fully restored? c) Does extensive livestock farming interfere with water quality?

To answer these questions, three water sampling campaigns were conducted at springs with different types of land use such as: agricultural area, forested, extensive livestock farming (faxinal), and urban areas. It is worth noting that research on the soil-cement technique is nascent, making this a pioneering study in evaluating the efficiency of this method.

2. Soil-cement method

The soil-cement method involves manually cleaning the area around the springs, removing organic materials such as roots, leaves, branches, and mud. Subsequently, fragments of rock are placed to fill the entire spring, followed by the installation of pipes. The spring is then sealed with a mixture made from sieved soil, cement, and water (in a ratio of 3 parts soil to 1 part cement). After preparing the mixture, a small reservoir is created to store water, which is filled to its maximum capacity with rock blocks (it is recommended to use igneous rocks) (Figure 1). It is important to note that the rock fragments are intended to filter the water.

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Figure 1 – Recovery of the spring through the soil-cement method. A) Spring is to be recovered. B) Spring cleaning. C) Mixture of soil and cement. D) Construction of the mini dam. E) Spring being covered by rock fragments. F) A recovered and functioning spring.
Source: Authors (2024).

Along with the addition of rocks, pipes are installed that perform different functions (Figure 2). The vertical pipe is used for the addition of bleach and chlorine, when necessary, for water disinfection. However, this practice is not common among farmers who use this technique.

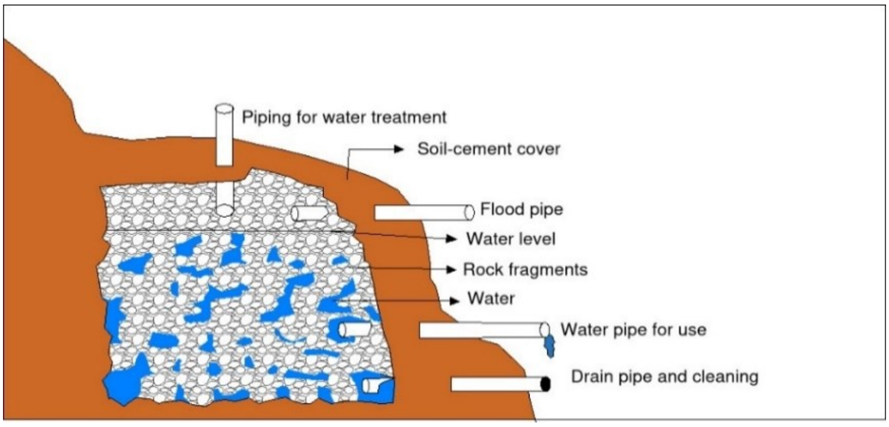


Figure 2 – Sketch of how a spring recovered by the soil-cement method functions. Adapted from Crispin et al. (2012).
Source: Authors (2024).

Above the water level inside the spring, a tube is installed to act as an overflow valve for excess water during rainy periods. Without it, there could be a rupture of the micro dam. Near the surface of the spring, a tube is installed for cleaning the internal structure of the spring. Approximately 25 cm above the spring bed, a tube is installed to export water from the interior of the recovered area for consumption and/or to follow the normal course of the river.

3. Methodology

The municipality of Prudentópolis is located in the Southeast Paraná Geographical Mesoregion, with an estimated population of 52,513 (IBGE, 2020). It is situated at Latitude 25º 12' 47" S and Longitude 50º 58' 40" O, with an average altitude of around 840 meters.

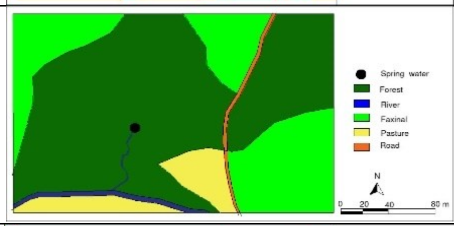
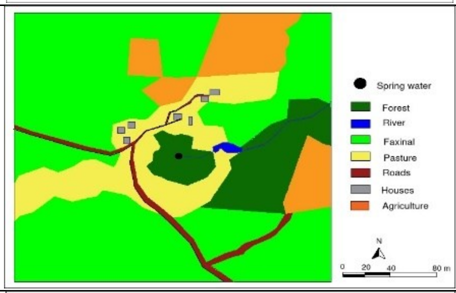
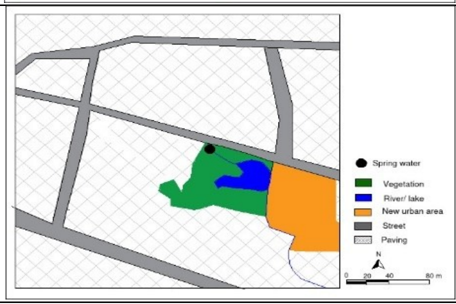
The agriculture practiced in the municipality, according to the classification of IAPAR (1995), falls within the conglomerate denominated C13, which defines the region with a high participation of temporary crops, mainly tobacco, corn, and beans, using family labor and animal traction. It is also composed of pastures, native forest, reforestation, and fallow areas associated with very low use of agro-industrial inputs and motorization. Additionally, there is the use of agricultural practices with low technology employing rudimentary implements and tools, mainly due to the predominance of small properties, where a significant portion of the agricultural area is dedicated to tobacco cultivation (ANTONELI, THOMAZ, and BEDNARZ, 2022).

Intermingled with the agricultural areas are fragments of Araucaria Forest used for extensive animal husbandry known as the Faxinal System. It is worth noting that the Faxinal System is a characteristic peasant organization form in Southern Brazil, based on family farming, collective use of resources, and collective labor in silvopastoral activities (ANTONELI, OLIVEIRA, and BEDNARZ, 2019).

3.1. Data Collection

The selected spring areas for this research followed a pattern of representativeness, meaning that various springs were visited in each type of land use, and those indicating similar characteristics were chosen (Table 1).

Table 1 – Characteristics of land use and occupation of the researched spring water.

Land Use	Spring water characteristic	Land use characteristics
Agriculture	Located under coordinates 25º14'12''S and 50º59'38''W. Around this spring, there is soybean and tobacco cultivation, with little vegetation around. Average slope of 10%. Deficient riparian forests with points of margin erosion.	
Forest	Mixed rain forest, without the presence of domestic animals. Located between coordinates 25º09'55''S and 51º01'09.'' Preserved riparian forest. Upstream slope: 14%, without bank erosion	
Faxinal	Extensive animal breeding area without conservation practices. Animal contact with rivers. Degraded riparian zone. Slope: 10%.	
Urban	Residential area with a 75% built area. Adequate basic sanitation. Located at coordinates 25º12'19.''S and 50º58'34.''W. The vegetation consists mainly of herbaceous plants.	

Source: Authors (2024).

As water samples were collected before the implementation of the soil-cement method for spring recovery, one year after implementation, and three years after recovery. This chronosequence with three distinct periods can demonstrate the potential efficiency of this technique over time. Three samples were collected from each spring, totaling 15 samples per campaign. The collected water was stored in sealed containers, properly labeled for transportation to the laboratory.

In the laboratory, the samples were analyzed following the standard methodology outlined in the "Standard Methods for Examination of Water and Wastewater" (APHA, 2018). The parameters analyses were: turbidity, pH, phosphorus, alkalinity, total coliforms, and Escherichia coli.

The characteristics of each land use and the surroundings of the springs were observed through fieldwork and aerial imagery analysis to quantify landscape fragments around the springs.

3.2. Data analysis

Principal component analysis (PCA) explored possible clusters between the land use of springs and their recovery time on water quality parameters (alkalinity, *E. coli*, pH, phosphorus, total coliforms, and turbidity). The Kaiser criteria was used to consider the significant components.

We modeled relationships between water quality parameters and factors: recovery time (three levels) and land use of springs (five levels) on a general linear mixed model (GLMM). The times after disturbance were not independent; therefore, we considered this factor as a repeated measure in the GLMM. The assumptions of the Gaussian distribution were checked using the Shapiro-Wilks test and log-transformed data when necessary. The significance level for all analyses was 5%. Analyses were carried out using RStudio software, version 4.0.2 (RSTUDIO, 2020).

4. Results and Discussions

Springs are widely recognized for their physical diversity and are abundant point sources of biodiversity and productivity, often holding substantial ecological, sociocultural, and economic functions and values (HERSHLER et al., 2014; MULLER et al., 2017). However, they have been impacted by anthropogenic activities (STEVENS et al., 2021), highlighting the importance of methods and techniques for their restoration.

Upon analyzing the data, we identified well-defined clusters strongly related to land use and occupation, as well as the water quality parameters of the springs determined in this study. According to the principal component analysis (PCA) diagram (Figure 3), cluster formation was primarily driven by the variables: Time (loading = 0.86), E. coli (-0.72), Total coliforms (-0.70), and Turbidity (-0.47), explaining approximately 34% of the clustering. Notably, as the recovery time of the springs increased, these parameters decreased, given their negative correlation indices. Other variables, including Phosphorus (-0.86), pH (-0.71), and Alkalinity (-0.47), explained around 28% and are more related to PCA2, represented in the ordination diagram as the perpendicular axis.

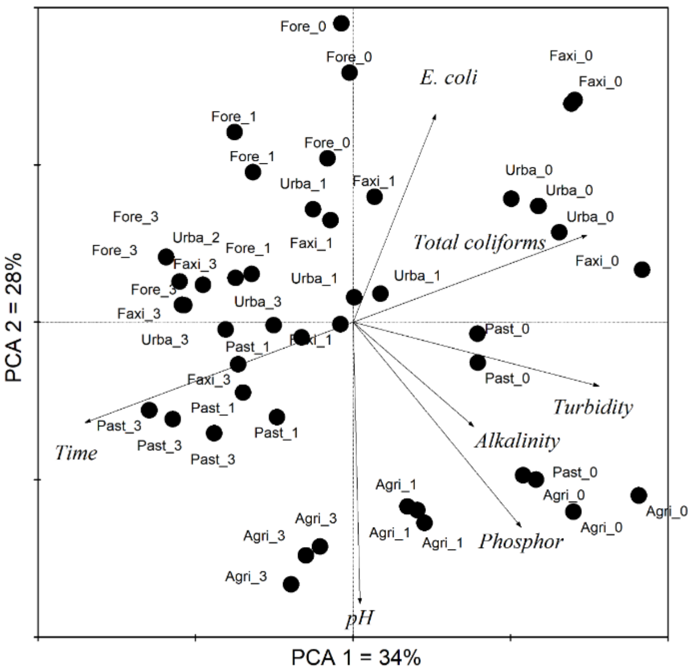


Figure 3 – Ordination diagram of the principal component analysis for water quality parameters as a function of recovery time in different types of land use and occupation (Agri - Agriculture; Urba - Urban; Fore - Forest; Past - Pasture; Fax - Faxinal Systems).
Source: Authors (2024).

The lower right quadrant is occupied by springs located in pasture and agricultural areas at time zero (before recovery) and agricultural areas after one year of recovery. These samples are associated with parameters such as Turbidity, Alkalinity, Phosphorus, and pH. The lower left quadrant mainly comprises pasture areas after recovery (one- and two-years post-recovery) and agricultural springs (two years of recovery). These samples are associated with the recovery time of the springs.

The upper left quadrant contains samples with the best water quality. This quadrant includes water samples from the Mixed Ombrophilous Forest across the three collection periods (zero, one, and three years). It also includes two urban areas and two faxinal system areas, both after two years of recovery. The upper right quadrant comprises springs with the worst water quality parameters: springs located in urban areas before recovery (time zero) and faxinal system areas (time zero). These samples are strongly related to high values of E. coli and total coliforms.

Through the analysis of variance calculated using the generalized linear mixed model (GLMM), it is evident that all parameters were significantly influenced by the recovery time. Regarding land use and occupation, it can be stated that only alkalinity was significantly influenced exclusively in the urban area. Therefore, there was no statistical difference in the alkalinity of spring water between the mixed ombrophilous forest and the urban area. However, there was a statistical difference between the other variables (Table 2).

Table 2 – Components of the Variance Analyses of the generalized linear models for water quality parameters of springs as a function of recovery time in different types of land use and occupation.

Dependent Variables	Effects	Degrees. f Freedom	F	P	R^2
	Springs	4	2.12	0.15	
Alkalinity	Time	2	17.57	<0.01*	0.85
	Time*Springs	8	9.05	<0.01*	
	Springs	4	15.73	<0.01*	
E. Coli	Time	2	65.72	<0.01*	0.91
	Time*Springs	8	6.43	<0.01*	

pH	Springs	4	9.30	.002*	0.87
	Time	2	14.06	<0.01*	
	Time*Springs	8	6.99	<0.01*	
Phosphorus	Springs	4	47.75	<0.01*	0.98
	Time	2	11.94	<0.01*	
	Time*Springs	8	1.96	0.11	
Total coliforms	Springs	4	11.84	<0.01*	0.96
	Time	2	86.22	<0.01*	
	Time*Springs	8	7.73	<0.01*	
Turbidity	Springs	4	14.19	<0.01*	0.87
	Time	2	33.68	<0.01*	
	Time*Springs	8	7.21	<0.01*	

Source: Authors (2024).
**Significant Results.*

It is worth noting that only Phosphorus did not show a significant interaction between the spring recovery time and the type of land use and occupation. In this context, the other variables fluctuate in value as the spring recovery time increases (Figure 4).

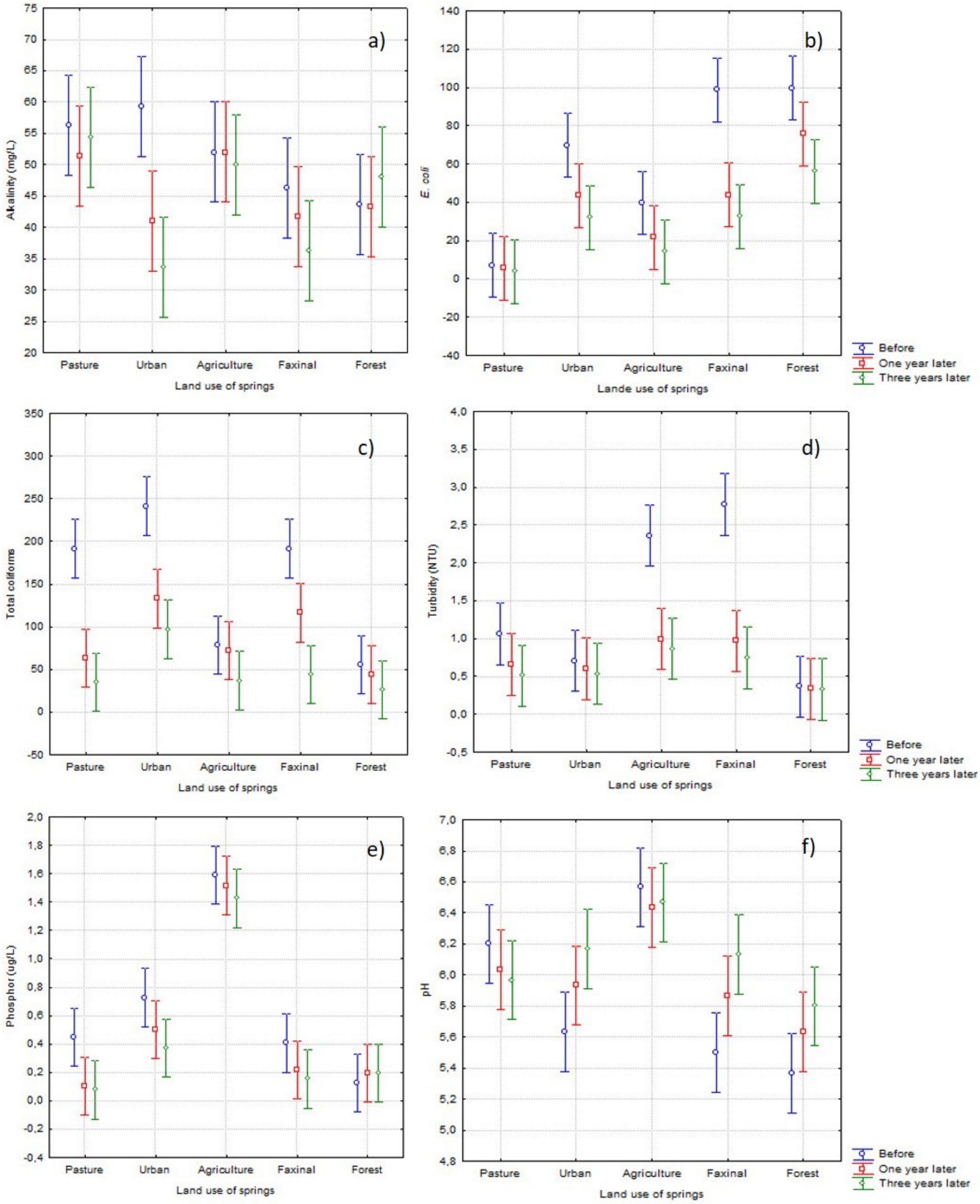


Figure 4 – Boxplots for water quality parameters of springs as a function of recovery time, across different types of land use and occupation.
Source: Authors (2024).

Through Figure 4, the behavior of each variable over time across different land use types can be observed. Urban areas showed the largest difference in alkalinity values after three years of recovery (an average of 59 before recovery and an average of 33 after three years), a reduction of 44% (Figure 3a). After three years of spring recovery, only forests indicated an increase in alkalinity. The other land uses showed a reduction in alkalinity after three years of recovery.

Alkalinity is a measure of a water's ability to neutralize acids, indicating the presence of alkaline substances such as carbonates, bicarbonates, and hydroxides. In springs, it can vary depending on the surrounding geology. Alkalinity can originate naturally through rock dissolution, the reaction of CO2 (from the atmosphere or organic matter decomposition) with water, or anthropogenic actions such as industrial discharge. In the pH range of 5.4 to 6.5, as observed in this study across five campaigns, bicarbonates appear to contribute significantly to alkalinity.

Parameters such as E. coli, total coliforms, and turbidity are crucial for assessing the potability of drinking water (Xavier et al., 2022), as periodically evaluated under Brazilian legislation (BRASIL, 2011). Generally, these parameters showed the most significant changes over time of recovery were influenced by land use and occupation, as indicated by PCA (Figure 2) and GLMM (Table 1).

In Figures 3b, 3c, and 3d, a similar pattern of decreasing values for E. coli, total coliforms, and turbidity can be observed. These results confirm the efficiency of the soil-cement methodology for spring recovery and highlight sensitive interferences of land use and occupation where springs are located. It is also noted that recovery in areas with traditional agroforestry systems (faxinal) and urban areas, as well as forests, was significantly faster than in agricultural areas.

Escherichia coli is an indicator of fecal pollution in drinking water. This type of contamination in water is commonly due to direct sewage disposal into drainage channels (GHANEM et al., 2021). It demonstrates that high concentrations of E. coli in animal farming areas are a result of direct contact of animal excreta (feces) with springs, which corroborate the findings presented by JEBREEN and GHANEM (2015).

Regarding total coliform concentrations, two distinct groups were observed, where the highest concentration was found in urban springs, followed by springs in traditional agroforestry systems (faxinal) and pastures, with the lowest concentrations observed in agriculture and forests. The greatest efficiency of spring recovery methods in reducing total coliform concentrations was observed in pastures and traditional agroforestry systems (faxinal). This may be attributed to the isolation of springs, which reduce direct animal contact.

The highest phosphorus values were found in agricultural springs. Even after recovery (three years), these values remained higher compared to other land uses. These findings are consistent with those reported by Pinto et al. (2012), where agricultural activity increased phosphorus concentrations in springs. Pastures, urban areas, and traditional agroforestry systems (faxinal) showed a reduction in phosphorus concentration after three years of recovery. Forests were the only land use type indicating an increase in phosphorus after three years of recovery.

Phosphorus is a critical indicator of water quality in agricultural drainage systems (TOOTOONCHI et al., 2018). In agricultural activities, phosphorus-containing fertilizers are commonly applied to promote plant growth. However, when applied excessively, these can be carried by rainwater or irrigation and reach water bodies. The dynamics of agricultural areas contribute to reduced water quality in springs compared to other land uses. Factors contributing to this include surface runoff (ANDRASKI and BUNDY, 2003), soil erosion (ZAHOOR and MUSHTAQ, 2023), fertilizers (YANG et al., 2017), and animal waste (SCHAFFNER et al., 2010), among others.

The highest water turbidity before recovery was found in agriculture and traditional agroforestry systems (faxinal). The water pH in agriculture springs (Figure 3f) indicated the highest values compared to other land use types. However, these springs showed the highest homogeneity compared to other areas. In pastures, water pH decreased over the recovery period. Urban areas, traditional agroforestry systems (faxinal), and forests showed similar behaviors with increasing pH over recovery time.

The pH increase in these areas may be attributed to reduced organic matter reaching the springs before recovery. Higher concentrations of organic matter increase water acidity due to the release of carbon dioxide and organic acids. Isolating springs in forest and traditional agroforestry systems (faxinal) areas reduced animal contact, thus reducing the connectivity of organic matter and animal waste with springs.

Our results indicate restrictions on the use of water from pasture, urban, and agricultural springs, except for water from mixed ombrophilous forests, which showed conditions suitable for consumption. These findings are consistent with those observed by WANG et al. (2006); JOSHI (2006), where water from forest springs is suitable for drinking while springs in cultivated lands or pastures become unsuitable and unsafe for human consumption.

4. Conclusion

The soil-cement method demonstrated improvements in water quality across all analyzed variables after three years. However, some variables, such as E. coli and total coliforms, showed more significant improvements in springs located in pasture, urban, and faxinal areas. The isolation of springs in pasture and faxinal areas (extensive animal husbandry) reduced the connectivity of sediments and organic matter from the surrounding areas, as well as the impact of animals seeking water in these areas.

Springs in agricultural areas did not show significant improvement in water quality, except for water turbidity. The isolation of springs in agricultural areas reduced the contact of sediments from erosive processes with the springs.

The soil-cement system for spring recovery is efficient for some parameters, especially those influenced by the contact of materials from areas upstream of the springs. However, there is a need to evaluate the effectiveness of this recovery method over a longer temporal scale.

It is also necessary to assess the conditions of land use and occupation upstream of the spring water, as the hydrological dynamics of these areas can affect water quality even with the soil-cement method.

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