REVISTA ÁGUAS SUBTERRÂNEAS

*Artigos*

# Indicators in groundwater in a rural region of Igarapé-Açu Municipality, northeastern Pará State, western Amazon, Brazil

## Indicadores em águas subterrâneas em região rural do município de Igarapé-Açu, nordeste do estado do Pará na Amazônia, Brasil

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**Keywords:**

Well water;
Riparian vegetation;
Soil management;
Watersheds;
land use.

**Abstract**

Rural areas in the Northeast of Pará influence surface (igarapés) and underground (artisan wells) water flows. The region's rainfall processes, and the water stored underground contribute to the distribution of the amount of water in these small channels that feed first order rivers belonging to the two micro basins studied. The region's land uses interfere with these flows in terms of intensity, quantity of sediment carried and quality with the insertion of nutrients and substances resulting from the type of soil management carried out. Contamination of artesian wells and streams are often present without soil management planning, which has been monitored in this region for over 10 years. It was observed in this samples a presence of E coli (1986 NMP/100 mL), total coliforms (6045 NMP/100 mL) and Thermotolerant coliforms (5450 NMP/10 mL) in water samples in important concentrations. This type of monitoring helps plant cultivation and animal management be carried out in conjunction with the preservation of riparian and secondary forests.

**Palavras-chave:**
Água de poço;
Vegetação ripária;
Manejo do solo;
Bacias hidrográficas;
Uso da terra.

**Resumo**

As áreas rurais do Nordeste do Pará influenciam os fluxos de água superficiais (igarapés) e subterrâneos (poços artesanais). Os processos pluviométricos da região e a água armazenada no subsolo contribuem para a distribuição da quantidade de água nesses pequenos canais que alimentam rios de primeira ordem pertencentes às duas microbacias estudadas. Os usos do solo da região interferem nesses fluxos em termos de intensidade, quantidade de sedimento carregado e qualidade com a inserção de nutrientes e substâncias resultantes do tipo de manejo do solo realizado. A contaminação de poços artesianos e córregos está frequentemente presente sem planejamento de manejo do solo, o que vem sendo monitorado nessa região há mais de 10 anos. Foi observada nessas amostras a presença de E. coli (1986 NMP/100 mL), coliformes totais (6045 NMP/100 mL) e coliformes termotolerantes (5450 NMP/10 mL) nas amostras de água em concentrações importantes. Este tipo de monitoramento auxilia no cultivo de plantas e no manejo animal em conjunto com a preservação de matas ribeirinhas e secundárias.

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## 1. INTRODUTION

The northeastern microregion of Pará has the state's greatest demographic density and is noted for its strong agricultural activity. The region started to be colonized in the seventeenth century, and since then it has undergone intense and sometimes disorderly land use. The presence of pesticides, fertilizers, and livestock wastes contributes to degrade the water quality in rural areas (Resende, 2002). This panorama has attracted the interest of researchers to analyze the environmental impacts and the adoption of measures to control these substances (Toledo & Nichella, 2002). However, only a few studies have focused on the quality of well water in the Amazon region, and fewer still in the state of Pará. The findings have indicated that the quality of well water is being impaired by the contamination of surface water bodies, in particular large Amazonian rivers such as the Madeira, Negro, and Solimões. It is crucial to study the water quantity, quality, and mobility of nutrients in urban and rural regions with extensive agricultural activities, focusing on longstanding land use by family farmers. Most of these farmers lack access to piped water and basic sanitation, relying instead on septic tanks localized near plantations of cassava, pepper, and various fruit trees. The irrigation water is generally obtained from wells and small streams (igarapés) running through the farms. Livestock grazing is also frequent after clearance of primary or secondary forest stands. These pastures are often poorly managed, and the livestock generate high levels of organic waste. Recent studies (Cosme de Oliveira Junior, R. *et al.,* 2015; Ricardo de O. Figueiredo *et al.,* 2020), along with an older one (Wickel B., 2004), have been conducted in small micro basins in the northeast region of the state of Pará, involving the effects of burning vegetation to prepare land for cultivation and the monitoring of well water. The results have indicated rapid loss of nutrients by leaching from the soil after deforestation by burning and subsequent cultivation, along with contamination by fertilizers and/or pesticides. Agroforestry systems have been used as an alternative to burning in the process of enrichment of nutrients in the soil, with different combinations of species (Cherubin *et al.,* 2019). There is a relative lack of data from chemical and microbiological analyses of well water, which is normally used for human and animal consumption along with irrigation. This means a lack of information on the agricultural products and byproducts sold, which can have undesirable residues. According to Rodrigues (2010), one of the main concerns of the scientific community is to understand how climate change and different plant cover and land uses have affected or have potential to affect the water resources in different Brazilian biomes, and to determine the effects on the environmental and economic sustainability of rural communities.

Climate changes have the potential to alter the processes of the hydrological cycle, affecting the availability of and demand for water for agriculture, depending on the rates of evaporation and precipitation. Indeed, climate changes are impacting the water availability in Brazil's various regions differently. Many rural municipalities use groundwater without considering proper technical criteria to detect contamination.

In this study, we monitored surface and groundwater for a period of one year, to determine bacteriological indicators and the presence of nutrients and metals in areas with different land uses (livestock grazing, agroforestry systems, and areas submitted to burning). Biomass was used from riparian and secondary forest vegetation in the municipality of Igarapé-Açu, specifically in two micro basins, chosen for their importance to the water quality of other rivers in northeastern Pará. This study shows some indicators of water quality in different soil management without environmental planning and control.

## 2. REGIONAL HISTORY AND CHARACTERISTICS OF THE AREAS STUDIED

The northeastern microregion has the greatest demographic density in the state of Pará and is noted for intensive agricultural activities. It is also noteworthy for the earliest European colonization of the Amazon region, dating to the seventeenth century, (Rosário, 2000).
Although agriculture is not the only activity responsible for the loss of water quality, it is directly or indirectly considered a diffuse source of pollutants that degrade wetlands. It can involve contamination of water bodies by organic and inorganic substances, both natural and synthetic, as well as biological agents. The widespread application (often inadequate) of pesticides, fertilizers, and wastes derived from intensive stock breeding are described as the main factors related to the loss of water quality in rural areas (Resende, 2002). Toledo and Nicolella (2002) pointed out that the pollution from agricultural activities has been a topic of attention in many countries due to the difficulty of establishing procedures to evaluate the environmental impacts and the adoption of acceptable standards.

In this study, we investigated two micro basins, those of Cumaru and São João streams, both of which are tributaries of the Maracanã River, located in the municipality of Igarapé-Açú. The main activity in this municipality is family farming, with the principal crops being corn, cowpea, cassava, black pepper, and passion fruit, along with small-scale stock breeding (Silva *et al.,* 1999).

These activities are generally associated with degraded soils due to the widespread use of pesticides, especially in passion fruit cultivation. Besides the agricultural areas, there are many areas of secondary forests in different successional stages, including along the banks of watercourses (riparian vegetation). However, these ri-parian forest stands are being removed for expansion of cultivation and for wood to build structures of small farms (Rosa, 2007).

The Cumaru Micro basin covers approximately 4,135 ha and is located at 01°11' S, 47°34' W, while the São João Microbasin covers about 2,654 ha and is located at 01° 10' S, 47° 32' W. Both are situated about 12 km from the municipal seat of Igarapé-Açu. The respective streams are tributaries of the Maracanã River, which serves as the border between the municipalities of Santa Maria and Nova Timboteua, approximately 100 km from Belém, the state capital of Pará (Figure 1).

The geology of Igarapé-Açu is represented by Cenozoic units. Stratigraphically, the region is composed of tertiary sediments (Pirabas Formation and Barreiras Group) and quaternary sediments (Post-Barreiras Formation). In northeastern Pará, pedological surveys have identified seven soil types: Dystrophic Yellow Oxisol; Typical Dystrophic Yellow Ar-gisol; Epiachic Dystrophic Yellow Argisol; Abrupt Dystrophic Yellow Argisol; Quartzarenic Neosol; and Haplic Gleisol (Costa Filha, 2005).

More specifically, according to Lima *et al.* (2007) and Silva *et al.* (2009), the soil in the two watersheds studied is mainly deep and well drained Dystrophic Yellow Argisol, with medium sandy texture and acidic pH. Unconsolidated, sandy-silty and sandy-clayey sediments also occur. These sediments have whitish, yellow and light orange color, are poorly selected and sometimes contain sparse quartz grains. The lithological characteristics of these sediments together with their regional geographic analysis allow associating them with Post-Barreiras Sediments (Góes & Truckenbrodt, 1980).

Starting at a depth of approximately 12 m, sediments occur with large lithological variations, ranging from clays to coarse sandstones of the Barreiras Group. The geology of the areas studied defines two aquifers, called Barreiras Aquifer and Quaternary Aquifer (Silva *et al.,* 2009). According to the same authors, the Quaternary Aquifer is composed of moderately selected sands with fine to medium grain size and depth of some 12 m. In higher topographic areas, the depth is about 13 m, while in lower areas the depth does not exceed 3 m.

The Bragantina region is considered an example of the early agricultural frontier in the Amazon, having been occupied by settlers for over 120 years. It is now dominated by landscapes generated by anthropogenic action, with only rare traces of the original vegetation (primary forest), mainly in uplands, floodplains and black-water flooded forest fragments (igapós), along with floodable meadows.

According to the classification of Köppen, the climate in the municipality of Igarapé-Açu is predominantly of the Ami type and Am2 subtype, with average annual temperature of 26.5 °C. The thermal amplitude is very slight and is moderated by proximity to the ocean and associated with the distribution of rainfall (Martorano *et al.,* 1993; Pachêco & Bastos, 2006).

In general, the precipitation in the region is relatively high (2500-3000 mm), mostly falling from January to June, while the dry season lasts from July to December (less than 60 mm). The relative humidity is between 80 to 85% (yearly average), depending on associated with the rainfall regime (Martorano *et al.,* 1993).

The agriculture in the region studied is mainly carried out in small farms (less than 50 ha), with typical crops of cassava, corn, black beans, rice, black pepper and passion fruit. The quantity of land used for pasture and perennial agriculture in the watersheds studied differed, covering approximately 25% of the area of the Cumaru Watershed and 7% of the São João Watershed. In contrast, the forested areas in the two watersheds are similar, mainly due to the riparian wetlands found in São João Watershed (Felizzola *et al.,* 2019). The soil characteristics of the watersheds are detailed in Felizzola *et al.,* 2022.

## 3. MATERIAL AND METHODS

In the period studied (all 12 months from 2014 to 2015), rainfall was lower than average in both seasons (Figure 2), possibly due to the El Niño phenomenon, which occurred from the start of 2014 to the middle of 2016. This phenomenon is characterized by lower than average rainfall in the eastern and northern parts of the Amazon Rainforest, at the extreme causing some cyclical droughts.

We used precipitation data from a conventional meteorological station in Igarapé-Açu, which recorded total rainfall of 1999.50 mm in the period studied. The wettest months were April, May, June and July 2014 and February and March 2015, during which the total rainfall was 1780.00 mm. In turn, the driest months were August, September, October, November, December 2014 and January 2015, with total of 219.50 mm.

The greatest water surpluses occurred in April 2014 (399.59 mm) and March 2015 (170.49 mm), while the greatest water deficits occurred in November (-135.19 mm), December (-127.78 mm) and January (-131.83 mm). To monitor the groundwater, we drilled 30 observation wells for installation of piezometers constructed of PVC tubes with diameter of 2 inches and lengths varying from 1.70 m to 16.94 m, distributed as indicated in Table 3 and measured according to the APHA method (1998).

The sites were selected according to the six land use/plant cover systems common to the two microbasins (watersheds), namely: secondary vegetation; agroforestry system (AFS); slash and burn agriculture; chop and mulch agriculture; pasture; and riparian vegetation. The results reported are the averages of the wells in each area.

More specifically, the sampling points were defined according to topographic and pedogeochemical criteria, aiming to include the most frequent types of land use and plant cover in the two watersheds, in areas with different degrees of a-thropic impact and also considering the ease of access of re-searchers. These criteria were applied both for collection of surface water and groundwater.

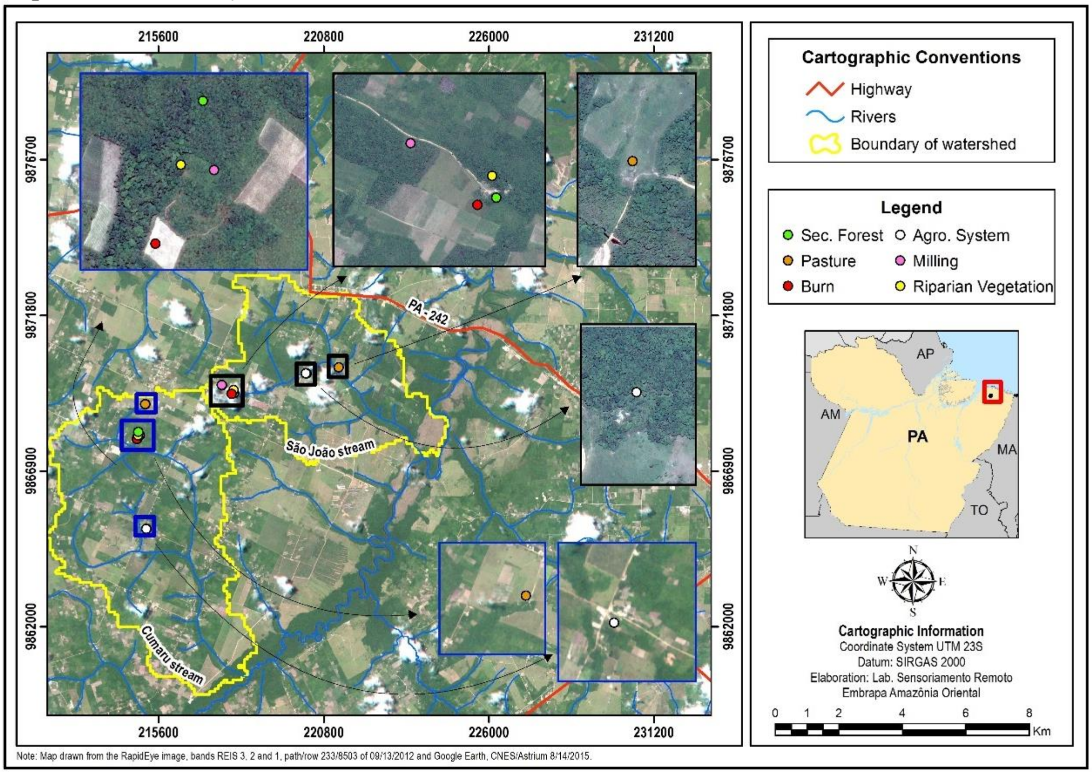
In the Cumaru Watershed, the slash and burn, chop and mulch, secondary vegetation and riparian vegetation areas are located in the terrain surrounding the headwaters. The criteria were the same for the São João Watershed, considering areas of riparian vegetation and secondary vegetation.

The different types of plant cover and the corresponding proportions in the two watersheds are reported in the article by “Autor” (2019).

**Table 1** - Location and distribution of the wells for collection of groundwater samples in the Cumaru (CU) and São João (SJ) watersheds.

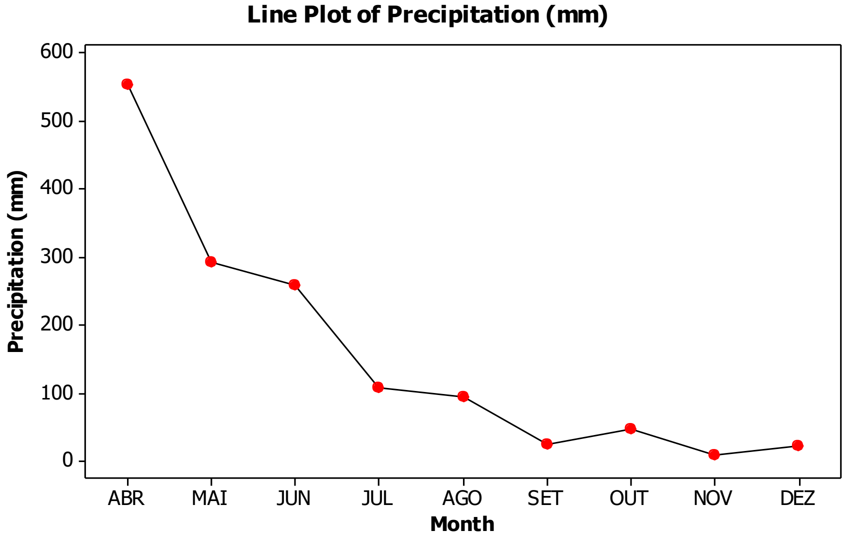
| Watershed | Type of Land Use/Plant Cover | Depth of Wells (m) – below ground level | Coordenates | Altitude |
|---|---|---|---|---|
| CU | Pasture | 8.57 | S 1° 11' 02.0" W 47° 33' 33.0" | 49 m |
| | | 8.9 | S 1° 11' 02.3" W 47° 33' 33.3" | 48 m |
| | Riparian Vegetation | 1.7 | S 1° 11' 34.7" W 47° 33' 40.6" | 41 m |
| | | 4.32 | S 1° 11' 34.4" W 47° 33' 40.6" | 40 m |
| | Secondary Vegetation | 9.71 | S 1° 11' 30.4" W 47° 33' 40.6" | 52 m |
| | | 10.58 | S 1° 11' 31.3" W 47° 33' 41.2" | 50 m |
| | Slash and Burn Agriculture | 6.33 | S 1° 11' 37.9" W 47° 33' 40.9" | 40 m |
| | | 5.92 | S 1° 11' 38.1" W 47° 33' 41.3" | 40 m |
| | | 6.74 | S 1° 11' 38.2" W 47° 33' 41.6" | 40 m |
| | Chop and Mulch Agriculture | 7.39 | S 1° 11' 34.4" W 47° 33' 39.1" | 45 m |
| | | 6.76 | S 1° 11' 34.4" W 47° 33' 38.8" | 45 m |
| | | 6.25 | S 1° 11' 34.3" W 47° 33' 38.4" | 46 m |
| | AFS | 9.73 | S 1° 13' 10.0" W 47° 33' 32.7" | 40 m |
| | | 10.29 | S 1° 13' 10.1" W 47° 33' 32.3" | 41 m |
| | | 10.14 | S 1° 13' 10.0" W 47° 33' 32.0" | 41 m |
| SJ | Pasture | 4.44 | S 1° 10' 24.7" W 47° 30' 16.1" | 20 m |
| | | 5.14 | S 1° 10' 24.8" W 47° 30' 16.4" | 20 m |
| | Riparian Vegetation | 6.25 | S 1° 10' 47.8" W 47° 32' 03.5" | 38 m |
| | | 3.36 | S 1° 10' 47.8" W 47° 32' 03.3" | 36 m |
| | Secondary Vegetation | 7.87 | S 1° 10' 51.0" W 47° 32' 02.9" | 43 m |
| | | 7.72 | S 1° 10' 51.1" W 47° 32' 02.6" | 42 m |
| | Slash and Burn Agriculture | 12.73 | S 1° 10' 52.0" W 47° 32' 05.3" | 45 m |
| | | 12.23 | S 1° 10' 51.8" W 47° 32' 05.5" | 45 m |
| | | 13.1 | S 1° 10' 51.5" W 47° 32' 05.6" | 45 m |
| | Chop and Mulch Agriculture | 16.94 | S 1° 10' 43.4" W 47° 32' 15.0" | 51 m |
| | | 16.32 | S 1° 10' 43.0" W 47° 32' 15.2" | 51 m |
| | | 16.44 | S 1° 10' 42.6" W 47° 32' 15.3" | 51 m |
| | AFS | 5.1 | S 1° 10' 31.1" W 47° 30" 48.8" | 28 m |
| | | 5.34 | S 1° 10' 31.2" W 47° 30' 49.2" | 28 m |
| | | 4.95 | S 1° 10' 31.1" W 47° 30' 49.6" | 28 m |

**Figure 1** - Location's Map of Microbasins




The method applied in this study was an adapted version of the Arbitrary Fixed Radius method (Hirata & Rebouças, 1999; Foster *et al.,* 2006). Although it might seem simplistic for not considering hydrodynamic variables of each aquifer, we believe it is suitable for the scale of detail applied, and mainly because the wells are in low-lying areas, where the water table is shallower (Menezes *et al.,* 2014).

Figure 2 - Mensal precipitation in 2014



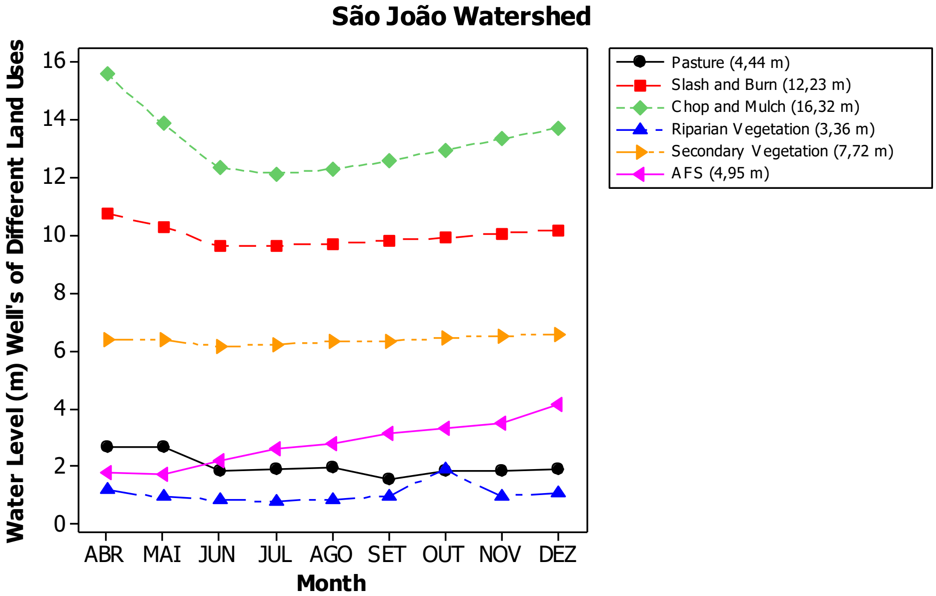

## 4. RESULTS

### 4.1. Water levels in the wells

In the wells located in the areas of riparian vegetation, we did not detect significant variations in volume during the year studied (2014), unlike in other areas in which the water volume varied according to the dry and wet seasons of the year, albeit with a delay of the impact of rainfall due to the time for infiltration in the soil.

After the end of the rainy season, water was still infiltrating from the surface and accumulating in the drier period from August to December. This delay in water movement was less in the Cumaru Watershed because its wells are shallower than in the São João Watershed. The steepness of the slopes also strongly affected the groundwater levels, mainly in areas of land management in Igarapé-Açu. It was observed this fact visually and with continuous water presence for the collect.

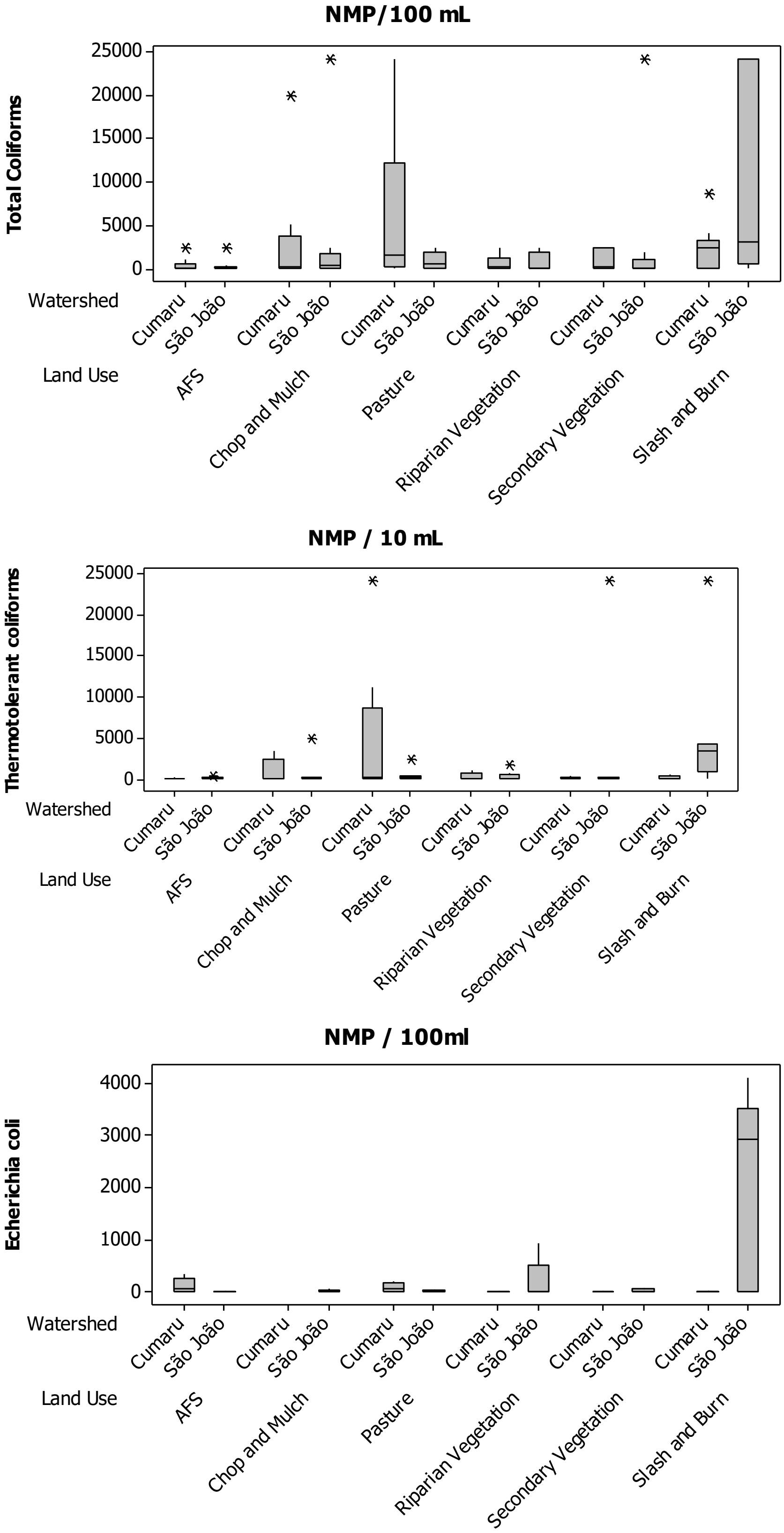
Figure 3 - Water level in wells in the Cumaru and São João watersheds with mensal measurements
Each point is na verage




### 4.2. Presence of Bactéria in the well water samples

The analyses revealed very high coliform values for all sampling points, which generally occurred during the less rainy period. Well installed in pastures (4625 NMP/10 mL) and submitted to slash –and – burn (5450 NMP/10 mL) agriculture stood out for levels of total and thermo-tolerant coliforms. Escherichia coli was observed in the areas of riparian vegetation in the São João Watershed and in areas submitted to burning (1986 NMP/100 mL).

**Figure 4** - Total coliforms, thermotolerant coliforms and Escherichia coli versus land use and watershed. Average and standard deviation of sampling points



Regarding the groundwater of the two micro-basins studied, it was observed that the shallower wells were more vulnerable to contamination (higher concentration of bacteria), since the soils in the region are characterized by being well-drained, with emphasis on the wells in the Chop-mulch Cumaru, Burn São João and Pasture São João areas. The latter was expected, since the São João pasture area has intense grazing pressure compared to the same area in the Cumaru. It is worth noting that bacteria from the thermotolerant coliform group normally live in the human body, existing in large quantities in the feces of humans, domestic animals, wild animals and birds. Thus, it is assumed that there is contamination by pathogenic bacteria.

### 4.3. Variability of parameters in well water in areas of different land use

Figure 5 shows the two groups of variables according to the land uses. Group 1: well depth, depth, Pb,Co, Cd, thermotolerant coliforms, total coliforms and Escherichia coli, showing the influences of well location and human contamination; and Group 2: Ba, Zn, precipitation, DBO, K, Na, Ni, Ca, Cu, Fe, Mn, Mg, indicating influence of land management (agriculture with burning) and rainfall conditions.

**Figure 5** - Variable groups of loading plot graph (principal component analysis)

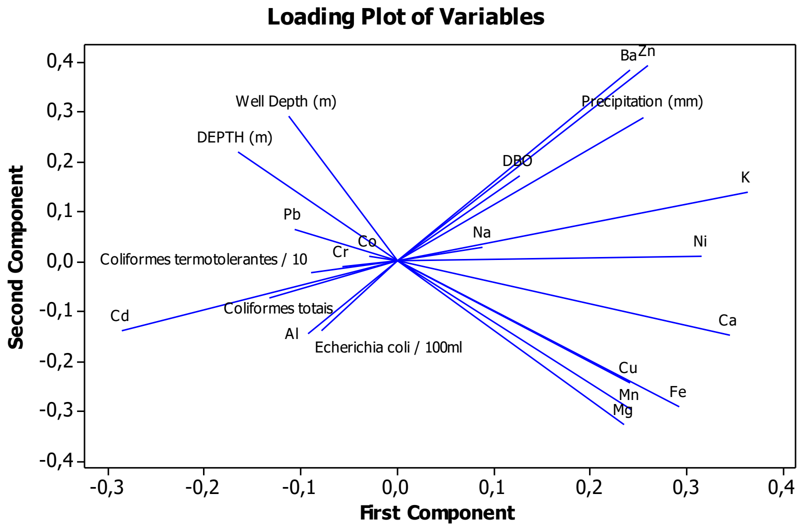



**Table 2** - Microorganisms in well water samples

| Water Well's samples<br>Mean (± SD)<br>Cumaru Watershed | DBO | Total Coliforms (NMP/100 mL) | Bacteria Termotolerant Coliforms (NMP/10 mL) | Escheria Coli (NMP/100 mL) |
|---|---|---|---|---|
| AFS | 20,56 (7,99) | 442 (810) | 44,8 (59,4) | 112 (145,2) |
| Chop and Mulch | 7,81 (5,88) | 3166 (6493) | 1004 (1352) | * |
| Pasture | 20,54 (13,91) | 6045 (9225) | 4625 (8792) | 77,5 (85,8) |
| Riparian Vegetation | 15,27 (9,22) | 643 (829) | 273 (457) | 3,58 (3,63) |
| Secondary Vegetation | 21,79 (9,54) | 1043 (1165) | 91 (144,2) | 1,667 (0,577) |
| Slash and Burn | 24,3 (29,1) | 2496 (2722) | 148 (273) | 0,176 (*) |
| **São João watershed** | | | | |
| AFS | 26,44 (8,08) | 356 (788) | 81,9 (138,4) | 1,50 (0,707) |
| Chop and Mulch | 17,59 (16,95) | 3250 (7891) | 658 (1709) | 16,8 (31,4) |
| Pasture | 21,10 (9,55) | 882 (968) | 480 (794) | 11,24 (15,01) |
| Riparian Vegetation | 25,00 (7,57) | 782 (1034) | 336 (630) | 205 (402) |
| Secondary Vegetation | 11,80 (3,66) | 3000 (7973) | 3507 (9123) | 24,7 (27,7) |
| Slash and Burn | 12,89 (8,58) | 9286 (11269) | 5450 (8455) | 1986 (1876) |

*from April to December 2014

Regarding the groundwater of the two micro-basins studied, all the observed wells presented values, in their majority, well above the maximum value permitted by current legislation (≤ 5.00 mg.L$^{-1}$) (Brasil, 2005), with emphasis on the wells in the AFS Cumaru (22.79) and AFS São João (26.09) areas, which presented the highest DBO averages.

For the groundwater of the two micro-basins studied, the ions presented (table 3) the highest concentrations among the observed wells, with emphasis on the wells in the slash and burn and pasture which suffered losses through burning and from the area impacted by the presence of cattle and without soil management. Most of the loss occurs through the transport of particles with the smoke from the fire and release by soil organic compounds.

**Table 3** - Metal concentrations in well water samples

| Water Well Samples | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | mg.L-1 | | | | | | | | | | | | | | |
| **Cumaru Watershed** | Al | Ba | Ca | Cd | Co | Cr | Cu | Fe | K | Mg | Mn | Na | Ni | Pb | Zn |
| AFS | **0.53** | 0.05 | 0.09 | 0.003 | 0.0005 | 0.0007 | 0.00005 | 0.04 | 0.03 | **0.34** | 0.002 | 1.88 | 0.002 | 0.004 | 0.0427 |
| Chop and Mulch | 0.29 | 0.07 | **0.36** | 0.003 | 0.007 | 0.0006 | 0.009 | 0.08 | 0.02 | 0.13 | 0.002 | **2.82** | 0.001 | 0.004 | 0.0585 |
| Pasture | 0.06 | 0.04 | 0.24 | 0.003 | 0.005 | 0.0005 | 0.007 | **0.40** | 0.01 | 0.10 | 0.002 | 1.86 | 0.003 | 0.005 | 0.0349 |
| Riparian Vegetation | **0.50** | 0.05 | 0.21 | 0.003 | 0.001 | 0.0007 | **0.016** | 0.05 | 0.02 | 0.21 | **0.004** | **2.01** | 0.001 | 0.005 | 0.0456 |
| Secondary Vegetation | 0.21 | 0.11 | 0.10 | 0.003 | 0.001 | 0.0005 | 0.008 | 0.02 | 0.02 | 0.23 | 0.002 | 1.94 | 0.0002 | 0.004 | 0.0694 |
| Slash and Burn | **0.62** | 0.04 | **0.48** | 0.003 | 0.001 | 0.0075 | **0.014** | 0.11 | **0.04** | **0.62** | **0.006** | 0.95 | **0.021** | 0.005 | **0.0677** |
| **São João Watershed** | | | | | | | | | | | | | | | |
| AFS | 0.05 | 0.05 | **1.58** | 0.002 | 0.0006 | 0.0004 | 0.004 | 0.23 | 0.03 | **0.66** | **0.025** | 2.79 | 0.002 | 0.004 | **0.0544** |
| Chop and Mulch | 0.14 | 0.05 | 0.55 | 0.002 | 0.0007 | 0.0004 | 0.0004 | 0.03 | 0.02 | 0.23 | 0.003 | 2.10 | 0.002 | 0.005 | 0.0513 |
| Pasture | 0.30 | 0.05 | **1.65** | 0.003 | 0.0008 | 0.0004 | **0.137** | **0.88** | **0.05** | **0.72** | 0.012 | 2.20 | 0.004 | 0.004 | 0.0463 |
| Riparian Vegetation | 0.09 | 0.04 | 0.16 | 0.003 | 0.0005 | 0.0004 | 0.001 | 0.002 | 0.01 | 0.17 | 0.000 | 1.31 | 0.001 | 0.004 | 0.0425 |
| Secondary Vegetation | **0.84** | 0.06 | 0.28 | 0.003 | 0.0006 | 0.0006 | 0.013 | 0.10 | 0.01 | 0.23 | 0.001 | **4.54** | 0.001 | 0.005 | 0.0365 |
| Slash and Burn | 0.22 | 0.02 | 0.17 | 0.003 | 0.0010 | 0.0003 | 0.003 | 0.01 | 0.02 | 0.45 | 0.003 | 1.53 | 0.002 | 0.005 | 0.0198 |
| Standard Desviation (SD) | 0.01 - 1 | 0.05-0.09 | 0.09-0.25 | * - 0.0014 | * - 0.0005 | * - 0.0001 | 0.0002 - 0.3 | 0.003 - 0.8 | 0.009 - 0.04 | 0.03 - 0.8 | 0.0005 - 0.01 | 0.5-1.5 | 0.0001 -0.05 | 0.0005 - 0.002 | 0.03 - 0.06 |
| Detection Limits (mg.L$^{-1}$) | 0.001-0.003 | | | | | | | | | | | | | | |
| *from April to December 2014 | | | | | | | | | | | | | | | |

## 5. DISCUSSION

The results of this study showed that the movement of metal ions in groundwater depends on the soil management and the predominant vegetation in the areas. The water table level depends on the slope of the terrain and is gradually affected by the variation and intensity of rainfall. We found higher nutrient concentrations in well water than in surface runoff, even in areas of sandy soils in the watersheds under analysis (Wickel, 2004). The cycling of nutrients and its effects on water flows are complex, influenced by vari-ous interactions, mainly between rainwater and the physi-cal-chemical properties of the soil (Moraes *et al.,* 2006). In the burned area of the Cumaru Watershed, the main elements accord-ing to concentration are identified in Table 3 and Figure 7. The elements that were leached and arrived in the groundwater were Al, Ca, Cu, Fe, K, Mg, Mn, Ni and Zn. In the São João Watershed, these elements were found in higher concentrations even though the depth of the well was greater than that of the Cumaru Watershed (12 m in relation to only 3 m, respectively), where there was greater movement of elements. It is important to consider that areas more recently planted and pastures are associated with degradation and wells with lower surface and groundwater quality (Ricardo de O. Figueiredo *et al.,* 2020; Cak *et al.,* 2016), as often happens in the São João Watershed. In older farms, with higher percentages of forests (riparian vegetation, primary and secondary forests) and agroforests (more frequent in the Cumaru Watershed) the water quality was better and the leaching of nutrients was lower. This watershed is located in a micro-region characterized by longstanding clearance of primary vegetation via traditional slash and burn farming (Hayden *et al.,* 2013). Furthermore, its occupation is characterized by a large variety of landscapes, reflecting the land use and occupation. The São João Watershed, subjected to more recent exploitation, had greater quantities of nutrients leached and higher levels of bacteria (Table 2), mainly in burned areas due to the presence of septic tanks in areas without sewage treatment. The pasture areas of the Cumaru Watershed are located at the lower part of slopes, so they receive all types of unsanitary runoff during strong rainstorms. The lack of basic sanitation in rural areas is very common due to the lack of governmental investments, along with the location of live-stock grazing near these wells. According to Edict 2914 from the Ministry of Health, for this water to be used for human consumption, it must be free of coliforms (bacteria frequently found in soil and decomposing plant matter), as well as Eschericia coli, the main indicator of fecal contamination by human and animal wastes (Silvio Carlos Coelho *et al.,* 2017).

**Figure 6**.- One way ANOVA K versus point water level in the Cu-maru Watershed in the treatments PT01 (Pasture), PT02 (Slash and Burn), PT03 (Chop and Mulch), PT04 (Riparian Vegetation), PT05 (Secondary Vegetation), and PT06 (Agroforest System - AFS). The treatments in São João Watershed were PT07 (Slash and Burn), PT08 (Chop and Mulch), PT09 (Riparian Vegetation), PT 10 (Sec-ondary Vegetation), PT 11 Agroforest System-AFS) and PT12 (Pasture). The means with same letter are similar by the Tukey test at 95% significance

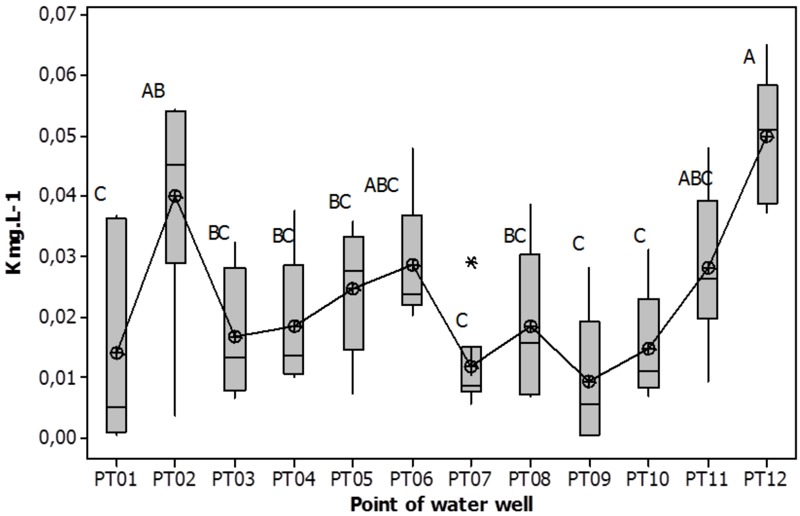



Figure 6 indicates land uses classified into four groups regarding variation of potassium: pasture; slash and burn; AFS; and the fourth group containing chop and mulch, riparian vegetation and secondary vegetation. Therefore, as also reported by Wickel (2004), the losses of nutrients to the groundwater were lower in areas sub-mitted to chop and mulch than in agroforestry systems (fruit pro-duction and livestock grazing). For some nutrients, such as potassium, slash and burn in Cumaru and pasture in São João had higher average values than the other land uses. The variable retention of nutrients from one land use to another depended on the soil management and climate season, as observed in Figure 7 for other elements. Farmers often use fire to prepare land for planting, where the secondary vegetation is burned during the dry season to release nutrients to the surface soil where they are available to plants, but also are prone to leaching to groundwater (Sá *et al.,* 2007). Soil preparation alternatives have been studied, such as cutting the vegetation and then chopping it to form a layer of mulch to protect the soil, and implementation of agroforestry. In both cases, more nutrients are retained in the soil, as indicated by our results and also reported by Sommer *et al.* (2004).

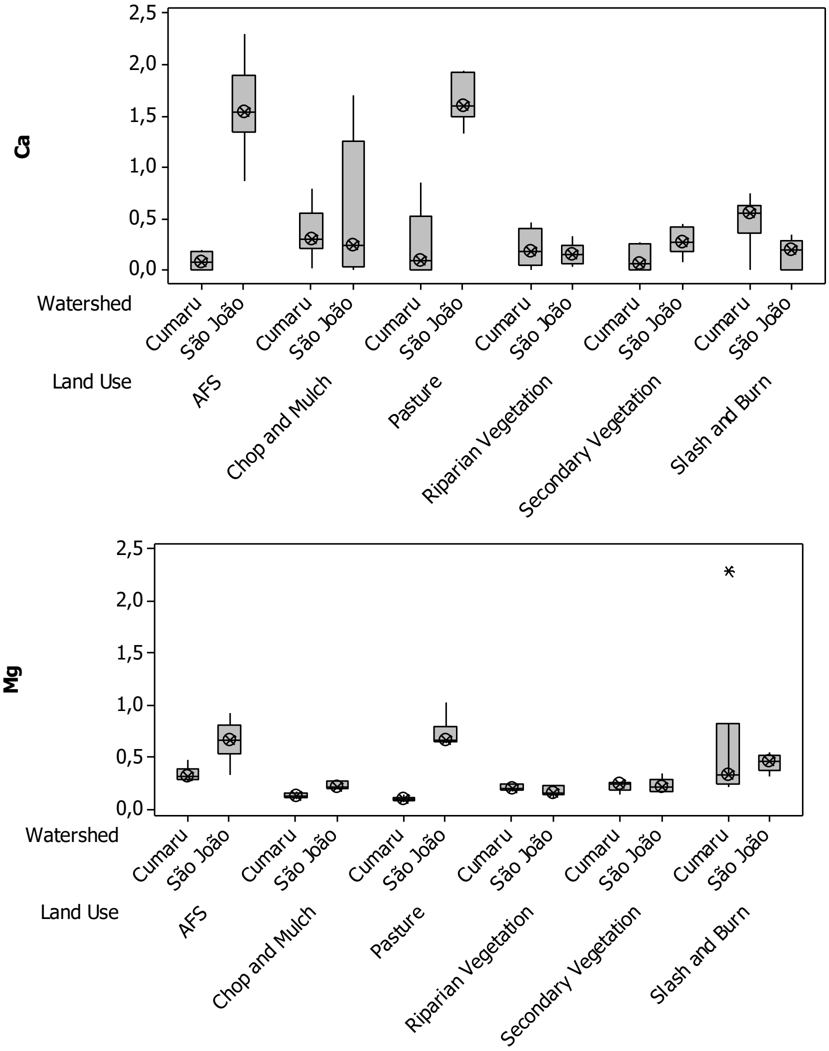
Riparian vegetation in both watersheds best conserved ions in the soil due to their low movement. The quantity of water stored in the wells was greater due to smaller losses in the dry season in comparison with the other land uses (Figure 2). Riparian vegetation is useful to mitigate the negative effects of agriculture by minimizing erosion and problems of sedimentation (from accumulation of water on the surface) (Figueiredo *et al.,* 2020).

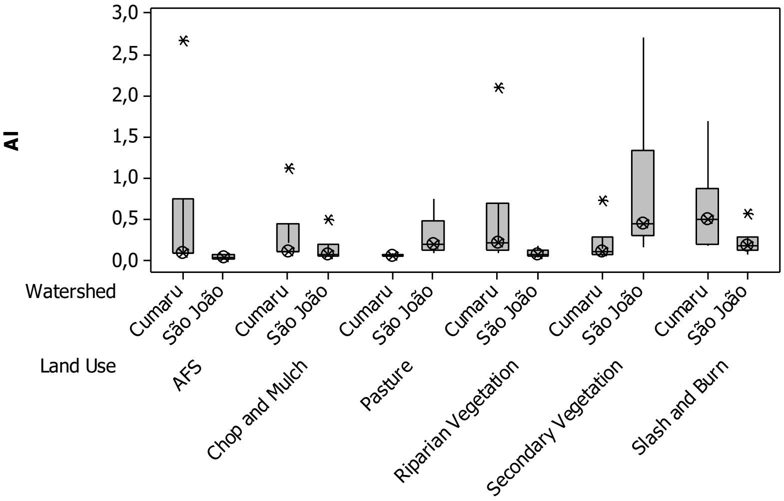
It is clear that burning vegetation for land preparation leads to faster exhaustion of nutrients in the soil due to leaching to groundwater or loss at the surface caused by the fire, altering the physical-chemical aspects of both surface and groundwater (tem-perature, electrical conductivity, pH, dissolved oxygen and carbon flows), as shown by the conceptual model of alteration of the bio-geochemistry of a watershed with small farms (Ricardo de O. Figueiredo *et al.,* 2020).

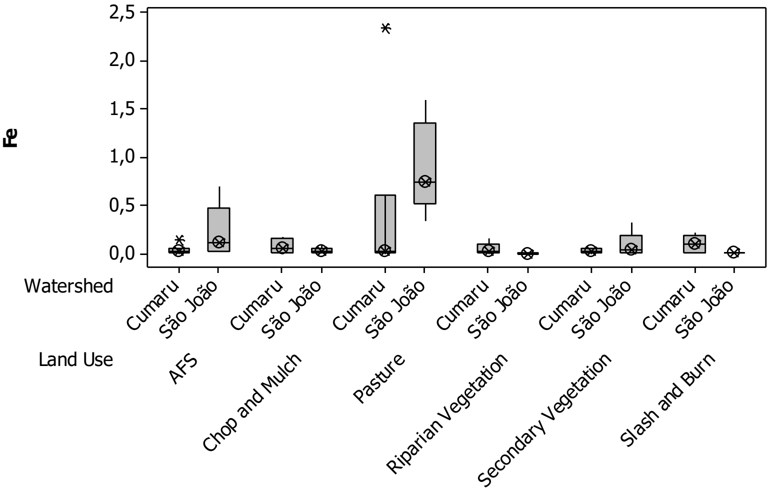
The loss of nutrients by conversion of forest into pasture, as well as from burning, has been widely discussed over the years, especially in the Amazon. Both conversion techniques affect the water flows at the surface and underground (Markewitz *et al.,* 2001; Leite *et al.,* 2011, Neill *et al.,* 2011). This change in the movement of nutrients is affected more by the intensity of management than the type of soil in the affected area (Markewitz *et al.,* 2011). The nutrients Ca, Cu, Fe, K and Mg stood out in the well water in the slash and burn area in the Cumaru Watershed and pasture in the São João Watershed (Table 3). The frequency of burning and planting of pasture and the proportion of organic matter affected by the de-mineralization processes intensify the mobility of these elements, which is also promoted by the predominantly sandy soils. According to Biggs *et al.* (2006), conversion of forests to pastures causes important losses of cations. The different land uses can thus affect the nutrient cycles in fluvial ecosystems, especially in the Amazon Basin. However, studies carried out in large areas dominated by pasture have detected high concentrations of ions in surface water and can also affect the levels of groundwater (Ballester *et al.,* 2003; Krusche *et al.,* 2005).

Chop and mulch agriculture involves the cutting of secondary vegetation followed by chopping to form mulch. It is an interesting alternative to the slash and burn method that preserves the moisture in the soil, reduces erosion and attenuates the entry of pesticides in the hydrogeochemical flows of watersheds (Peigné, 2007). In this study, we found small quantities of metals and ions in well water, with the standouts being Ca and Mg (Figure 7). The use of agroforestry is considered a sustainable agricultural alternative due to accumulation of biomass and restoration of degraded areas, with social and economic benefits (Ricardo de O. Figueiredo *et al.,* 2020). This system preserves more nutrients in the soil, as indicated by the low concentrations of these in the well water of the two micro-basins (Table 3).

Figure 7 - Metals (aluminiun, iron, calcium and magnesium) in each watershed with the respectives land uses






## 6. CONCLUSIONS

According to our results together with the cited literature, areas with riparian vegetation, secondary vegetation, chop and mulch farming and agroforestry management underwent 15 to 18% lower leaching of nutrients than the areas submitted to slash and burn agriculture and unmanaged pasture. These latter areas were also impacted by higher quantities of bacteria in the well water, especially due to the presence of septic tanks. The wells in areas of riparian vegetation preserved 90 to100% of the water during both the dry and wet periods, due mainly to the retention of water and nutrients from the excess biomass deposited in the soil. Depending on how the soil is managed at the surface, there were alterations in the volume and quality of the water. In this regard, preservation of riparian vegetation and maintenance of secondary vegetation can help maintain water and nutrients in the soil.

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