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ORIGINAL ARTICLE – Conservation of Nature

# Environmental Fragility in a Permanent Preservation Area

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## Abstract

Permanent preservation areas reduce the exposure of sediments and nutrients in aquatic medium and improve the quality of water. The analysis of natural features and anthropic use in rivers' surroundings makes it possible detecting potential ecological unbalance. This study analyzed the potential and emerging environmental fragility in Permanent Preservation Areas (PPA). Environmental fragilities around drainage areas composing the sub-basin were assessed based on soil, relief, rainfall, land use/land cover (LULC) features. The degrees of emerging environmental fragility observed in the second-order stream were lower than those in first-order ones: 3.07 and 2.68, on average, respectively; and standard deviation of approximately 0.7 was recorded in each group. First-order streams are more closely associated with high slopes, and it increases their fragility. Then reduction of fragility levels around water springs due to conservationist practices will decrease material and energy transfer throughout network connections and rebalance the assessed aquatic ecosystem.

**Keywords:** Mapping, environmental stability, river hierarchy, Permanent Preservation Areas, drainage basin.

## 1. INTRODUCTION

The risk of reducing the quality and amount of water for human consumption is among the main threats for a global social crisis (WEF, 2015; Nunes et al., 2017). Countries have observed that the need of improving water management practices will turn those that adopt efficient practices into benchmark for other nations (Biswas & Tortajada, 2019). The agricultural sector consumes approximately 70% of the water available, but even this sector has made efforts to show the possibility of improving water-use efficiency (Du et al., 2019; Doczi et al., 2014). Intense water use for agricultural and livestock purposes in Brazil (60%), and water infrastructure and supply in its counties (40%), place great challenges for water sustainable management in the country (Metzger et al., 2019). Factors such as climate change, population growth and economic pressure tend to speed up future crises (Carvalho, 2019).

Despite the world trend to deal with water conservation based on the crisis-risk management perspective, since 1965 the legal framework in Brazil has been based on the water ecological preservation and function concept. In practical terms, it supports the idea that the reduction of resources increases the probability of facing ecological hazards and ecosystems' integrity losses (Valera et al., 2019).

Advancements in livestock activity carried out in restriction areas is one of the main factors affecting the quality of water, since it leads to chemical changes resulting from factors such as excessive addition of soil nutrients and pollutants, inappropriate soil management, sediment transport, diffuse water and soil contamination, and surface erosion processes (Pessi et al., 2018; Filizola et al., 2002; Ribeiro et al., 2005). Land use/land cover (LULC) features in areas surrounding lotic systems have direct effect on the quality of water (Molina, 2017); therefore, vegetation width close to waterbodies is the reference for the conservation and application of conservation policies worldwide (Pessi et al., 2018). Siltation in watercourses due to erosions in the basin have straight effect on water quality and availability. Such a process could be avoided through both land use planning and soil conservation, since these practices lead to significant socioeconomic and environmental gains (Anjinho et al., 2021).

PPA stand out among the main conditions to the maintenance of waterbodies. These areas are protected by a whole variety of vegetal covers (Brasil, 2012) and their maintenance has straight interference in the quality of water, as well as reduces the exports of sediments and nutrients to aquatic media (Valera et al., 2019). The sustainable use of PPA is allowed; however, vegetation suppression is forbidden. Controlling crops and pasture on PPA borders' growth is one of the challenges for the conservation of water resources (Ribeiro et al., 2005; Rodrigues et al., 2013).

When drainage basins are seen as integrating units of landscape elements, they become areas where man and nature coexist and self-sustain themselves (Valera et al., 2019); therefore, the flow of energy and materials in these media reflect on environmental quality. Anthropic activity and changes in vegetal covers are determining elements for water production in the assessed basin (do Rêgo et al., 2020; Moreira et al., 2015)

Ecosystem stability depends on how the interaction between natural and anthropic elements take place in a given environment (Martines et al., 2020; Ross, 2011). Natural elements are related to morphodynamic and pedogenic processes; therefore, soil type, slope, rainfall and soil protection have straight influence on the dynamic balance that favors the natural state of different landscapes (Ross, 2012; Anjinho et al., 2021). Anthropogenic interferences in several components of nature trigger instability in the environmental system, so the mapping of natural elements in landscapes and LULC allows analyzing the environmental fragility (Ross, 2011).

Environmental fragility analysis assesses the environmental-system sustainability when it is facing changes in its dynamic balance due to anthropic interventions that cause temporary or permanent unbalance in ecosystems (Ross, 2011). The empirical analysis of environmental fragility can follow two perspectives: (1) potential environmental fragility (PEF), which basically comprises relief, rock, soil, rainfall and vegetal cover elements featuring the emerging balance in the environment and reflects on morphodynamic and pedogenic processes; (2) emerging environmental fragility (EEF), which integrates PEF to current land uses and shows areas facing changes in their ecosystems' dynamic balance due to human interference in the environment (Anjinho et al., 2021; Ross, 2011).

Environmental fragility studies have been broadly applied in both diagnostic studies and environmental planning in Brazil, as well as in the integration of other landscape analysis models (Donha et al., 2006; Spörl et al., 2011; Gouveia & Ross, 2019). Accordingly, geotechnologies represented by Geographical Information Systems (GIS) became efficient tools for landscape integrated analysis (do Rêgo et al., 2020), either because they map and feature land use (Nowatzki, 2010) or because they collect relevant morphometric, climate and soil information of drainage basins (Leite & Rocha, 2016). These features turn these geotechnologies into an instrument for the empirical analysis and monitoring of potentially fragile areas.

The aim of the present study was to analyze PEF and EEF of Córrego Alegria Basin's PPA, Uberaba municipality – Minas Gerais State. The study aims to contribute to the detection of both water springs and drainage flow potentially threatened by sediment production and transport processes.

## 2. MATERIALS AND METHODS

Córrego Alegria basin is located in Uberaba municipality, Minas Gerais State, Brazil, between geographic coordinates 19°39'24.79"S, 19°41'23.74"S latitude, and 47°54'39.70"W, 47°50'29.43"W longitude. It covers 1,489.74 ha (Figure 1) and is inserted in a Sustainable Use Conservation Unit – Uberaba River Environmental Protection Area (EPA) -, which has surface water capture for urban supply as its main anthropic use; therefore, this location has relevant environmental value for the local community (Valle Junior et al., 2013). This basin flows Upstream Uberaba River (MG) and Córrego Alegria's main course covers approximately 8,750 m, it lays at altitudes ranging from 900m (spring) to 764m (mouth). Uberaba River basin presents type Aw climate, based on Köppen's international classification - it is featured as tropical, semi-wet area, with 4 to 5 dry months throughout the year.

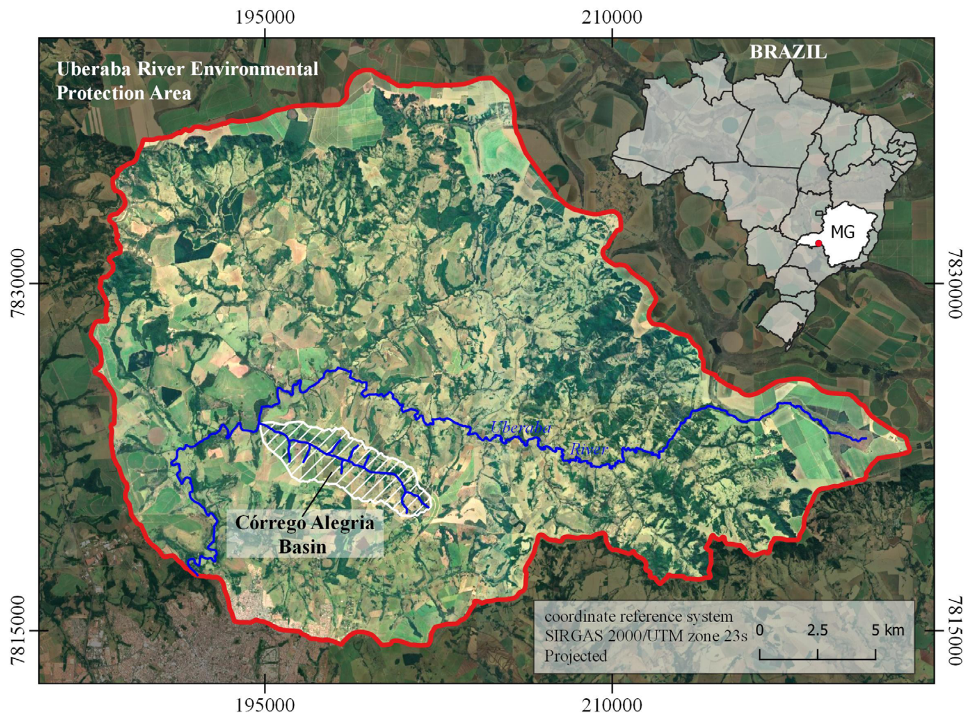


**Figure 1.** Map of Córrego Alegria Basin location, Uberaba/MG, Brazil, 2020.

## *2.1. Data*

The following data were used in the present study: altimetry and drainage data available in topographic charts, Uberaba – N, S. Escale 1:25.000, série: MI-2527/1-SO. Folha SE.23-Y-C-IV/1-SO. Brasília: Ministério do Exército, Departamento de Engenharia e Comunicações 1988 (DSG, 1988), soil chart elaborated at 1:50,000 scale – it corresponds to a survey carried out in Uberaba River EPA by Siqueira (2019) -, orbital image taken by the Planet Scope sensor (2018) – at 3m spatial resolution and crossing recorded on February 11th, 2018.

All data were processed in Geographical Information Systems (GIS) and projected on datum horizontal Sirgas 2000, Universal Transverse Mercator, Zone 23, South hemisphere.

Four (4) geo-spatial layers were prepared; they corresponded to the following topics: Soil, Slope, Geomorphology and LULC map. Each layer corresponded to an environmental topic composing the integrated environmental analysis.

Slope map was found by digitalizing and interpolating the altimetry curves and points in topographic charts. A Digital Terrain Model (DTM) was generated by TIN (Triangulated Irregular Network) interpolator, which is processed over isolines and quote altimetry points. DTM was used to generate a raster model for declivities grouped in classes that adapt themselves to criteria adopted in agricultural use/ability studies. These studies are in compliance with the critical slope limits adopted by geotechniques applied to erosion, landslide and flood processes (Ross, 2011) (Frame 1). Data were standardized at values ranging from 1 (very low fragility) to 5 (very high fragility), depending on the fragility degrees proposed by Ross (2011).

Terrain morphology was classified based on the "*r.geomorphons*" automatic process available in the QGIS software, according to which, the generated classes correspond to relief features categorized according to the shapes; they can be grouped by scores weighed by Gouveia and Ross (2019), namely: 1, for flat, peak, crest, shoulder and secondary crest relief; 3, for slope and ditch; 4, for valley; and 5, for slope base and excavated site.

The classification of soils in degrees of fragility was adapted from Ross (1994), which considers characteristics of texture, structure, plasticity, degree of particle cohesion and depth/ thickness of surface and sub-surface soil horizons. In this research the types of soil red latosol, red-yellow latosol and gleisoil (EMBRAPA, 2013), were associated with fragility criteria 2, 3, 3 respectively (Ross, 2011).

The LULC were mapped through visual interpretation of satellite data according to Marchetti and Garcia (1988). Fieldwork was done in locations where was not possible to differentiate Grassland and Agriculture. The identified classes were reclassified based on numerical terms in order to meet the classification by Ross (2011): 1 for native vegetation; 2 for pasture; 3 for agriculture and forestry; 4 for short-term crops; and 5 for buildings, dam and exposed soil (Frame 1).

**Frame 1.** Environmental Thematic Classes and fragility relationships.

| Geospatial layer / cartographic scale | Classes (fragility) |
|---|---|
| Slope (1/25.000) | 0<6% (1); 6<12% (2); 12<20% (3); 20<30% (4); >30% (5). |
| Geomorphology (1/25.000) | flat area (1), shoulder (1), secondary ridge (1), slope (3), excavated (5), slope base (5), valley (5). |
| Soil (1/50.000) | red latosol (2), gleisoil (3), red-yellow latosol (3) |
| Rainfall (1/500.000) | Annual unequally distributed rainfall with dry season lasting from 3 to 4 months in Winter; rainy Summer from December to March – volumes ranging from 1,000 to 1,750 mm/year. |
| Land use/land cover (1/10.000) | Forest, water (1); countryside, cottages (2), paved area, pasture, semi-perennial cultivation (3), degraded pasture, temporary cultivation (4), exposed soil (5). |

## 2.2. Methods

The flowchart in Figure 2 shows the steps of the fragility model applied to PPA environments adopted in this study.

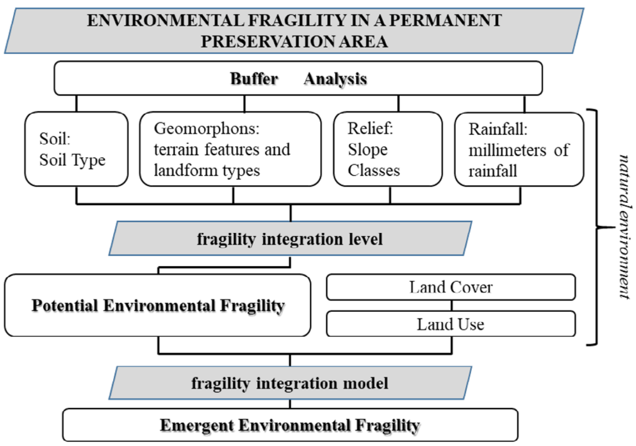


**Figure 2.** Flowchart of the integration of environmental variables in the construction of the Environmental Fragility model in PPA, modified from Anjinho (2021).

We use Law 12651/12 to determine the width of the PPA buffer strip. Under this law, farms with 96 hectares or more in the municipality of Uberaba must protect within a buffer area of 30m. In the Córrego Alegria basin, 68% of rural properties meet this requirement, but in this study we adopted a more conservationist criterion, applying a buffer of 30m in first-order streams and 50m in second-order streams over springs, aligning this criterion with the study by Valera et al. (2012) and GAEMA (2014), who suggest a more protective reference. Based on the research by Valera et al. (2019), although these values are critical, these limits implement protection ranges higher than those provided on law n. 12651/12 (BRASIL, 2012), the so-called New Forest Code.

Areas surrounding water springs covered 50m. GIS is carried out through buffer tool application (map of distance) in these delimitations.

Based on the PPA delimitation, its area overlapped the land use and occupation map, and it allowed estimating the areas where anthropic activities were conflicting to land use in environmental restriction areas.

Relief fragility was estimated based on the methodology by Gouveia and Ross (2019). Thus, the mean values collected from slope, geomorphology and soil maps were calculated, and values were reclassified from 1 to 5 (Frame 1) to plot the PEF map. Rainfall recorded for the whole basin ranged from approximately 1,000 to 1,750mm, with rainy Summer and dry Winter. These values meet the mean rainfall features of Triângulo Mineiro Region (Sanches et al., 2017), which accounts for mean fragility (3), based on the method by Ross (2012).

$$PEF = (D+G+S+R)/4 \qquad \text{(eq. 1)}$$

D = slope
G = geomorphology
S = Soil
R = rainfall

EEF was found through mean PEF, and LULC.

$$EEF = (PEF + LULC)/2 \qquad \text{(eq. 2)}$$

Stream orders were adopted as EEF analysis criterion in Córrego Alegria Basin (Figure 2); in other words, the goal was to identify whether there were differences in environmental features of drainage streams by taking into account their hierarchy in the network. According to Strahler & Strahler (1974), river order concerns the linear properties divided by segments; the most external of them is classified as “first-order”, and so on. Therefore, there are stream hierarchies that make it possible performing a detailed analysis of PEF associations with attributes that set the PPA fragility degrees.

Figure 3 first and second order streams. Córrego Alegria Basin.

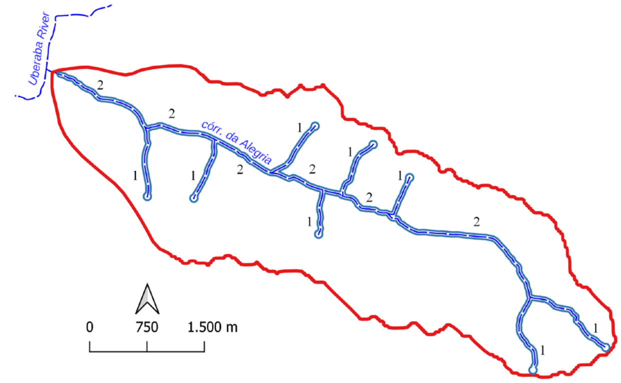


**Figure 3.** Córrego Alegria Basin. Drainage network with distance areas (30 m in streams and 50 m in water springs). 1 – First-order drainage streams; 2 – second-order drainage streams.

Analysis of Variance (ANOVA) was applied to FAE results in the two drainage classes (1st order and 2nd order) to identify whether there was difference between these two sets of streams. Subsequently, it was possible observing the land-use types and coverages associated with these sets, since PEF is explained by the association between the natural (PEF) and anthropic elements (LULC) composing the landscape (dos Santos & Machioro, 2020). Accordingly, the herein established methodological sequence may result in an indicator for the management of the assessed PPA environmental units.

## 3. RESULTS AND DISCUSSIONS

In total, 76.47% of the PPA in Córrego Alegria Basin is covered by native vegetation. Pasture is the prevailing land use type - it accounts for 9.55% of it. Because these areas are not degraded they present moderate fragility level. Overall, anthropic uses contributing to PEF in the assessed PPA account for 23.5% of the total area (Table 1).

**Table 1.** Area and rate of use classes in Córrego Alegria's PPA.

| Use class | Area (ha) | Area (%) |
|---|---|---|
| Forest formation | 43.1 | 49.0 |
| Country formation | 24.2 | 27.5 |
| Pasture | 8.4 | 9.6 |
| Fish farming | 3.7 | 4.2 |
| Long-term crop | 3.5 | 4.0 |
| Short-term crop | 2.0 | 2.2 |
| Degraded pasture | 1.5 | 1.8 |
| Dam | 0.7 | 0.8 |
| Cottage area | 0.5 | 0.5 |
| Exposed soil | 0.3 | 0.4 |
| Paved surface | 0.2 | 0.2 |
| Total | 87.98 | 100.00 |

### *3.1. Fragility levels in the assessed PPA*

Overall, Córrego Alegria Basin's PPA mostly presents very low (69.7%) and moderate (2) fragility, and it is followed by fractions of moderate risk (25.8%). Steep declivities, rugged relief and red-yellow oxisol are more associated with first-order streams, and it features moderate and high fragility. Second-order streams mostly show lower slopes, smooth relief, hydromorphic and oxisol soils – altogether, these features point towards low PEF (Figure 4).

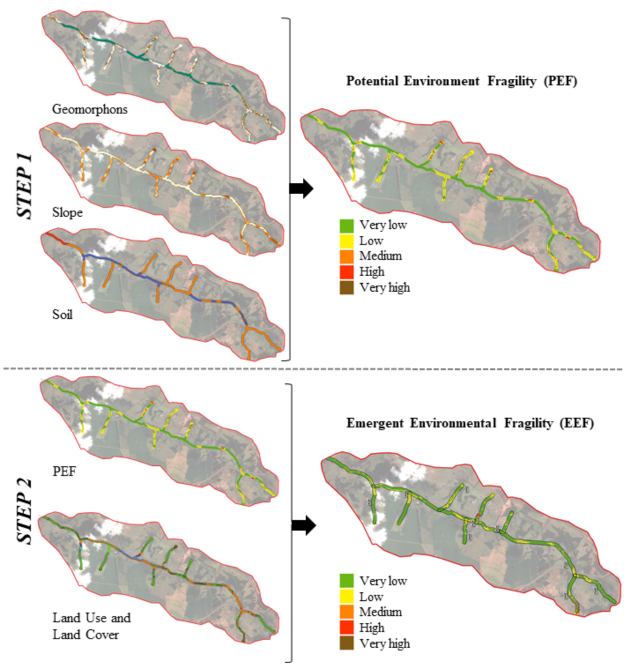


**Figure 4.** Spatial integration layers of Potential Environment Fragility and Emergent Environmental Fragility models' construction.

Overall, natural vegetal cover provides natural stability to the set of PPA (80.37 %); this profile features the environment as "low EEF". However, the highest fragility levels are associated with first-order courses where 8 water springs flowing to the main stream were detected (Table 2).

If one takes into consideration EEF's polygon units, it is possible observing statistical difference between the 1st order and 2nd order streams, ANOVA: $F(1, 166) = 14.8$, $p<0.01$. Thus, EEF degrees observed in the main stream (Córrego Alegria) are lower than those shown by first class streams – mean values 3.07 and 2.68, respectively, and standard deviation close to 0.7 in each group (Figure 5).

**Table 2.** Emergent Environmental Fragility (EEF) based on the order of drainage streams.

| Drainage order | EEF | area (ha) | % PPA |
|---|---|---|---|
| 1 | low (2) | 31.5 | 36.7 |
| | moderate (3) | 12.2 | 14.2 |
| | high (4) | 1.7 | 2.0 |
| | Very high (5) | 0.0 | 0.0 |
| 2 | Very low (1) | 2.0 | 2.3 |
| | low (2) | 28.4 | 33.0 |
| | moderate (3) | 10.0 | 11.6 |
| | high (4) | 0.2 | 0.2 |
| | **Total** | **86.0** | **100.0** |

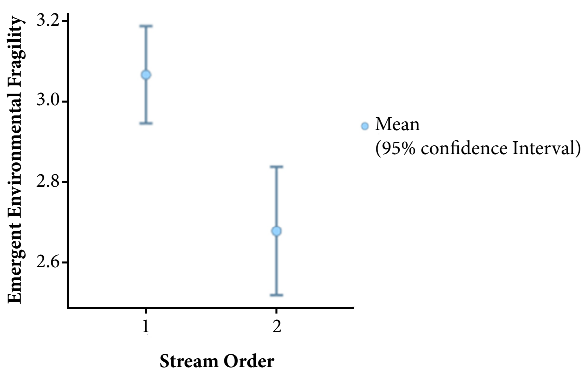


**Figure 5.** Mean Emergent Environmental Fragility in first- and second-order streams in Córrego Alegria, MG.

Tributaries closer to the mouth of Alegria and Uberaba rivers tend to be less fragile, but fragility increases as they flow upstream, except for tributary 1, where the combination of high slopes to degraded pasture leads to moderate fragility.

If one takes into account segments in the main stream, which are separated by the reception point set for first order tributaries, it is possible stating that the EEF analysis did not show statistical differences. Overall, fragilities recorded low and moderate values throughout the stream.

### *3.2. Land use/land cover fragment analysis*

The prevailing uses in the assessed PPA are forestry, country fields, pasture and agriculture. The other uses included in diversified and "smaller-sized" areal dimension categories can be interpreted as generic anthropic classes, such as: cottage areas, paved roads, fish farms, dam, exposed soil (Table 3). Grouping these categories in a general class allows better interpreting the assessed PPA undesired uses and spatial distribution.

Natural country coverage types are weaker and prevail in the PPA 2$^{nd}$ order streams; whereas forest coverages featured by lower fragility cover the 1$^{st}$ order streams. Anthropic use polygons for pasture, agriculture and other diversified uses have smaller areas, except for few cases (outliers).

**Table 3.** Land use classes and prevailing coverage in Córrego Alegria basin's PPA.

| | 1st order channel | | 2nd order channel | | *Total* | |
|---|---|---|---|---|---|---|
| Use type | *n* use polygons | Area | *n* Use polygon | Area | *N polygon* | *Area* |
| agriculture | 9 | 3.1 | 11 | 2.4 | *20* | *5.5* |
| grassland | 11 | 7.2 | 12 | 17.0 | *23* | *24.2* |
| forestry | 13 | 28.5 | 13 | 14.6 | *26* | *43.1* |
| pasture | 30 | 5.4 | 23 | 4.6 | *53* | *9.9* |
| others | 9 | 2.3 | 6 | 3.0 | *15* | *0.5* |
| ***Total*** | ***72*** | ***46.5*** | ***65*** | ***4.1*** | ***137*** | ***88.0*** |

The greatest fragilities in first-order streams are explained by the observed steeper slope, rather than by uses and coverages, because the forest cover that provides high land protection prevail in these surfaces. Such a slope also distributed itself into little fragmented polygons. Second-order streams accounted for the highest occurrence of country field covers, and it was followed by forest cover, with two bigger dimension polygons (outliers) that provide more ecological stability to the mouth of the main stream and to the upstream junction (Figure 6). PPA are more affected by anthropic uses focused on pasture and agriculture. Dams are practices set by fish farms and they emerge from the moderate flow of the main stream (second order). Other uses of exposed soil and cottage areas were distributed in space, they appeared in first- and second-order streams.

Córrego Alegria Basin is featured as 'smaller-sized' basin that tends to have higher drainage density and lower order streams placed where slope is steeper, and this finding meets the explanation by Christofoletti (1979). It explains why EEF in the basin was higher in the PPA first-order streams, although they are mostly covered by forests. Such a fact shows that forest conservation in these areas is essential for environmental system balance stability.

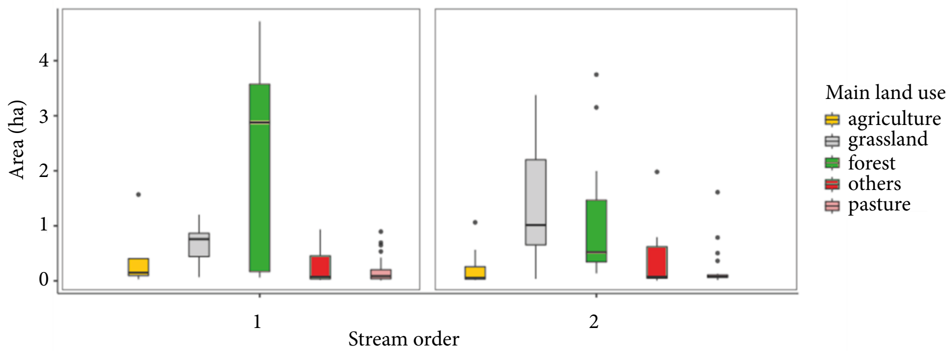


**Figure 6.** Distribution of land use/land cover polygons in first- and second-order streams.

Assumingly, different LULC at lower drainage orders (1st and 2nd) influence fragility determination in the higher order steams (2nd order) because they transfer materials and energy in network connections; this process has effect on the balance of water ecosystems (Wyrwoll, 2018). Moreover, anthropic elements are mostly susceptible to short-term changes, be them conservation or environmental unbalance, given their interference in pasture due to economic, social or political drives.

PEF features the area's propensity to develop erosion processes depending on natural relief, soil and rainfall aspects.

Environmental degradation by human activities near the APP affects the environmental quality of the valley bottoms, due to the transfer of sediments or chemical residues from agricultural applications, generating costs for managers to maintain quality and preservation/conservation. of the PPA (Anjinho et al. 2021).

The association between moderate fragility and soil type covering more than 90 % of the basin, such as red-yellow oxisol, works as stabilizer of potentially fragile conditions observed in the assessed region. EEF features the propensity of an area to develop erosion process based on anthropic changes in the environment; this process can imply in soil losses due to the suppression of forests that account for stabilizing the river heads.

Alegria Basin's PPA covers approximately 6% of the total basin area, its classes highlight that, although the legislation does not allow using these areas for economic activities, except for few cases, there are locations where natural pasture was replaced by agroforestry activities. Intervention in this PPA and the suppression of its riparian vegetation changed its natural ecosystem and led to losses in its biotic and abiotic resources.

In this research, we consider the conservation of restricted areas provided for by law, such as the PPA buffer strips, which aim to maintain the natural balance, however, Valera et al. (2019) highlight that there is an inability of these strips to fulfill the environmental function of preserving water resources and ensuring the well-being of human populations.

The EEF model is an indicator of the dynamics of environmental balance, as it favors the integrated analysis of natural elements (Ross, 2012), and the use of the EEF model provides a low-cost, flexible and easy-to-use application, facilitating its adoption by public or private managers and technicians (Anjinho, 2021).

Sustainable management practices in areas adjacent to riparian buffers are important activities to reverse degradation and preserve freshwater quality, through restoration or rehabilitation of degraded lands and to reduce sediment and nutrient loads carried by surface runoff (Pacheco et al. 2018).

## 4. CONCLUSION

The herein assessed area presents moderate risk of relief fragility, and such a finding is attributed to its morphological features.

Moderate potential fragility is caused by local pedological factors that potentiate the process that makes the assessed area fragile. On the other hand, EEF recorded for the assessed PPA is of low risk given its major occupation by natural vegetation. However, because this is a Cerrado domain (Brazilian Savanna) area, forest formations in it are less dense, although there is native vegetation in there. Thus, attention must be paid in its conservation in order to keep its riparian vegetation, due to its erosion-process controlling function.

Decrease in environmental levels in areas around water springs can be achieved through conservationist practices. This process imply in reducing the transfer of materials and energy throughout the network and in rebalancing the assessed aquatic ecosystem.

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