Environmental fragility as an indicator of the risk of contamination by human action in watersheds used for public supply in western Paraná, Brazil

Kelly Krampe Peres1 · Ricardo Guicho1 · Gabriela Medeiros2 · Mailor Wellinton Wedig Amaral2 · Thaís Tagliati da Silva3 · Maria Clara Pilatti4 · Maritane Prior1 · Norma Catarina Bueno3

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Abstract
The application of environmental fragility in studies evaluating watersheds can guide policy decisions on monitoring and land use management, improving water quality for public supply. The aim of this study is to characterize the environmental fragility of public water supply watersheds and relate it to water quality factors. Physical, chemical, and microbiological data associated with water quality were measured in nine rivers. Landscape features were used to calculate fragility, such as slope, soil type, and land use and land cover were assessed with the help of geoprocessing tools, in addition to Köppen-Geiger-based climate characterization. The municipalities with the largest areas classified with high fragility are: Guaraniaçu, Catanduvas and Cascavel, requiring greater attention. The variation in fragility responded mainly to the values of temperature, pH, E. coli and COD, which may be strongly associated with the difference in land use and slope of the evaluated areas.

Keywords Geoprocessing · Environmental impacts · Water quality · Health

Introduction

Water is one of the most essential natural resources for human development and societies, and its scarcity occurs due to irrational land use that negatively affects its quality (Zhang et al. 2019; Dou et al. 2022; Li et al. 2022). In Brazil, recent studies associated with institutional research, highlight that almost 35 million people still do lack water supply availability, representing 16.38% of the Brazilian population; moreover, the distribution of drinking water supply and sewage treatment is uneven across the country’s regions (ITB 2020; Araujo et al. 2022). This scenario is intensified by urban and agricultural growth that, when uncontrolled, degrades ecosystems through deforestation of riverbanks, irregular occupations, and inadequate disposal and treatment of effluents, contributing to environmental fragility (Malik and Bhat 2014; Johanssen et al. 2016; Tiecher et al. 2017; Karakurt et al. 2019; Lechuga-Crespo et al. 2020).

Environmental fragility is defined as the sensitivity and resilience of an ecosystem, driven by natural characteristics and anthropogenic stressors (Turner et al. 2003; Anjinho et al. 2018). The application of this concept in environmental assessment studies consists of ordering fragility into hierarchical levels within the established territorial zoning, portraying degrees of susceptibility of the environment to undergo disruptions in its dynamic equilibrium (Tran et al. 2012). Integrating landscape characteristics in an integrated manner can more accurately point to the level of vulnerability of the studied environment (Sutil et al. 2020). Thus, applying environmental fragility in studies evaluating watershed can guide policy decisions on monitoring and management regarding soil use planning, improving water quality for public supply. (Braga et al. 2017; Abrão and Bacani 2018).
In this scenario, the sanitation sector still requires improvement in its management models, especially those of water supply and sanitation (Rossoni et al. 2020), since the effective assessment of water quality parameters has a profound impact on the overall quality of a catchment area (O’Grady et al. 2021). Regarding the assessment of catchment rivers for public supply, it is necessary to consider the spatial interactions between climate, water distribution, relief and geology (Silva et al. 2011; Fraga et al. 2020), using physico-chemical parameters that interfere with potability (Kannel et al. 2007; Tripathi and Singal 2019).

In view of this, geotechnologies are strong allies regarding environmental fragility, providing important tools for the characterization, management, and monitoring of space, detecting possible impacts on water bodies (Alves et al. 2021; Silva et al. 2021). Among them, the Integrated Management Systems (GIS) aggregate variables and spatial information, facilitating environmental characterization (Storto and Cocato 2018; Sutil et al. 2020; Alves et al. 2021).

Studies evaluating watersheds using data provided through geoprocessing associated with physical and chemical water parameters are still scarce in Brazil. Among them, it is possible to mention Bilich and Lacerda (2005) who analyzed the Water Quality Index in water source protection areas for ten years in Distrito Federal; Lopes et al. (2008) who made a water quality map of the Acaraú watershed in the state of Ceará, using the Water Quality Index associated with a Geographic Information System (GIS); Lemke et al. (2012) quantified the influence of land use and occupation on the water quality of the Dourados River Basin in the state of Mato Grosso do Sul; Justus (2012) used GIS’s to monitor some physico-chemical parameters of the surface waters of the São Pedro River watershed in the state of Paraná; Gomes et al. (2017) used interpolated maps covering water quality parameters in Piracicaba River Basin in the state of Minas Gerais; and Dino and Toledo (2020) evaluated land use and occupation in two sub-basins, associated with surface water quality in the confluence area of the Paranapanema and Itapetininga rivers in the state of São Paulo.

Therefore, due to the need of studies that evaluate the water quality for catchment and supply to justify prevention and mitigation measures of anthropic impacts on such environments, the aim of this study is to characterize the environmental fragility and relate it to water quality of nine catchment rivers for public supply in western Paraná, Brazil, to assess the influence of anthropic actions on the catchment sources.

## Materials and methods

### Study area

The state of Paraná is divided into 16 watersheds (Resolution number 024/2006/SEMA) of which three, Paraná III, Piquiri and Iguacu, bathe the western region of the state. This region covers 54 municipalities (AMOP 2018), with the most populous being Cascavel, Foz do Iguacu, Toledo, and Medianeira. Although the western region comprises a small population, it stands out for its intense agricultural production, with a large part of its extension of monoculture areas, the country’s main power and water stations and tourist centers. All municipalities in western Paraná have some agricultural and livestock production, while only a few have extractive production (PNUD 2018).

Therefore, for this study, 9 water catchment watersheds were selected for public supply in the western region of Paraná. To obtain a representative sample N, nine municipalities were selected: (GUAR), Catanduvas (CTD), Três Barras do Paraná (TBP), Boa Vista Aparecida (BVA), Foz do Iguacu (FOZ), Medianeira (MED), Santa Tereza do Oeste (STO), Cascavel (CVEL), Toledo (TOL) belonging to the three watersheds that bathe the region (Fig. 1).

Water samplings were performed in March 2020, and two points were sampled at the headwater and close to the water collection station of the sanitation company (Table 1). At the same time, the points descriptive characterization was performed, as well as photographic recording of the areas for further confirmation of terrestrial truth.

### Abiotic and biotic variables

Data regarding the sampling of physical and chemical variables such as temperature (Temp; °C), electrical conductivity (Ec; mS/cm−1), dissolved oxygen (DO; mg L−1), pH and turbidity (Turb; NTU) were measured on site by the multi-parameter probe HORIBA brand, model U-5000. The following variables were analyzed by the Limnology Laboratory of GERPEL, Unioeste-Campus Toledo: the oxygen consumption due to the chemical oxidation (DQO; mg L−1) and organic matter (BOD; mg L−1) the concentrations of total nitrogen Kjeidahl (TN; mg L−1), nitrate (NO3; mg L−1), ammonium (NH4; mg L−1), total dissolved phosphorus (TP; mg L−1), orthophosphate (PO4; mg L−1), chlorophyll a (CLA; mg L−1), total solids (TS; mg L−1), total coliforms (CT; NMP/100 mL) and *Escherichia coli* (Ec; NMP/100 mL). The analyzes were performed using the methods standardized in Standard methods (APHA 2017). Chemical variables were measured after the material was collected by subsurface immersion.
of polyethylene bottles, properly refrigerated and kept in the dark until their destination.

**Mapping and analysis of environmental fragility**

The analysis of environmental fragility was performed with the QGis raster calculator, using map algebra, where a mathematical function is used to weight defined values for each subclass of the variable considered.

One of the variables analyzed in this study was the slope obtained from the National Institute of Space Research (INPE) website and reclassified into 4 thematic classes, namely: 0–3, 3–8, 8–20, 20–45%, according to EMBRAPA (1979).

The second variable was the land use and occupation, performed by manual classification, in the QGis software, with images obtained from the Sentinel 2A Satellite (04-25-2020, 04-15-2020, and 05-15-2020) with a spatial resolution of 10 m. For the classification of the study area, five main...
classes were considered: Agriculture and Livestock, Water, Urban Area, Forest, and Mining, based on the Earth Use Technical Manual (IBGE 2013), which contains information on what types of use are contemplated in each class.

In addition to slope and land use, climate type was the third variable considered. For this purpose, the information proposed by Alvares et al. (2013), which provides shapefiles, for the whole country, of the areas that are influenced by the climatic conditions based on the Köppen-Geiger classification were used.

For the performing of the environmental fragility maps, each of the variables analyzed (slope, climate and land use and occupation) had their subclasses weighted with values from 1 to 5, where 1 is the lowest and 5 is the highest sign of fragility—“Very Low”, “Low”, “Intermediate”, “High” and “Very High” (Table 2). As a weighting parameter, the determination of subclasses was based on studies by Ross (1994); Souza et al. (2011); Franco et al. (2012) and Massa and Ross (2012).

\[ \text{fragility} = \sum (\text{weight of variable} \times \text{value of subclass}) \]

| Watershed           | City              | River               | Sampling station | Lat/long         | Depth (cm) | Width (m) | Average stream flow (m$^3$/s) |
|---------------------|-------------------|---------------------|------------------|-----------------|------------|-----------|--------------------------------|
| Piquiri             | Guaraniacu        | Baú river           | GUA_P1           | 25°40'56"S 52°53'29"O | 0.16       | 5.23      | 0.08                           |
|                     |                   |                     | GUA_P2           | 25°40'27"S 52°53'20"O |            |           |                                |
| Paraná III          | Catanduvas        | Arroio river Passo Liso | CTD_P1     | 25°11'13"S 53°08'18"O | 0.17       | 4.1       | 0.17                           |
|                     |                   |                     | CTD_P2           | 25°12'38"S 53°07'51"O |            |           |                                |
|                     | Boa vista Aparecida | Jacutinga River   | BVA_P1           | 25°25'17"S 53°25'46"O | 0.26       | 5.2       | 0.22                           |
|                     |                   |                     | BVA_P2           | 25°25'46"S 53°26'17"O |            |           |                                |
|                     | Três Barras do Paraná | Itaguacu Creek | TBP_P1           | 25°26'11"S 53°11'17"O | 0.32       | 2.8       | 0.1                            |
|                     |                   |                     | TBP_P2           | 25°26'21"S 53°10'50"O |            |           |                                |
| Baixo Iguacu RIVER | Cascavel          | Cascavel River      | CVEL_P1          | 52°53'29"S 53°26'06"O | 0.41       | 4.25      | 0.41                           |
|                     |                   |                     | CVEL_P2          | 52°53'20"S 53°26'19"O |            |           |                                |
|                     | Toledo            | Toledo River        | TOL_P1           | 24°45'49"S 53°39'50"O | 0.44       | 6.1       | 1.81                           |
|                     |                   |                     | TOL_P2           | 24°43'51"S 53°42'40"O |            |           |                                |
|                     | Santa Tereza do Oeste | Gonçalves Dias River | STO_P1          | 25°20'29"S 53°35'20"O | 0.2        | 3.25      | 0.19                           |
|                     |                   |                     | STO_P2           | 25°30'47"S 53°36'14"O |            |           |                                |
|                     | Medianeira        | Alegria River       | MED_P1           | 25°18'35"S 54°30'31"O | 0.21       | 3.3       | 0.06                           |
|                     |                   |                     | MED_P2           | 25°17'30"S 54°40'35"O |            |           |                                |
|                     | Foz do Iguacu     | Tamanduá River      | FOZ_P1           | 25°30'26"S 54°31'50"O | 0.19       | 3        | 0.21                           |
|                     |                   |                     | FOZ_P2           | 25°32'13"S 54°31'25"O |            |           |                                |
Equation 1: Calculation of the average fragility, where: \( F \) is the environmental fragility, \( D \) is the slope, US is the land use and occupation, and Cl is the climate.

Thus, pixel-by-pixel is generated, considering all the variables, the results that determine the final environmental fragility. The method was applied in the same way for each of the watersheds of the studied municipalities.

This paper is concerned to be inclusive with color blind people, thus, for the thematic maps identified by colors, colorimetric scales that make their distinctions possible were used, with the help of the Color Brewer 2.0 (2021) site.

### Data statistical processing

Considering the different sampling points and the strong influence on water quality, all collected variables were previously analyzed using descriptive statistics (mean and coefficient of variation) according to their nature. To compare possible statistical differences of each variable between the municipalities, one-way analysis of variance (one-way ANOVA) was used to evaluate the variation of the factors individually according to the municipality, and, when significant, a posteriori Tukey’s test.

The variation of environmental factors between sampling stations was verified multivariately by means of a non-parametric permutational multivariate analysis of variance (PERMANOVA), applied to the Bray–Curtis similarity matrix with 9999 permutations. The environmental variables were also subjected to the principal component analysis (PCA) to characterize the stations by identifying the variables with the greatest power to differentiate them (Wiegleb 1980).

In addition, after the characterization of fragility, a linear correlation was used to evaluate the dependence of environmental variables as a function of the percentage of each environmental fragility class among the municipalities.

Environmental data were standardized to have equal weight in the analyzes (Borcard et al. 2011). All the analyzes were performed using the language and environment for computational statistics R (R CORE TEAM 2014), along with the Vegan library (Oksanen et al. 2015).

### Results

Differences were observed between the evaluated means of the physico-chemical variables among the rivers based on the analysis of variance (ANOVA-one-way) and the grouping performed by Tukey’s post-test (see complete table in supplementary material S1). The municipalities of Boa Vista da Aparecida (BVA), Catanduvas (CTD) and Três Barras do Paraná (TBP) presented pH values above 7, while the municipalities of Cascavel (CVEL) and Toledo (TOL) presented values close to 5. The municipalities of Três Barras do Paraná (TBP) and Santa Tereza do Oeste (STO), presented average values of COD higher than 70 mg/L. The electrical conductivity showed the highest values (of 0.08 MS/cm–1) for the municipalities of Boa Vista da Aparecida (BVA), Catanduvas (CTD), Guaraniaçu (GUAR) and Três Barras do Paraná (TBP). The total dissolved solids showed higher values for the municipalities of Três Barras do Paraná (71.75 mg/L), Boa Vista da Aparecida (77.25 mg/L) followed by Catanduvas (71.00 mg/L). Turbidity (NTU) suggests a variation of 16.18 between the indicator for the municipality of Toledo (TOL) with 22.25 and Catanduvas of 6.07 (Fig. 2).

The principal component analysis (PCA) for environmental variables summarized 49.77% of the total variability of the sampled data on the first two axes (Fig. 2). The dispersion of the scores of the sites sampled on these axes showed a separation in the diagram of the sampled municipalities, suggesting some similarities among them (Fig. 2). The first PCA axis explained the variability mainly in relation to chlorophyll \( a \) (correlation value: 0.30) and turbidity (0.32) positively for the Cascavel and Toledo municipalities; and pH (–0.37), total solids (–0.37) and COD (–0.32) negatively. This axis accounts for the samplings of Guaraniaçu, Três...
Barras do Paraná, Catanduvas, Medianeira and Boa Vista da Aparecida (negatively), due to the similarity of the highest correlation factors (Fig. 2). The second axis is positively related to Ammoniacal Nitrogen (0.51) Total phosphorus (0.37) and Orthophosphate (0.32), and negatively by Dissolved oxygen (–0.38), depth (–0.364) and COD (–0.25). This axis isolates the sampling site of the municipality of Foz do Iguaçu (5.00) positively and the sampling site of the municipality of Cascavel (–2.55) negatively, highlighting them from the others due to discrepant values before the variables with the highest correlation (Fig. 2).

When evaluated multivariately, the environmental variables characterizing water quality indicate a representative difference as a function of municipalities according to PERMANOVA (Gl: 8; $R^2$: 0.73; $F$: 3.10; $p$ valor: 0.001). This factor effectively confirms the statistical difference in water quality of the environments, as indicated in the ordination represented by PCA (Fig. 2).

Among the landscape variables considered for watersheds is the slope of the terrain (see complete table in supplementary material S2). Analyzing the eight study areas, the predominance of the gentle undulating class (3–8%) was identified, mainly in the municipalities of Foz do Iguaçu (70.86% of the area) (Fig. 3A), Três Barras do Paraná (60.80% of the area) (Fig. 3B), Medianeira (56.20% of the area) (Fig. 4A), Santa Tereza do Oeste (53.17% of the area) (Fig. 3D) and Toledo (52.85% of the area) (Fig. 4B). Then the wavy class (8—20% slope), with predominance in the municipalities of Catanduvas (58.06%) (Fig. 3C), Cascavel (53.27%) (Fig. 3E), Boa Vista da Aparecida (49.55%) (Fig. 3F) and Guaraniçu (47.63%) (Fig. 4C). The watersheds with steeper relief, represented by the strongly undulating class (20—45% of the slope) were Guaraniçu (38.43%), Boa Vista da Aparecida (29.65%) and Catanduvas (21.03%). However, the basins that indicated the largest extensions classified as flat (0–3%) were Santa Tereza do Oeste (29.60%), Três Barras do Paraná (16.40%), Foz do Iguaçu (9.95%) and Toledo (5.02%).

Another important variable in studies of water quality associated with the areas of influence is the use and occupation of the watershed where the catchment occurs. With the survey carried out it was possible to highlight the "agricultural" class, which predominated in the municipalities of Boa Vista da Aparecida (70.18%) (Fig. 5f), Toledo (68.90%) (Fig. 6b), Catanduvas (62.24%) (Fig. 5c), Foz do Iguaçu (56.64%) (Fig. 5a), Três Barras do Paraná (56.03%) (Fig. 5b), Guaraniçu (55.48%) (Fig. 6c) and Medianeira (54.31%) (Fig. 6b) (see complete table in supplementary material S3). The "forest" class was identified with greater extensions in the Santa Tereza do Oeste (55.08%) (Fig. 5d), Três Barras do Paraná (43.02%) and Guaraniçu (39.64%) watersheds. The other study areas had less than 30% of the area identified with this class.

It is important to emphasize that all the collection points are inserted in the "forest" class. However, due to the proximity of polluting agents, the areas of influence were considered, that is, at least one of the two points of each basin is located near areas classified as "agricultural".
In some watersheds the collection point that is not close to the "agricultural" class is close to areas classified as "urban area", such as the points Toledo (TOL_P2), Santa Tereza do Oeste (STO_P1 and STO_P2), Medianeira (MED_P1), Foz do Iguaçu (FOZ_P1 and FOZ_P2) and Cascavel (CVEL_P1). It is important to point out that in Cascavel and Toledo there are mining areas, and that in Cascavel one of the collection points is located close to this region (CVEL_P2).

The municipalities of the watersheds fall within the same macro-region of the state, with similar climatic characteristics. The predominant climate type identified, according to the Brazilian climate classification of Köppen, adapted by Alvares et al. (2013) was the Cfa, characterized as subtropical, with an average temperature in the coldest month below 18°C and the hottest month with a temperature above 22°C. Only the municipality of Catanduvas presented two climate types, Cfa seen previously and Cfb with characteristics of...
temperate climate with mild summer. Evenly distributed rainfall, no dry season and the average temperature of the hottest month does not reach 22 °C (EMBRAPA 2012).

Considering the slope, climate classification, and use and occupation variables of the study areas, we obtained the environmental fragility maps, represented by Figs. 7 and 8. The mapping indicates a predominance of the intermediate class in the watersheds of Boa Vista da Aparecida (94.94%) (Fig. 7f), Toledo (90.93%) (Fig. 8b), Santa Tereza do Oeste (87.27%) (Fig. 7d) and Medianeira (83.80%) (Fig. 8a) (see complete table in supplementary material S4).

When we visualize the largest areas with environmental fragility classified as "high", we can mention the Guaraniaçu (1.34% of the total area) (Fig. 6c), Catanduvas (0.33% of the total area) (Fig. 5b) and Cascavel (0.26% of the total area) basins (Fig. 5e).

In other way, the largest areas that have the lowest environmental fragility, i.e. classified as "very low", we
identified the basins of Três Barras do Paraná (0.49% of the total area) (Fig. 7b) and Santa Tereza do Oeste (0.21% of the total area) (Fig. 7d).

It is important to note that no areas classified as "very high" were identified in any of the study areas.

Environmental fragility presented significant dependence on temperature and pH variables, and the higher the rate of, the higher temperatures and lower pH are observed (Table 3). Another point to be highlighted is E. coli and COD, which, although not reaching $p < 0.05$, pointed to a tendency toward higher concentrations of E. coli and lower COD for higher fragilities (Table 3).
Discussion

The municipalities studied are differentiated not only by water quality, but also by having naturally distinct physical characteristics among the watersheds evaluated. This trend agrees with the continuous river theory of Vannote et al. (1980), which is still associated today with other approaches in studies for the preservation of aquatic ecosystems (Doretto et al. 2020). However, in our study the environmental variables indicated different levels of anthropic interference by land use and occupation that reflected directly on the environmental fragility. The Analysis of Variance initially highlighted differences between the environments mainly as a function of pH, conductivity, COD, orthophosphate, and total solids. These variables directly interfere in the quality and process of water treatment for supply (Collares et al. 2021), which has its cost raised by the demand for chemicals responsible for...
ensuring that these parameters are at safe levels for human consumption (Martins et al. 2022).

The cities of Cascavel and Medianeira stand out with low pH values, around 5, and the cities of Foz do Iguaçu, Catanduvas, and Santa Tereza do Oeste presented average COD values above 70 mg/L. These values obtained in both variables can be related to the influence of residential activities, such as irregular discharge of domestic sewage, in addition to industrial effluents, as well as agricultural activities (Chen and Lu 2014; Carvalho et al. 2015; Hua 2017; Shi et al. 2017; Almeida et al. 2022).

As pointed out in the ordination represented by the PCA (Fig. 2) the municipalities of Boa Vista da Aparecida, Catanduvas and Guaraniaçu showed similarity mainly in function of pH, total solids, orthophosphate and conductivity, variables that are directly linked to water quality (Dou et al. 2022; Shi et al. 2022). These municipalities, with undulating to strongly undulating relief, have a dominance of small
farms (Kawano et al. 2021), as the predominant variables in these spots are strongly indicative of non-point source pollutants such as fertilizer use (Hua 2017; Cheng et al. 2018; Lu et al. 2022). Another factor that reinforces the correlation is that water COD levels are higher in agricultural areas, as there is carryover of nutrients that are not taken up in crops, accumulating in the water during drainage (Shi et al. 2017; Lu et al. 2022). In addition, these environments are susceptible to the erosion process given their high slope, which increases the speed and capacity of water transport in liquid state (Costa et al. 2018; Souza and Oliveira 2018).

The fragility class with predominance in this study was the intermediate class. Similar results that attribute the areas with intermediate fragility to sloping areas allied to agriculture and cattle ranching, due to the inadequate management of the soil, because areas destined for temporary crops and pasture areas with conventional planting expose the soil, the lack of contour lines, making the soil susceptible to erosion,
and also the cattle near the waterways allowing the direct contact of the cattle with the course of the rivers, causing erosion in ravines. These factors, which combined end up generating the contamination of water sources (Abrão and Bacani 2018; Anjinho et al. 2018; Bisognin et al. 2018; Bueno et al. 2018; Silva et al. 2018; Nörnberg and Rehbein 2020; Mohammadzadeh et al. 2021).

The variation in fragility responded mainly to tempera-
ture values of pH, E. coli, and COD, which can be strongly associated with the difference in land use and slope of the assessed areas (Ren et al. 2022). Higher temperatures were related to intermediate fragility and lower to high fragility, which can be associated with more intensified slope causing increased river flow, as flowing water tends to receive less direct insolation and therefore making it colder (Wang et al. 2021). Another factor is lower pH and higher E. coli concentration are related to intermediate to high fragility, these factors are indicative of urban densification (Hu et al. 2022). As well as temperature and COD, also reflecting the agricultural extension of the municipality, characterizing great use of pesticides that increase the load of nutrients carried to water bodies, favoring the development of bacteria (Lötjönen and Ollikainen 2019; Lu et al. 2022).

Thus, the most vulnerable watersheds can be considered those of Cascavel, Foz do Iguaçu, Toledo and Medianeira, because they have large urbanized regions near the collection points. Anthropogenic activities directly affect the fragility of these environments as well as water quality, this occurs because urbanization has point sources of pollution, such as defects in wastewater pipes, improper disposal of domestic waste and from factories, also affecting soil availability, altering the landscape and ecosystems (Pereira et al. 2018; Silva et al. 2018; Odeh et al. 2022). For this reason, areas with steep relief with exposed soil or with vegetation are associated with intermediate to high fragility, as well as, regions of urban area, where human activities can intensify the degradation process altering the balance of the environment. making this environment fragile (Schiavo et al. 2016; Valle et al. 2016; Belato et al. 2019; Costa et al. 2020; Doad et al. 2022a, b).

It is observed in a general aspect, that the municipalities that have higher percentages of forest also have lower percentages of urban area and vice versa, since they present themselves inversely proportional. This trend is related to Carvalho et al. (2016) that the presence of residences near the watercourse evidences the absence of permanent preservation areas (APP) in the region, causing environmental damage, as well as surface imperviousness, irregular runoff, flooding, and inadequate disposal of organic matter/sanitary matter.

Research that includes geosystemic approaches in water resources management is a strong trend in more recent studies (Silva and Amorim 2022). Relating environmental
fragility with water analysis allows for a deeper understanding of aspects that directly or indirectly influence lotic environments used in public supply, consequently the health of the population that uses these resources (Doad et al. 2022a, b). We emphasize in this study the macro-scale perspective (environmental fragility) and micro-scale perspective (water quality), which together allow for a more refined interpretation in the environmental diagnosis of a watershed. Thus, our results are essential in decision-making for public policies regarding the management of water resources, as well as the preservation and management of these environments.

**Conclusion**

The present study showed that the intermediate fragility class predominates in the nine municipalities studied in the west of Paraná, namely: Boa Vista da Aparecida, Catanduvas, Cascavel, Foz do Iguaçu, Guaraniacu, Medianeira, Santa Tereza do Oeste, Três Barras do Paraná and Toledo. Management of the same is necessary for restoration and conservation, aiming to prevent the advance of fragility added to minimize the anthropic impacts of the use and occupation of such environments. The municipalities that have the largest areas with high fragility class, with the most fragile ones, are: Guaraniacu, Catanduvas and Cascavel, demanding greater attention, because they are harmful to the water sources and the water quality of the water bodies.

It also pointed out distinct characteristics among the water catchment rivers for public supply, of the west of Paraná, due to the water quality and due to its natural characteristics. The variation in fragility mainly responded to the pH, E. coli and DQO temperature values, which can be strongly associated with the difference in soil use and slope of the areas evaluated.

The use of geoprocessing tools made it possible to make the fragility maps as well as, how to associate it with water quality factors of 9 catchment rivers for public supply in the west of Paraná, Brazil, proving to be an efficient tool for the study of environmental changes, emphasizing the limitation of studies that combine geoprocessing with water quality indices. The results obtained can be used for future decision-making regarding environmental management based on the water quality improvement and restoration of the studied sources.

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**Code availability** Not applicable.

**Declarations**

**Conflict of interest** Not applicable.

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