Article

Proposal of environmental zoning for watersheds: application in the Water Resources Planning and Management Unit from Low Paranaíba River, Minas Gerais State, Brazil

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Proposal of environmental zoning for watersheds: application in the Water Resources Planning and Management Unit from Low Paranaíba River, Minas Gerais State, Brazil[1]

Abstract

The growing – and almost always devoid of criterion – exploitation of natural resources raised the importance of initiatives related to environmental conservation. In this context, environmental zoning has become a fundamental instrument in territorial management. This article proposes a methodological procedure for environmental zoning specifically oriented for watersheds, with demonstrative application in the Water Resources Planning and Management Unit from Lower Paranaíba River Tributary Watersheds, state of Minas Gerais (Brazil). The proposal includes assessing vulnerability to soil loss, qualitative and quantitative vulnerability of surface waters, and the situation of legally protected areas. The methodology involves recognizing conflicts from the intersection of the above-mentioned vulnerabilities and legally protected areas with land use, constituting a zoning model capable of indicating areas for preservation, recovery, and management. The work is expected to be useful to managers and the model to be applied in similar territorial units.

Keywords: Environmental zoning. Watersheds. Lower Paranaíba River tributaries.

Proposta de zoneamento ambiental para bacias hidrográficas: aplicação na Unidade de Planejamento e Gestão dos Recursos Hídricos Afluentes Mineiros do Baixo Paranaíba[1]

Resumo

A crescente exploração – quase sempre sem critério – de recursos naturais advertiu da importância de iniciativas voltadas à conservação ambiental. Nesse contexto, o

1 Rafael Mendes Rosa thanks the Coordination for the Improvement of Higher Education Personnel (Capes) for the granting of the doctoral scholarship, process n. 88882.428732/2019-01.

zoneamento ambiental tornou-se um instrumento fundamental na gestão territorial. Este artigo propõe um procedimento metodológico de zoneamento ambiental especificamente orientado para bacias hidrográficas, com aplicação demonstrativa na Unidade de Planejamento e Gestão de Recursos Hídricos das Bacias Hidrográficas dos Afluentes Mineiros do Baixo Paranaíba, no estado de Minas Gerais. A proposta contempla a avaliação da vulnerabilidade à perda de solos, da vulnerabilidade quali-quantitativa das águas superficiais e da situação das áreas legalmente protegidas. A metodologia envolve o reconhecimento de conflitos a partir da interseção dessas vulnerabilidades e das áreas legalmente protegidas com o uso da terra, constituindo um modelo de zoneamento capaz de indicar áreas para preservação, recuperação ou manejo. Espera-se que o trabalho possa ser útil aos gestores e que o modelo possa ser aplicado em unidades territoriais análogas.

Palavras-chave: Zoneamento ambiental. Bacias hidrográficas. Afluentes do Baixo Paranaíba.

Propuesta de zonificación ambiental para cuencas hidrográficas: aplicación en la Unidad de Planificación y Gestión de los Recursos Hídricos Afluentes del Bajo Paranaíba, Minas Gerais, Brasil

Resumen

La creciente y casi siempre desacreditada explotación de los recursos naturales planteó la importancia de las iniciativas de conservación del medio ambiente. En este contexto, la zonificación ambiental se ha convertido en un instrumento en la gestión territorial. Este artículo propone un procedimiento metodológico para la zonificación ambiental específicamente orientada a cuencas hidrográficas, con aplicación en la Unidad de Planificación y Manejo de Recursos Hídricos de las Cuencas Hidrográficas de los Afluentes del Bajo Paranaíba, Minas Gerais (Brasil). La propuesta incluye la evaluación de las vulnerabilidades a la pérdida de suelos, cuali-cuantitativa de las aguas superficiales y las áreas legalmente protegidas. La metodología implica reconocer conflictos desde la intersección de las vulnerabilidades y áreas legalmente protegidas con el uso del suelo para señalar áreas para conservación, recuperación y manejo. Se espera que el trabajo pueda ser de utilidad para los gestores y que el modelo se pueda aplicar en unidades territoriales similares.

Palabras clave: Zonificación ambiental. Cuencas hidrográficas. Afluentes del Bajo Paranaíba.

Introduction

The exploitation of natural resources, intensified after the second half of the 20th century, brought to public debate the importance of environmental conservation. Since the 1970s, international conferences and commissions have been responsible for the more incisive introduction of the environment in public policies. In this context, environmental laws and regulations were proposed to minimally balance economic action and preservation of nature. Thus, environmental planning and management tools have been developed and applied in several countries, such as environmental zoning, which is one of the main territory management tools.

In Brazil, zoning for environmental purposes was defined by Law No. 6,938, of August 31, 1981 (Brazil, 1981), despite being regulated only by Decree No. 4,297, of July 10, 2002 (Brazil, 2002). According to this decree, the instrument aims at territorial planning, and must be followed in plans and projects of a public or private nature. In addition, its application allows establishing standards of water resources and soil protection, of biodiversity conservation, and of improvement of the population's living conditions, among others.

The principles of Decree No. 4,297, of July 10, 2002 (Brazil, 2002) state that environmental zoning should be constituted based on the potentialities and weaknesses of the landscape, considering the productive activities (land use), vulnerability to soil loss, and the quantity and quality of surface waters. Another aspect is legal incompatibilities, which consist of the conditions of legally protected areas and with inappropriate occupations, which reveals circumstantial conflicts.

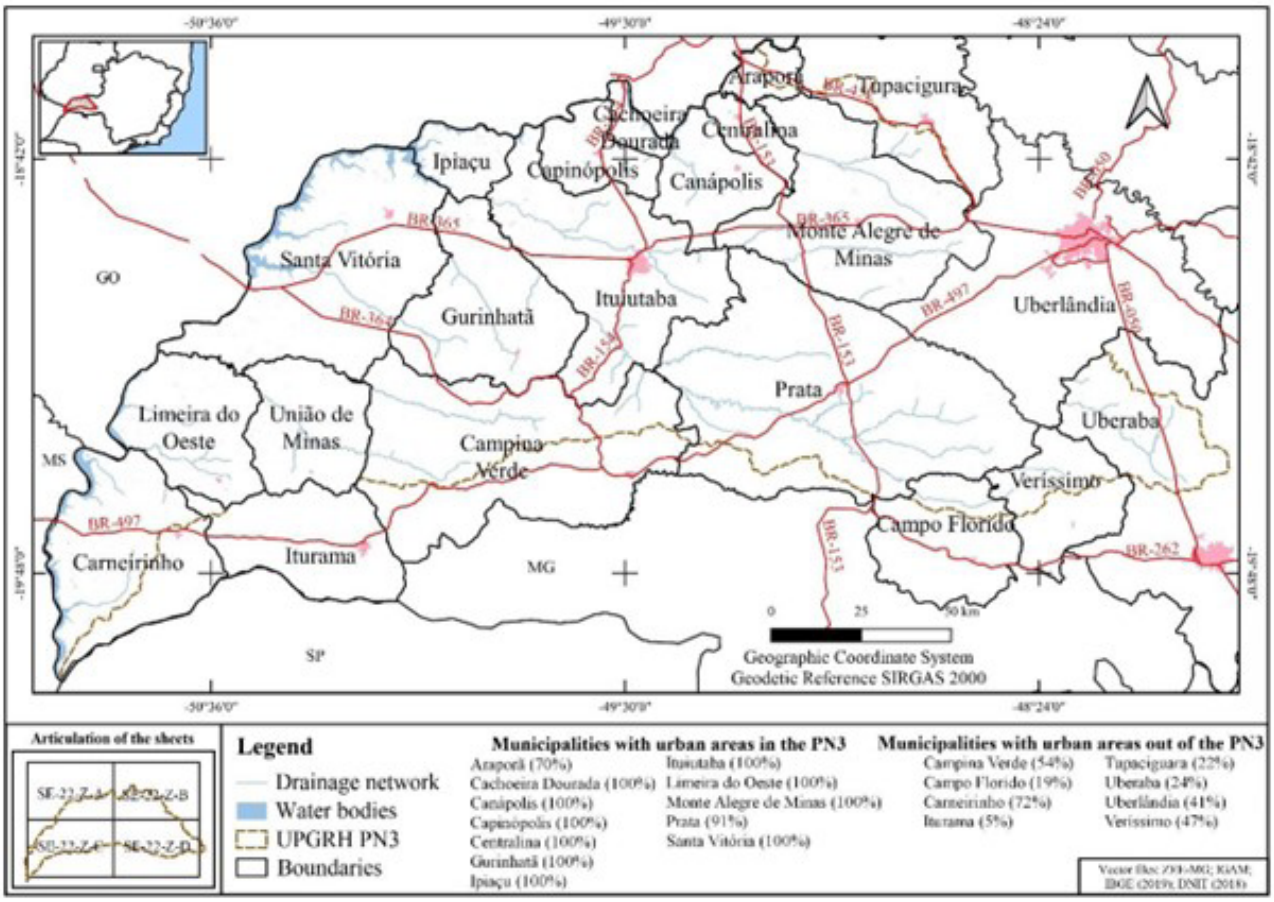
Thus, this article aims to propose a methodological procedure of environmental zoning for watersheds since they are the basic units for planning and management of water resources according to Law No. 9,433, of January 8, 1997 (Brazil, 1997). For demonstrative purposes, the methodology was applied in the Water Resources Planning and Management Unit from Lower Paranaíba River Tributary Watersheds (UPGRH PN3), in the state of Minas Gerais. This is a methodological alternative for the master plans of water resources of watersheds, including UPGRH PN3, to obtain an instrument that effectively considers variables directly or indirectly related to the situation of water resources.

The hypothesis of the reported research is based on the expectation of methodological feasibility of obtaining an environmental zoning that includes integrated information of physical-geographical and environmental components, emphasizing variables directly related to water dynamics. The methodological procedure is expected to contribute as a path not only to cover the gap of the UPGRH PN3 Water Resources Master Plan (which currently lacks environmental zoning), but also to be an alternative to other territorial units.

Area selected for demonstrative study

The area selected for study is UPGRH PN3, in the state of Minas Gerais, in the intermediate geographic regions of Uberlândia and Uberaba (Regional Division of Brazil..., 2017). It is a set of watersheds with an area of 26,892.39 km^2 belonging to the federal basin of the Paranaíba River, which is one of the 36 UPGRH of Minas Gerais (Igam, 2010). Map 1 shows this location, with the municipalities and their percentages of occupation, as well as access through federal highways.

Map 1 – Location of UPGRH PN3



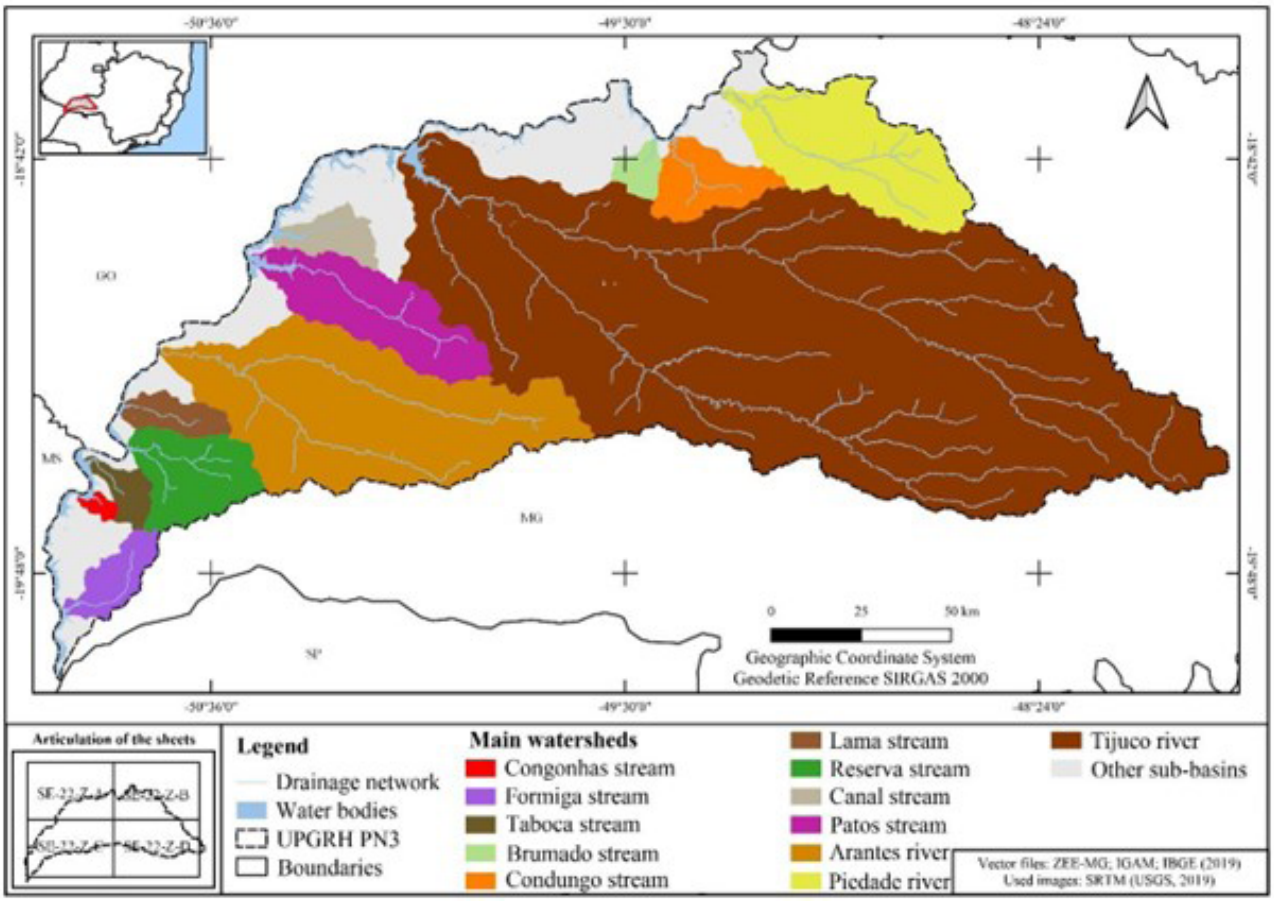
source: Authors' own elaboration.

To complement the location of the study area, the main sub-hydrographic sub-basins of UPGRH PN3 are indicated. Map 2 shows the 12 most representative watersheds in the territorial unit. This condition was established due to the size, importance of major rivers, or recognition in official topographic charts. Among these 12 main watersheds, the Tijuco, Piedade, and Arantes rivers stand out, since they are the best known in the entire scope of the study area.

Methodological procedures

The methodological procedure of environmental zoning is based on the integration of physical-geographical and environmental variables, especially those related to water resources. Thus, the proposal was conducted in five stages: (1) obtaining thematic maps of physical-geographical and environmental components; (2) survey of natural vulnerability to soil loss, qualitative and quantitative vulnerability of surface waters and legally protected areas; (3) recognition of conflicts between land use and the two above-mentioned vulnerabilities and between land use and legally protected areas (legal incompatibilities) by Boolean logic (intersection); (4) configuration of the environmental zoning proposal; and (5) indication of areas for preservation, recovery, and management as indicated in the previous stage. Table 1 shows a summary of the aspects found and worked on.

Map 2 – Location of the main watersheds of UPGRH PN3



source: Authors' own elaboration.

In the first stage, the themes geology and soils were obtained from IBGE (2018) shapefiles. Slope was obtained from images of the Shuttle Radar Topography Mission (SRTM) (USGS, [2019]), with class slicing based on Santos et al. (2018): 0% to 3% (flat), 3% to 8% (soft wavy), 8% to 20% (wavy) and > 20% (strong wavy). The annual average precipitation data come from rainfall stations located inside and in the adjacencies of the study area (ANA, [s.d.]), period from 1988 to 2018. The average annual precipitation contributed to the rainfall intensity considering the rainy season from seven to nine months (Crepani et al., 2001). For the land cover and land use map, the shapefile of TerraClass Cerrado (Mapeamento do uso..., 2015), adapted by MapBiomas (2018), was used. All maps were created in QGIS 2.18.25 *software* with GRASS 7.4.2.

The natural availability of surface waters in the estuary of the main river (considering $Q_{7,10}$ due to being the reference streamflow of Minas Gerais for granting the right to use water resources) came from the vector file of the drainage network, scale 1:100,000 (IDE-Sisema, [2019]; Igam, 2012). The areas of conflict over water use, on the other hand, were obtained in the *IDE-Sisema shapefile* (2019). Note that the maximum catchment limit in most watersheds in Minas Gerais is 50% of $Q_{7,10}$ and, when the demand is superior, a Conflict Area Declaration (DAC) is generated (Igam, 2019a; Minas Gerais, 2019).

The quality of surface water was based on the Igam 2018 report (2018, 2019b). The indicators are the water quality index (WQI) (dissolved oxygen, thermotolerant coliforms, pH, biochemical oxygen demand, nitrates, total phosphate, temperature variation, turbidity, and total solids), toxic contamination (TC) (total arsenic, total barium, total cadmium, total lead, free cyanide, dissolved copper, total chromium, total phenols, total mercury, nitrite, nitrate, total ammoniacal nitrogen, and total zinc) and trophic state index (TSI) (total phosphorus and chlorophyll-a.).

Table 1 – Summary of the aspects found and worked on in the methodological proposal

stage	aspects found and worked on
(1) thematic maps of the physical-geographical and environmental components	Geology, slope, soils, rainfall intensity, land cover and land use, natural surface water availability, areas of conflict over water use, and surface water quality were found.
(2) natural vulnerability to soil loss, quali-quantitative vulnerability of surface waters and legally protected areas	Natural vulnerability to soil loss was found by adapting Crepani et al.'s (2001) proposal according to the first five themes of the previous stage. With the same logic, the quali-quantitative vulnerability of surface waters was established from the three other themes. In the legally protected areas, Permanent Preservation Areas, Legal Reserve, and Conservation Units were found.
(3) recognition of conflicts between land use and vulnerability and between land use and legally protected areas	The base map is land cover and use, which was used at the intersection with maps of natural vulnerability to soil loss, quali-quantitative vulnerability of surface waters, and legally protected areas.
4) proposed environmental zoning	Zones of conservation or recoverable interventions and of consolidated occupations and/or productive activities were defined. The two zones aim to separate areas protected by environmental laws (called legally protected areas) from those with consolidated occupation or where productive activities are carried out. The interior of the two zones was subdivided into areas (subzones) in conflict levels to support the indications of the later stage.
(5) indication of areas for preservation, recovery, and management	The proposal covers a set of actions to be applied in the areas (sub-areas) according to the levels of conflicts previously established.

source: Authors' own elaboration.

The second stage obtained the natural vulnerability to soil loss by adapting the methodology of Crepani et al. (2001), assigning weights to the variables of the following physical-geographic components: (1) lithology, (2) slope, (3) soil classes, (4) rainfall intensity, and (5) classes of cover and land use. The themes were overlapped to obtain the arithmetic mean, using the following equation:

$$V = (Lit + Slo + Sol + RI + CLU)5 \quad (1)$$

Where:
V = vulnerability
Lit = vulnerability values of the theme lithology
Slo = vulnerability values of the theme slope
Sol = vulnerability values of the theme soils
RI = vulnerability values of the theme rainfall intensity
CLU = vulnerability values of the theme coverage and land use

The weights followed the suggestion of Crepani et al. (2001): values close to 1.0 tend to stability; near 2.0, indicate intermediate conditions; and close to 3.0, vulnerability. To simplify the legend, five tracks were defined (Table 2).

Table 2 – Degrees of vulnerability to soil loss with added values

landscape units	added vulnerability values	vulnerability degree
U1, U2, U3, and U4	3.0, 2.9, 2.8, and 2.7	vulnerable
U5, U6, U7, and U8	2.6, 2.5, 2.4, and 2.3	moderately vulnerable
U9, U10, U11, U12, and U13	2.2, 2.1, 2.0, 1.9, and 1.8	medium stable/vulnerable
U14, U15, U16, and U17	1.7, 1.6, 1.5, and 1.4	moderately stable
U18, U19, U20, and U21	1.3, 1.2, 1.1, and 1.0	stable

source: Adapted from Crepani et al. (2001).

The quali-quantitative vulnerability of surface waters was obtained by the overlap of components related to water resources: (1) availability of surface water, (2) areas of conflict over water use, and (3) surface water quality. The availability of surface water was assigned values according to Table 3.

For the areas of conflict over water use, a practical and direct criterion was adopted: the watersheds with declared conflict have the highest vulnerability value, and those with no declared conflict, the lowest (Table 4).

Table 3 – Degrees of vulnerability in surface water availability

surface water availability ($Q_{7,10}$)	vulnerability value	availability degree
< 3.00 m^3/s	3.0	very low
3.00 to 8.00 m^3/s	2.5	low
8.01 to 13.00 m^3/s	2.0	medium
13.01 to 18.00 m^3/s	1.5	high
> 18.00 m^3/s	1.0	very high

source: Authors' own elaboration.

Table 4 – Degrees of vulnerability of areas of conflict over water use

areas of conflict over water use	vulnerability value	vulnerability degree
watersheds with declared conflict	3.0	very high
watersheds without declared conflict	1.0	very low

source: Authors' own elaboration.

Regarding surface water quality, we opted for a synthesis of the indicators (WQI, TC, and TSI). To perform the process, vulnerability values were attributed according to the logic that, the closer to 3.0, the worse the surface water quality, applying the following equation:

$$V = (WQI + TC + TSI)3 \quad (2)$$

Where:
V = vulnerability
WQI = vulnerability values of the theme water quality index
TC = vulnerability values of the theme toxic contamination
TSI = vulnerability values of the theme trophic state index

Table 5 shows the vulnerability values of the indicators (WQI, TC, and TSI) and a representative color scale of each class (vulnerability degrees).

The values resulting from the overlap of the three themes (WQI, TC, and TSI) were added, and the surface water quality summary was indicated in the legend of the map (Table 6).

Considering all the established themes (surface water availability, areas of conflict over water use and water quality), the synthesis map was designed, which establishes the quali-quantitative vulnerability of surface waters. This map was obtained from overlapping the three themes, again in an equation:

$$V = (SWA + CA + SWQ)3 \quad (3)$$

Where:
V = vulnerability
SWA = vulnerability values of the theme surface water availability
CA = vulnerability values of the theme areas of conflict over water use
SWQ = vulnerability values of the theme surface water quality

Table 5 – Degrees of vulnerability in surface water quality

indicator	vulnerability value	class (vulnerability degree)
WQI	1.0	excellent (90 < WQI ≤ 100)
	1.5	good (70 < WQI ≤ 90)
	2.0	medium (50 < WQI ≤ 70)
	2.5	bad (25 < WQI ≤ 50)
	3.0	very bad (≤ 25)
TC	1.2	low (≤ 20% above the legal limit)
	2.0	medium (> 20% and ≤ 100% above the legal limit)
	2.8	high (> 100% above the legal limit)
TSI	1.0	ultraoligotrophic (= 47)
	1.4	oligotrophic (47 < TSI = 52)
	1.8	mesotrophic (52 < TSI = 59)
	2.2	eutrophic (59 < TSI = 63)
	2.6	supereutrophic (63 < TSI = 67)
	3.0	hypereutrophic (> 67)

source: Adapted from Igam (2019a).

Table 6 – Degrees of vulnerability in surface water quality with added values

added vulnerability values	quality degree
1.0, 1.1, 1.2, 1.3	very high
1.4, 1.5, 1.6, 1.7	high
1.8, 1.9, 2.0, 2.1, 2.2	medium
2.3, 2.4, 2.5, 2.6	low
2.7, 2.8, 2.9, 3.0	very low

source: Authors' own elaboration.

From the results obtained by this equation, the quali-quantitative vulnerability values of surface waters were aggregated according to the criteria in Table 7.

Also in the second phase, the legally protected areas were delimited from files from official sources or created for this purpose. For the conservation units (CU), the shapefiles of the IDE-Sisema (2019) were used and the legal reserves (LR) were obtained in the National Rural Environmental Registry System (Sicar, [2020]). For the permanent preservation areas (PPA), a buffer of the drainage network was made according to the New Forest Code (Brasil, 2012).

Table 7 – Degrees of quali-quantitative vulnerability of surface waters

added vulnerability values	vulnerability degree
3.0, 2.9, 2.8, 2.7	very high
2.6, 2.5, 2.4, 2.3	high
2.2, 2.1, 2.0, 1.9, 1.8	medium
1.7, 1.6, 1.5, 1.4	low
1.3, 1.2, 1.1, 1.0	very low

source: Authors' own elaboration.

The third phase is establishing conflicts to identify, with a pre-established process, how anthropic activities, which modify nature, compromise the loss of soils, the quali-quantitative situation of surface waters, and the preservation of areas to be protected by environmental laws. The base map is coverage and land use, which was used at the intersection with maps of natural vulnerability to soil loss, quali-quantitative vulnerability of surface waters, and legally protected areas. Specifically for the conflict between land use and quali-quantitative vulnerability of surface waters, conflicting watersheds were indicated by estimating the largest class of conflict. The intersections followed the criteria in Table 8.

The fourth phase defines conservation zones or recoverable interventions and consolidated occupations and/or productive activities. From these two zones, subdivisions were proposed considering the previously installed conflicts. The aim is to determine that, in both zones, actions are developed to improve the environmental quality compatible with internal particularities, especially regarding water resources. However, the conflict between land use and quali-quantitative vulnerability of surface waters indicates watersheds with priority for recovery and management measures. Table 9 shows the criteria defined for the subdivision of areas (subzones).

The fifth stage suggests guidelines for preservation or recovery and management to implement the instrument for planning and environmental management of watersheds.

Results and discussion

UPGRH PN3 is composed predominantly of sandstones (moderately vulnerable rocks) and basalts (moderately stable rocks). Alluvial deposits and undifferentiated coverage, much less representative, are vulnerable. As for slope, the smooth wavy relief predominates (3% to 8%). Soils are largely stable, such as red latosols and medium-stable/vulnerable such as red-yellow argisols. The average annual precipitation ranges from 1,250 mm to 1,550 mm and the classes of land cover and land use are: urbanized areas, bodies of water, crops, pastures, forestry, and native vegetation.

With the overlap of the five themes, the result of natural vulnerability to soil loss was obtained. In 73.78% of its area, UPGRH PN3 presented a vulnerability classified as medium stable/vulnerable. This vulnerability can be found in parts of topographic dividers and watershed

strands of watercourses up to 4th order. The moderately stable degree, present in 23.02%, is located in areas of flat to smooth relief, river valleys of at least 4th order, in addition to the areas of native vegetation, which constitute a coverage of greater stability. Note that the degree of greater vulnerability to soil loss in the study area is moderately vulnerable, but in only 1.13%, in the most sloping areas, being insignificant in the territory of the planning unit. Map 3, which presents the result of the natural vulnerability of the study area to soil loss, shows these characteristics.

Table 8 – Defined intersections for the establishment of conflicts

defined intersection for the conflict between land use and vulnerability to soil loss					
	vulnerable	moderately vulnerable	medium stable/ vulnerable	moderately stable	stable
urbanized areas	very high	very high	very high	high	medium
temporary crops	very high	high	medium	low	low
permanent crops	very high	high	medium	low	very low
pastures	very high	very high	high	medium	low
forestry	very high	high	medium	low	very low
defined intersection for the conflict between land use and quali-quantitative vulnerability of surface waters					
	very high	high	medium	low	very low
urbanized areas	very high	very high	high	medium	medium
temporary crops	very high	very high	high	medium	low
permanent crops	high	high	medium	medium	low
pastures	very high	high	high	medium	medium
forestry	high	high	medium	medium	low
defined intersection for the conflict between land use and legally protected areas					
	conservation unit		legal reserve		permanent preservation area
urbanized areas	high		high		high
temporary crops	high		medium		medium
permanent crops	high		medium		medium
pastures	medium		medium		low
forestry	medium		medium		medium

source: Authors' own elaboration.

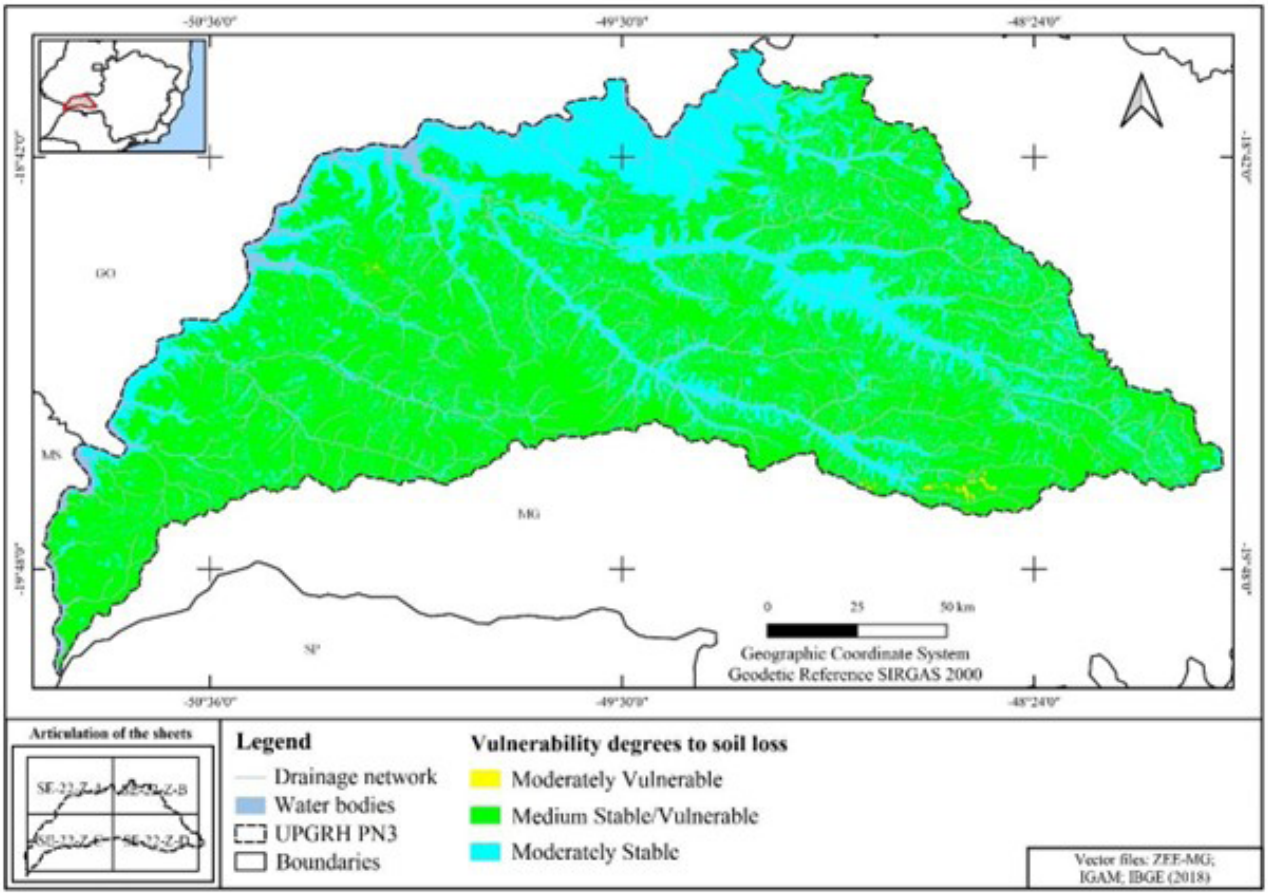
Table 9 – Criteria for defining areas (sub-areas)

zone of conservation or recovering interventions	
conflict between land use and legally protected areas	**area definition**
high	areas for low-urgency recovery
medium	areas for medium-urgency recovery
low	areas for high-urgency recovery
nonexistent (native vegetation)	areas for preservation
zone of consolidated occupations and/or productive activities	
conflict between land use and vulnerability to land loss	**area definition**
any	urbanized areas
very high	inappropriate areas
high	apt areas with relevant restrictions
medium	apt areas with moderate restrictions
low	apt areas with elementary restrictions
very low	apt areas
nonexistent (native vegetation to be inserted in the conservation area)	areas for preservation
river basins with priority to recovery and management actions	
priority	**criteria**
very high	Watershed with very high conflict or watershed with high conflict but that has a DAC.
high	Watershed with high conflict or watershed with medium conflict but that has a DAC. When the conflict is high and there is a DAC and yet another basin in the same situation, set the priority for the one with the oldest UPGRH DAC.
medium	Watershed with medium conflict or watershed with high conflict, without a DAC and at least two watersheds already with a DAC in the UPGRH.
low	Watershed with low conflict or watershed with medium conflict, without a DAC and at least two watersheds already with a DAC in the UPGRH.
very low	Watershed with very low conflict.

source: Authors' own elaboration.

Regarding the natural availability of surface waters, watersheds of the Reserva and Patos streams (to the west), the São Jerônimo stream (a tributary of the left bank of the Tijuco River) and the Condungo or the Cerrado streams (to the north) have the lowest natural availability. The Tijuco river basin has the highest availability of surface waters, presenting a very high (Tijuco river) and a high (Rio da Prata) part. On the other hand, the São Jerônimo watershed has very low availability.

Map 3 – Natural vulnerability of UPGRH PN3 to soil loss



source: Authors' own elaboration.

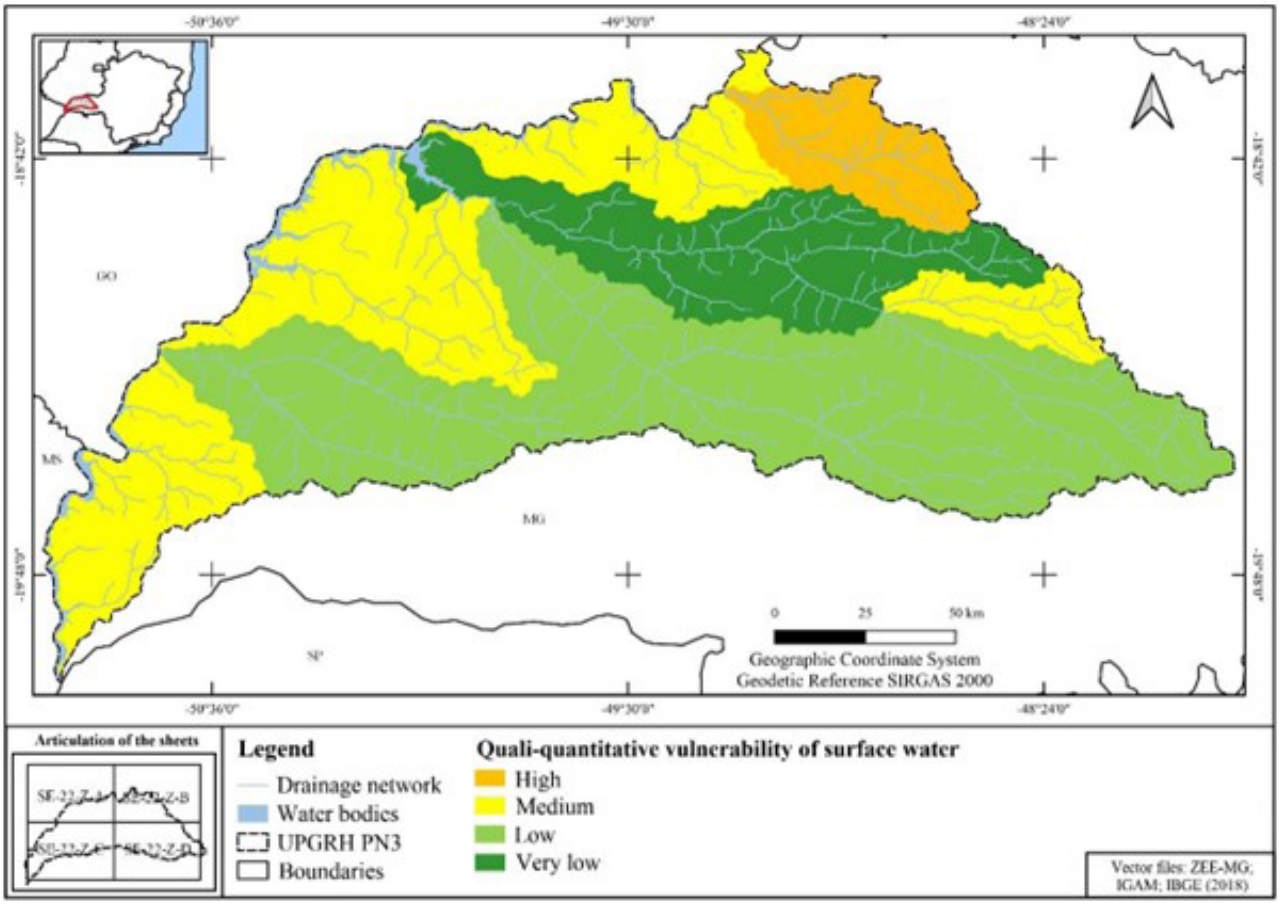
The UPGRH PN3 has seven watersheds in conflict over water use, three areas in the Piedade watershed (upper Piedade, Bebedouro watershed, and lower Piedade) and four others in the Douradinho watershed (upper Douradinho, Água Limpa stream, Panga stream, and lower Douradinho). On surface water quality, in general, UPGRH PN3 has a high quality, except for the upper Tijuco watershed, of medium quality.

With the information on the availability of surface water, the areas of conflict over use of water, and the quality of surface water, their integration was carried out. The high vulnerability, present in 6.54% of the UPGRH PN3, is only found in the Piedade watershed. The areas of medium vulnerability, which cover 31.93%, represent watersheds of the Formiga, Congonhas, Taboca streams, the Reserva, Lama, Patos, Canal, and São Jerônimo streams (west and central), in addition to the Brumado or Paiol, streams, Condungo or Cerrado (north) and Douradinho (east) streams. In 43.90%, vulnerability is low, found in the watersheds of the Arantes (west), Prata (central), and upper Tijuco rivers (east). The very low vulnerability, present in 15.56%, is restricted to a part of the Tijuco watershed. Map 4 presents the quali-quantitative vulnerability of surface waters.

Legally protected areas cover CU, LR, and PPA. According to the National System of Conservation Units (SNUC), the study area comprises one area of integral protection (Wildlife

Refuge of the Tijuco and Prata Rivers) and six of sustainable use (RPPN), (Brazil, 2000). The LRs delimited are the ones registered and/or approved by the Rural Environmental Registry (CAR) (Sicar, [2020]), since the rest are still subject to approval.

Map 4 – Quali-quantitative vulnerability of UPGRH PN3 surface waters



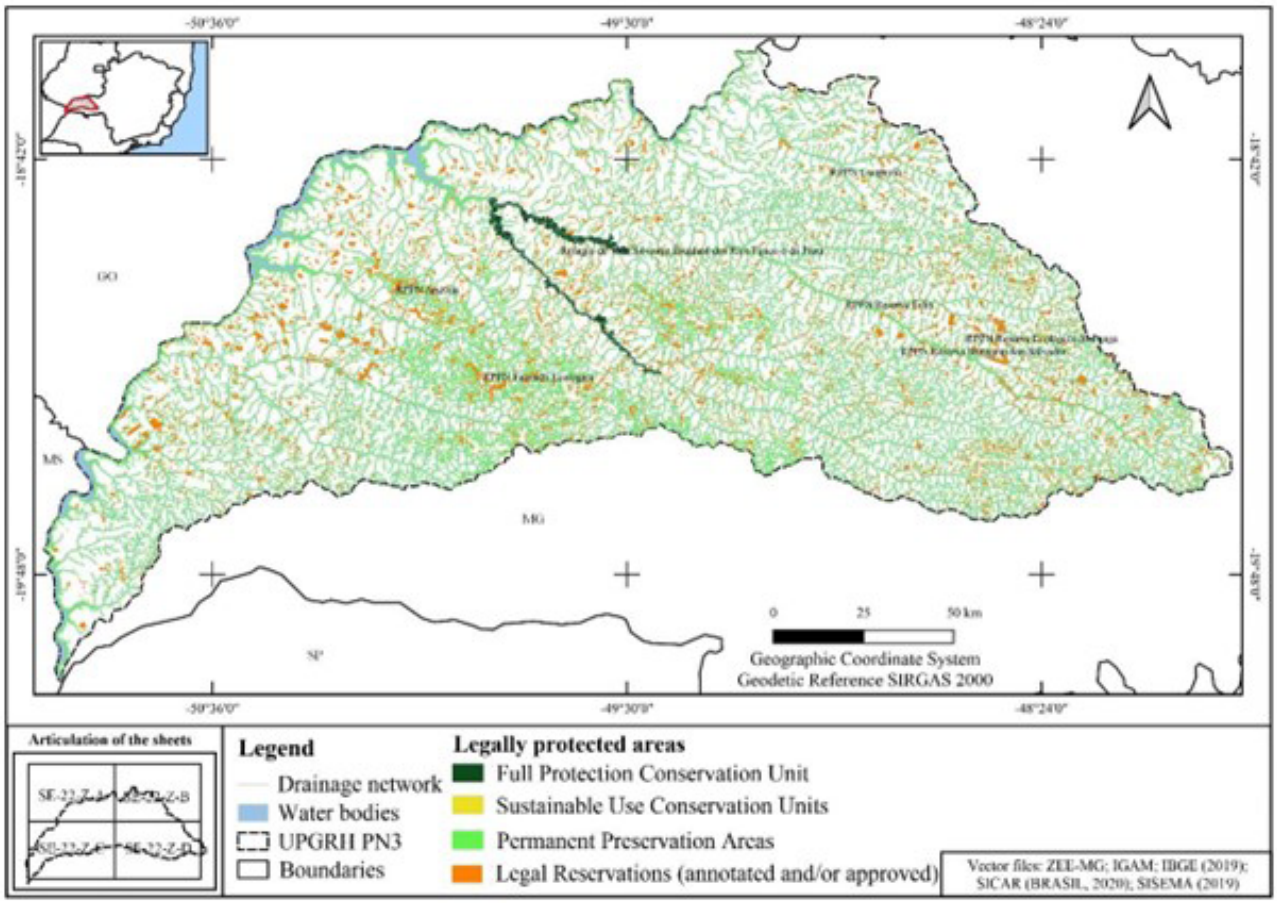
source: Authors' own elaboration.

In the PPA, the bands were defined by the width of the watercourses, being 30 m those of up to 4th order, due to presenting a width lower than 10 m. The watercourses of 5th order onwards, such as the Reserva stream, the Arantes, Piedade, and a stretch of the Prata rivers, have a 50 m PAP, due to having width between 10 m and 50 m. The exceptions are the lower Prata river and the Tijuco river, with widths between 50 m and 200 m, in which case the PPA has 100 m. For the PPA of the artificial reservoirs, the 100 meters were maintained, although the New Forest Code (Brasil, 2012) changed this determination. Map 5 shows legally protected areas with CU, LR, and PPA.

Based on the information on natural vulnerability to soil loss, quali-quantitative vulnerability of surface waters, and legally protected areas, the third phase of the methodology was carried out: recognizing conflicts between land use and the two vulnerabilities and between land use and legally protected areas (legal incompatibilities), by intersection (Boolean logic). For the conflict between land use and natural vulnerability to soil loss, we sought to determine the conditions that

each land use interferes with triggering erosive processes. The predominant pastures determined a high conflict in much of the study area, which resulted from the intersection between pastures and medium stable/vulnerable areas.

Map 5 – Legally protected areas of UPGRH PN3

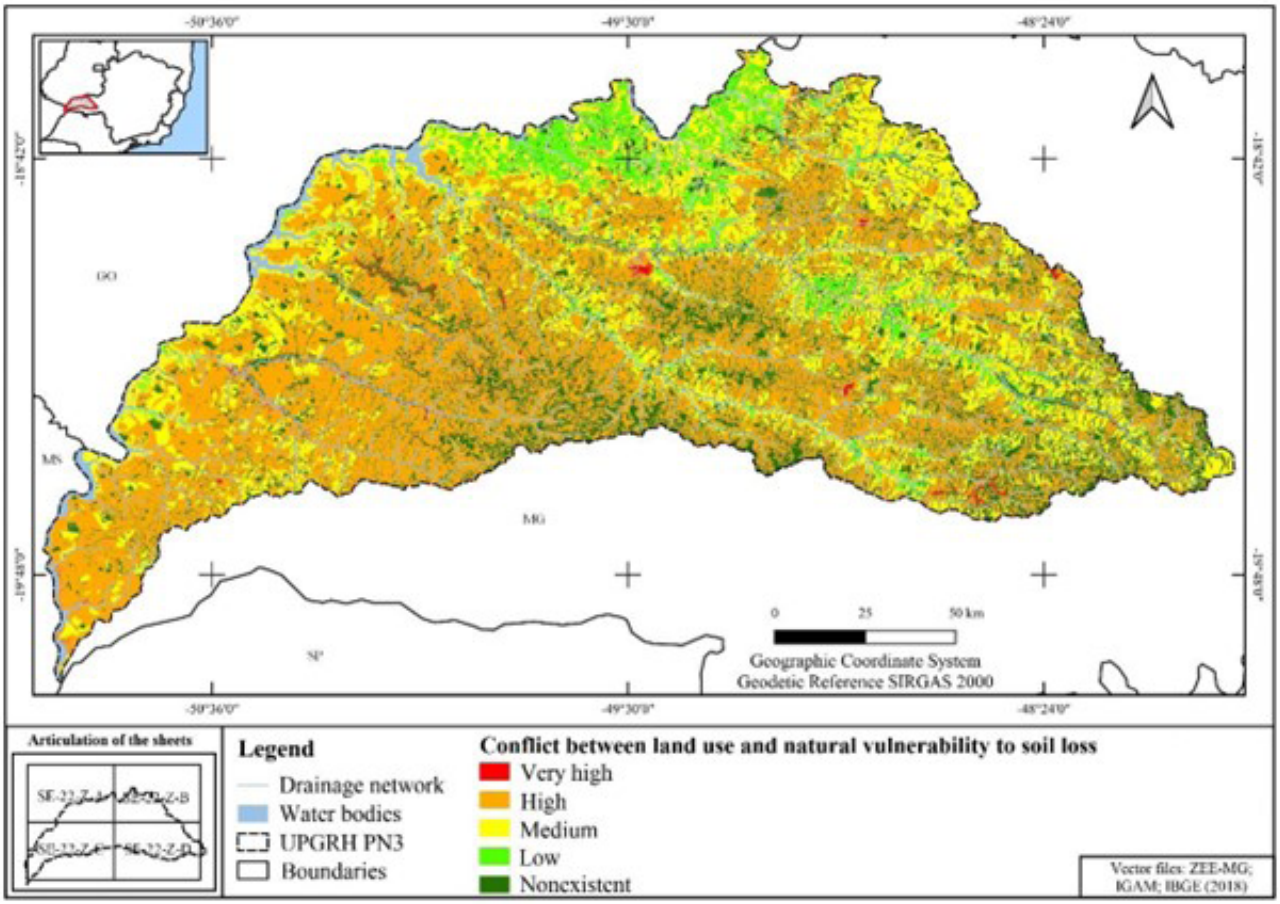


source: Authors' own elaboration.

The second class in scope corresponded to the medium conflict, where pastures are in moderately stable areas, in addition to crops (temporary and permanent), and forestry in medium stable/vulnerable areas. The low conflict was identified in the crop (temporary and permanent) and forestry portions in moderately stable areas. Finally, urbanized areas, located on medium stable land, and pastures, in moderately vulnerable areas, presented a very high conflict. In view of these considerations, Map 6 shows the result of the conflict between land use and natural vulnerability to soil loss.

Identifying the conflict in the hydrographic basins, obtained by the intersection between land use and quali-quantitative vulnerability of surface waters, aimed to reflect how much land uses can affect surface waters. The areas where land uses with very high conflict predominate, as in the Piedade watershed, reflect this perspective, since they portray the territory of greatest conflict due to water use. In this watershed, the water demand for economic activities is significant, but its surface waters have low availability. In these terms, the pressure on water resources is a conflict to be identified and mitigated with recovery and management actions.

Map 6 – Conflict between land use and natural vulnerability to soil loss of UPGRH PN3



source: Authors' own elaboration.

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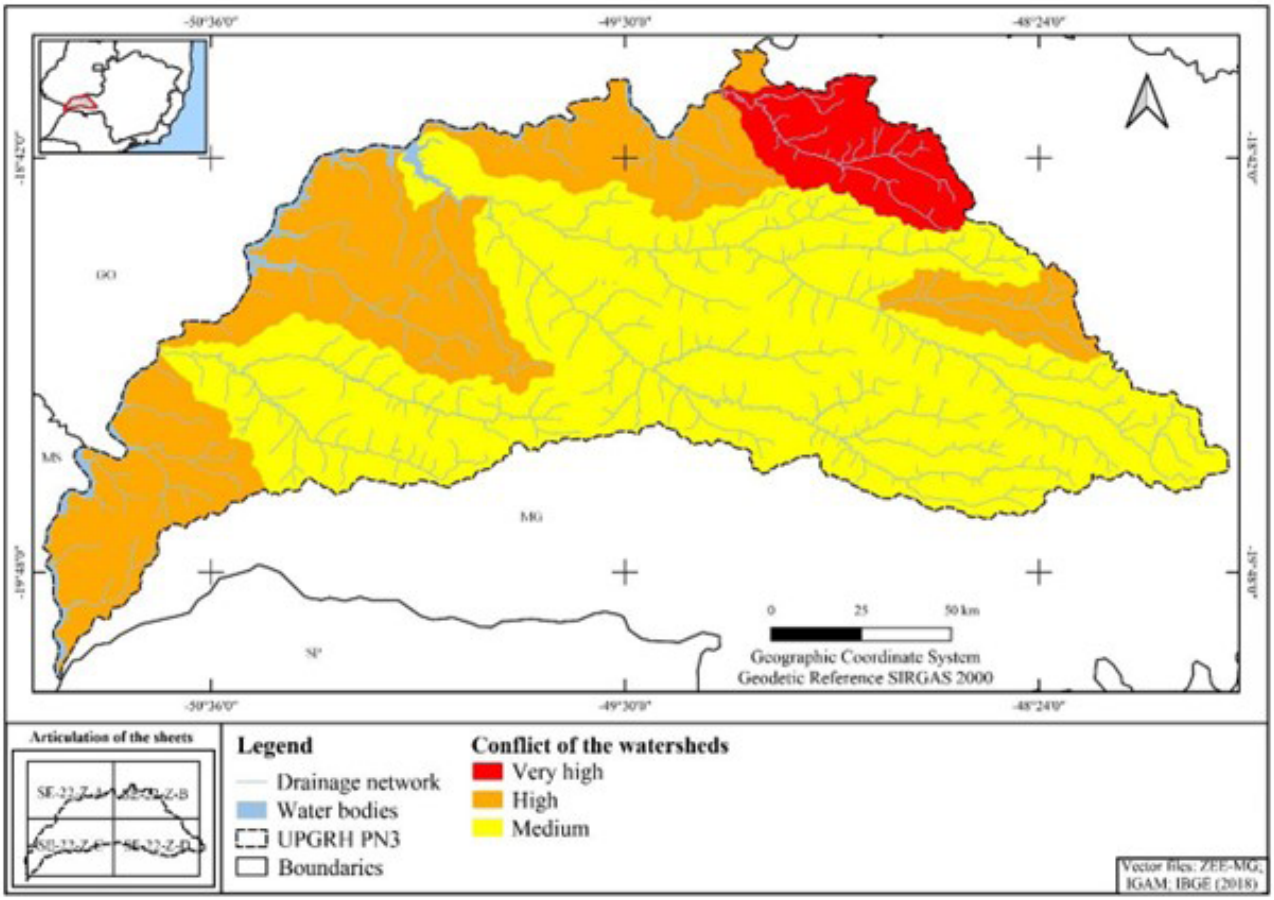
After the intersection process and then the identification of the predominance of conflicting land uses, presenting the conflicts of the hydrographic basins was possible. Therefore, the Piedade watershed showed the greatest conflict. Other watersheds that, whether due to having a DAC or developing conflicting uses, ended up defining the high conflict, as were the cases of the Douradinho and the São Jerônimo river watersheds, respectively. Evidencing the results, Map 7 shows the degree of conflict of the UPGRH PN3 watersheds.

The survey of the conflict between land use and legally protected areas in the UPGRH PN3 showed that the average conflict occurs basically in crops (temporary and permanent) in

LR and PPA, pastures in LR, or forestry in PPA. The pastures in PPA generate low conflict, and small areas of crops in CU, high conflict. When the legally protected area presents native vegetation, it shows no conflict.

Map 7 – Watershed conflict of UPGRH PN3



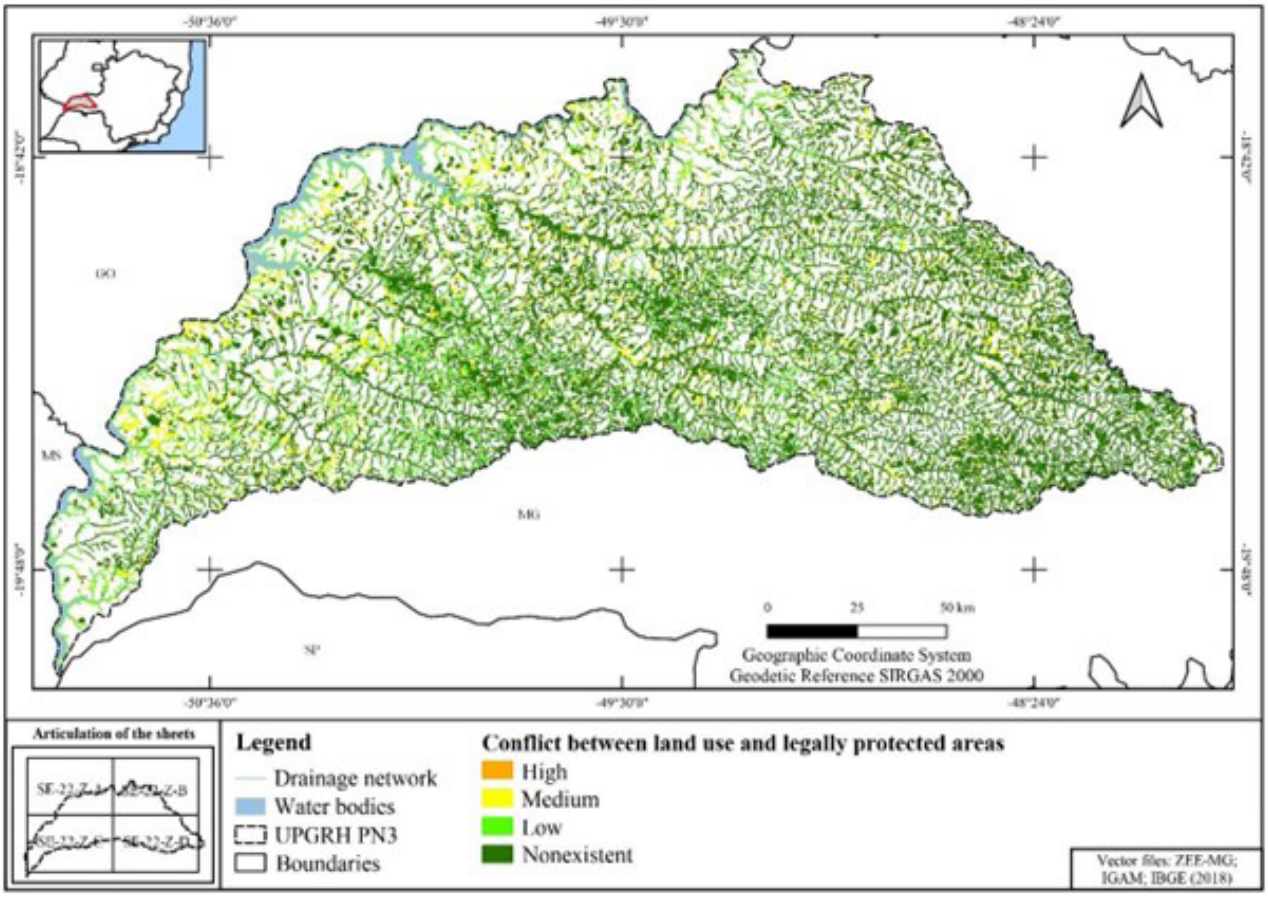
source: Authors' own elaboration.

Although PPAs and other legally protected areas also have crops and forestry, recovery may not have the same urgency as pastures, since irregular occupations by crops and forestry are more restricted in terms of area. Temporary and permanent crops in legally protected areas have the highest degrees of conflict, but correspond to a very small area. Map 8 shows the degree of conflict between land use and legally protected areas.

From the identified conflicts, progress was made to establish environmental zoning, initially consisting of two zones. The first, zone of conservation or recovery interventions, corresponds to protected areas and is established by ecological and legal conditions. The other, zone of consolidated occupations and/or productive activities, defined by the economic aspect, refers to the occupations that are established and, simultaneously, are dedicated to economic activities, provided that appropriate management practices are implemented, in addition to the adequacy to the legal precepts provided for.

In the zone of conservation or recovery interventions, establishing the conflict between land use and legally protected areas allowed to indicate areas in need of recovery and their urgency. For the zone of consolidated occupations and/or productive activities, the conflict between land use and natural vulnerability to soil loss allowed us to point out the adequacies and restrictions of productive activities. However, the conflict between land use and quali-quantitative vulnerability of surface waters indicates watersheds with priority for recovery and management measures. This determination aims to contribute to organizing the direction of actions in the territorial unit studied.

Map 8 – Conflict between land use and UPGRH PN3 legally protected areas



source: Authors' own elaboration.

The native vegetation found in the zones of conservation or recuperative interventions should continue to be preserved, whereas areas occupied by crops (temporary and permanent), pastures, and forestry should be recovered. Inappropriate areas in the zone of consolidated occupations and/or productive activities must also be recovered and those considered apt may be restricted, and appropriate measures should be applied to environmental quality. Thus, subdivisions were established in the two areas where urgencies of recovery (zone of conservation or recovery interventions) and restriction (zone of consolidated occupations and/or productive activities) are different. Table 10 shows the subdivisions and priority basins for recovery.

Table 10 – Priority zones and basins of recovery and management actions of UPGRH PN3

zone of conservation or recovering interventions		
subdivision of the zone (subzone)	**area**	**percentage**
areas for preservation	5,335.14 km²	19.84%
areas for low-urgency recovery	1.27 km²	0.01%
areas for medium-urgency recovery	953.29 km²	3.54%
areas for high-urgency recovery	563.77 km²	2.09%
total	6,853.47 km²	25.48%
zone of consolidated occupations and/or productive activities		
subdivision of the zone (subzone)	**area**	**percentage**
apt areas with elementary restrictions	1,076.45 km²	4.01%
apt areas with moderate restrictions	6,252.17 km²	23.25%
apt areas with relevant restrictions	11,890.15 km²	44.22%
inappropriate areas	199.43 km²	0.74%
consolidated urban areas	63.61 km²	0.23%
total	19,481.81 km²	72.45%
bodies of water		
bodies of water	557.11 km²	2.07%
total (zones + bodies of water)	26,892.39 km²	100%
watersheds with priority to recovery and management actions		
priority	**area**	**percentage**
very high (Piedade watershed)	1,759.20 km²	6.54%
high (Douradinho watershed)	922.66 km²	3.43%
medium (other watersheds)	8,221.56 km²	30.57%
(Tijuco and Arantes rivers)	15,988.97 km²	59.46%
total	26,892.39 km²	100%

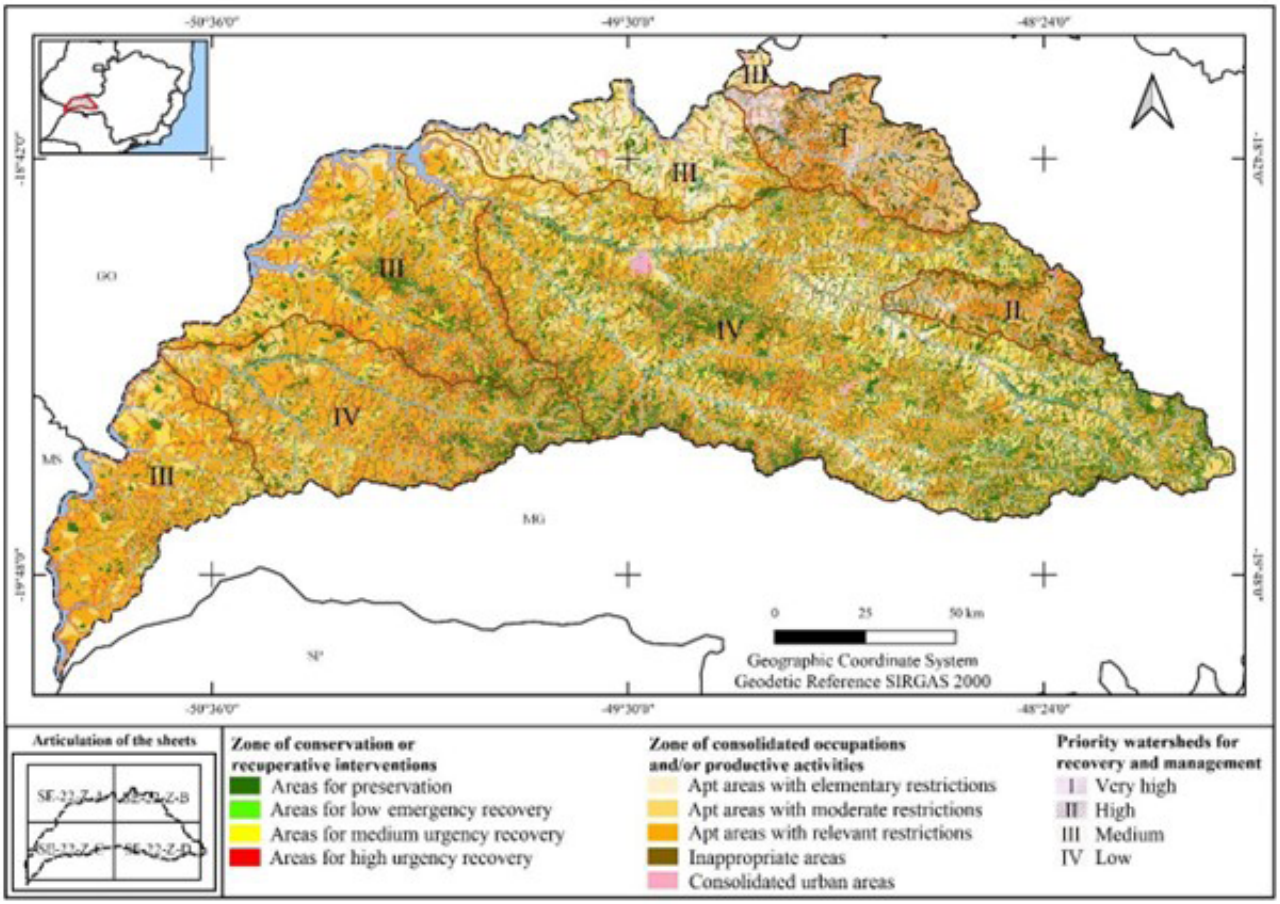
source: Authors' own elaboration.

The areas for the recovery of the zone of conservation or recovery interventions and the apt areas with restrictions of the zone of consolidated occupations and/or productive activities of the Piedade watershed should be a priority in the planning of recovery and management actions of UPGRH PN3. The Douradinho watershed is the second in priority, followed by the others, but equally important for recovery and management actions. Based on the results and the discussion presented so far, Map 9 shows the environmental zoning of UPGRH PN3.

The proposed environmental zoning consists of a tool with objective suggestions for the planning and environmental management of UPGRH PN3. With the establishment of the two zones, each has specific actions to improve the environmental quality of the territory as a whole. The zone of conservation or recovery interventions was subdivided into four areas and the zone of consolidated occupations and/or productive activities, into five, whose organization

of recovery and management work should have as its criterion the priority watersheds for recovery and management. Thus, we suggest recovery and management guidelines for the areas (subzones) defined by the proposal for environmental zoning (Table 11).

Map 9 – Environmental zoning of UPGRH PN3



source: Authors' own elaboration.

Table 11 – UPGRH PN3 guidelines for preservation, recovery, and management

zone	area (subzone)	land cover and use	preservation or recovery guidelines	preservation or recovery actions
zone of conservation or recovering interventions	areas for preservation	native vegetation (100%)	maintenance of native vegetation	general protection measures for the native vegetation cover
	areas for low-urgency recovery	temporary crops (5.51%) permanent crops (94.49%)	recomposition of native vegetation from areas of legal incompatibility	– natural regeneration without management – direct seeding – enriching – densification – nucleation – planting by seedlings – control of competing plants

Table 11 – Cont.

zone	area (subzone)	land cover and use	preservation or recovery guidelines	preservation or recovery actions
zone of conservation or recovering interventions	areas for medium-urgency recovery	temporary crops (16.15%) permanent crops (21.18%) pastures (60.36%) forestry (2.31%)	recomposition of native vegetation from areas of legal incompatibility	– natural regeneration without management – direct seeding – enriching – densification – nucleation – planting by seedlings – control of competing plants
	areas for high-urgency recovery	pastures (100%)		
zone	**area (subzone)**	**land cover and use**	**land use management guidelines**	**land use management actions**
zone of consolidated occupations and/or productive activities	apt areas with elementary restrictions	temporary crops (59.97%) permanent crops (35.16%) pastures (0.81%) forestry (4.06%)	crop and pasture management for areas with elementary restrictions	– no-tillage – controlled application of pesticides and fertilizers – terracing techniques – level planting
	apt areas with moderate restrictions	temporary crops (25.80%) permanent crops (30.85%) pastures (35.60%) forestry (7.75%)	crop and pasture management for areas with moderate restrictions	– no-tillage – crop-livestock integration – controlled application of pesticides and fertilizers – terracing techniques – planting and pasture formation techniques – erosive process control techniques – level planting and controlled cutting of forestry
	apt areas with relevant restrictions	temporary crops (0.04%) permanent crops (0.24%) pastures (99.72%)	crop and pasture management for areas with relevant restrictions	– no-tillage – crop-livestock integration – controlled application of pesticides and fertilizers – terracing techniques – planting and pasture formation techniques – adoption of pasture support capacity – erosive process control techniques

zone	area (subzone)	land cover and use	preservation or recovery guidelines	preservation or recovery actions
zone of consolidated occupations and/or productive activities	inappropriate areas	pastures (100%)	re-composition of native vegetation from inappropriate areas	– natural regeneration without management – direct sowing – enriching – densification – nucleation – planting by seedlings – control of competing plants
	consolidated urban areas	urbanized areas (100%)	environmental improvement of urbanized areas	– relative reduction of – waterproofing of urban soil – expansion of the sewage treatment system – effective management of solid waste

source: Authors' own elaboration.

Note that adopting the environmental zoning proposed does not prevent the actions already indicated by the Water Resources Master Plan of UPGRH PN3, and should be treated as a complementation of the recommendations in future revisions. In addition to the measures for the management of water resources and activities of the productive and governmental sectors, this environmental zoning removes the implementation flexibility of the indications of the Master Plan that prove to be very generic. This rigidity of the zoning was determined by the survey of natural vulnerability to soil loss and also by inappropriate occupations of legally protected areas (conflicts), complemented by defining priority watersheds for recovery and management actions.

Final considerations

This article presented the results of a research aimed at the methodological proposition of environmental zoning for watersheds, an important instrument to be considered in the Master Plans of Water Resources. The methodology was applied in UPGRH PN3 not only for demonstrative purposes, but also as a contribution to future revisions of the Water Resources Master Plan of the planning unit. Environmental zoning can contribute to the planning and management of watersheds, as it can indicate landscape specificities of the territory, a basic condition for decisions related to the environment and, in particular, to water resources.

The integration of physical-geographical and environmental components is a principle of any environmental zoning methodology. The issue is to establish the relevant components and appropriate procedures to achieve the proposed objectives. In this study, the selected components

are somehow related to aspects that synthesize the landscape and the situation of water resources (especially surface waters), in addition to legally protected areas. The results obtained show that obtaining a cartographic product from integrating varied physical-geographical and environmental components, especially functionally linked to hydrological dynamics, is possible since they could provide different degrees of vulnerability and conflicts.

Thus, presenting environmental zoning led to a combination of ecological and economic aspects since objective criteria for applying recovery and management actions according to the situation of each area (subzone) are established. Whereas the zone of conservation or recovery interventions has two guidelines with ecologically strong actions, the zone of consolidated occupations and/or productive activities presents guidelines with actions aimed at the sustainability of the areas (subzones), which configures the treatment of ecological and economic relations expected in an environmental zoning. Therefore, this cartographic product can be considered by the managers of the planning unit, especially due to the possibility of application as a public policy.

The environmental zoning proposed can be a useful tool for planning and managing the study area, especially if integrated with other environmental policy instruments. In any case, note that possible criticisms are indispensable for improving methodological procedures and, consequently, for advancing research in geography and environment. Finally, the ideas developed here are expected to serve future revisions of the UPGRH PN3 Water Resources Master Plan or the methodology to be applied in analogous territorial units.

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Authors' contribution:

Rafael Mendes Rosa: conception of the study, collection of data and bibliography related to the theme, application of methodological strategy including geoprocessing techniques, and writing and formatting of the text.

Vanderlei de Oliveira Ferreira: contribution to defining the object of study, monitoring of the definition and application of the methodological script, indication of sources related to the theme, and collaboration in the writing of the results and in the final review.

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