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FORESTRY SCIENCE

Association between forest resources and water availability: temporal analysis of the Serra Azul stream sub-basin

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Abstract: Vegetation is expected to influence processes in the water cycle through its structural effects on key ecosystem functions in watersheds. However tropical forests are being submitted to anthropogenic pressures that result in great disturbances in the functioning of ecosystem services. Thus, the present study uses a landscape scale analysis for exploring the associations between land use changes and water availability in the Serra Azul stream watershed. The land use transitions from years 2013 to 2018 were investigated and a set of robust landscape metrics were analyzed across the study region, including water bodies Permanent Preservation Areas. A correlation analysis between the water volume of the Serra Azul reservoir and the landscape metrics was also performed to verify the association between forest resources and water availability. The results show that the region has been submitted to several impacts associated with the loss of forest areas resulting from landscape transformations throughout the region. Forest fragmentation associated to loss of connectivity severely limit water resources availability besides reducing the basin environmental resilience. The role of different management instruments for water resources protection was also discussed, emphasizing the need for participation of stakeholder in the creation process of these environmental protection instruments.

Key words: ecosystem services, landscape ecology, landscape analysis, land use, landscape metrics.

INTRODUCTION

The degradation of natural resources has been occurring over the years in a disorderly fashion, contributing to drastic transformations in the earth's surface use and occupation. Currently, tropical forests are being submitted to great anthropogenic pressures exposing them to degrading actions that result in great loss of biodiversity disturbing the functioning of ecosystem services (Neto et al. 2017, Ortiz & Freitas 2005).

Land use changes in forest areas, mainly those from agricultural activities, can cause several damages to the water regime and to the local climate. Thus, scientific studies that highlight forest contribution to ecosystem services have been of major importance, being welcome in the scientific literature. It is widely known that forested areas contribute to maintaining the environmental quality through carbon sequestration, contributing to different water and earth-atmosphere energy cycles. So developing ways for avoiding or, at least, minimize environmental conflicts by means of appropriate governance instruments and guidance become an essential towards a more sustainable future (Ellison et al. 2017).

In order to reduce anthropogenic pressures on the environment, one of the objectives of the millennium focuses its emphasis in the protection, recovery and intensification of the ecosystems sustainable use. Such a goal enables the sustainable use of forests, in addition to decrease desertification, preventing land degradation and reversing loss of biodiversity. Following the same direction, the Aichi Biodiversity Targets are an ambitious set of global goals aimed at protecting and conserving global biodiversity. These goals were defined at the Aichi city in the 10^{th} Conference of the Parties to the Convention on Biological Diversity (COP-10) and have two main objectives: reducing pressures on biodiversity and increasing the sustainable use of environmental resources. The achievement of such objectives will result in increased benefits for biodiversity and ecosystem services, so many environmental conservation efforts are being undertaken through participatory planning, knowledge management and staff training to achieve the desired goals (Sanahuja 2014).

In this context, one of the main impacts of disordered environmental exploitation is forest fragmentation, which causes wide pressure on forest ecosystems resulting in loss of biological diversity in the region. Thus, studies that contribute to explore possible pathways for forest conservation, especially in association with the preservation of water springs, have become useful and necessary instruments for researchers and managers interested in river basins protection and natural resources sustainable management. Studies of landscape assessment and structure are of great relevance for diagnosing current environmental problems in a region, helping to forecast scenarios and developing proposals for natural resources conservation (Bremer et al. 2019, Calegari et al. 2010).

The environmental contribution of preserving forest has been the focus of several scientific studies which have been source of information for various players involved in water springs preservation. These studies involve economic contributions, such as reducing water treatment costs by native forests preservation (Vincent et al. 2016), government actions taken to emphasize preservation areas (Raharjo & Nakagoshi 2018), forest cover preservation for feeding the groundwater springs (Bremer et al. 2019), and topics related to current legislation analysis (Biggs et al. 2019).

One of the most effective ways to identify the forest cover benefits for the health of water environments is through the analysis of landscape structure (composition and configuration). The characterization of the landscape structure allows the development of a straightforward diagnostic situation. Based on this we can further design appropriate intervention actions in the basins focused on prognostic actions targeted to maintain ecosystem services. According to Shen et al. (2015) and Xiao et al. (2016), the relationship between the landscape and the water courses maintenance can be influenced by several factors, including the spatial structure of the landscape. The urban centers growth and agricultural activities expansion have caused the progressive degradation of water springs and the removal of forest cover, resulting in harmful consequences for river basins. Landscape analyses studies provides a systemic view of environmental problems and may propose integrated solutions.

This study aims to contribute to the state of the art by assessing land cover changes in the landscape, mainly due to forest fragmentation, and explore its associations with the availability of water in a hydrographic basin. In addition, the study proposes alternatives that can help to halt environmental degradation and improving ecosystem resources. The actions proposed include environmental restoration focused on the recovery of permanent preservation areas.

MATERIALS AND METHODS

Case study: Forest fragmentation in the Serra Azul stream sub-basin

The study was carried out in the Serra Azul stream sub-basin region which is inserted in the Paraopeba river basin. It is geographically located in the central part of Brazilian State of Minas Gerais, between the South Latitude parallels of 20º 15' and 20º 00' and the West Longitude meridians 44º 15' and 44º 35'. The watershed territorial drainage area comprises 447.83 km², covering the municipalities of Mateus Leme, Igarapé, Juatuba and Itaúna.

Since year 1983, the sub-basin has been the subject of studies related to the landscape modeling and analysis, as well as studies related to evapotranspiration (Neves 2005), social and environmental impacts (Ferraz 2009), Serra Azul reservoir water quality (Fernandes 2012) and hydrogeological modeling (Matos et al. 2017). The region was subjected to several changes in land use and occupation, mainly due to the local reduction in rainfall happened from years 2013 to 2015. Since year 1987, several studies have investigated changes in land use and occupation throughout the studied region with emphasis on issues related to agricultural expansion and mining activities (Matos et al. 2017).

The region registers the presence of seasonal semideciduous forest which, according to Law 11428, December 22, 2006, is inserted in the Atlantic Forest biome. According to Brasil (2006), the protection of these fragments takes on great importance for the maintenance and restoration of biodiversity as well as for encouraging research. Such protection helps to maintain ecological balance, aiding to equalize rural and urban occupation also having an important role to harmonize economic growth with biodiversity and ecological balance maintenance.

Inserted into the study region, the State of Minas Gerais recognized the APE protection category (Special Protection Area), Figure 1. The APE is intended to preserve the existing water springs in the Serra Azul stream hydrographic basin by maintaining permanent preservation of forests and other forms of natural vegetation. The protected region is confined between the South latitudes of 19º58' and 20º10' and West longitudes of 44º17' and 44º31', encompassing an area of 256 km² (Minas-Gerais 1980)

Multitemporal analysis of land cover changes

The forest cover mapping present in the study region from years 2013 to 2018 was carried out through the images of the MAPBIOMAS project, which uses the Google Earth Engine platform to map the land use of all biomes in the Brazilian territory, in 31 classes, through the use of images from the Landsat 8 project, allowing the user to access information in a resolution of 30 meters (Souza et al. 2020). As the region is located in the biome transition area, it was necessary to use images from both Brazil Savanna and Forest Atlantic projects. The use of data from the years 2013 to 2015 is due to issues of availability of public data and by the fact that the region suffered an episode of water scarcity, Minas-Gerais (2015), in year 2015.

The images were reclassified into three classes, namely forest, non-forest and water (Supplementary Material – Figure S1). The reclassification was necessary because analyzed timeline should present similar classes. Thus, it was possible to assess the land use and occupation dynamics, enabling the construction of the diagnostic area along the analyzed period.

The land use change rates in the region were performed by calculating the transition matrix available in DINAMICA EGO software (Soares Filho

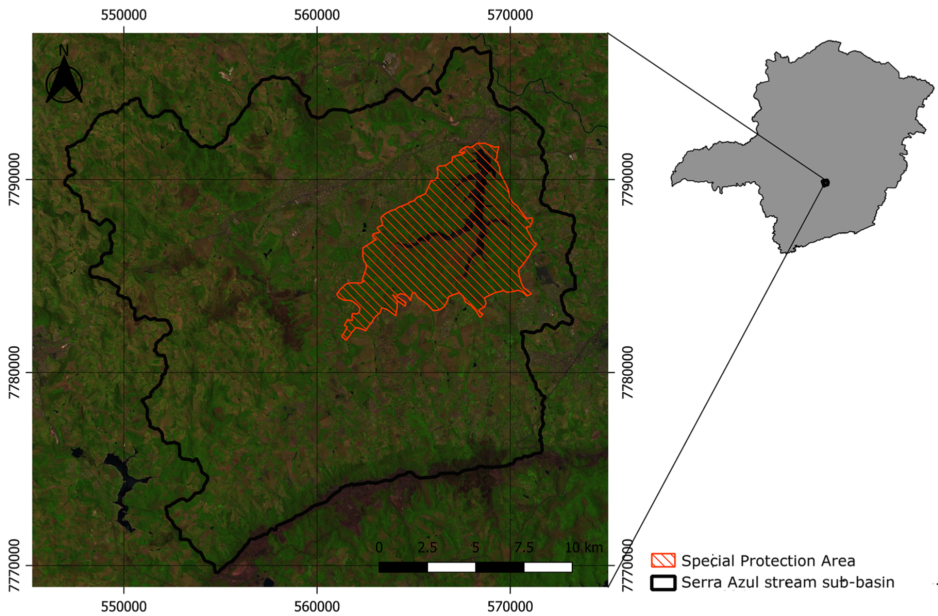

Figure 1. Case study region: Serra Azul stream sub-basin and the Special Protection Area.

et al. 2004). This process results in two matrices called simple and multiple (Supplementary Material – Tables SI and SII). The simple matrix consists of the transition's presentation in the analyzed period (2013 to 2018) and the multiple matrixes consists of the transitions that occur in the analyzed time unit (year). The transition rates presented by the matrices show the net number of changes, that is, the percentage of land that will be changed to another class.

Delimitation of Permanent Preservation Areas (PPA) close to water courses

PPA are types of protected area defined in legislation, covered or not by native vegetation, which have the function of preserving water resources, the landscape, geological stability and biodiversity. In Brazilian forestry legislation, they are divided into two typologies, namely: proximity to water bodies and hilltops. The objective of PPA is to facilitate the gene flow of fauna and flora, protect the soil and guarantee the well-being of human populations (Brasil 2012).

For this work, we considered only the permanent preservation areas close to water bodies in the study region (Figure S2). The delimitation of these areas was carried out in accordance with the rules established by Law Nº 12,651, of May 25.2012, called New Brazilian Forest Code (Brasil 2012), and by State Law Nº 20.922, of October 16, 2013, (Minas-Gerais 2013). The delimitation of the analyzed PPAs was performed using the buffer tool of the QGis 3.4.6 software. We use the 30 meters buffer for watercourse regions smaller than 10 meters wide; 50 meters for courses between 10 and 50 meters wide; 100 meters for watercourses that are 50 to 200 meters long; 200 meters for those that are 200 to 600 meters wide; and 500 meters for courses with widths greater than 600 meters.

Landscape composition and configuration of forest fragments: use of metrics

One of the most used indicators to verify the hydrographic basin fragmentation degree and the forest occupation is that of land use analysis (Goerl et al. 2012, Maes et al. 2018). So, the landscape indexes were calculated based on the attributes of the classes found in the sub-basin and the fragments were linked to each forest class. This technique allows a comparative analysis between the land use classes present in the region, as well as the formulation of a diagnostic situation of the basin's behavior in relation to the impacts caused by anthropogenic pressures.

The quantification in the complete landscape structure including the PPA regions was carried out using tools available in Fragstats 4.2 software, which allows describing the percentages and values of area, central area, border, density, shape, proximity and isolation, contagion and dispersion, as demonstrated by McGarigal (2015, 1994). The choice of selected spatial indices was based on deforestation and forest fragmentation researches conducted by Metzger (2009), Singh et al. (2017) and Cadavid-Florez et al. (2019). The analysis was carried out at the level of each class and separated by area, fragment, shape, edges, nearest neighbor, juxtaposition, interleaving and cohesion (Table I). Association between forest resources and water availability: correlation between Serra Azul reservoir volume data and landscape metrics

The RStudio software was used to calculate the correlation (Supplementary Material – Results S1) between the volume of the Serra Azul reservoir (Figure S3) and the landscape metrics (Tables SIII-SVIII). For this purpose, it is used the results obtained in the Fragstat software and the percentage data of the volume of the reservoir available to the public on the website of the water supply company. The correlation

Table I. Metrics used to quantify the landscape structure of the case study.

Category: Area	
Class area	CA > 0 (ha)
% of fragments of the same class	0 < PLAND < 100 (%)
% the largest fragment area	0 < LPI < 100 (%)
Average fragment area	AREA_MN > 0 (ha)
Standard deviation of fragments	AREA_SD
Category: Fragments	
Number of fragments	NP (unit)
Patch density	PD
Category: Edge	
Total Edge	TE > 0 (ha)
Edge Density	ED > 0 ($m.ha^{-1}$)
Average shape index	SHAPE_MN > 1
Category: Juxtaposition, merge (or blend) and cohesion metrics	
Interleaving and juxtaposition index	IJI
Aggregation index	AI
Adjacency proportion	PLADJ
Connectivity	0 < COHESION < 100 (%)
Category: Nearest neighbor	
Distance (standard deviation)	ENN_SD
Average distance from nearest neighbor	ENN_MN > 0 (m)
Proximity index (deviation)	PROX_SD
Proximity (average)	PROX MN

Font: McGarigal (1994).

is calculated by Equation 1, proposed by Pearson (1982) and Pearson et al. (1994). The r corresponds to Pearson's correlation coefficient; $\bar{x}$ corresponds to sample mean of x; and $\bar{y}$ corresponds to sample mean of y.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (1)$$

RESULTS

Multitemporal analysis of land cover changes

Regarding the land use class transition in the studied period, the transition matrix shows that forest and water classes undergo a transition to non-forest class. This happened throughout the region with greater emphasis on close to water PPA regions (see Table II). The annual rate of change remained constant throughout the study region, with the highest rate of 6.5% assigned to a transition from the water class to the non-forest class (Table SIX).

In the evaluated period the transition rate from water to non-forest class was 28%, corresponding to 222.21 ha, from forest to non-forest class the rate was 13.6%, corresponding to 2295.54 ha, and from non-forest to forest it was 2.8%, corresponding to 934.02 ha. The results show that the region is submitted to deforestation actions, since the rates and quantities of deforestation areas in the region are higher than the regeneration areas, resulting in a difference of 1361.52 ha, corresponding to 3.04% of the whole basin area.

A similar relationship can be identified in the permanent preservation areas, where the transition from water to non-forest occurring at a rate of 26%, corresponding to 200.7 ha, from forest to non-forest, 16%, related to 206.1 ha, and from non-forest to forest, 13%, equivalent to 197.28 ha. One can observe that the difference between deforestation and regeneration in the region is smaller when compared to the total area of the basin, corresponding to 8.82 ha. In addition, it can also be noted that 8.98% of deforestation along the basin occurs in PPA regions.

Association of forest fragmentation with reservoir water availability

The correlation analysis (Figures S4-S27) between the percentage of the volume of the reservoir and the calculated metrics allowed to explore how the different classes of land use interact and influence the landscape dynamics of the study region. Regarding the landscape configuration (Table III), it was possible to identify that the non-forest class showed a greater influence

Table II. Analysis report of the transition matrix for the entire permanent preservation area and all area referring the period 2013 to 2018.

All area					
Simple Matrix			**Multiple Matrix**		
Forest	0,136	0,000224	Forest	0,029	0,0000538
0,029	Non-forest	0,0000854	0,006	Non-forest	0,0000193
0,035	0,280	Water	0,008	0,065	Water
PPA area					
Simple Matrix			Multiple Matrix		
Forest	0,166	0,004271	Forest	0,038	0,0009979
0,134	Non-forest	0,0043529	0,031	Non-forest	0,0010203
0,067	0,265	Water	0,013	0,065	Water

on the volume of the reservoir compared to the forest class. This relationship can be saw mainly in the PPA regions, which presented a strong positive relationship in the class area (CA) indexes, percentage of the landscape (PLAND) and the largest fragment index (LPI) for the regions without vegetation cover. Regarding the total area of the study region, it is possible to identify that the number of patch (NP) and the patch density (PD) are those that present a stronger correlation for regions without the presence of forests.

As shown in Figure 2, the analysis of the configuration metrics allowed the identification of several landscape transformations for the forest and water classes. From 2013 to 2018 the CA belonging to the forest category decreased by 7.87%, considering the entire basin and increased by 4.39% in PPA regions. Regarding the water class, it can be observed a decrease of 30.66% along the entire extent of the basin. This relationship can be seen in terms of PLAND, where it is possible to identify that along the period studied the forestry class exhibited a decrease of 2.64% in relation to the entire extent of the basin and an increase of 1.65% for the PPA regions by itself.

The water class also showed a reduction of 0.48% in PLAND along the entire basin extent. Throughout the study area, there was an increase in forest fragmentation as well as in permanent preservation areas, indicated by NP. The PD for the analyzed classes indicated few changes, showing values close to those found in the start period. The LPI oscillates in about 0.4, being considered insignificant to determine a drastic decrease in fragment size. It means that, in fact, occurred fragmentation, but it is less observed than the actual loss of the forest area.

A similar relationship can be identified as far as the shape of the landscape class is concerned (Table IV), it is possible to identify that the regions without the presence of vegetation have a greater influence on the volume of the reservoir as the forested regions. The total of edge (TE) and edge density (ED) presented a moderate and strong relationship for the classes of forest and non-forest, respectively, in relation to the volume of the reservoir in the PPA areas. In conjunction with the landscape shape index (LSI), it was possible to show that as deforestation occurs in the region, the greater is the influence of these actions on the water availability of the reservoir.

Figure 3 shows for the forestry class, that the TE decreased by 3.58% while in the permanent preservation areas it increased by 4.09%. Regarding the DE, it was seen a 3.59% decrease in edge density of the entire region and an increase of 4.25% in PPA regions. It was observed a significant change in the boundaries between the years 2016 and 2017 in the permanent

Table III. Correlation between Serra Azul reservoir volume and configuration landscape metrics throughout the study region and in the permanent preservation areas.

All area			Correlation	PPA		
Water	**Non-Forest**	**Forest**	**VOLUME**	**Forest**	**Non-Forest**	**Water**
0.97	0.41	0.24	CA	0.40	0.84	0.97
0.96	0.43	0.23	PLAND	0.40	0.84	0.97
0.017	0.84	0.11	NP	0.19	0.069	0.46
0.016	0.84	0.12	PD	0.19	0.0067	0.46
0.97	0.38	0.19	LPI	0.88	0.98	0.97

preservation areas and in the years 2015 to 2016 throughout the entire extent of the basin.

The LSI showed an increase over the study period, close to a constant rate, but peaks were shown between 2015 and 2017. The mean fragment area (AREA_MN) remained constant throughout the study period, showing an average increase of 0.08 ha for year 2018. For permanent preservation areas, the average area decreased, remaining constant from 2016 to 2018. The average shape index (SHAPE_MN) remained constant throughout the study period, showing peaks between 2015 and 2017 in the entire study area. In relation to PPA regions, this index increased 0.018 and varied between the years 2014 to 2017.

The analysis of landscape connectivity confirms this relation, because the forest fragmentation influences the volume of the reservoir, as demonstrated by Table V. This can be strengthened by the analysis presented between the forest and non-forest classes regarding the proximity of the fragments (PROX_MN and PROX_SD) and distance from the nearest neighbor (ENN_MN and ENN_SD).

Regarding the connectivity between the forest fragments, several changes were identified throughout the study area, Figure 4. In relation to the ENN_MN, the region showed an increase of 0.61% in the entire study area. Regarding the permanent preservation area, it was possible to identify a decrease of 9.31% in the distance between the forest fragments. Regarding the PROX_MN, considering a search radius of 500 m, there was a decrease in the proximity of the fragments throughout the basin area, since there was a fall of 27.32%. On the other hand, PPA regions showed an increase of 18.59% in the proximity of the fragments.

Regarding class cohesion, the Table VI showed that the greater interaction between the patches class, especially in the non-forest

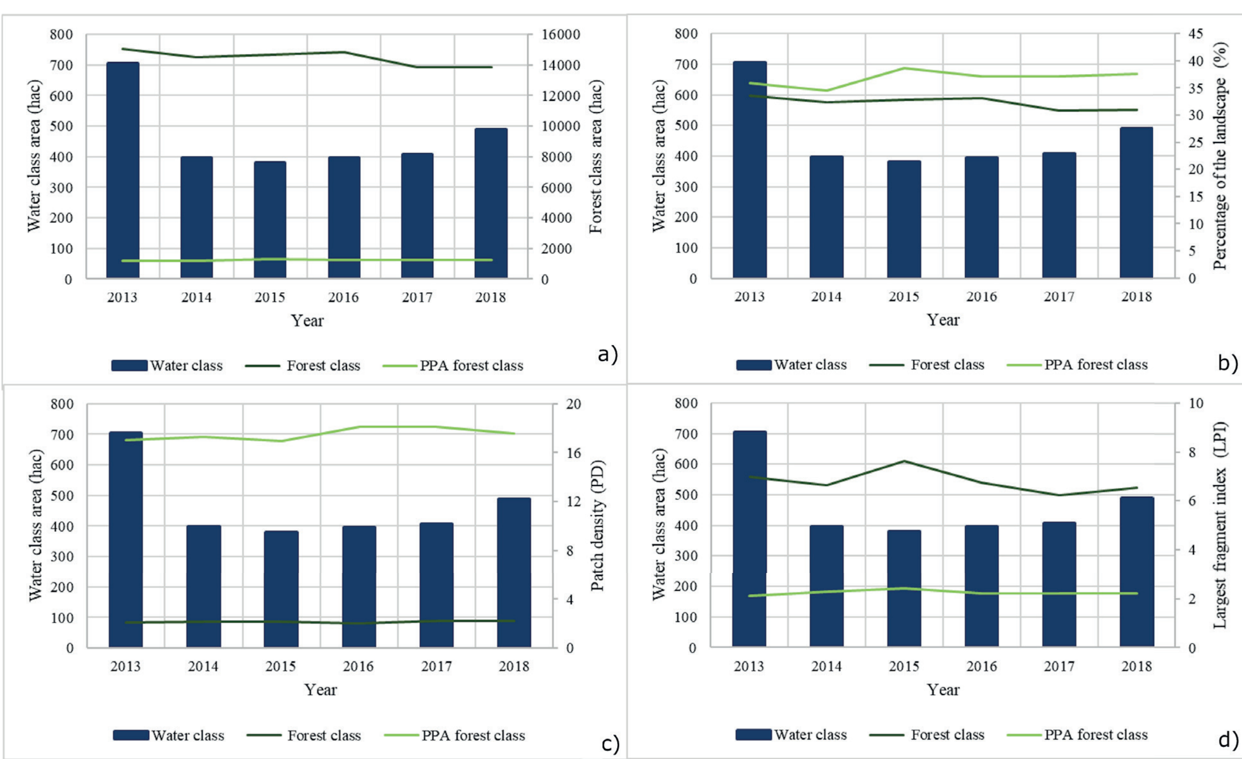

Figure 2. Variation of configuration metrics along landscape, where a) class area - CA, b) percentage of the landscape - PLAND, c) patch density - PD and d) largest fragment index LPI.

class, indicates that the region presented a trend of greater changes in the landscape near the reservoir. It was observed that the greater the juxtaposition between the classes, the forest class showed a greater influence in the study region, mainly in the volume of the reservoir.

It was observed that, as the percentage, the local density and the number of fragments of riparian forest increase, the reservoir water volume tends to increase too, presenting a directly proportional behavior. In addition, it was identified that, as the forest fragments get closer, there is a contribution to the reservoir water recharge, increasing its volume. Finally, it is noticed that, as the number of edges increases in the region, the reservoir volume decreases. On the other hand, it is important to highlight that, in the period from 2015 to 2016, the region presented peaks that caused changes in this relationship. This change allows inferring those external factors may contribute to landscape changes as well as to availability of water in the region.

DISCUSSION

The application of the of land use changes and landscape metrics analysis allowed to identify that there are difficulties in associating forest areas with the water quantity in a region because it is not a so straightforward relationship. In fact, there are several aspects that can influence the water availability for a population that may be associated with external events, such as the El Niño and La Niña phenomena. Such events can influence the hydrological cycle and cause a decrease in the rainfall regime, resulting in a consequent water loss in a hydrographic basin. Barnard et al. (2017) and Michalak (2016), in their studies about the influence of the two phenomena in the years 2015 and 2016, argue that these factors can cause low water availability in a region.

Some studies indicate that this complexity in the association can be intensified by basins degradation and vegetation cover loss caused by urban expansion and agricultural activities processes. Such interventions can lead to degradation of permanent preservation areas which are regions of great importance to guarantee the water availability and quality (Lima et al. 2018). In addition, the proximity of developed regions can contribute to the increase of environmental degradation, as discussed by Sun & Lockaby (2012), when addressing the matter that rural areas tend to obtain economic benefits through the transition from rural to urban space.

Table IV. Correlation between Serra Azul reservoir volume and form landscape metrics throughout the study region and in the permanent preservation areas.

All area			Correlation	PPA		
Water	**Non-Forest**	**Forest**	**VOLUME**	**Forest**	**Non-Forest**	**Water**
0.95	0.22	0.053	TE	0.52	0.92	0.96
0.95	0.23	0.059	ED	0.52	0.92	0.96
0.18	0.079	0.37	LSI	0.61	0.96	0.16
0.43	0.088	0.15	AREA_MN	0.28	0.55	0.42
0.96	0.66	0.021	AREA_SD	0.037	0.95	0.97
0.69	0.35	0.23	SHAPE_MN	0.17	0.89	0.70
0.71	0.89	0.083	SHAPE_SD	0.55	0.11	0.72

In the study region, Dutra (2021) discusses, through water balance analyses, that changes in land use have provided a decrease in the maximum storage of the basin's water volume, since the expansion of urban areas together with the agricultural and mining activities in the region have provided greater suppression of vegetation and consequent changes in the sub-basin's hydrological cycle, such as the reduction in the water volume of the reservoir throughout the analyzed time series. According to Dutra (2021) and Dutra et al. (2020, 2021), the main consequence of these activities is the increase in the output of water, mainly due to grants, in relation to the inflow, arising from natural processes, such as precipitation. In addition, according to Dutra (2021), vegetation suppression together with climate change has favored changes in the relative humidity of the air and evapotranspiration, which are important meteorological factors for cloud formation and precipitation in the study region.

Regarding to landscape change, it can be said that forest fragmentation and loss of connectivity contribute to water loss increasing, especially in reservoirs supply that depends on the hydrographic basins recharge. Beecham & Razzaghmanesh (2015) and Celentano et al. (2017) report that water tends to be retained in vegetation areas and drained in deforested areas, presenting smaller volumes and areas. According to Newbold et al. (2010), Ellison et al. (2017) and Rieger et al. (2014), riparian forest and vegetation cover are very important for the humidity regulation, forming a barrier against erosion. About connectivity, Estevam et al. (2017) reported that the connection between forest areas must be ensured to guarantee local biodiversity.

A harmful consequence of this problem is the limitation of resources, which affects

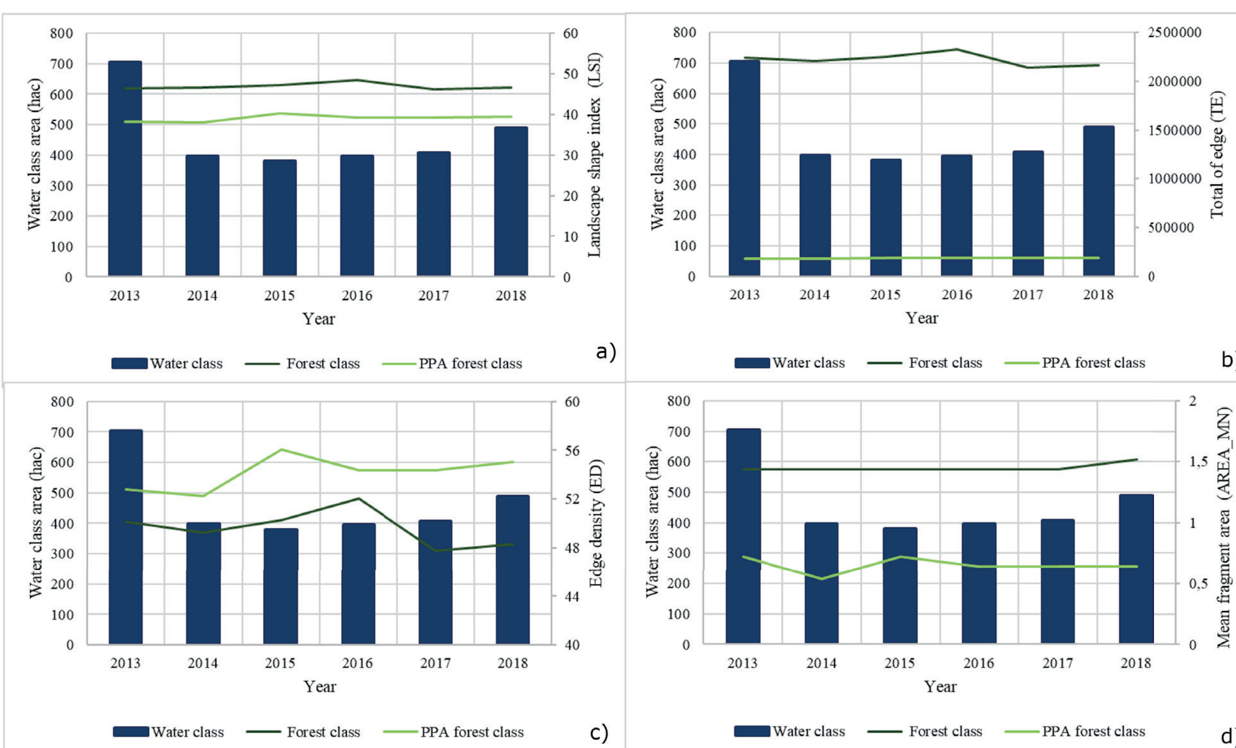

Figure 3. Variation of form metrics along landscape, where a) landscape shape index - LSI, b) total of edge - TE, c) edge density - ED and d) mean fragment area - AREA_MN.

many interested players, reducing the region's resilience in periods of extreme drought, which can cause water crisis phenomena, as one occurred in 2015 and 2016 in the case study area and regulated in the legislation of Minas-Gerais (2015). Thus, it is necessary to undertake effective actions for reducing forest losses in river basins environments and, above all, guaranteeing the integrity and protection of permanent preservation areas (PPA). It is highly necessary to highlight the importance of proactively managing the landscape, applying solutions that help to achieve the goal of sustainable development.

The management can be done by creation or expansion of environmental services payment programs (PSA), aiming to involve the interested people, government and institutions that depend directly on the services provided by the resource (water availability). According to Durham et al. (2013), stakeholder participation can be done by involvement, collaboration, information and consultation among those involved in the process of implementing landscape prognostic actions.

An application of PSA model is approached by Blignaut (2019) where it is argued that the action must have the involvement of several interested actors, because the rural producer generally cannot pay for the preservation of forest areas. Thus, it is necessary that the government, water supply company, foundation or legal entity have an interest in the environmental restoration and invest capital in these projects. The application of these types of projects allows for several long-term benefits, such as economic development, job creation, degraded areas restoration and adaptation to climate change. According to Ellison et al. (2017) and Siqueira et al. (2016), the guarantee of ecosystem services through PSA actions enables the conservation of fauna and flora genetic flow and guarantees the preservation of water bodies PPA, contributing to the water springs do not undergo erosion processes.

Another model to be used in reducing forest fragmentation across river basins is the creation of Conservation Units (UC) in areas that already have the potential to include these activities. An example, based on the case study, is the conversion of the Special Protection Area (APE), which has no guarantee of protection given by the law of the National System of Conservation Units (SNUC). Based on Brasil (2000) legislation, through actions taken by environmental agencies and legislators, this region could become an area of sustainable use and could be included in the areas of environmental protection (APA). According to legislation APA is considered "an area generally large with a certain degree of human occupation [...] whose basic objectives are to protect biological diversity, to discipline the occupation process and to guarantee use of natural resources sustainability".

Table V. Correlation between Serra Azul reservoir volume and connectivity landscape metrics throughout the study region and in the permanent preservation areas.

All area			Correlation	PPA		
Water	**Non-Forest**	**Forest**	**VOLUME**	**Forest**	**Non-Forest**	**Water**
0.80	0.91	0.097	PROX_MN	0.70	0.93	0.53
0.81	0.19	0.039	PROX_SD	0.67	0.95	0.38
0.65	0.035	0.36	ENN_MN	0.26	0.88	0.24
0.92	0.37	0.23	ENN_SD	0.18	0.58	0.045

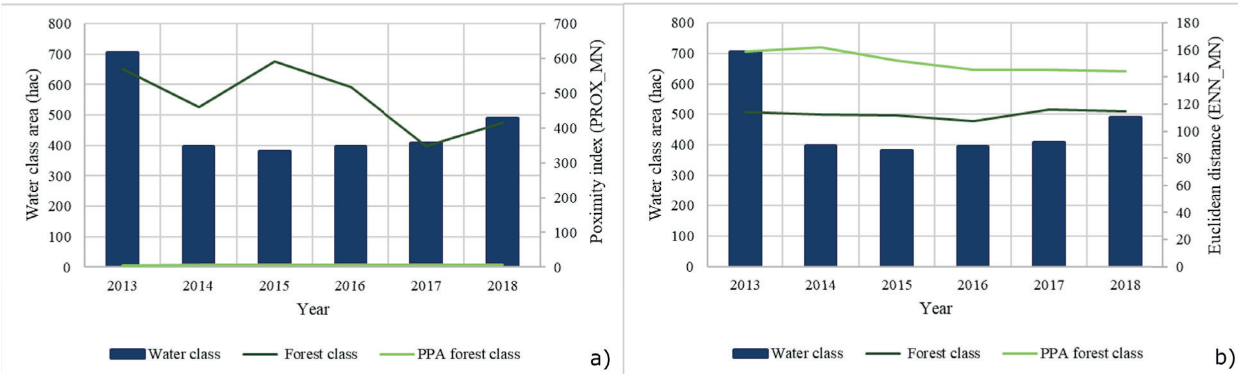

Figure 4. Variation of form metrics along landscape, where **a)** proximity index – PROX_MN and **b)** Euclidian distance – ENN_MN.

Table VI. Correlation between Serra Azul reservoir volume and cohesion landscape metrics throughout the study region and in the permanent preservation areas.

All area			Correlation	PPA		
Water	**Non-Forest**	**Forest**	**VOLUME**	**Forest**	**Non-Forest**	**Water**
0.95	0.029	0.60	PLADJ	0.38	0.94	0.95
0.96	0.45	0.95	IJI	0.95	0.12	0.98
0.97	0.39	0.037	COHESION	0.68	0.94	0.99
0.94	0.027	0.60	AI	0.38	0.94	0.95

CONCLUSIONS

This study puts together land use changes and landscape analysis based in landscape metrics. This combined strategy used in the study allowed identifying that the region of Serra Azul stream hydrographic basin has been submitted to several impacts associated with the loss of forest areas. It was also evident in the case study that there is an unknown factor of complexity in the association of forest areas with the amount of water in a basin region because of some watershed external effects. Although this association, forest versus amount of water, did not present itself as a very simple procedure the study results fully achieved the initially proposed objectives pointing out that forest fragmentation within the context of the basin can severely intensify the decrease in amount of water, so reducing the environment resilience and intensifying phenomena such as water crises. Environmental problems, such as those diagnosed in the case study, require objective actions to remedy them, especially those as the creation of PSA and UCs recognized as efficient by experts. These types of solutions, although expensive in time and money and also requiring involvement of several interested players, are very important to guarantee water resources through the preservation of PPA's and by guaranteeing a greater connectivity between forest fragments.

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SUPPLEMENTARY MATERIAL

Figures S1-S27
Tables SI-SIX
Results S1

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DJD and SMCR designed the general study guidelines. DJD performed the detailed analyses with contributions from MATE and SMCR. DJD and MATE wrote the article with contributions from SMCR. All authors have revised and corrected the text several times, both in full and in parts, both alone and together.