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Environmental Quality of forest remnants in the Capivari River Sub-basin (Campinas – Sao Paulo – Brazil)

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Abstract
The forest remnants present a relevant multi-functionality for the provision of ecosystem services to cities, especially the ones related to water availability in quantitative and qualitative terms, since they contribute to the control of runoff and floods, reduction of water filtration pollution, among others. Therefore, the present study aimed to assess the environmental quality of the forest remnants of the Capivari River sub-basin, in Campinas-SP, which has high water potential, by using landscape metrics. The analyzes were performed in ArcGIS on the following metrics: AREA, CAI, CI, ENN, PROXFLOW, WAT, SUR, EROD, applied for the calculation of the Environmental Quality Index (IQrem). It was identified that 78.0% of remnants have medium environmental quality, followed by 15.2% with low quality and only 6.8% with high quality. This condition is mainly related to the predominance of remnants with little or no central area, associated with predominantly elongated shapes and the distribution of these remnants in a predominantly anthropized mesh. On the other hand, these remnants have considerable connectivity, since more than 50% are close to a neighboring remnant within 60 m. A key point identified is the fact that 93.2% of the remnants are distant up to 60 m from some watercourse. Thus, it was found that the forest remnants play a significant role in maintaining water availability for the municipality of Campinas, in terms of quality and quantity. This increases the importance of carrying out effective management actions that contribute to increasing and ensuring the environmental quality of these remnants.

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INTRODUCTION

In many regions in the country and in the world, one of the alterations of anthropogenic origin which have significantly contributed to the change in the natural landscape is the expansion of the urban projects, a process called fragmentation. This phenomenon mainly contributes to the transformation of large areas of the forest into a mosaic of fragments with different characteristics and regeneration levels (PATRA et al., 2018; HERSPERGER et al., 2018; MASSOLI; STATELLA; SANTOS, 2016; SAITO et al., 2016; OLIVEIRA et al., 2015).

According to Benedict and McMahon (2006) a lot of specialists recognize that the most efficient manner of combating the fragmentation of habitats and promote the preservation of the natural ecological processes, including in the cities, is by establishing an interconnected conservation system of natural areas which combat the habitats fragmentation, this system is called urban infrastructure. This infrastructure includes humid areas, forests, corridors and green parks, among others (HERZOG, 2016; CHICA; TAVARES, 2017).

As Calderón-Contreras and Quiroz-Rosas (2017) state, in order to build urban resiliency, it is essential to examine and potentialize the diverse functions of the green infrastructure so as to support the urban demands. In this context, the urban forest remnants present a relevant multi-functionality of benefits to the city, named ecosystem services to the city which is possible to mainly mention: the efficient contribution to the regulation of the urban temperature; contention of the hillsides; water outflow mitigation of rainwater and consequent reduction of floods; reduction on the environmental pollution; guarantee of habitats to the urban biodiversity and also, the cultural services supply, such as, recreation, leisure and sport (MARTINI et al., 2017; ELMQVIST et. al., 2015; BARÓ et al., 2014; HERZOG; ROSA, 2010).

Regarding to the water issue, specifically, the forest remnants present significant interference over quantitative and qualitative aspects related to the water availability in a hydrographic basin, which directly affects the city government. Studies suggest that the major parts of the hydrographic basins which suffer from water quality are the ones which have been through an intense and fast process of occupation, having had their vegetation drastically reduced (CAMARGO et al., 2013; CHAVES; SANTOS, 2009).

Besides, the vegetation remnants promote interception of rainwater, reducing the percentage of superficial water outflow; benefiting the control of erosive processes and contributing to the flood controls (BARGOS; MATIAS, 2011; FRANCO et al., 2007; SANCHOTENE, 2004 apud TOLEDO; SANTOS, 2008). Even in an urbanized basin, there are sharp differences between the quality of the water in areas close to the sources which hosts forest remnants when compared to the rest of the watercourse which does not have this protection (MENEZES et al., 2016).

These factors, related to the water resources, urban microclimate, air quality, among others, are environmental aspects directly associated to the dynamic of the city and, therefore, are related to the whole environmental quality (RUFFATO-FERREIRA et al., 2018). The cities present a great potential of integrating the ecosystem services in the spatial urban projects, indeed, in order to promoting the restoration of the degraded ecosystems and reinforcing the integration among projects of soil usage and Green urban structures; however, that potential is little explored yet (ANDERSSON et al., 2014).

In general, the strategic planning developed in the urban scale is set as documents, either written or cartographic, guides of a regional development which include, among others, the delimitation of the areas which must be protected in order to guarantee the sustainability of the natural and cultural resources (HERSPERGER et al., 2018). However, as mentioned by Calderón-Contreras and Quiroz-Rosas (2017), the major part of traditional approaches of urban sustainability only aims to promote the increase of the Green infrastructure, not considering its importance, which implies in a most efficient usage of the "Green spaces" in the cities.

However, studies such as the ones by Calderón-Contreas and Quiroz-Rosas (2017) and Damane, Oliveira and Longo (2019) suggest that, in general, the quality of the current Green infrastructure, in local scale, is mainly from medium to low, significantly implying in the provision of the ecosystem services. In this case, one of the first steps for an efficient urban-environmental planning is diagnosing the environmental quality of the remaining natural areas. Therefore, the use of geo-technology and remote sensing has been really useful (MASSOLI; STATELLA; SANTOS, 2016; OLIVEIRA et al., 2015).

When applied to the forest remnants, these tools may comprehend the spatial patterns of the fragments, also identifying critical issues of degradation and promoting subsidies for the decision making which leads to a suitable management of the resources, allying biodiversity conservation, spatial and socio-economic aspects and local demands (JESUS et al., 2015).

By having that considered, the present study has the aim to evaluate under quanti-qualitative objectives, the forest remnants of the sub-basin of Capivari River, in Campinas-Sao Paulo, by landscape metric, in order to verify whether it is possible to comprehend if there is an established relation among these spatial indicators and the main environmental fragilities and potentialities of these remnants.

MATERIAL AND METHODS

Area of Study

The Capivari River sub-basin is the second-largest sub-basin in Campinas-Sao Paulo, presenting an area of 21.820,23 ha (218,20km2) in the city. There is a total drainage length of 410,70km and a demographic density of 3.776,79 hab./Km2, according to the Demographic Census of 2010 (CAMPINAS, 2017).

The sub-basin is integrally located inside the Atlantic Forest Biome (BRASIL, 2018) and according to the Semi-detailed Pedagogical Map of Campinas (CAMPINAS, 2018), the predominant types of soil in the Capivari sub-basin are Red-Yellow oxisols (occupying an area of 45.7%); Red-Yellow Argissolos (32.1%); Haplic Cambisols (11.9%); Red oxisols (3.8%); Haplic Gleisoles (3.8%) and other typologies (2.7%).

Considering a river frequency of 2.10Km2, this sub-basin presents a high water potential in Campinas. However, it is responsible for supporting 6.4% of the water demand of the municipality, while it concentrates almost half of the population of Campinas. These issues may interfere and have straight relation with the population densification and the patterns of usage and soil occupation and, according to the Master Plan of the city, the fact that the Capivari River sub-basin is not self-sufficient in water resources may be abounding factor for the growing and developing of that region (CAMPINAS, 2017; CAMPINAS, 2013).

Forest Remnants and Spatial Indicators

According to a mapping of the natural vegetation of the city of Campinas (CAMPINAS, 2018), 323 forest remnants were presented in the Capivari River sub-basin by the following typologies: Semi-deciduous Broadleaved Forest; Mixed Forest; Paludosa Forest; Semi-deciduous Broadleaved Forest and Cerrado.

The quantitative and qualitative analyses and evaluation of these forest remnants had been made by ArcGIS software through landscape metrics selected according to Silva and Longo (2020), as shown in Table 1.

From the evaluation of these spatial landscape metrics, the environmental quality has been evaluated in each forest remnant, regarding the Environmental Quality Index (IQ_{rem}) presented by Silva e Longo (2020) and given by Equation 1.

$$IQ_{rem} = 0{,}079.AREA + 0{,}215.CAI + 0{,}101.CI + 0{,}108.ENN + 0{,}053.PROXFLOW + 0{,}224.WAT + 0{,}085.SUR + 0{,}136.EROD \quad \text{(Equation 1)}$$

Where:
AREA – Remnant area
CAI - Central Area Index
CI - Circularity Index
ENN - Euclidean nearest-neighbor
PROXFLOW - Proximity to water flow
WAT - Water production
SUR - Land use and occupation in the surrounding areas
EROD - Soil erodibility level

This method is based on the principle of the values consideration, in which there is the possibility of comparing the evaluated points regarding a specific point considered as the ideal point (SILVA; LONGO, 2020).

The parts associated to each indicator in this equation were determined by the application of the Analytic Hierarchy Process Method associated to consultancies to specialists. Throughout this process, the specialists considered the level of importance of each metric in relation to the other. That comparison in pairs allowed all the metrics to be compared and calculate the final weight associated to each indicator.

For application in the IQ_{rem} index, the results of each metric in each remnant of the sub-basin were classified and considered regarding the criteria presented in Table 2. Finally, the environmental quality of the remnants has received the following classification: Very low (IQ_{rem} between 0,00 and 0,20), Low (0,20 – 0,40), Moderate (0,40 – 0,60), High (0,60 – 0,80) or Very High (0,80 – 1,00).

Table 1 - Landscape metrics calculated per each mapped Forest remnant.

Metric	Description
a) Remnant area (AREA)	According to Freitas (2012), the size of a Forest remnant can be classified in: very small (smaller than 0.50 ha); small (0.50 - 1.00 ha); medium (1.00 - 5.00 ha); good (5.00 - 20.00 ha) and appropriate (up to 20.00 ha).
b) Central Area Index (CAI)	Percentage of the core area of a Forest remnant regardless of its marginal rate (60m, considered in this study) and subject to the edge effects (MASSOLI; STATELLA; SANTOS, 2016; CALEGARI et al., 2010).
c) Circularity Index (CI)	Relation between the perimeter P (m) and area A (m²) by the equation $CI = \frac{(2.\sqrt{\pi.A})}{L}$, which allows to evaluate the form of a remnant and classify it into long (ICI < 0,65), moderately long (0,65 ≤ CI < 0,85) or round (CI ≥ 0.85) (FENGLER et al., 2015; ETTO et al., 2013).
d) Euclidean Nearest-Neighbor (ENN)	Euclidean distance calculated in meters from the edge of a remnant to the edge of the closest remnant around (FERNANDES et al., 2017).
e) Proximity to Water Flow (PROXFLOW) and Water Production (WAT)	Euclidean distance calculated in meters of a Forest remnant to the closest water flow (PROXFLOW) and presence of sources in the remnants (WATER). This has been evaluated from the survey on hydrography and sources updated by the *Secretaria do Verde, Meio Ambiente e do Desenvolvimento Sustentável* from Campinas City Hall, to the scale 1:5.000 in 2014 (CAMPINAS, 2018).
f) Land Use and Occupation in the Surrounding Areas (SUR):	Identification of the class with the highest modification levels present in the surrounding areas of each fragment, within a radius of 175m. For this purpose, Silva and Longo's (2020) classification for the mapping of usage and soil occupation of UGRHI 5, in which: Class 0 (Landscape has not been modified) Class 1 (Simple modification); Class 2 (Medium-level Modification); Class 3 (Large modification); Class 4 (Very large modification).
g) Soil Erodibility Level (EROD):	Predominant soil typology evaluation in each Forest remnant, from the *Mapa Pedológico Semidetalhado* from Campinas Municipality and correlation to the correspondent level of erosion, in which: Haplic Gleisoles (very weak); Red-Yellow oxisols and Yellow oxisols (weak); Haplic Cambisols (strong/very strong); Red-Yellow Argissolos (very strong), according to Salomão (1999) and Ross (2005)* * To any other soil classes which correspond to only 2.5% of the area of the basin and had not provided specific information, a moderate level of erosion has been considered.

Source: The authors (2021).

Table 2 - Forest remnants metrics evaluation criteria

INDICATOR	WEIGHTING 1	3	5	8	10
Remnant area (ha) (AREA)	< 0,50	0,50 -1,00	1,00 – 5,00	5,00 – 20,00	> 20,00
Central Area Index (CAI)	< 5 %	5 – 30 %	30 – 50 %	50 – 70 %	> 70 %
Circularity Index (IC)	-	-	< 0,65	0,65 - 0,85	> 0,85
Euclidean Nearest-Neighbor (ENN)	-	> 200	120 – 200	60 – 120	< 60
Proximity to Water Flow (PROXFLOW)	-	> 200 m	120 – 200 m	60 – 120 m	< 60 m
Water Production (WAT)	-	-	No	-	Yes
Level of Usage and Soil Occupation in the Surrounding Areas (SUR)	Class 4	Class 3	Class 2	Class 1	Class 0
Soil Erosion Level (EROD)**	Very strong	Strong	Moderate	Weak	Very weak

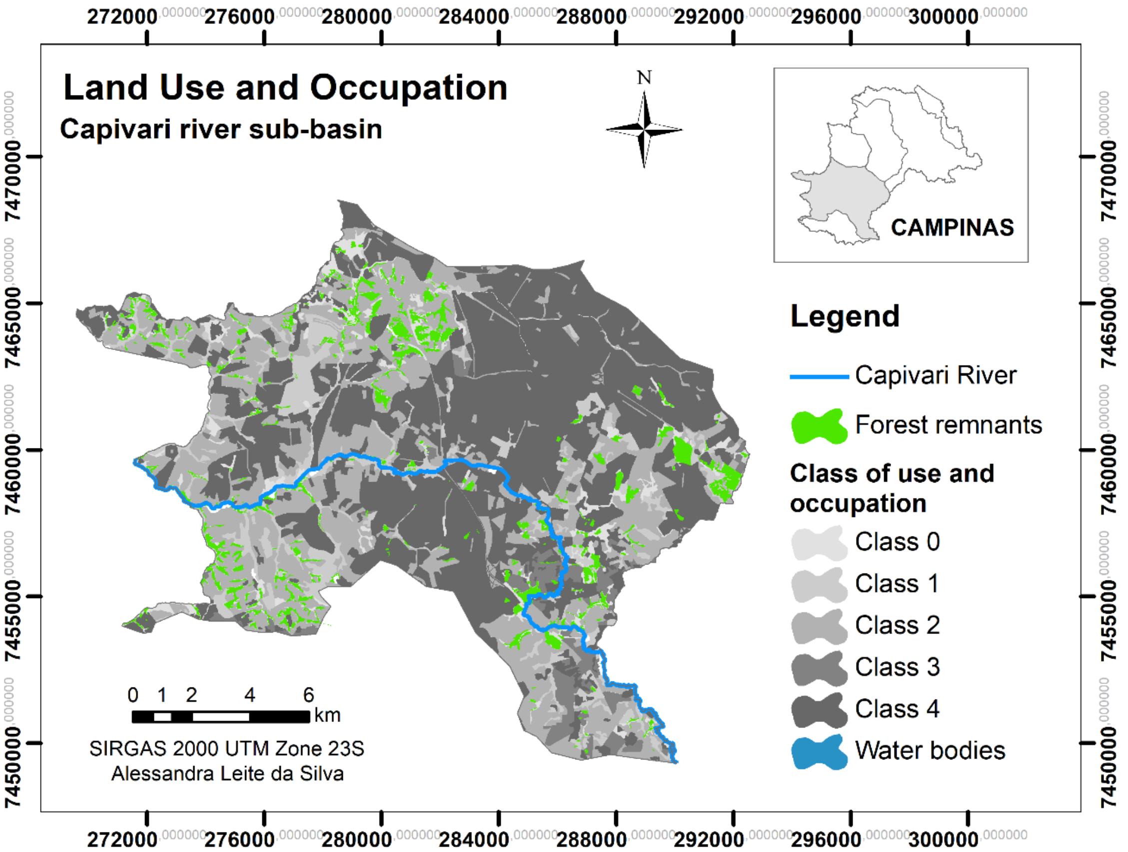
*The intermediate erosion classifications "Very strong/ Strong" and "Weak/ Very weak" have received weighting 9 and 2, respectively. Source: Silva e Longo (2020).

DISCUSSION AND RESULTS

According to the Municipal Master Plan, in Campinas the urban expansion was characterized by the horizontality and peripherization of the urban spaces, making the conurbation process with the other cities intense. This fact has been verified especially in the west and southwest and along the Anhanguera Road and Jornalista Francisco Aguirre Proença Road, towards the cities such as Sumaré, Hortolândia and Monte-Mor (CAMPINAS, 2017).

The Capivari sub-basin is included in the urban perimeter of Campinas and it comprises its core area (CAMPINAS, 2017), which is evidenced by the large urbanization and occupation by non-natural usage classes and predominantly sealed. It is 47%, approximately, of the area with occupations, for instance: buildings, land divisions and big equipment (Class 4), followed by the areas of Class 2: pastures and urban green space (31%); Class 1: (10%) which includes natural fields, humid areas and areas of reforestation (Figure 1).

Figure 1 - Land Use and Occupation in the Capivari River sub-basin, in Campinas- São Paulo



Where:

Class o – Natural landscape has not been modified

Class 1 – Simple modification on natural landscape

Class 2 – Medium-level Modification on natural landscape

Class 3 – Large modification on natural landscape

Class 4 – Very large modification on natural landscape

Source: The authors (2021).

From the 21.820,23 ha of the total area of the sub-basin, 1.241,26 ha are constituted in remnant forest area, in other words, 5.7% of the basin. That vegetation is distributed in the 323 remnants. Regarding the size, they are mainly: medium (45.2%); small (18.0%); very small (16.7%) and good size (16.1%) and, finally, only 4.0% are classified as "adequate", in other words, up to 20.00 ha.

In Table 3 it is possible to confirm the average values which were observed in the metrics of the quantitative landscape which were analyzed for the forest remnants located in the water basin. All of those metrics, as well as the qualitative metrics, will be thoroughly presented and discussed below.

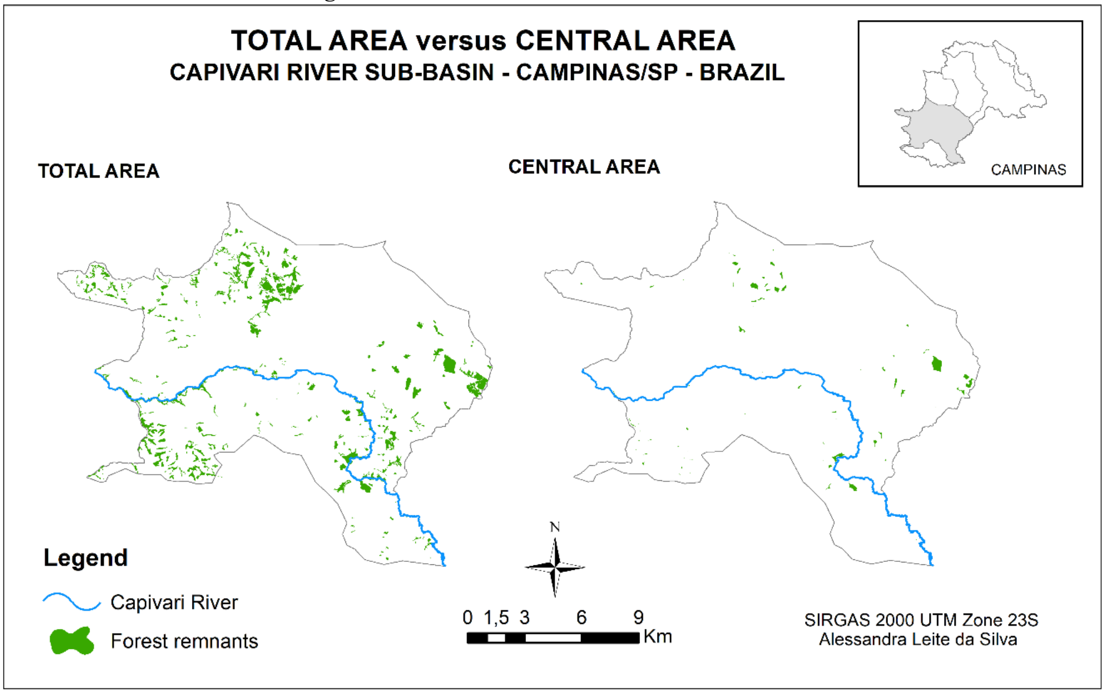
Table 3 - Basic statistics of the quantitative metrics- Capivari sub-basin

Descriptive Statistic	AREA (m)	CAI (%)	CI	ENN (m)	PROXFLOW (m)
Minimum	0,03	0,00	0,17	0,00	0,00
Maximum	45,50	64,28	0,94	1294,85	316,48
Medium	1,82	0,00	0,60	54,22	0,00
Moderate	3,84	2,43	0,59	116,73	12,10
Standard-deviation	6,05	7,43	0,18	172,31	37,82

In which: Fragment size (ha) (AREA); Central Area Index (CAI); Circularity Index (CI); Euclidean Nearest-Neighbor (ENN); Proximity to Water Flow (PROXFLOW) Source: The authors (2021).

From the CAI metric it has been possible to identify that, from the 5.7% of the remnant forest area in the sub-basin, only 11.1% correspond to the central area. That implies that 89.0% of the forest area corresponds to the edge area, which means that, from the 323 remnants, only 66 present central area, as shown in Figure 2. That represents a significant loss of effective area of natural ecosystem, indicating the great fragility of these remnants. This condition directly affects the sensitive species which has specific ecological requisites, such as well preserved forest area and absence of edge effect (MASSOLI; STATELLA; SANTOS, 2016; SILVA et al., 2019).

Figure 2 - Total Area versus Central Area



Source: The authors (2021).

This is a fragility condition which directly affects in the quality of these remnants, and it is also associated to the form of the remnants. The circularity index (CI) indicated that only a low percentage (8.1%) of the present round shape and, therefore, more favorable; while 59.1% present long shape and 32.8% moderately long. It is important to point out that all of the few long-shaped remnants present an area lower than 3.00 ha, considering that 73.1% of these are smaller than 1.00 ha, in other words, very small.

As observed by other researchers, more regular formats are especially associated to small fragments and/or very small; that indicates that the increase of the size of the fragments usually results in more irregular formats (FERNANDES; FERNANDES, 2017; SILVA et al., 2019). Therefore, it is possible to conclude that, although the smaller fragments are highly susceptible to the edge effect due to their reduced area, in the larger fragments the occurrence of the edge effect is mainly associated to the irregularity of the format of the remnant.

Regarding the proximity of the remnants to each other, the following results were obtained: 53.3% are less than 60m distant from their closest neighbor; 19.5% are between 60 and 120m; 11,5% are between 120 and 200m and a significant percentage of 16.7% are more than 200m distant from each other. However, the apparent connectivity of great part of the remnants, which are not quite distant from their closest neighbor, is a metric which cannot be separately evaluated.

As mentioned by Massoli, Statella and Santos (2016), the connectivity parameter, when evaluated by the distance from the closest neighbor, may be slightly affected by the process of deforestation or even suffer significant improvement. That is because maybe a reduction of medium isolation among the fragments associated to the shredding of large remnants into others that are smaller, nevertheless, there is reduced distance between them. In other words, a similar condition to this one which may be identified in the Capivari River sub-basin not necessarily indicates an increase in connectivity, on the contrary, it may suggest an increase in the phenomenon of the forest fragmentation.

It is viable, therefore, to analyze this metric together with the others. In this case, it is important to point out that the Capivari sub-basin is also a basin with predominantly urban use; there are 76.2% of area inside the urban perimeter in the municipality, with 47.0% of the total area occupied with buildings, land divisions and big equipment (Class 4, as presented previously). This way, therefore, the remnants are also very close to some type of traffic route. Besides, over 76.5% of the remnants are in contact, in any part of their edge, with predominantly anthropized uses (Class 4) which exert considerable pressure on the natural ecosystem, the second class of predominant use in the surroundings of the remnants is Class 2 (21.4%).

Since it is a water basin in which the land use is more consolidated, usual initiatives such as the implementation of ecological corridors may present major difficulties to reach the aimed effectiveness, on the other hand, they must be prioritized in the areas which allow their effective implementation.

Regarding the proximity of the remnants and water flows (PROXFLOW), the Capivari sub-basin has presented satisfactory indexes: 93.2% of the remnants are less than 60m from any water flow; 3.7% are between 60m and 120m and 2.2% are between 120m and 200m. Besides, 35.3% of these remnants present at least one source in the inside. This is some quite important information for the management of these areas, since, as mentioned before, in the Capivari sub-basin, the forest remnants show such a significant function to the maintenance of the hydrological availability, in terms of quality and quantity.

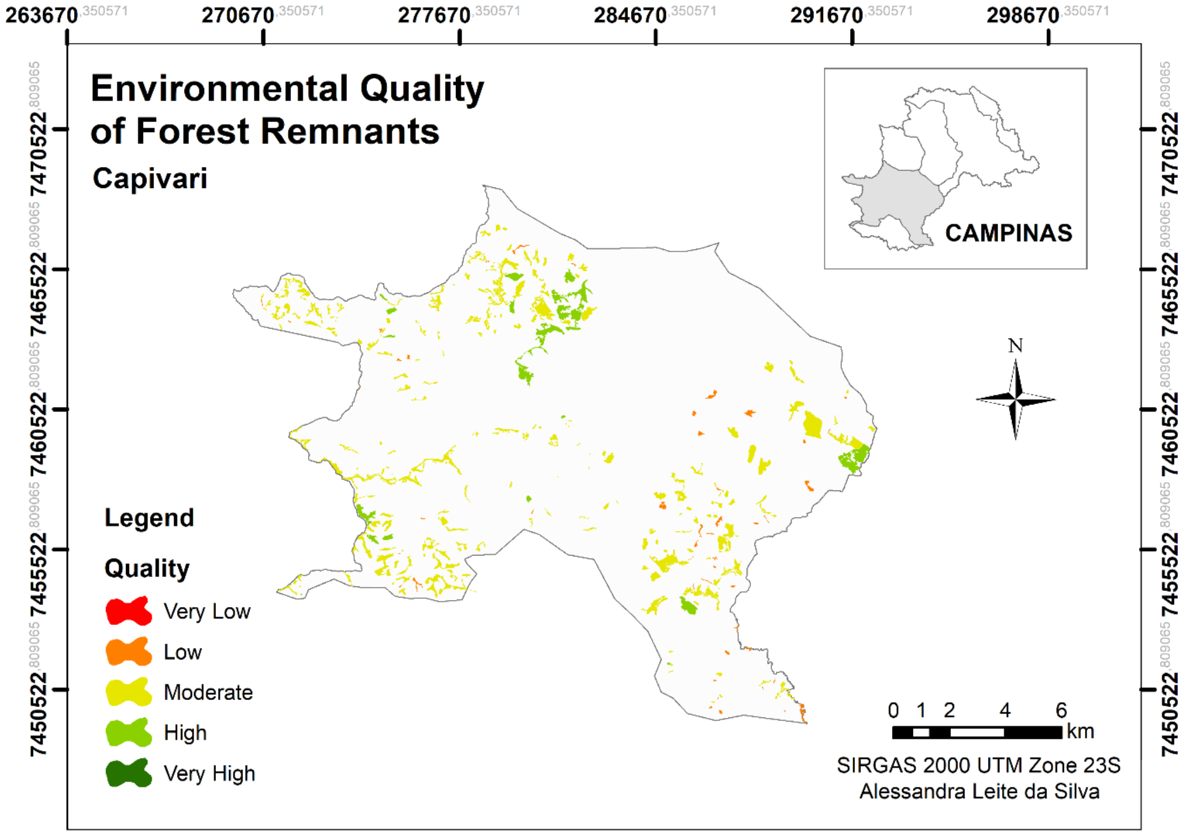
The growth of the demand of urban water is a phenomenon which should be considered and may have its cause due to two factors: the increase of the number of urban users, resulting from the total urban population expansion and the increase of the consumption of water per capita, resulting from the improvement of the population's economic condition. However, due to these circumstances, the water resources start to be explored excessively, affecting the balance between supply and demand of urban water and as a result, decreasing the quality of urbanization (WU et al., 2018; WU; TAN, 2012).

Regarding the Sewage Plan of Campinas, the Capivari River is responsible for supplying the south region of the city, especially in the region surrounding the Viracopos International Airport, and it is also responsible for supplying 6.5% from the total necessary volume for the provision of Campinas city (CAMPINAS, 2013). This increases the importance that actions be effectively conducted in order to contribute to increase and guarantee the environmental quality of these remnants.

In this basin, 41.5% of the remnants are located in soils classified in very strong erosion level and 24.8% with strong/very strong level, which evidences the vulnerability of the area to the erosion and the environmental importance of the remnants in this area, which act as a source of vegetal protective covering for the soil. Only 24.5% of the remnants in the Capivari River sub-basin are in soil of weak/very weak erosion level and 9.3% in very weak.

From these metrics, after having calculated the Environmental Quality Indexes (IQ_{rem}), it has been identified that 78.0% of the remnants in the sub-basin of the Capivari river present moderate environmental quality, followed by 15.2% of low quality and only 6.8% of very high quality. There has not been any remnant classified in very low quality nor very high (Figure 3).

Figure 3 - Capivari River sub-basin remnants Environmental Quality



Source: The authors (2021).

FINAL CONSIDERATIONS

From this study, it has been possible to verify that the forest remnants in the Capivari River sub-basin, in Campinas, have presented a significant contribution to the maintenance of the hydrological availability in the city, in terms of quality and quantity. This increases the necessity of efficient actions be taken in order to contribute to the increase and assure the environmental quality of these remnants.

Besides, as indicated by the Environmental Quality Index (IQ_{rem}), the major part of the remnants nowadays present a moderate condition of quality, which suggests the necessity of adequate management, especially to soothe the fragilities of these remnants and propose measures of environmental recovering. As presented by the landscape metrics, these fragilities are especially related to the potentialized edge effect by the absence of the central area and irregular shape of these remnants, associated to the anthropic pressures from the surroundings.

This way, it is evident that the methodology which had been used in the study was efficient to highlight, through spatial analysis instruments, the main fragilities of the forest remnants in water basin scale.

Confronted with this it is possible to propose some impact mitigation measures and protection of these sensitive areas. In general, in conditions similar to this one, some measures such as the implementation of ecological corridors shall be proposed. However, the implementation of ecological corridors must be very well pondered and maybe not be generalized as the main alternative for management for these remnants.

In this case, according to the conditions which were indicated by the landscape metrics in the Capivari sub-basin and aiming to guarantee the environmental quality of the remnants, it is recommended that initiatives which promote the increase of the effective area of the remnants be taken.

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AUTHORS' CONTRIBUTION

Alessandra Leite da Silva made the acquisition of financing, worked with the data; analyzed; investigated and wrote. Admilson Írio Ribeiro supervised, validated and revised the writing. Regina Márcia Longo conceptualized, acquired financing, supervised and revised the writing.