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Analysis of vegetation cover distribution in Public Green Areas in Governador Valadares, Minas Gerais State, Brazil

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Abstract
Urban population growth in Brazil is expected to remain on rising until 2050, and it will affect the relationship between city residents and urban green areas, whose vegetation favor the environment and human health. These areas must be conserved and they can be monitored through the application of techniques and through measurement and distribution indicators by relating their area and vegetation cover (VC) to the urban population. VC distribution in Public Green Areas (PGA) in Governador Valadares City, Minas Gerais State, Brazil, was measured and assessed. An orthophoto and the AutoCad(R) software were used to measure VC and to calculate and classify PGA and PGAVC indices for the city and its neighborhoods. Also, the association between VC and PGA area, and urban zoning, as well as between indices and neighborhoods' age, were analyzed. VC ratio in the PGA area is inconstant; moreover, more populated zones presented less VC. PGAs presenting the recommended size did not present satisfactory VC in the neighborhoods and most indices recorded value equal to zero. PGAs did not remain the same due to VC prevalence, and it may limit vegetation's ecological services to the urban population. Therefore, alternative green spaces are needed in old regions without PGAs, PGA conservation in regions with satisfactory VC, as well as it is essential reforesting areas recording unsatisfactory VC. Urban VC was measured in an orthophoto (0.1 pixel/cm) and it indicated that PGA and PGAVC indices and PGAs VC distribution map are suitable and low-cost urban planning tools aimed at environmental services offered by vegetation to the population.

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INTRODUCTION

Urban population growth in Brazil is expected to keep on rising until 2050 (UN, 2018). The direction taken by, and strength of, this expansion process can affect the relationship between the city population and urban green areas; and, consequently, the ecological services offered by these areas to people (FEIBER, 2004; TZOULAS et al., 2007).

Therefore, besides being an ornamental attribute, green areas are a legal requirement for the conservation of the urban environment. Brazilian National Law 12651/2012 defines green areas as spaces mostly housing native, natural or recovered vegetation that are free from urban constructions (BRASIL, 2012). Based on some studies, among other definitions, public squares and areas with vegetation cover located in urban environment are considered green areas (CAVALHEIRO; NUCCI, 1998; BOLDRIN et al., 2016). Despite the conceptual diversity of green areas, vegetation cover is inherent to urban green areas and it accounts for ecological services that reach the population.

Nucci and Cavalheiro (1999) have listed the vegetation cover functions, namely: stabilizing surfaces, being a shield to wind, protecting the quality of the water, filtering air and balancing moisture index, supplying food, helping to preserve springs, accomplishing visual and ornamental enhancement and reducing suspended din and dust particles.

Natural elements, including vegetation, make life in cities better and are loosely related to human health. (BONZI, 2017; SOLTANIFARD; JAFARI, 2019). “The lack of connection to nature leads to numerous psychological issues, such as increased stress and attention deficit hyperactivity disorder” (FARR, 2013, p.36). The attempt to cope with the coronavirus (COVID-19) pandemic highlights the importance of green areas and the physical and mental benefits they bring to people (SANTOS, 2020). Social interaction in external areas, mainly in green places can be beneficial and safe if social distancing and individual protection rules are followed. Furthermore, outdoor places account for dispersing the viral load and for exposing viral particles to different climatic factors (GUADAGNIN, 2020).

All these attributions require urban green areas to be covered with vegetation (GUZZO; CARNEIRO; OLIVEIRA JÚNIOR, 2006), and to have at least 70% of their surface formed of permeable soil and to be free from buildings (BOLDRIN et al., 2016). Altogether, these conditions justify using vegetation cover in these areas as environmental indicator (WHITFORD; ENNOS; HANDLEY, 2001).

Urban vegetation cover indicators help assessing environmental quality; therefore, it must be taken into consideration in urban interventions related to life quality (NUCCI; CAVALHEIRO, 1999). The elaboration and application of these tools must be clear due to climate, biogeographic, geomorphological, socioeconomic, population, historical and infrastructure features in order to ensure their appropriate use (DA ROCHA; NUCCI, 2018; 2019). Nevertheless, information provided by these indicators for the qualitative and quantitative evaluation of green areas helps detecting ecological degradation/improvement areas (ZHANG et al., 2020). In addition, this information can support the development of metrics maps (SOLTANIFARD; JAFARI, 2019) capable of guiding urban planning by valuing the benefits of green areas to the population (DE OLIVEIRA, 1996; DE CARVALHO, 2001).

These indices have been used to relate urban green area (m²) to the number of city residents (HARDER; RIBEIRO; TAVARES, 2006; BARGOS; MATIAS, 2012; SINGH, 2018; SOLTANIFARD; JAFARI, 2019). García and Guerrero (2006) and De Arruda et al. (2013) have also evaluated the vegetation cover area (m²) in comparison to the impermeable surface area and the population, respectively.

The vegetation cover of Public Green Areas (PGA) was measured and their distribution was assessed based on the local population living in the urban area of Governador Valadares City, Minas Gerais State, Brazil.

We tested the hypothesis that PGAs have been kept the same due to the prevalence of vegetation cover, since it helps the provision of ecological services for the population. This finding regards the premise that vegetation cover is proportional to PGAs areas, which are bigger in more populated sites.

METHODOLOGY

Study site

Governador Valadares is located in Eastern Minas Gerais State, Vale do Rio Doce region, Brazil (18º51'03" S 41º56'58" W) (PMSB, 2015). The county has territorial area of 2,342 km² (IBGE, 2010), and 24.37 km² of urban perimeter (PMSB, 2015). The population in 2010 was 263,689 (96% urban) and estimates for 2020 expected 281,046 inhabitants in the county. Population density in 2010 corresponded to 112.58 inhabitants/km².

Governador Valadares County is in the Atlantic Forest biome. It presents Ombrophilous Dense forests in higher areas and Seasonal Semideciduous and Deciduous composition in lower and dissected areas (PMSB, 2015). Climate in the county is of the AW type – sub-hot and sub-dry tropical (KÖPPEN, 1948); its temperature is high – it reaches historical mean of 26.9 °C in summer and 21.5 °C in winter. Mean annual rainfall and relative humidity are 1,113.80 mm and 75%, respectively. The rainy season goes from November to January and the dry one, from July to September (PMSB, 2015).

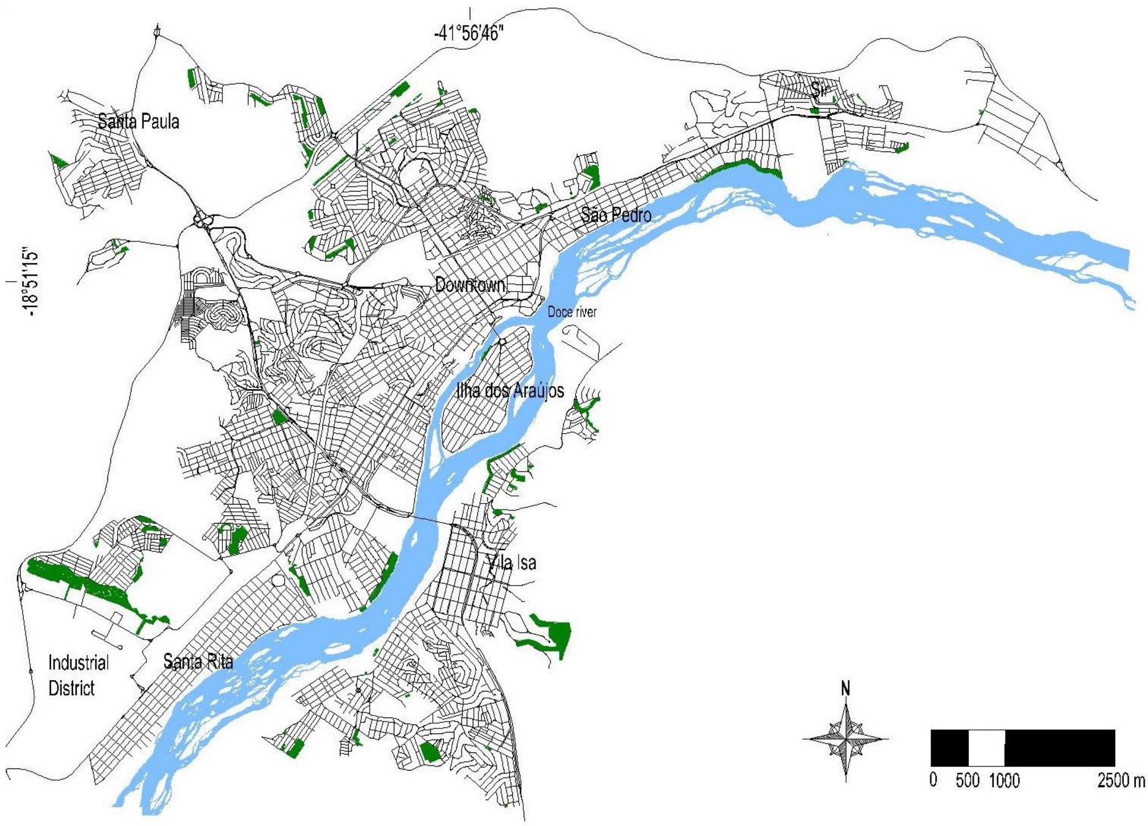
Governador Valadares City is on the bank of Doce River, which crosses Minas Gerais and Espírito Santo states, Brazil. This region favored the city's demographic expansion and the intense use of natural resources, including mineral and forest exploration, mainly from 1940 to 1970, which created long-term environmental issues (ESPÍNDOLA, 2015).

PGAs featuring and vegetation cover measurement

Governador Valadares City has 114 sites registered as PGA by its Municipality (PMGV – *Prefeitura Municipal de Governador Valadares in Portuguese*). PGAs' establishment was equivalent to Municipality Complementary Law n. 178 (GOVERNADOR VALADARES, 2014), according to which 12% of land use can be allocated to "reforested areas with or without paths and trails to keep the features of green areas with continuous and wide vegetation, and free from buildings".

Data survey only took into account PGAs from the urban perimeter (24.37 km²) within all city neighborhoods (Figure 1). These PGAs included squares and ponds, most of which are unused spaces. They were chosen because they are registered and controlled by PMGV. Once PGAs are also required for the opening of new neighborhoods, they may be monitored along urban expansion zones. Of the 114 PGAs registered by PMGV, 78 PGAs and their respective areas (m²) were delimited, since different, but connected, PGAs sites form a single PGA unit.

Figure 1 – PGAs (in green) within the urban perimeter of Governador Valadares City, Minas Gerais State, Brazil, registered by Municipality.



Source: PMGV (2017). Adapted by the authors, 2018.

Similarly to several PGAs, there were different components other than vegetation cover; therefore, each PGA area (m^2) was determined in order to highlight: Vegetation Cover (VC) – green projections in planimetric charts identified through orthophotographs (CAVALHEIRO et al., 1999); Permeable/free area (space without VC); Built area (buildings inside the PGAs) and water surface.

This assessment was carried out based on the formation of polygons within PGA bounds by using the *AutoCad(R) 2018* software (DE CARVALHO, 2001) and a georeferenced orthophotography from 2015 (GSD – Ground Sample Distance of 10 cm – 0.1 pixel/cm), which was provided by PMGV. VC proportion of the area of each PGA was also determined.

PGAs distribution

The spatial availability of PGAs and its association with people highlight the sense of physical proximity as a way to assess population's accessibility to these areas (SINGH, 2018). Two methods were applied to assess PGAs distribution in urban areas in comparison to the population. Initially, PGAs were classified based on the urban zoning in Governador Valadares City (GOVERNADOR VALADARES, 2015), namely: Populous Zone (PZ); Central Zone (CZ); Social Interest Housing Zone (SIHZ); Water Influence Zone (WIZ); Environmental and Urban Interest Zone (EUIZ); Industrial and Large Equipment Zone (ILEZ).

The second method included the calculation of indices capable of indicating PGA and the VC of PGAs offer in the city – this process helps monitoring and maintaining these areas (COSTA; FERREIRA, 2011). PGA Index (PGAI) was calculated through Equation 1 and PGAs Vegetation Cover Index (PGAVCI) was calculated through Equation 2.

$$PGAI\left(\frac{m^2}{inhab.}\right) = \frac{total\ area\ of\ PGA\,(m^2)}{total\ number\ of\ inhabitants} \qquad Equation\ 1$$

$$\text{PGAVCI}\left(\frac{m^2}{inhab.}\right) = \frac{total\ area\ of\ PGA\ Vegetation\ Cover\,(m^2)}{total\ number\ of\ inhabitants} \qquad Equation\ 2$$

Total PGA (m^2) areas and the VC of PGAs were determined for each neighborhood in the city in order to investigate PGAs distribution along the urban expansion. Age groups neighborhoods belonged to were established based on the Basic Sanitation Municipal Plan of Governador Valadares (PMSB, 2015). The number of residents and the limits of each neighborhood were provided by data collected in the 2010 census database (IBGE 2010b).

PGAI and PGAVCI were calculated at two levels, namely: for the city, by taking into consideration all PGAs and the total number of inhabitants in the city – this number was found by summing the population in the neighborhoods; and at lower scale, for each neighborhood within the city if one takes into consideration the number of residents in each neighborhood.

Data analysis

The way vegetation cover is distributed inside PGAs was assessed in order to observe whether PGAs have been kept due to vegetation cover prevalence, since this component leads to ecological service supply to the population. Therefore, the relationship between total PGA area and its VC proportion was evaluated through Analysis of Variance (ANOVA) carried out in *R* software (Project for Statistical Computing) (TEAM, 2013).

The relationship between VC and city urban zoning was also analyzed through ANOVA in order to assess PGAs distribution in comparison to the urban population. City PGAI and PGAVCI were compared to mean indices recorded for the neighborhoods. The effects of the application scale of indices were assessed. This comparison was carried out to evaluate the possible scenario where PGAs distribution could be masked depending on the application scale of index (BARGOS; MATIAS, 2012).

The relationship between indices calculated above (PGAI and PGAVCI) was tested. The same test model was used to analyze the relationship between indices and the age groups set for the neighborhoods. This procedure was followed to evaluate PGAs and VC of PGAs' distribution throughout the urban-expansion time in the study site. Subsequently, the correlation between the age group of each neighborhood and its number of inhabitants was tested to complete the previous analysis and to verify the relationship between PGA and VC existence, with population distribution in the city.

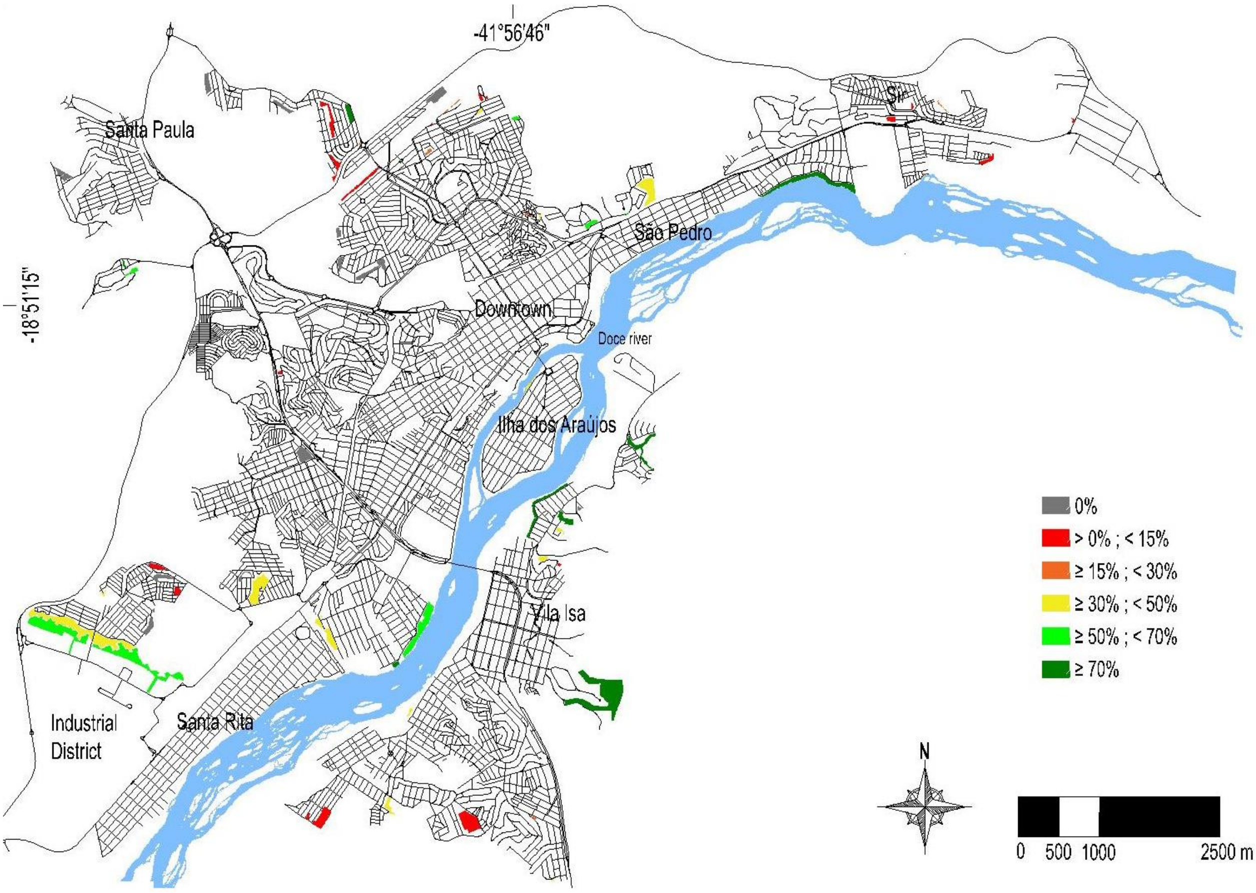
Finally, PGAI and PGAVCI of each neighborhood were separately classified and divided into "Satisfactory" – PGAI/PGAVCI > 12 m^2/inhab.; "Not Satisfactory" – PGAI/PGAVCI < 12 m^2/inhab.; and "Null" – PGAI/ PGAVCI equals zero. Campinas (2006) adopted this value to assess the urban environmental performance in comparison to green areas in Brazil. This same number also meets the range of 10 to 16 m^2/inhab., which is considered ideal by other authors (DA SILVA; DOS SANTOS; DE

OLIVEIRA, 2016).

RESULTS

Figure 2 shows PGAs within the urban area of Governador Valadares City, Minas Gerais State, Brazil, and their respective VC proportion. PGAs presented 52.88% of permeable/free area, but only less than half of the total assessed areas were covered by vegetation (43.34%) (Table 1). Water surface (1.96%) and buildings (1.82%) inside PGAs account for the smallest part of them. More than half of the analyzed 83 neighborhoods (53%) did not have PGA and five neighborhoods had PGA without vegetation cover.

Figure 2 – Percentage of PGAs' VC within the urban area of Governador Valadares City, Minas Gerais State, Brazil in 2015.



Org: Authors, 2018.

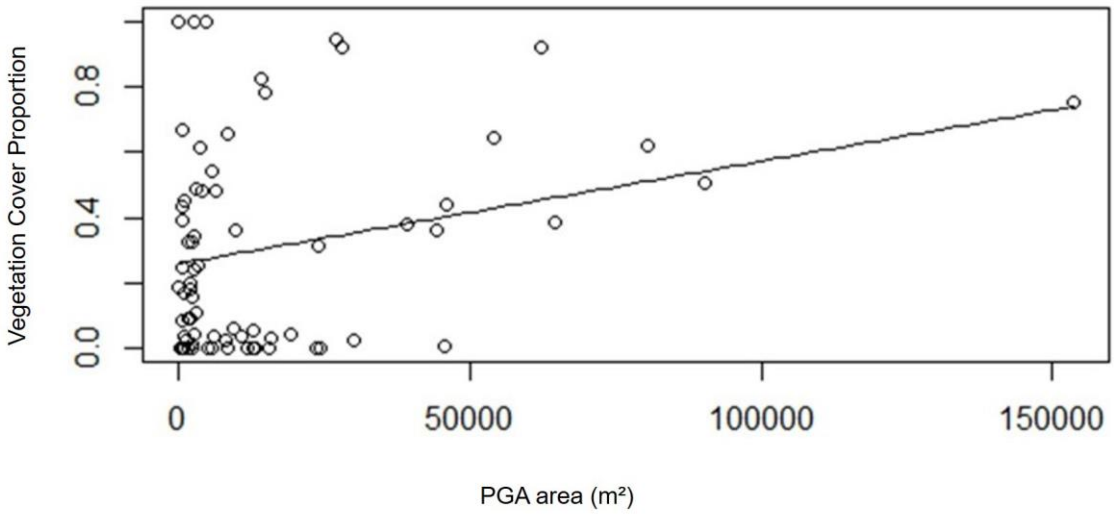
Table 1. Physical featuring (m²) of PGAs in Governador Valadares City, Minas Gerais State, Brazil.

Total PGAs' area	1,159,265.31 (m2)	100%
Permeable area	613,077.15	52.88%
Vegetation Cover area	502,428.30	43.34%
Water surface area	22,686.15	1.96%
Built area	21,073.71	1.82%

Org: Authors, 2018.

There was positive correlation between VC proportion and PGAs area ($F_{(1.76)}$=4.3665; p=0.04). This finding indicates that VC proportion rises due to PGA area increase (Figure 3).

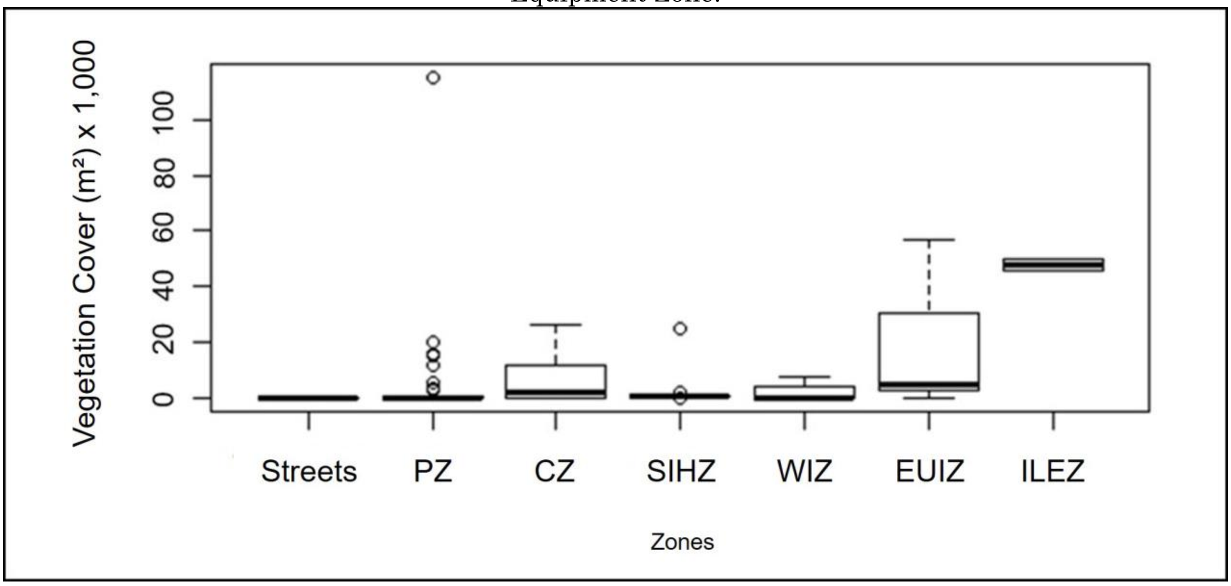
Figure 3 – Relationship between VC and PGA areas in Governador Valadares City, Minas Gerais State, Brazil.



Org: Authors, 2018.

The analysis of the relationship between VC of PGAs and city's urban zoning showed significant differences among areas ($F_{(9.68)}$=5.061; p=3.155e-05), similarly to results recorded by Soltanifard and Jafari (2019). Most zones presented PGAs recording low VC values (Figure 4), with emphasis on the PZ, which was formed by populous neighborhoods presenting tendency to continuous urban expansion. EUIZ showed greater data variation and low mean VC values. On the other hand, ILEZ was a differentiated finding because of its higher VC values.

Figure 4 – Distribution of PGAs VC in urban zones of Governador Valadares City, Minas Gerais State, Brazil. PZ: Populous Zone; CZ: Central Zone; SIHZ: Social Interest Housing Zone; WIZ: Water Influence Zone; EUIZ: Environmental and Urban Interest Zone; ILEZ: Industrial and Large Equipment Zone.



Org: Authors, 2018.

The City's PGAI and PGAVCI and the mean indices of neighborhoods were significantly different from each other, and the averages of neighborhoods indices were always the highest ones (Table 2). City indices were assumingly lower than the 21.7 m²/inhab. recorded for a city in India with population close to 285 thousand inhabitants (SINGH, 2018).

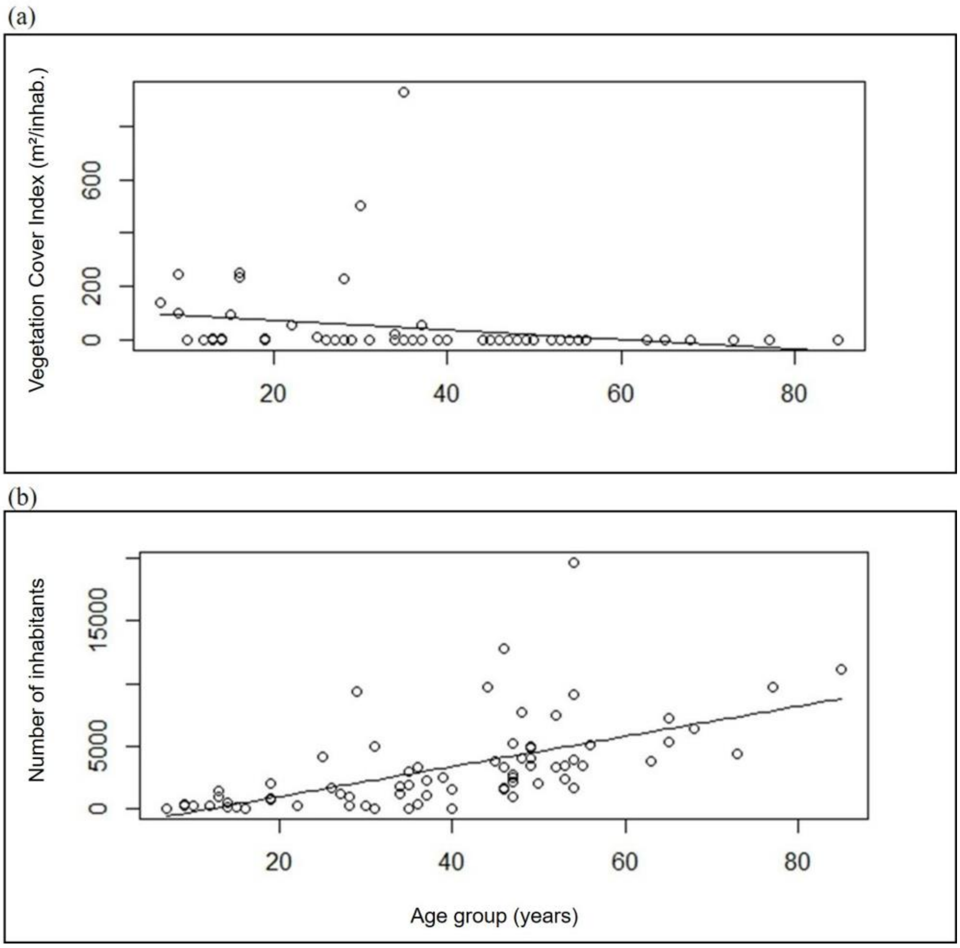
Table 2. PGAI and PGAVCI of Governador Valadares City, Minas Gerais State, Brazil.

	City	Average of neighborhoods
PGAI (m²/inhab.)	4.77	158.27
PGAVCI (m²/inhab.)	2.07	36.52

Org: Authors, 2018.

The association between neighborhoods' PGAI and PGAVCI showed positive correlation between these two variables ($F_{(1.71)}$=5.223; p=0.02528). Therefore, only PGAVCI – which is inherent to the VC of PGAs, i.e., to the ecological services provision by urban vegetation – was used in the following analyses. Thus, PGAVCI got lower due to age groups encompassing older neighborhoods (Figure 5a) ($F_{(1.71)}$=4.2523; p=0.04286). The analysis applied to the relationship between number of residents in the neighborhoods and age groups encompassing these sites completed the previous results ($F_{(1.71)}$=39.755; p=2.148e-8). Based on the current findings, the population is larger in older neighborhoods (Figure 5b); then, results in Figure 5 point out that VC of PGAs is lower in older neighborhoods, which, in their turn, are more populated.

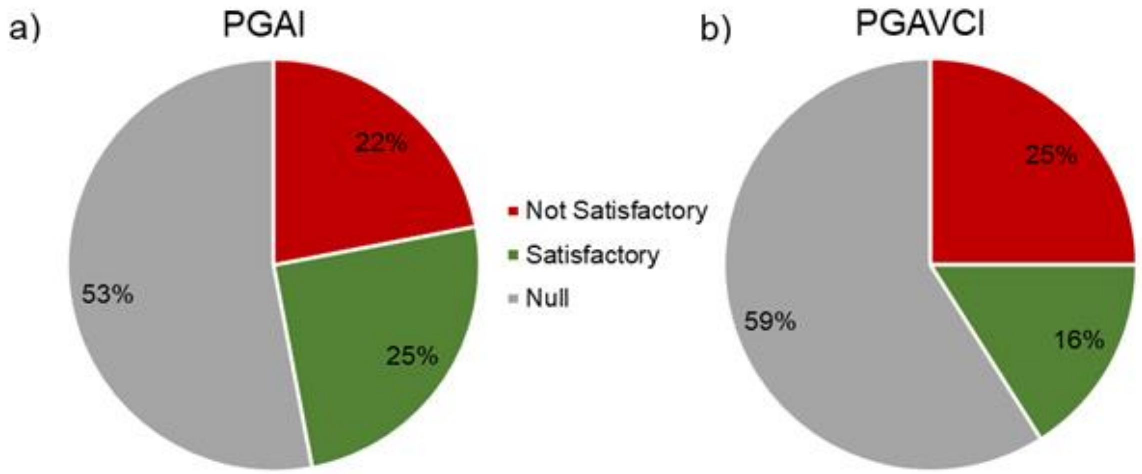
Figure 5 – PGAVCI (a) and the population (b) in neighborhoods belonging to different age groups in Governador Valadares City, Minas Gerais State, Brazil.



Org: Authors, 2018.

Based on the PGAI and PGAVCI classification of each neighborhood according to the parameter of 12 m²/inhab. (CAMPINAS, 2006), Governador Valadares City is mostly composed of neighborhoods recording null indices. This finding points towards lack of both PGA (Figure 6a) and VC in PGAs (Figure 6b). It is also evident that the number of Satisfactory indices recorded for PGAI to PGAVCI dropped from 25% to 16% in the city's neighborhoods, respectively.

Figure 6 –PGAI (a) and PGAVCI (b) classification for neighborhoods in Governador Valadares City, Minas Gerais State, Brazil. Not Satisfactory: lesser than 12 m²/inhab.; Satisfactory: greater than 12 m²/inhab.



Org: Authors, 2018.

DISCUSSION

Absolute values presented in Table 1 have shown that less than 5% of Governador Valadares' urban area is formed by PGAs – this value is lower than that found in a previous study (9.1%) carried out in a city with number of inhabitants close to the herein used one (SINGH, 2018). The sum of Permeable Area to Vegetation Cover exceeded PGAs' total area by 70%, which is the least value recommended (GUZZO; CARNEIRO; OLIVEIRA JÚNIOR, 2006). This result is likely positive; however, when it comes to VC proportion, alone, the recorded value does not even represent 50% of PGAs' total area.

Nevertheless, Figure 3 shows that VC distribution in PGAs is not even. Regardless of the value recorded for the PGA area, VC proportion should be constant and cover more than 70% of the PGA area. Such a scenario was not observed in most PGAs; therefore, these results (Table 1 and Figure 3) are strong indications that VC is not a priority in the evaluated PGAs. These circumstances are contrary to the legislation (BRASIL, 2012; GOVERNADOR VALADARES, 2014), which defines PGAs as areas mostly covered by vegetation to ensure their ecological services (NUCCI; CAVALHEIRO, 1999; EDWARDS, 2008).

Figure 2 illustrates the aforementioned scenario and may be seen as a metric tool to analyze urban spatial heterogeneity in relation to PGAs, forming the called status of green spaces (SOLTANIFARD; JAFARI, 2019). This information is valuable for the decision-making process and helps ensuring that actions have been taken to improve urban VC. Figure 2 shows the prevalence of PGAs with VC proportion lower than 70% of the PGA area. Only 12 PGAs out of the 78 evaluated ones presented VC equal to, or higher, than 70%. Five (5) of these 78 are located close to the border of the urban perimeter; consequently, they are far from the most populated zones. Figure 2 corroborates results in recent studies (SINGH, 2018) whose uneven PGAs distribution in urban areas is visible, which increases spatial heterogeneity and has negative influence on PGAs' ecological quality (SOLTANIFARD; JAFARI, 2019). PGAs location in points distant from the population are limitations to the positive effects of PGA vegetation over the urban population.

Results of the analysis that take into consideration the urban zoning are initially encouraging, because most PGAs are located in PZ (urbanized and populous regions). It represents the link between people and the benefits from PGAs. However, these PGAs have low VC value (Figure 4) and almost zero VC, on average. On the other hand, ILEZ recorded the highest VC values in PGAs; areas of these PGAs corresponded to approximately 15% of the total PGA area in the city. VC values recorded for ILEZ are high when it comes to sparsely populated areas and the benefits of PGA to the urban population. Yet, given chances of industrial growth in the city (PMSB, 2015), these PGAs are susceptible to degradation due to the likely arrival of new industries (HARDER, 2002; SINGH, 2018). Results reinforced the importance of making sure about high VC rates in PGAs. They also warned about the need of conserving PGAs in industrial areas and of appreciating their existence in densely populated areas. It may helps improving the quality of urban life, mainly humans' physical and mental health (DE OLIVEIRA, 1996; NUCCI; CAVALHEIRO, 1999; DE CARVALHO, 2001; LOBODA; DE ANGELIS, 2005).

PGAs located in EUIZ were expected to show high VC values, once this zone refers to regions of environmental interest – but the expectation was not fulfilled (Figure 4). A small part of the total of PGAs in the city (9%) was in the EUIZ and 57% of it is Permanent Preservation Area (*Área de Preservação Permanente – APP – in Portuguese*) located by the bank of a waterbody (Doce River) whose preservation is established by law. APPs registered as PGAs also remain among the 12 PGAs that have more than 70% of their area covered by vegetation. This scenario points out the importance of urban environmental policies focusing on the recovery, maintenance, monitoring and inspection of these areas in order to guarantee their ecological, historical, cultural, landscape and tourist value (MMA, 2020).

Application scale of indices (PGAI and PGAVCI), in their turn, refers to the political-administrative system of cities' territorial division in Brazil – neighborhoods, zoning – which ought to guide public policies focused on PGAs. Newly created neighborhoods showed higher PGAVCI values (Figure 5a); however, the location of these neighborhoods in areas of urban/rural interface with characteristic green spaces assumingly explains the high rates of VC (SOLTANIFARD; JAFARI, 2019). Many of these neighborhoods are not yet fully urbanized and population increase may account for changes in this index if no measures are taken to conserve and/or proportionally increase PGAs with VC.

The results have warned about the oldest neighborhoods, which do not have PGAs (Figure 5a), but have larger populations (Figure 5b) and are located close to the city's downtown area. De Paula and Ferreira (2017) observed the same conditions and showed that cities' older regions and centers often suffer from lack of plans for the development of green areas (SINGH, 2018). Therefore, the population in these neighborhoods may not benefit from the environmental services provided by PGAs, and such a finding draws closer attention due to the COVID-19 pandemic. PGAs may help to safely prevent the negative effects of social distancing on the population's physical and psychological health (GUADAGNIN, 2020; SANTOS; 2020). Alternatives like green tunnels (SALVI et al., 2011) and squares' revitalization (BARROS; VIRGILIO, 2003) may contribute to change the lack of green spaces. These measures would also help avoiding the fragmentation of green spaces and creating greater ecological connections in the city by increasing ecological stability and improving the quality of urban environment (SOLTANIFARD; JAFARI, 2019).

The classification recommended by Campinas (2006) – 12 m² of PGA for each inhabitant - was herein adopted. Results evidenced that only one quarter of the assessed neighborhoods met recommendation set for PGAI (Figure 6a). Both the green areas (Figure 6a) and vegetation cover (Figure 6b) did not exist in more than half of the evaluated locations. The situation is even more worrisome if one takes the recommendation of the Brazilian Society of Urban Afforestation – 15 m²/inhab. – into account (DE ARRUDA et al., 2013; LUCON; DO PRADO FILHO; SOBREIRA, 2013). In addition, satisfactory registrations dropped from 25% to 16%, in PGAI and PGAVCI, respectively. Then, part of PGAs, despite having recommended size, do not have enough vegetation cover and require reforestation.

Results reinforced the use of PGAVCI for PGAs' evaluation, as already recommended (CAVALHEIRO; NUCCI, 1998; NUCCI, 2008). This index likely helps visualizing changes in ecological services and guiding urban planning concerning areas presenting ecological degradation/improvement (ZHANG et al., 2020). PGAVCI can also complete other indices used to assess the effects of vegetation on the real estate market (JIAO et al., 2017) or to analyze vegetation and soil's physical conditions (DHAWALE; PAUL, 2018).

The herein presented results are inherent to the existing VC in PGAs and disregard the VC from other locations in the city, such as green tunnels, parks and environmental protection areas, which should also be controlled by PMGV. The VC portrait of PGAs was presented in the current study – these PGAs are controlled by the municipality. This portrait helps monitoring whether the creation of new neighborhoods is in compliance with the legislation, as well as monitoring the relationship between VC and city growth. However, the oversight of all urban green areas would represent greater contribution to vegetation cover conservation in the city.

CONCLUSION

PGAs account for approximately 1.15 km² of the study site, although they represent less than 5% of the total urban area in the city. Less than half of the PGA area is covered by vegetation, and the existing VC is inconstant and occupies less than 70% of the area in most units. It is necessary creating green spaces in older regions without PGAs, as well as conserving and reforesting PGAs with satisfactory and unsatisfactory VC, respectively.

The legislation establishing the PGAs certainly helps to change the history of urban-expansion environmental degradation, although the law is not clear enough about PGAs' identification/implementation aspects. Nevertheless, PGAs' and their VC status of uneven distribution are indicative that these areas have not been primarily kept through vegetation prevalence. PGAs are likely the response to the regular legislation/inspection in recent urbanization processes.

PGA and PGAVC indices and PGAs' VC distribution map (Figure 2) are suitable and low-cost tools that enable the conduction of the urban vegetation coverage analysis. A 0.1 pixel/cm-orthophotography provided high-quality information for urban planning focused on the environmental services vegetation offers to the population. Further research should relate these tools to the physical distance and economic factors linked to the population, as well as to the specific featuring of the existing vegetation and PGAs' mid- and long-term monitoring.

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AUTHORS' CONTRIBUTIONS

Antônio Carlos, Sarah L., Estêvão P., Matheus L. and Rebeca B. planned the study, collected and analyzed the data and wrote the text. Renata Campos guided the entire development of the work, especially the data analysis stage, and contributed to the writing of the final text. Pollyana C. contributed to the literature review and writing of the final text.

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