An Acad Bras Cienc (2022) 94(Suppl. 4): e20210015 DOI 10.1590/0001-3765202220210015
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

FORESTRY SCIENCE

A fuzzy-based methodological proposal for analysing green areas in urban neighborhoods

MAURÍCIO T. DA MOTA, AMANDA LOUISI DOS S. GALVÃO, ADRIANO BRESSANE, ROGÉRIO G. NEGRI, JOSÉ ARNALDO F. ROVEDA & SANDRA REGINA M.M. ROVEDA

Abstract: The reduction of the green areas due to the growth of the built-up areas has affected the environmental quality in cities. Nevertheless, some uncertainties remain about the adequate amount of such areas in the urban landscape. This study aims at introducing a methodology to support analysis of green areas in urban neighborhoods. The methodological proposal was based on a fuzzy expert system (FES), a soft computing approach capable of dealing with uncertainties in complex multiple-criteria decision-making. As empirical research, some case studies to introduce and validate the proposed methodology were performed. An agglomerative hierarchical clustering, followed by a Kruskal-Wallis test and multiple pairwise comparisons using the Conover-Iman procedure (significance 0.05), demonstrated that the FES was able to provide outcomes consistent with hypothetical situations, simulated as ideal and critical conditions of green areas. In conclusion, our findings indicate that the methodological proposal based on FES is a promising tool for complex case-by-case analysis in urban neighborhoods.

Key words: land use, sustainable cities, expert system, decision model.

INTRODUCTION

According to the World Urbanization Prospects report, the urban population corresponds to 3.9 million people, about 54 % of the total world population, and may reach 66% by 2050 (DESA United Nations 2015). Urbanization is a global trend that oftentimes leads to soil sealing, deforestation and habitat fragmentation, requiring integrated management of anthropic and natural issues to achieve healthy and sustainable cities (Adler & Tanner 2015, Aronson et al. 2017, Bressane et al. 2017b, 2019, Ribeiro et al. 2018). It is widely acknowledged that green areas not only contribute to biodiversity conservation but that they also provide environmental quality in urban landscapes (Zhou & Wang 2011, Sperandelli et al. 2013, Andersson et al. 2014, Kabisch & Haase 2014, Gavrilidis et al. 2017, Meerow & Newell 2017, Bressane et al. 2018b, Rocha & Mussury 2020).

Although green areas are one of the most important elements to be considered for urban planning (Attwell 2000), the adequate quantity of theses green areas is still under investigation around the world (Maryanti et al. 2016). Discussion of the ideal percentage of canopy cover in urban areas is not recent, but it has not reached consensus in the scientific literature (Mell et al. 2017). For instance, the World Health Organization (WHO 2012) recommends a minimum of 9 m^2 of green space should be available per individual. In Brazil, while local studies recommend that residential areas with low verticalization should have 50% of vegetation, of which 25% are trees and shrubs, areas with high urban verticalization should have 30%, and industrial areasones, 20% (Nucci & Presotto 2009). State legislation requires a minimum of 20% of green areas and recreational space in urban neighborhoods in São Paulo (Resolution SMA 72: São Paulo 2017).

The lack of consensus creates uncertainties that make the treatment of green areas more complex. To deal with these uncertainties, this paper introduces a fuzzy-based methodological proposal, as a tool for analysing the condition of green areas (CGA) in urban neighborhoods. Thereby, the proposed model aims to support decisions that seek to conciliate the expansion of built-up areas with the adequate conservation of green areas. In particular, the model can contribute to the determination of the minimum percentages of green areas based on the integrated analysis of local attributes on a case-by-case basis.

Fuzzy set theory is a soft computing approach that has been widely applied in the building of complex decision support systems, due to its ability to approximate expert reasoning, to equate parameters of a dissimilar nature, to deal with subjectivity and other issues associated with uncertainties (Barros et al. 2017, Bressane et al. 2020, Ewbank et al. 2020, França et al. 2020). Whilst in classical logic elements either do or do not belong to a given set (hard boundary), in fuzzy logic membership can be partial (soft boundaries), as well as assuming linguistic values (Bressane et al. 2018a, Roveda et al. 2018). Thus, as green area analysis can be complex due to the uncertainties involved, fuzzy modelling can provide a promising alternative. Comparison with other methods will be carried out in the continuity of the research.

It is noteworthy that currently, there is no justification for determining percentages of green areas in the process of occupation of urban land (allotments). The percentages used by different municipalities are variable and without any technical justification. The proposed model analyses and recommends percentages of green area based on variables related to existing natural attributes and their potential to promote environmental services. As empirical research, case studies were performed in a medium-sized city in Brazil, in order to validate the proposed methodology.

MATERIALS AND METHODS

Fuzzy-based tool

In a hard computing approach, membership (φ) of an element in a set is evaluated in a Boolean fashion (classical set theory or type-0 fuzzy set), so that the element assumes value 0 (not pertinent) or 1 (pertinent). In turn, in soft computing based on fuzzy sets theory (type-1 fuzzy sets), the partial membership of an element in several linguistic values becomes possible, assuming a certainty factor in an interval [0,1] (Figure 1).

In Figure 1, (*i*) shows the classical case (type-0 fuzzy set), where parameter ‘b’ is a crisp value that defines a hard boundary between sets, assuming that there is no uncertainty. In the case of (*ii*) the type-1 fuzzy set, there is uncertainty about the real value of a variable (fuzzyness), which will be quantified as a ‘value around b’. While the, threshold parameters provide a gradual transition between sets (soft boundaries), the ‘a’ and ‘c’ parameters are rigid, real, and well-known numbers.

The membership functions of an element in linguistic values can be trapezoidal, triangular, sigmoidal, Z-shaped, or generalized bell-shaped, among others. In the present study, type-1 fuzzy sets were used, and fuzzification of variables was performed using triangular and trapezoidal membership functions, given by:

$$\varphi_F(x) = \left\{ \left\{ \frac{x-a}{b-a} \;\; ,1, \frac{c-x}{c-b'} \right\} ,0 \right\}$$

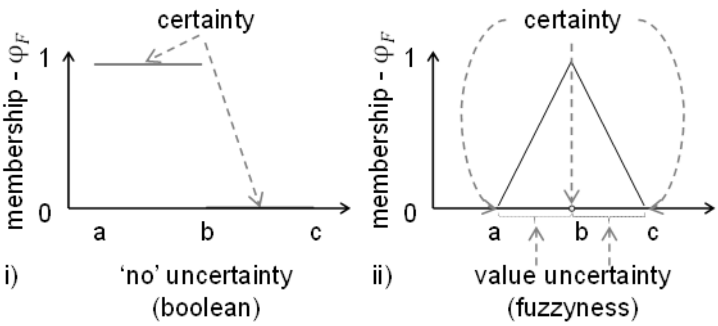

Figure 1. Regions of certainty, with membership equal to 1 or 0, and uncertainty, with transition between conditions of pertinence and non-pertinence: (*i*) classical (type-0 fuzzy set), and (*ii*) type-1 fuzzy set. Source: Bressane et al. (2020).

where $Q_F(x)$ measures the membership of *x* in the linguistic value modelled by fuzzy set *F*; *a, b, b* and *c* are scalar parameters defined by experts for delimiting regions of certainty and uncertainty, so that for triangular-shaped functions, the parameter *b* is equal to *b*.

Figure 2 presents the tool architecture based on fuzzy expert system (FES), introduced above. Firstly, modelling consisted of the fuzzification of variables, by means of pertinence functions associated to linguistic values, i.e. sets with soft boundaries. The model inputs were indicators of 'density (DEN)', 'quality (FSQ)' and 'quantity (FCQ)' of green areas in urban neighborhoods. In turn, the output from the FES is the condition of green area (CGA).

Taking into account the different nomenclatures found in the literature (FAO 2016) green areas were designated as areas of collective use in which buildings are not allowed. 'Quality' of green area was based on the forest succession stage (FSQ), so that more advanced stages were considered to be of higher quality (Brown et al. 2015, Cohen-Cline et al. 2015, Klemm et al. 2015, Middel et al. 2015, Berland et al. 2017, Derkzen et al. 2017, Fanelli et al. 2017, Gunawardena et al. 2017, Jayasooriya et al. 2017, Meerow & Newell 2017, Sanusi et al. 2017, Graça et al. 2018, Mota et al. 2019). The fuzzification of this variable is shown in Figure 3a.

Data for FSQ variable were collected using the Bitterlich method, which consists of evaluating the trees in a 360° rotation, whose breast height diameter (BHD) is equal to or greater than the angular aperture of selected individuals (Bitterlich 1948). Trees were measured systematically in transects that crossed large vegetation patches.

'Quantity' evaluates the percentage of green areas occupied by forest cover (Forest Cover-based Quantity - FCQ) in relation to the total green area. As a reference value, 50% of the area to be occupied by forest cover were considered (Nucci & Presotto 2009, Figure 3b). Forest cover was inventoried using satellite images and field work.

In turn, 'density' (DEN) expresses the relation between a green area and the estimated human population size of an urban neighborhood. For this, the number of plots was multiplied by the average number of household residents (according to the IBGE census of 2015). Then, density was calculated as the ratio between total green area divided by the estimated population. Taking into account the lack of a global or regional density number the fuzzification shown in Figure 3c were adopted.

After the fuzzification step, a rule base was constructed, which consisted of a set of conditional propositions defined by the form "IF – THEN" (Bressane et al. 2016). In the proposed model, 64 *modus ponens* rules were created, combining linguistic values of input variables, such as in:

if 'FSQ' is 'middle' and 'FCQ' is 'good' and 'DEN' is 'optimum'

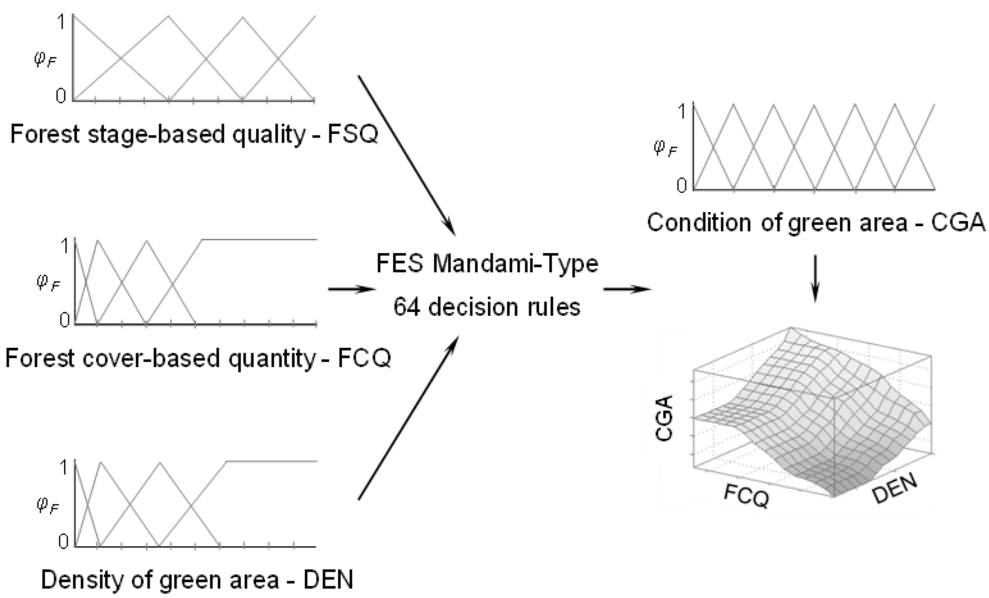

Figure 2. Architecture of the fuzzy-based tool.

then 'GCA' is 'adequate'.

For the mathematical treatment of rule base propositions, a Mamdani-type fuzzy inference system was used, adopting the 'max-min' relational composition (Mamdani & Assilian 1975). Using the architecture presented in Figure 2, modelling produces recommended ratios for green areas, varying from 20% to 50%. The conversion of fuzzy outputs to a crisp value was performed by the centroid method (Barros et al. 2017, Bressane et al. 2017a). Figure 3d presents the fuzzification of this output, normalized to range [0,50].

Case studies and data collection

As empirical research, case studies were performed to validate the methodological proposal. For that, the developed methodology were applied to analyse green areas in urban neighborhoods of a middle-sized city (Sorocaba), São Paulo State, Brazil. Sorocaba occupies an area of 448.9 km^2 and has an estimated population of 644,919 inhabitants (IBGE 2015). The municipality is located in a transitional ecoregion between the Atlantic Forest (mostly Semideciduous Seasonal Forest) and the Cerrado (Brazilian Savanna).

The sample size was calculated based on the total urban area, using the population proportion method (Montgomery & Runger 2011), this resulted in including 70.4% of municipal territory. Thus, seeking a confidence level of 95% and an error margin of 2%, the resulting sample size was 1,597 ha. To select the neighborhoods approval plans for the urban development project were analysed and then only urban neighborhoods larger than 30 ha were selected. So the sample dataset included 30 urban neighborhoods (Table I and Figure 4), with a total area of 1630.73 ha (a larger area than the minimum, described above).

A field survey was carried out in the first half of 2018. Based on on-site observations, the green area of each urban neighborhood were delimited on a map, and then forest cover was measured using aerial images acquired in 2018.

Data analysis

Firstly, agglomerative hierarchical clustering, based on FSQ, FCQ and DEN variables, using Euclidean distance as the dissimilarity measure,

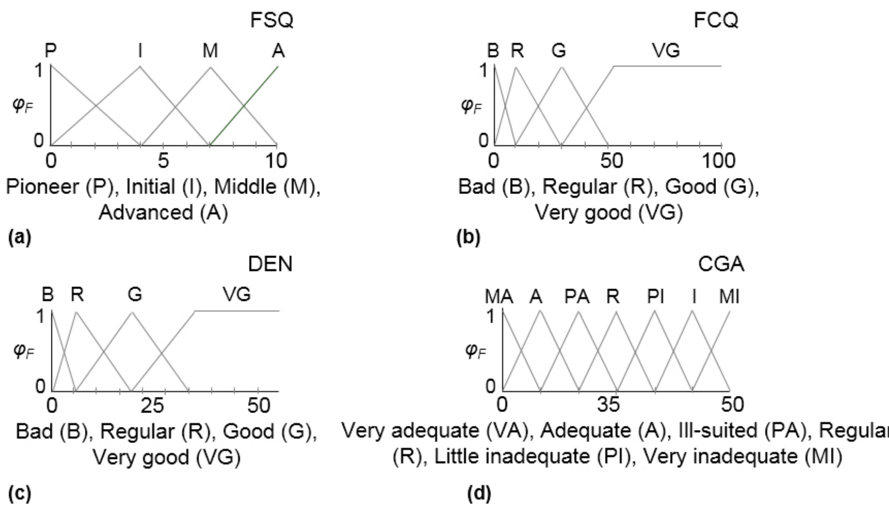

Figure 3. Model variables fuzzification: a) Forest Stage-based Quality (FSQ), b) Forest Cover-based Quantity (FCQ), c) Density (DEN), and d) Condition of Green Area (CGA).

and agglomeration based on Ward's minimum variance method (Ward 1963, Fengler et al. 2017), were applied to split the data into two groups: (Group 1) urban neighborhoods with green area in critical condition; and (Group 2) urban neighborhoods with green area in ideal condition. To achieve this, a cut-off was established by defining the largest width range among these two groups formed in the dendrogram (Figure 5).

After verifying by the Shapiro-Wilk test that some model variables does not follow a normal distribution (p-value < 0.05), non-parametric techniques were applied with a significance of 5%. Then the Kruskal-Wallis test and multiple pairwise comparisons using the Conover-Iman procedure were performed to test the following research hypotheses:

H_0: the green area condition recommend by FES is not different from one in Group 1 (critical condition) or is not equal to one in Group 2 (ideal condition);

H_A: the green area condition recommend by FES is different from one in Group 1 (critical condition) and is equal to one in Group 2 (ideal condition).

Thus, if the computed p-value is lower than the significance level (0.05) the null hypothesis H_0 should be rejected, and the alternative hypothesis H_A should be accepted. IF the H_A is accepted, then the FES should be considered a promising alternative to deal with uncertainties in the analysis of green areas in urban neighborhoods.

RESULTS

From the case studies, Table II presents the condition of green area (CGA) recommended as adequate by the fuzzy expert system (FES) for the urban neighborhoods and the current CGA, that exist in each neighborhood.

As a result from the agglomerative hierarchical clustering, the Figure 5 presents a classification of the neighborhoods according to the condition of the green areas, in which it can be seen that the most of the gated communities had similar condition.

Figure 6 show the findings from the multiple pairwise comparisons with regard to condition of green areas in the urban neighborhoods, pointing out that the green area condition recommend by FES is different from one in Group 1 (critical condition) and is equal to one in Group 2 (ideal condition). Therefore, one should reject the null hypothesis H_0, and accept the alternative hypothesis H_A.

Table I. **Urban neighbourhoods selected for the sample dataset.**

Index**	Urban neighborhoods	TA (ha)	NL (un.)	PGA (%)	DGA (m^2)	DEN (m^2/inh)
31	Pq. Leonanrdo Kehdi 1	34.67	1,173	8.92	30,923	8.09
15	Jd. Montreal	36.76	1,294	11.47	42,165	10.00
8	Jd.Wanel Ville V	57.67	2,044	11.59	66,839	10.03
13	Jd. Califórnia	38.05	1,332	19.54	74,344	17.12
32	Jd. Prestes de barros	57.81	1,212	13.73	79,378	20.09
11	Jd. Golden Park Residence*	35.44	635	12.06	42,740	20.65
26	Jd. Sta Esmeralda	58.08	1,570	18.61	108,087	21.12
18	Jd. Piazza Di Roma (2nd phase)	38.28	871	16.13	61,744	21.74
20	Jd. Piazza Di Roma	43.76	970	15.83	69,266	21.90
27	Pq. Res. Horto Florestal*	59.58	1,569	24.93	148,540	29.04
9	Jd.Wanel Ville IV	42.68	1,130	25.08	107,050	29.06
6	Pq. Esmeralda	53.91	1,045	19.33	104,198	30.59
5	Jd. Pagliato	36.44	497	14.12	51,455	31.76
42	Jd. Terras de São Francisco*	36.69	900	28.48	104,505	35.62
12	Jd. Ipanema Ville	48.73	1,291	35.57	173,343	41.19
21, 22, 24	Jd. Nilton Torres	38.51	1,007	37.20	143,252	43.64
43	Pq. Res. Villa dos Ingleses*	64.18	1,070	25.03	160,654	46.06
38, 39, 40	Jd. Res. Mont Blanc*	39.51	560	21.60	85,337	46.74
25	Jd. Paulista	45.48	898	40.44	183,929	62.83
30	Pq. Ibiti Royal Park*	77.26	1,177	32.42	250,477	65.28
16	Jd. Vale do lago*	42.25	205	11.24	47,486	71.06
29	Pq. Ibiti Reserva*	70.44	1,032	38.29	269,730	80.17
46, 47, 48	Pq. Res. Chácara Ondina*	53.54	596	38.26	204,852	105.43
44	Jd. Terras D`Oro*	37.73	191	19.62	74,022	118.88
34	Jd. Res. Campos do Conde II*	53.10	464	45.60	242,152	160.09
33	Jd. Res. Campos do Conde*	33.94	312	48.43	164,384	161.62
45	Jd. Res. Saint Patrick*	55.30	265	27.03	149,468	173.02
2 ,3, 4	Pq. Reserva faz. Imperial*	100.00	359	27.29	272,900	233.18
36, 37	Castello 90*	205.40	698	31.82	653,579	287.23
41	Jd. Solar do Bosque*	35.54	206	16.67	59,241	88.21

***Gated community; TA - Total area of urban neighbourhood; NL - Number of lots; PGA – Percentage of green area; DGA - Dimensions of green area; DEN – green area per inhabitant. Source: developed by the authors. ** Index of the study areas, as numbered in Figure 4.**

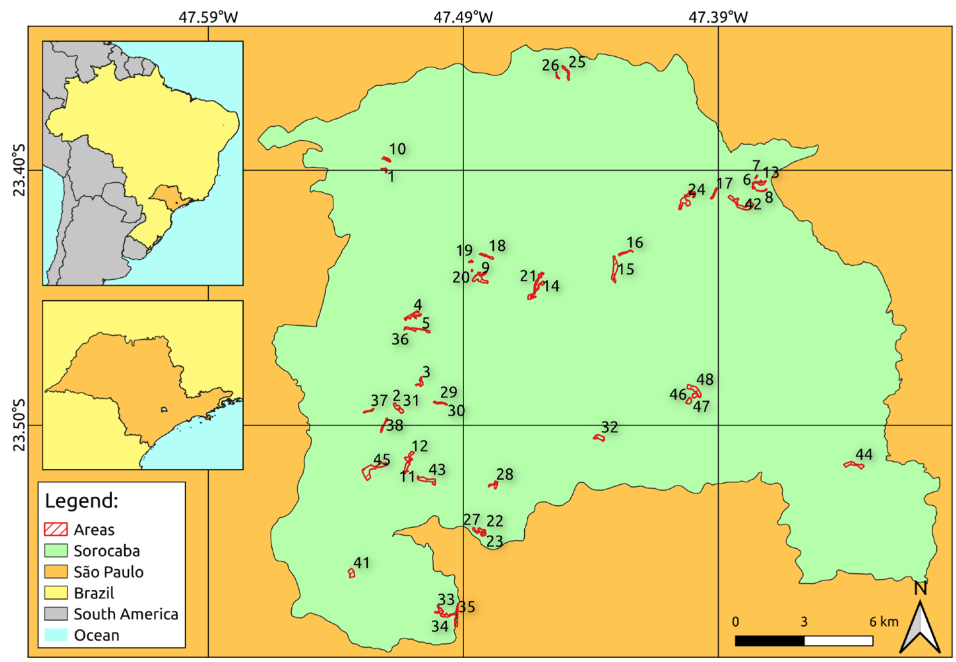

Figure 4. Urban neighborhoods analysed as case studies.

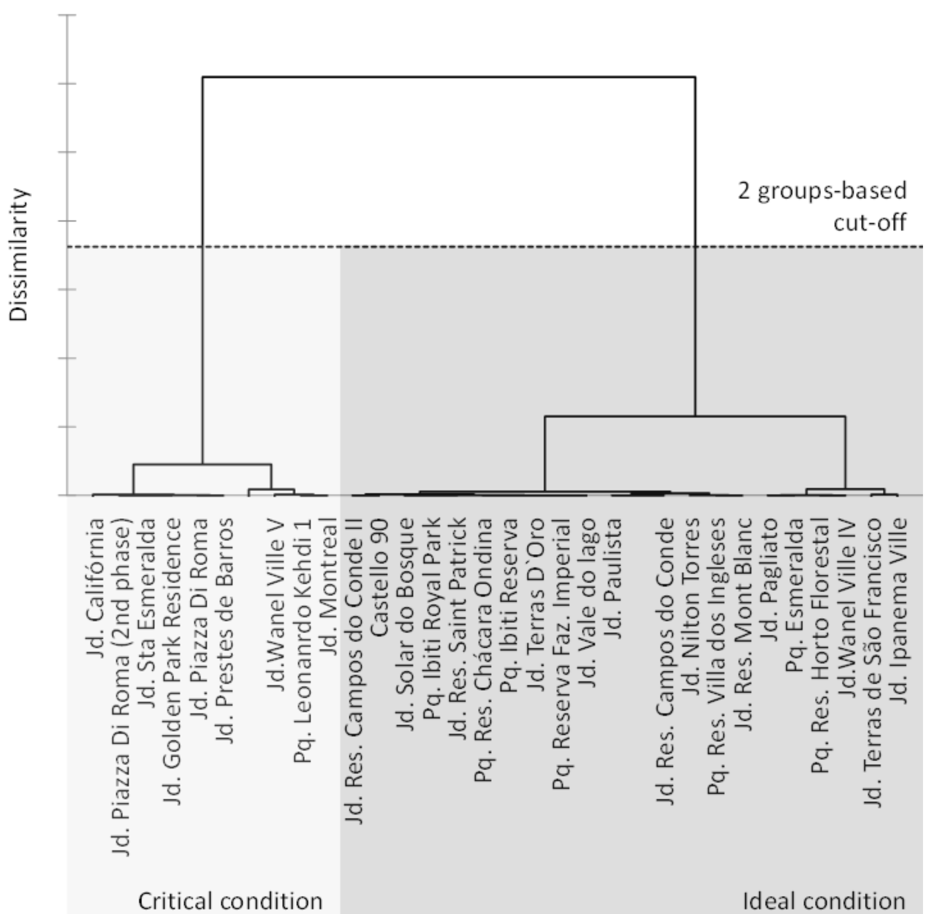

Figure 5. Urban neighborhoods clustering with regard to condition of green areas.

Table II. Green areas recommended as adequate by the fuzzy expert system (FES).

Urban neighborhoods	Input Variables			FES Output	Current CGA (%)
	FCQ	FSQ	DEN	CGA (%)	
Ideal scenario	1.00	10.00	50.0	20.00	20.00
Jd. Paulista	0.66	9.99	50.0	20.06	40.44
Jd. Res. Campos do Conde	0.96	9.99	50.0	20.06	48.43
Pq. Res. Horto Florestal	0.60	10.00	29.0	20.93	24.93
Jd. Terras de São Francisco	0.46	8.78	36.0	22.78	28.48
Jd. Nilton Torres	0.48	8.45	44.0	23.13	37.20
Jd. Pagliato	0.73	8.05	32.0	23.45	14.12
Jd. Piazza Di Roma	0.94	9.99	22.0	23.52	15.83
Pq. Res. Villa dos Ingleses	0.35	8.72	46.0	23.60	25.03
Jd. Solar do Bosque	0.84	7.66	50.0	23.66	16.67
Jd. Ipanema Ville	0.35	7.41	41.0	23.75	35.57
Pq. Ibiti Royal Park	0.52	7.41	50.0	23.76	32.42
Jd. Res. Mont Blanc	0.80	7.41	47.0	23.76	21.60
Jd. Res. Saint Patrick	0.59	7.41	50.0	23.76	27.03
Jd. Prestes de Barros	0.82	9.96	20.0	23.85	13.73
Jd.Wanel Ville IV	0.62	8.05	29.0	24.13	25.08
Pq. Esmeralda	0.28	8.45	31.0	24.76	19.33
Pq. Res. Chácara Ondina	0.56	6.62	50.0	26.00	38.26
Jd. Piazza Di Roma (2nd phase)	0.81	7.41	22.0	27.29	16.13
Pq. Ibiti Reserva	0.89	6.21	50.0	27.52	38.29
Jd. Terras D`Oro	0.28	5.84	50.0	28.56	19.62
Jd. Sta Esmeralda	0.44	8.05	21.0	28.94	18.61
Jd. Califórnia	0.77	7.41	17.0	29.03	19.54
Pq. Reserva Faz. Imperial	0.62	5.50	50.0	29.42	27.29
Jd. Vale do lago	0.76	5.33	50.0	29.84	11.24
Pq. Leonanrdo Kehdi 1	0.52	8.45	08.0	30.63	8.92
Jd. Golden Park Residence	0.38	7.41	20.0	31.21	12.06
Jd. Montreal	0.80	7.41	10.0	31.60	11.47
Jd. Res. Campos do Conde II	0.12	3.10	50.0	36.86	45.60
Castello 90	0.08	3.59	50.0	37.64	31.82
Jd.Wanel Ville V	0.52	3.59	10.00	43.90	11.59
Critical scenario	0.00	1.00	0.00	50.00	0.00

FCQ - Forest cover-based quantity; FSQ - Forest stage-based quality; DEN - Density; CGA – Condition of Green Area.
Source: developed by the authors.

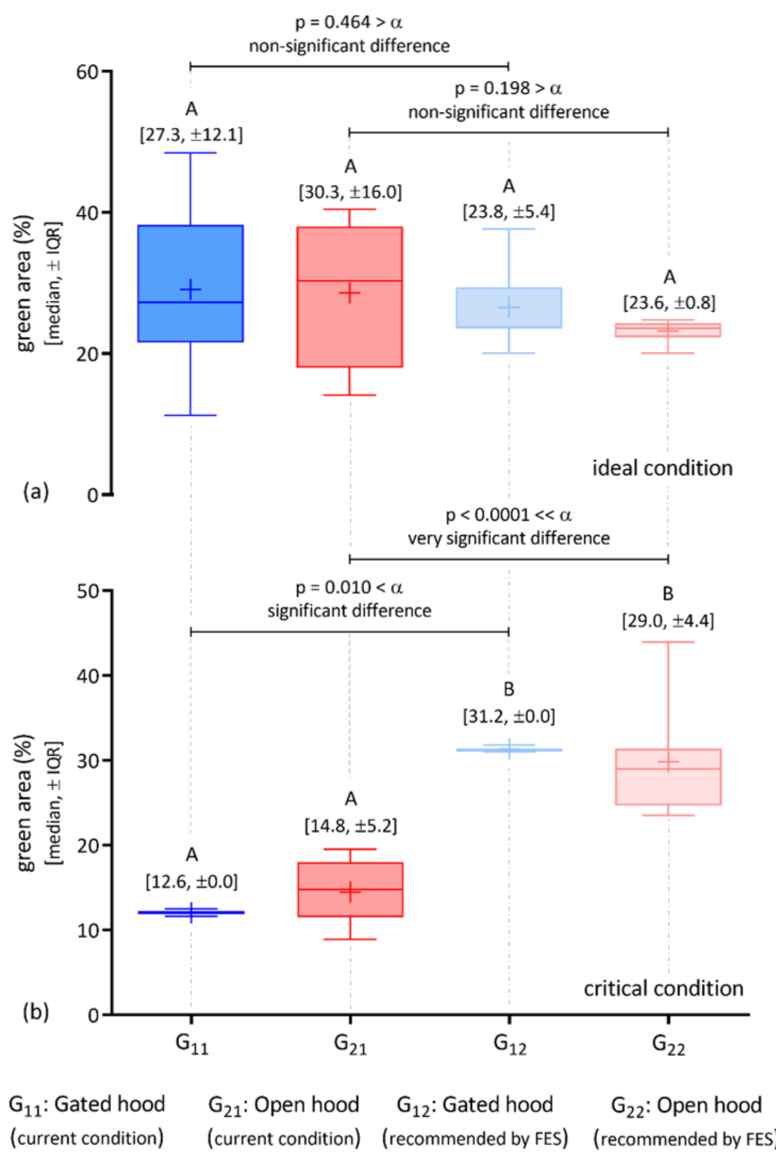

Figure 6. **Comparative analysis between condition of green areas, (a) ideal and (b) critical, and Fuzzy Expert System (FES) recommendation. Groups (G_{ij}) with same letter do not differ at 5% probability.**

DISCUSSION

The findings indicate the FES produced outputs consistent with the expected, as discussed below. The case studies included 16 gated communities and 14 open neighborhoods. Gated communities comprised 1000 ha, of which an average of 28.04% was allocated to green areas, equivalent to 107.6 m^2/inhab. Conversely, open neighborhoods comprised 630.8 ha, with a natural site coverage of 20.54%, corresponding to 26.37 m^2/inhab.

Analysing Table II, findings showed that in 17 of the 30 analysed neighborhoods the current CGA were worse (in terms of density, quantity and quality) than FES recommendation, pointing out that there is a need to restore 56.7% of forest cover in these 17 neighborhoods. Most of these neighborhoods with green areas of lower quality than the FES recommendation (Jd. Sta Esmeralda, Jd. Califórnia, Pq. Leonanrdo Kehdi 1, Jd. Montreal, and Jd.Wanel Ville V) are urban open neighborhoods, which correspond to low income neighborhoods. On the other hand, gated communities accounted for 70% of neighborhoods where the percentage of green areas was better than the one recommended by the FES.

Thus, gated communities present green areas with better conservation condition than open neighborhoods, as observed by Byrne & Wolch (2009) in Europe. According to these authors, well conserved green areas are more frequent in wealthy regions. There are inequalities in the distribution of green areas and recreational spaces in the urban environment (Anguelovski 2015) and marginalized regions, especially poor neighborhoods, have less access to leisure spaces, recreation, and parks (Rupprecht & Byrne 2014).

From the outcomes in Figure 6, as the alternative hypothesis H_A was accepted, the FES should be considered a promising alternative to deal with uncertainties in the analysis of green areas in urban neighborhoods. The fuzzy system was consistent in recommending higher percentages of green areas to neighborhoods with lower forest cover (FCQ). For example, Jd. Paulista, with high quantity, quality and density of green areas, had a FES-based green area recommendation that was lower (20.06%) than its current condition (40.44%). This additional area is explained by a Brazilian legal requirement for permanent preservation areas to be associated with water bodies (Forest Code, Law 12651: Brasil 2012). On the other hand, Jd. Wanel Ville V neighborhood had green area of low quality and density, which explained its 11.59% current condition and the recommendation to increase tree cover to 43.9%. Current condition of green areas in both gated communities and open neighborhoods were significantly lower than fuzzy-based recommendation in the cases in critical condition (p-value = 0.358; Figure 6); moreover, for the cases in ideal condition, the current green areas and the on recommended by FES did not differ (p-value < 0.05).

From the integrated analysis of parameters of quantity, quality and density of the existing vegetation, the proposed model allows classifying the condition of an urban green area at different levels of suitability for local characteristics. Based on this classification, the model can support public and private managers in proposing and analysing the feasibility of projects that impact urban green areas. For example, based on a case-by-case assessment using the proposed model, the authorization for new constructions can be conditioned to measures of adequacy of the green area at the project site.

Take measures to guarantee adequate treatment of green areas is a fundamental issue in planning healthy cities. As a management tool, the proposed model can support decision-making in the urban planning process. The municipal public administration can use the results from the model to justify the adoption of local quantitative and qualitative parameters in determining urban guidelines related to the minimum percentage of green areas destined to leisure, recreation and preservation of natural attributes. Thereby, we believe that the proposed methodology can contribute as an applied management tool for assessing and improving environmental quality in urban neighborhoods.

According to the obtained results, it is worth highlighting some novelty and usefulness of the present study. Firstly, the current decisions about the percentage of green area in urban settlements do not consider indicators like the succession stage, the forest cover, and the human population size in the urban neighborhood. In this context, the introduced model, assessed and discussed in the light of presented study cases, comprises an alternative approach that yields systematic decision-making based on a multi-criteria analysis over the indicators mentioned above. The second novelty lies in the fuzzy artificial intelligence concepts employed to model the decision-making system applicable to green areas management, capable of case-by-case analysis rather than standardized and/or arbitrary decisions.

The proposed fuzzy artificial intelligence-based system offers a convenient mathematical treatment concerning the information/indexes that embraces the discussed decision-making process. Since such indicators comprise continuous variables, it naturally imposes difficulties on the choice of hard thresholds towards the transitions of classes (i.e., bad, regular, good, and very good, for instance). Consequently, using an Artificial Intelligence approach based on soft transitions rises as a prominent approach, as verified in the presented study cases. For further advances in future studies, the proposed model can be compared with other soft computing approaches, aiming its continuous improvement as a tool for managing urban green areas.

CONCLUSIONS

Disorderly urban expansion has impacted the environmental quality of cities, requiring tools capable of supporting managers in the correct conservation of green areas. On the other hand, the uncertainties involved in the case-by-case analysis of green areas make it difficult to define the ideal conditions for proper conservation. There is a trend in the real estate market to expand urban occupations by maximizing the percentages of commercial areas, associated with entrepreneurs' desire to decrease the percentages of green areas under the allegation of reducing real estate costs. However, the indiscriminate reduction of green areas can compromise the quality of life of its future residents. They will not have the option of practicing leisure, recreation and offering environmental services provided by such areas. This study introduced a fuzzy expert system (FES) as tool for analysing the condition of green areas in urban neighborhoods. The findings indicate the FES produced outputs consistent with the expected. Thereby, as the main contributions of this study, they can be highlighted: (i) fuzzy modelling of indicator variables of green area condition based on expert knowledge; (ii) a novel fuzzy-based tool capable of dealing with uncertainties; and (iii) a promising approach for a case-by-case analysis applied to green area management in urban neighborhoods.

REFERENCES

ADLER FR & TANNER JC. 2015. Ecossistemas Urbanos: Princípios Ecológicos para o ambiente construído. São Paulo, Oficina de Textos, 384 p.

ANDERSSON E, BARTHEL S, BORGSTRÖM S, COLDING J, ELMQVIST T, FOLKE C & GREN A. 2014. Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. Ambio 43: 445-453. https://doi.org/10.1007/s13280-014-0506-y.

ANGUELOVSKI I. 2015. From Toxic Sites to Parks as (Green) LULUs? New Challenges of Inequity, Privilege, Gentrification, and Exclusion for Urban Environmental Justice. J Plan Lit 31(1): 23-36. https://doi.org/10.1177/0885412215610491.

ARONSON MFJ, LEPCZYK CA, EVANS KL, GODDARD MA, LERMAN SB, MACIVOR JS, NILON CH & VARGO T. 2017. Biodiversity in the city: Key challenges for urban green space management. Front Ecol Evol 15: 189-196. https://doi.org/10.1002/taxa.1480.

ATTWELL K. 2000. Urban land resources and urban planting — case studies from Denmark. Landsc Urban Plan 52: 145-163. https://doi.org/10.1016/S0169-2046(00)00129-8.

BARROS LC, BASSANEZI RC & LODWICK WA. 2017. A first course in fuzzy logic, fuzzy dynamical systems, and biomathematics. Berlin Heidelberg, Springer-Verlag, 304 p.

BERLAND A, SHIFLETT SA, SHUSTER WD, GARMESTANI AS, GODDARD HC, HERRMANN DL & HOPTON ME. 2017. The role of trees in urban stormwater management. Landsc Urban Plan 162: 167-177. https://doi.org/10.1016/j.landurbplan.2017.02.017.

BITTERLICH W. 1948. Die winkelzahlprobe. algemeine forst und holzwirts chaftliche zeitung. Wein 59: 4-5.

BRASIL. Lei no 12.651 of 2012. http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/L12651compilado.htm Accessed 15th August 2021.

BRESSANE A, BAGATINI JA, BIAGOLINI CH, ROVEDA JAF, ROVEDA SRMM, LONGO RW & FENGLER FH. 2018b. Neuro-fuzzy modeling: a promising alternative for risk analysis in urban afforestation management. Arvore 42: 1-10. https://doi.org/10.1590/1806-90882018000100006.

BRESSANE A, BIAGOLINI CH, MOCHIZUKI PS, ROVEDA JAF & LOURENÇO RW. 2017a. Fuzzy-based methodological proposal for participatory diagnosis in the linear parks management. Ecol Indic 80: 153-162. https://doi.org/10.1016/j.ecolind.2017.05.023.

BRESSANE A, FENGLER FH, ROVEDA SRMM, ROVEDA JAF & MARTINS ACG. 2018a. Arboreal identification supported by fuzzy modeling for trunk texture recognition. Trends Appl Computat Mathemat 19: 111-126. https://doi.org/10.5540/tema.2018.019.01.0111.

BRESSANE A, MOCHIZUKI PS, CARAM RM & ROVEDA JAF. 2016. A system for evaluating the impact of noise pollution on the population's health. Cad Saude Publica 32: e00021215. https://doi.org/10.1590/0102-311X00021215.

BRESSANE A, MOTA MT, FENGLER FH, ROVEDA SRMM, ROVEDA JAF, MEDEIROS GA & RIBEIRO AI. 2019. Alternative scenario simulation for urban sprawl based on population dynamics: a methodological proposal. J Environ Sci Technol 8: 265-281. https://doi.org/10.21664/2238-8869.2019v8i1.p265-281.

BRESSANE A, REIS FAGV, GIORDANO LC, ROVEDA JAF, ROVEDA SRMM, MARTINS ACG & MOCHIZUKI PS. 2017b. Construction of an impact global index for comparative environmental analysis applied to the settlement of irregular activities. Eng Sanit e Ambient 22: 111-122. https://doi.org/10.1590/S1413-41522016140136.

BRESSANE A, SILVA PM, FIORE FA, CARRA TA, EWBANK H, DE-CARLI BP & MOTA MT. 2020. Fuzzy-based computational intelligence to support screening decision in environmental impact assessment: A complementary tool for a case-by-case project appraisal. Environ Impact Assess Rev 85: 106446. https://doi.org/10.1016/j.eiar.2020.106446.

BROWN R, VANOS JK, KENNY NA & LENZHOLZER S. 2015. Designing urban parks that ameliorate the effects of climate change. Landsc Urban Plan 138: 118-131. https://doi.org/10.1016/j.landurbplan.2015.02.006.

BYRNE J & WOLCH J. 2009. Nature, race, and parks: past research and future directions for geographic research. Prog Hum Geogr 33: 743-765. https://doi.org/10.1177/0309132509103156.

COHEN-CLINE H, TURKHEIMER E & DUNCAN GE. 2015. Access to green space, physical activity and mental health: a twin study. J Epidemiol Community Health 69: 523-529. https://doi.org/10.1136/jech-2014-204667.

DERKZEN ML, VAN TEEFFELEN AJA & VERBURG PH. 2017. Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences? Landsc Urban Plan 157: 106-130. https://doi.org/10.1016/j.landurbplan.2016.05.027.

DESA UNITED NATIONS. 2015. World urbanization prospects: The 2014 revision. New York, United Nations Department of Economics and Social Affairs, 517 p.

EWBANK H, ROVEDA JAF, ROVEDA SRMM, RIBEIRO AI, BRESSANE A, HADI-VENCHEH A & WANKE P. 2020. Sustainable resource management in a supply chain: a methodological proposal combining zero-inflated fuzzy time series and clustering techniques. J Enterp Inf Manag 33: 1059-1076. https://doi.org/10.1108/JEIM-09-2019-0289.

FANELLI R, PRESTEGAARD K & PALMER M. 2017. Evaluation of infiltration-based stormwater management to restore hydrological processes in urban headwater streams. Hydrol Process 31: 3306-3319. https://doi.org/10.1002/hyp.11266.

FAO - FOOD AND AGRICULTURE ORGANIZATION. 2016. Guidelines on urban and peri-urban forestry. Rome, Food and Agriculture Organization of United Nations, 178 p.

FENGLER FH, BRESSANE A, CARVALHO MM, LONGO RM, MEDEIROS GA, MELO WJ, JAKOVAC CC & RIBEIRO AI. 2017. Forest restoration assessment in Brazilian Amazonia: A new clustering-based methodology considering the reference ecosystem. Ecol Eng 108: 93-99. https://doi.org/10.1016/j.ecoleng.2017.08.008.

FRANÇA LVG, BRESSANE A, CARRA TA, ROVEDA SRMM & ROVEDA JAF. 2020. Fuzzy systems for aid in decision-making in environmental licensing of road enterprises. In: Costa LRF (Ed), Estudos teórico-metodológicos nas ciências exatas, tecnológicas e da terra. Atena, p. 72-81.

GAVRILIDIS AA, NITA MR, ONOSE DA, BADIU DL & NĂSTASE II. 2017. Methodological framework for urban sprawl control through sustainable planning of urban green infrastructure. Ecol Indic 96: 67-78. https://doi.org/10.1016/j.ecolind.2017.10.054.

GRAÇA M, ALVES P, GONÇALVES J, NOWAK DJ, HOEHN R, FARINHA-MARQUES P & CUNHA M. 2018. Assessing how green space types affect ecosystem services delivery in Porto, Portugal. Landsc Urban Plan 170: 195-208. https://doi.org/10.1016/j.landurbplan.2017.10.007.

GUNAWARDENA KR, WELLS MJ & KERSHAW T. 2017. Utilising green and bluespace to mitigate urban heat island intensity. Sci Total Environ 584: 1040-1055. https://doi.org/10.1016/j.scitotenv.2017.01.158.

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2015. Cidades. http://cidades.ibge.gov.br/xtras/perfil.php?codmun=355220. Accessed 15th August 2021.

JAYASOORIYA VM, ANNE NG, MUTHUKUMARAN S & PERERA BJC. 2017. Green infrastructure practices for improvement of urban air quality. Urban For Urban Green 21: 34-47. https://doi.org/10.1016/j.ufug.2016.11.007.

KABISCH N & HAASE D. 2014. Green justice or just green? Provision of urban green spaces in Berlin, Germany. Landsc Urban Plan 122: 129-139. https://doi.org/10.1016/j.landurbplan.2013.11.016.

KLEMM W, HEUSINKVELD BG, LENZHOLZER S, JACOBS MH & VAN HOVE B. 2015. Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Build Environ 83: 120-128. https://doi.org/10.1016/j.buildenv.2014.05.013.

MAMDANI EH & ASSILIAN S. 1975. An experiment in linguistic synthesis with a fuzzy logic controller. Int J Hum Comput Stud 7: 1-13.

MARYANTI MR, KHADIJAH H, UZAIR AM & GHAZALI MAR. 2016. The urban green space provision using the standards approach: issues and challenges of its implementation in Malaysia. Trans Ecol Environ 210: 369-379. https://doi.org/10.2495/SDP160311.

MEEROW S & NEWELL JP. 2017. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. Landsc Urban Plan 159: 62-75. https://doi.org/10.1016/j.landurbplan.2016.10.005.

MELL I, ALLIN S, REIMER M & WILKER J. 2017. Strategic green infrastructure planning in Germany and the UK: a transnational evaluation of the evolution of urban greening policy and practice. Int Plan Studies 1: 1-17. https://doi.org/10.1080/13563475.2017.1291334.

MIDDEL A, CHHETRI N & QUAY R. 2015. Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods. Urban For Urban Green 14: 178-186. https://doi.org/10.1016/j.ufug.2014.09.010.

MOTA MT, BRESSANE A, ROVEDA JAF & ROVEDA SRMM. 2019. Successional stages classification in Atlantic forests: a methodological proposal based on fuzzy modeling. Arvore 29: 31-42. https://doi.org/10.5902/1980509830688.

MONTGOMERY DC & RUNGER CR. 2011. Applied statistics and probability for engineers. Arizona: J Wiley & Sons, 821 p.

NUCCI JC & PRESSOTO A. 2009. Planejamento dos Espaços Livres Localizados nas Zonas Urbanas. In: Santos DG & Nucci JC. Paisagens Geográficas: Um tributo a Felisberto Cavalheiro. FECILCAM, p. 65-77.

RIBEIRO AI, BRESSANE A, FENGLER FH, LONGO RM, SILVA AL, ROVEDA JAF, RIBEIRO MV & MEDEIROS GA. 2018. Environmental impact assessment using a weighted global index: a methodological proposal. Trans. Ecol. Environment 215: 13-24. https://doi.org/10.2495/EID180021.

ROCHA AN & MUSSURY MM. 2020. Green Areas in an Urban Environment Minimize the Mutagenic Effects of Polluting Gases. Water Air Soil Pollut 213: 1-7. https://doi.org/10.1007/s11270-020-04929-9.

ROVEDA JAF, BURGHI ACA, ROVEDA SRMM, BRESSANE A & FRANCA LGA. 2018. New methodology for application of Impact's identification using fuzzy relation. In: Zadeh L, Yager R, Shahbazova S, Reformat M & Kreinovich V (Eds), Studies in Fuzziness and Soft Computing. 361. Springer International Publishing, p. 627-637.

RUPPRECHT CDD & BYRNE JA. 2014. Informal urban greenspace: a typology a trilingual systemic review of its role for urban residents and trends in the literature. Urban For Urban Green 14: 597-611. https://doi.org/10.1016/j.ufug.2014.09.002.

SANUSI R, JOHNSTONE D, MAY P & LIVESLEY SJ. 2017. Microclimate benefits that different street tree species provide to sidewalk pedestrians relate to differences in Plant Area Index. Landsc Urban Plan 157: 502-511. https://doi.org/10.1016/j.landurbplan.2016.08.010.

SÃO PAULO. 2017. Resolution SMA Nº 72, de 18 de julho de 2017. https://www.infraestruturameioambiente.sp.gov.br/legislacao/2017/07/resolucao-sma-72-2017/. Accessed 15th August 2021.

SPERANDELLI DI, DUPAS FA & DIAS PNA. 2013. Dynamics of urban sprawl, vacant land, and green spaces on the metropolitan fringe of São Paulo, Brazil. J Urban Plan Dev 139: 274-279. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000154.

WARD JH. 1963. Hierarchical Grouping to Optimize an Objective Function. J Am Stat Assoc 58: 236-244.

WHO - WORLD HEALTH ORGANIZATION. 2012. Health Indicators of Sustainable Cities in the Context of the Rio+20 UN

Conference on Sustainable Development. Geneva, WHO, 6 p.

ZHOU X & WANG YC. 2011. Spatial–temporal dynamics of urban green space in response to rapid urbanization and greening policies. Landsc Urban Plan 100: 268-277. https://doi.org/10.1016/j.landurbplan.2010.12.013.

How to cite
MOTA MT, GALVÃO ALS, BRESSANE A, NEGRI RG, ROVEDA JAF & ROVEDA SRMM. 2022. A fuzzy-based methodological proposal for analysing green areas in urban neighborhoods. An Acad Bras Cienc 94: e20210015. DOI 10.1590/0001-3765202220210015.

Mansucript received on January 11, 2021; accepted for publication on January 21, 2022

MAURÍCIO T. DA MOTA[1]
https://orcid.org/0000-0003-4844-1457

AMANDA LOUISI DOS S. GALVÃO[2]
https://orcid.org/0000-0001-5768-6929

ADRIANO BRESSANE[1]
https://orcid.org/0000-0002-4899-3983

ROGÉRIO G. NEGRI[3]
https://orcid.org/000-0002-4808-2362

JOSÉ ARNALDO F. ROVEDA[4]
https://orcid.org/0000-0002-0158-1586

SANDRA REGINA M. M. ROVEDA[4]
https://orcid.org/0000-0003-3390-8747

[1]Programa de Pós-Graduação em Ciências Ambientais, Instituto de Ciência e Tecnologia, Avenida Três de Março, 511, Alto da Boa Vista, 18087-180 Sorocaba, SP, Brazil

[2]Engenharia Ambiental, Instituto de Ciência e Tecnologia, Estrada Dr. Altino Bondensan, 500, Eugênio de Melo, 12247-016 São José dos Campos, SP, Brazil

[3]Programa de Pós-Graduação em Computação Aplicada, Instituto Nacional de Pesquisas Espaciais, Avenida dos Astronautas, 1758, Jardim da Granja, 12227-010 São José dos Campos, SP, Brazil

[4]Programa de Pós-Graduação em Matemática, Universidade de Brasília, Asa Norte, 70910-900 Brasília, DF, Brazil

Correspondence to: **Adriano Bressane**
E-mail: adriano.bressane@unesp.br

Author contributions

Conception: Adriano Bressane and Maurício T. da Mota; Data curation: Adriano Bressane, Amanda Louisi dos S. Galvão, José Arnaldo F. Roveda, and Sandra Regina M. M. Roveda; Formal analysis: Rogério G. Negri, Amanda Louisi dos S. Galvão, Maurício T. da Mota, and Sandra Regina M. M. Roveda; Methodology: Adriano Bressane, Rogerio G. Negri, and Amanda Louisi dos S. Galvão; Validation: Adriano Bressane and Rogério G. Negri; Writing – original draft: Adriano Bressane, Maurício T. da Mota, and Sandra Regina M. M. Roveda – Revision and editing: Adriano Bressane, José Arnaldo F. Roveda, Amanda Louisi dos S. Galvão, and Rogério G. Negri.