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URBAN GRADIENT

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Abstract

As in many other countries, official measures of urbanization in Brazil have been unable to properly distinguish spatial patterns of rural and urban organization. The literature discusses various classification systems and recognizes the existence of a "rural-urban continuum", as well as theoretical frameworks and alternative categorizations that aim to look beyond the urban-rural dichotomy. However, there are no practical solutions to properly formalize or operationalize them, especially at the micro-level such as census tracts. We propose a methodology that assumes a measurable rural-urban continuum. The "Urban Gradient Index" uses simple and comprehensive variables to quantify the degree to which a certain area is urban based on demographic and spatial features. We build it at the level of census tracts for both Brazil and the Belo Horizonte Metropolitan Region to verify consistency at distinct aggregation levels. Results indicate that the index provides a much more nuanced picture of settlement patterns, unveiling a spatial gradient between rural and urban in distinct spatial extents. It offers an advantage over the traditional measure "degree of urbanization" by revealing "hidden ruralities" in predominantly urban areas that require specific territorial planning and public policy interventions.

Keywords: Urban Gradient, Rural-Urban Continuum, Territorial Planning, Belo Horizonte Metropolitan Region, Brazil.

Resumo / Resumen

GRADIENTE URBANO

Como em muitos outros países, as medidas oficiais de urbanização no Brasil têm sido incapazes de distinguir adequadamente os padrões espaciais de organização rural e urbana. A literatura discute diversos sistemas de classificação e reconhece a existência de um "continuum rural-urbano", assim como marcos teóricos e categorizações alternativas com o objetivo de superar a dicotomia urbano-rural. Entretanto, não existem soluções práticas que adequadamente as formalize ou operacionalize, especialmente no nível micro como os setores censitários. Propomos uma metodologia que assume um continuum rural-urbano mensurável. O Índice de Gradiente Urbano usa variáveis simples e abrangentes para quantificar o grau em que uma determinada área é urbana com base em características demográficas e espaciais. Nós o construímos no nível dos setores censitários para o Brasil e para a Região Metropolitana de Belo Horizonte para verificar a consistência em níveis de agregação distintos. Os resultados indicam que o índice fornece uma imagem muito mais matizada dos padrões de assentamento, revelando um gradiente espacial entre o rural e o urbano em distintas extensões espaciais. Ele oferece uma vantagem sobre a tradicional medida "grau de urbanização" ao revelar "ruralidades ocultas" em áreas predominantemente urbanas que requerem planejamento territorial específico e intervenções de políticas públicas.

Palavras-chave: Gradiente Urbano, Continuum Rural-Urbano, Planejamento Territorial, Região Metropolitana de Belo Horizonte, Brasil.

GRADIENTE URBANO

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Palabras-clave: Gradiente Urbano, Continuum Rural-Urbano, Planificación Territorial, Región Metropolitana De Belo Horizonte, Brasil.

INTRODUCTION

Several studies discuss the spatial diffusion of different dimensions of urbanization processes and the increasing blurring of the urban-rural dualistic notion. Discussions about the existence of a "rural-urban continuum" have been pervasive in sociological literature since the middle of the last century, (DUNCAN, 1957; DEWEY, 1960; RAJAGOPALAN, 1961; PAHL, 1966). However, beyond sociocultural aspects (as urban and rural "ways of life"), this idea has been increasingly incorporated to other fields as the diffusion of more modern forms of (re)production of space across areas traditionally identified as rural is weakening the sharp contrasts that conventionally distinguished them from urban areas. From the urban end of the continuum, contemporary patterns of urban growth differ from historical patterns in terms of scale, rate, location, form, and function (SETO et al., 2010, p.167) producing new urban forms beyond cities and towns that challenge traditional classifications.

The fact that urban and rural areas cannot be so easily distinguished does not mean that these categories have become obsolete. There are functional and morphological characteristics of spaces still deeply entrenched in these notions, as the higher demographic density and the presence of certain services and equipment in urban areas (IBGE, 2017). The wide recognition of the insufficiency of a dichotomous classification of human settlements led to the creation of a plethora of new concepts in recent decades, as "extensive urbanization" (MONTE-MÓR, 1994, 2007), "new rural" (SILVA, 1997), "ruralopolises" (QADEER, 2000), "urban-regional arrangements" (MOURA, 2009), "protourbanization" (BARBIERI et al., 2009), "widespread urban" (MATTOS, 2010), "rurban" (LERNER; EAKIN, 2011), "planetary urbanization" (BRENNER, 2013) among others.

The problem becomes even more complex when analyzed in the light of recent developments in critical urban theory, anchored in the thesis of the complete urbanization of society. This analytical perspective has its origins in the work of Henri Lefebvre (LEFEBVRE, 1999). This author was the first to postulate the thesis - still seen as a virtual possibility at the time of his writings - of the emergence of a planetary urban society, a development of the industrial society prevailing in the first centuries of the capitalist era. In urban society, the whole planet would be encompassed by an uninterrupted urban fabric, which would be the expression of the dominance of the city - the original locus of the urban way of life - over the countryside. Within this perspective, it would be necessary to stop seeing space from contrasts and, thus, it would no longer be possible to speak of an "outside" or an "outside" of the city or the urban world (BRENNER; SMITH, 2015; BRENNER, 2013) requiring a new lexicon to capture the spatial differentiation of the contemporary world.

Besides new terminology, several typologies have already been proposed to include intermediate categories between prototypical rural and urban areas in different countries around the world. See, for example, the "Rural-Urban Continuum Codes" (RUCC) proposed by the Economic Research Service of the U.S. Department of Agriculture, first released in 1975 and updated in a decennial basis (USDA, 2013); the OECD typology to account for differences among rural and urban regions (OECD, 2009) and the extend version proposed by Brezzi et al. (2011); the methodology proposed by Firoz et al. (2014) to define "the typology of rural urban continuum settlements" in Kerala, India. More recently, the Brazilian National Institute of Geography and Statistics published a report proposing five intermediate categories to better characterize urban and rural spaces (IBGE, 2017), in recognition of the insufficiency of the current system of classification used in Brazil. Finally, the "World Cities Report 2022", published by the United Nations Human Settlements Programme (UN-HABITAT, 2022), defines a new harmonized "Degree of Urbanization" to facilitate international comparisons of urbanization based on three classes of human settlements (cities, towns and semi-dense areas, and rural areas). According to the report, the "Degree of Urbanization captures the urban-rural continuum as recommended by research" (p.XVII) – in our view, a questionable claim.

Despite all efforts to deal with the complexities in classifying areas, no attempts were made to properly formalize the "rural-urban continuum" concept, i.e., no continuous indicator to quantify the degree to which a certain area is urban (and, by extension, rural) was proposed in the literature. Given the widespread recognition of the inexistence of a clear divide between rural and urban areas and the interpenetration of rural and urban elements in space, it makes sense to use a continuous indicator instead of a set of discrete categories. Such a measure could prevent arbitrariness and artificial distinctions between similar areas that fall between classes, i.e., areas that do not perfectly fit any

category. Thus, the main objective of this study is to propose an index that takes into account undisputable and discerning characteristics such as population and infrastructure features to indicate a gradient of urbanization within a spectrum. It is a standardized methodology that facilitates classification of urban to rural features at multiple spatial extents, such as census tracts and neighborhoods, as well as larger aggregated regions, such as municipalities and states.

In Brazil, the term "urban" has been used as an imprecise and sometimes misleading concept, for defining distinctly different settlement patterns across the country. The political-administrative criteria used in Brazil to define urban and rural areas dates back to the 1930s (BRASIL, 1938), and is insufficient for current purposes, given profound structural or morphological changes in the Brazilian urbanization in recent decades. This is because it does not properly capture sociospatial heterogeneities and is subject to variations in its application by municipal administrations. Since the middle of the 20th century, urbanization in Brazil has been characterized by a rapid pace of urban population growth, mainly driven by high fertility rates (especially in rural areas) and rural–urban migrations. Despite efforts to occupy the interior areas of Brazil, an intense process of demographic and economic concentration has occurred, particularly in large urban areas in southeast and coastal Brazil.

Studies that challenge the pertinence of the differentiation between rural and urban and the adequacy of the rural-urban dichotomy have already been conducted, even having the Metropolitan Region of Belo Horizonte as the focus of analysis (COSTA et al., 2013). According to this study, the notion of what is rural and urban in the official statistics does not translate the living space and sociability of the population, indicating that a population in a rural domiciliary situation may be, in practice, as urban as those who live within the urban perimeter.

While urbanization in the 1970's was mostly driven by industrialization, in recent decades it has been more closely linked to the development of urban systems, hierarchies and networks, as well as social phenomena linked to poverty, lack of adequate infrastructure and higher population density. Besides the continued concentration of population in middle and large-size (or metropolitan) cities, recent urban growth has also driven rapid growth of some long-settled small villages in traditional rural areas, such as in the Amazon and the Northeast. This process includes the formation of new pioneer urban areas and the incipient transformation of many rural communities, which are acquiring urban characteristics through population growth and acquisition of basic infrastructure (BARBIERI; OJIMA, 2021; BARBIERI et al. 2009). These new and highly complex spatial dynamics are producing extremely heterogeneous urban spaces that challenge developing appropriate public policies. Thus, the aim of this paper is to propose an Urban Gradient Index to oppose the current classification based on the rural-urban dichotomy and contribute for a more nuanced classification, potentially useful for territorial planning and public policy interventions.

This paper is organized in six sections, including this introduction. The next section provides a brief overview of the challenges in the conceptual definition and measurement of urbanization. In the third section, we propose a method to measure the urban-rural gradient and apply it to a case study on the Belo Horizonte Metropolitan Region (RMBH), the third-largest in Brazil. In the subsequent three sections, we present and discuss the results, followed by concluding remarks.

MEASURING URBANIZATION: CONCEPTUAL AND METHODOLOGICAL CHALLENGES

Some authors have discussed the difficulties in establishing the meaning of the terms "rural" and "urban", especially in the context of developing countries (BROWDER; GODFREY, 1997; HUGO et al., 2003; BROWN; CROMARTIE, 2004; HALFACREE, 2004). A key lesson from these studies is that, rather than being universal, definitions should be context-specific and take into account the inherent characteristics of the places to which they apply.

To develop a methodology for quantifying the degree to which a certain area is urban, it is important, firstly, to outline the unambiguous characteristics that define an urban area as such. This section will focus on the operational aspects regarding urban-rural classifications and measurements that will reflect the manifestation of environmental, cultural, social and economic dimensions embedded in these concepts.

Regarding spatial structure, the formalization of the "urban" concept is mainly based on the following criteria (UNPD, 2019; UNSD, 2017; IBGE, 2017; IICA, 2013):

●Political-administrative delimitations, as in the case of Brazil and South Africa;

●Spatial morphology or configuration, which includes provisioning of equipment and services (transportation networks, sanitation, water supply, electricity, garbage collection, etc.), building density, street layout etc. This is the main criterion adopted in the territorial typology in England and Wales;

●Demographic density, i.e., the number of inhabitants per area, the main criterion adopted by OCDE and the European Union.

Besides the above mentioned criteria, two others are frequently used, although not directly related to spatial structure: the definition of a demographic threshold (or population size, the main criteria adopted by the USA and Argentina) and the main economic occupation, used as a complementary criterion in many different typologies.

Demographic density is the primary criterion recommended by the United Nations Statistics Division (UNSD, 2017, p.188) to classify an area as urban or rural, from the most densely occupied to the most sparsely settled areas. Likewise, the OECD classification is also mainly based on this criterion. It has been a highly influential classification and has been applied in several countries in different continents, being the main reference for other international organizations such as the European Union. However, settlement density is not a sufficient criterion because demographic density can vary significantly in rural and urban areas (IBGE, 2017). In fact, in a meta-analysis of 326 studies regarding the global urban land expansion made by Seto et al. (2011), they concluded that in the period 1970-2000 urban land expansion rates were higher than or equal to urban population growth rates. This suggests that urban growth is becoming more spread than compact and shows the limitations of using consistent built up-areas as a single indicator. As expressed in UNSD (2017), additional criteria may be necessary for a more distinctive urban-rural differentiation, such as "percentage of the population engaged in agriculture, the general availability of electricity or piped water in living quarters and the ease of access to medical care, schools, recreation facilities and transportation" (UNSD, 2017, p. 188).

In Brazil, the Decree-Law ("Decreto-lei", in Portuguese) number 311, dated March 2, 1938, constitutes the legal framework to distinguish and classify urban and rural areas within a municipality. It defines all areas not included in the urban perimeter by municipal law as "rural" (BRASIL, 1938). This definition is mainly driven by administrative and fiscal purposes and does not necessarily take into account the social and spatial characteristics of the territory, as patterns of spatial organization, population density or infrastructure. In addition, it is not able to follow changes in spatial configurations, such as the redistribution of the population and economic activities (IBGE, 2017). Furthermore, rural areas are defined by exclusion, a highly criticized procedure because it ignores the heterogeneity of rural areas, the ongoing economic and social processes in these spaces, and the different relations of complementarity and interdependence with urban areas (IICA, 2013).

A further complication in the Brazilian case is the huge qualitative differences in the meaning of "urban" and "rural" across the country. Brazil has been characterized by huge sociospatial and development inequalities among its five great regions (North, Northeast, Southeast, Center West and South). Each of these regions presents distinct characteristics regarding the nature of the urbanization process, such as patterns of settlement (e.g., riverine communities in the Amazon compared to peri-urban areas in the southeast) and infrastructure levels (for example, coverage of sanitation). Even within them, there are significant heterogeneities in socioeconomic and welfare levels.

The advantage of our Urban Gradient Index is not to propose an alternative classification system, but to offer one that captures a measurable rural-urban continuum. Such an index can be a useful tool for territorial planning and management and is consistent with data available at the smallest census collection unit in Brazil. It also focuses on the most essential feature that distinguishes urban and rural areas regarding spatial structure: population density. We suggest that it, in combination with factors representing urban infrastructure, may provide a more reliable picture of the urban–rural gradient in Brazil, with potential applications for other countries.

METHODS

SPATIAL UNITS AND CENSUS DATA

The basic spatial unit of analysis in this paper is the census tract, defined by the Brazilian National Institute of Geography and Statistics (IBGE) as the smallest spatial unit for which census data are available. It consists of contiguous areas, designed with appropriate dimensions for data collection, following political-administrative divisions and the urban-rural framework as defined by municipal administrations and other territorial structures of interest (IBGE, 2011). The information provided by census tract data has great potential for studies based on urban aspects, especially on urban morphology (SILVA et al., 2022). Although IBGE's definition has been based primarily on political-administrative criteria since the 1940's Demographic Census, it also considers population density and morphological aspects in the classification of census tracts, taking into account the volume of households and distance between buildings (IBGE, 2017).

IBGE's Territorial Base Operational Report (IBGE, 2014) classifies census tracts in eight categories within urban and rural groups. The urban group comprises three types of sectors located within the municipal legal urban perimeter: i) urban areas (s1), ii) non-urbanized areas of cities or towns (s2) (areas legally classified as urban but with no buildings or characteristics of rural occupation), iii) isolated urban areas (s3) (legal urban areas disjointed from the central town). The rural group comprises five types of sectors located outside the legal urban perimeter: iv) rural areas (s8) (characterized by rustic land use, large expanses of land with low housing density, including fields, forests, crops, pastures, environmental protected areas etc.), v) rural agglomeration of urban extension (s4) (occupations with urban characteristics located outside the municipal urban perimeter, in general, precarious housing or slums), vi) village (s5) (areas with 50 houses or more, and presence of at least 3 types of equipment or services, i.e. schools, health clinics, religious temples or stores), vii) habitational core (s6) (house set belonging to a single owner), and viii) locality (s7) (areas with 50 houses or more with low coverage of equipment or services). This is a fundamentally operational classification, subject to periodic updates, and it is of little use for the purposes of territorial planning and management. Thus, to avoid purely urban or rural classifications, it is empirically possible to order these eight categories in a hierarchy, from the most urban to the most rural areas through morphological and demographic criteria (s1 - s4 - s3 - s6 - s2 - s5 - s7 - s8).

Information collected through the "basic questionnaire" of the Brazilian demographic census (applied to all households) is the only one that allows spatial disaggregation at the level of census tracts, i.e., the use of data from the entire population in a relatively small area within municipal boundaries. The "sample questionnaire" applied to approximately 10% of the households, brings information that, despite being much more detailed, can only be used at the level of "weighting areas" ("areas de ponderação") - which consist of aggregates of census tracts – and only for the proportionally few municipalities that had a population over 190,000 inhabitants in the 2010 Census. The household information collected in the basic questionnaire includes, among other characteristics, the provision of services such as sanitation, water supply, electricity and garbage collection.

VARIABLES IN THE URBAN GRADIENT INDEX

Our definition of Urban Gradient Index included spatial and demographic features. We used spatial features as a proxy of urban infrastructure to reflect the higher standard of living commonly associated with urban areas. We initially tested the following variables concerning household census data (i.e., available at census tract extension): (1) "water supply", (2) "sewerage" (3) "garbage collection" and (4) "electricity". Giving more weight to the "demographic density" variable ensures that peripheral urban areas that lack basic urban structures and services are properly classified as urban. It is reasonable to assume that the lack of such structures and services makes these areas "less urban" than central areas with better infrastructure. Although the presence of these structures and services is indicative that an area is urban, it is important to highlight that the opposite is not true – it could indicate situations of precariousness (deprivation of basic services) or "rurality".

The variable (5) "population density" in each census tract represents the demographic component of the index. To avoid imbalance in the indicator caused by super-dense sectors, we use the 75th percentile value as a ceiling, as used in the built of multimetric indices nationwide in the USA (STODDARD et al., 2008). Thus, the maximum value of this indicator was 10,000 inhabitants/km2. Additionally, we used (6) "Residents per household" in each census tract as an alternative estimate of demographic density.

We then proceeded to variable screening and estimation (STODDARD et al., 2008, MACEDO et al., 2018). The first step was to select variables that could potentially discriminate between urban and rural census tracts at the national level. First, we analyzed which variables were the most distinct in the comparison between urban (s1) and rural census tracts (s8), according to IBGE's classification. We considered these as "reference conditions" to strictly urban and rural conditions, respectively. The criterion was the visual analysis of interquartile intervals congruence, using boxplots. The smaller the overlap between two interquartile intervals, the more discriminating we considered the variables (WILLIAMSOM et al., 1989). Second, the variables with a correlation above 70% were excluded (STODDARD et al., 2008, MACEDO et al., 2018); we retained the most homogeneous variables, that is, those with the lowest standard deviation (MACEDO et al., 2016) within the set of urban tracts (s1). After that, the values of the selected variables were normalized between 0 (lowest degree of urban) and 1 (highest degree of urban). Finally, the variables were weighted, creating an index 50% composed of urban infrastructure variables and 50% composed by population density.

CONSISTENCY ANALYSIS: CORRELATION OF THE URBAN GRADIENT INDEX AND OTHER MEASURES AT DIFFERENT LEVELS OF SPATIAL AGGREGATION

To verify the robustness of our index, we performed correlation analyses to investigate its relationship with the traditional "degree of urbanization" and other variables at the municipal level. We used the expanded results of the sample questionnaire of the 2010 Census data. Because it is a more extensive questionnaire, we developed several additional indicators related to the urban or rural conditions of the households: (i) "Human Development Index - HDI", (ii) "commuting", (iii) "total fertility rate", (iv) "bathrooms per inhabitant", (v) "percentage of the employed population in the industry sector", (vi) "percentage of the population employed in the service sector" and (vii) "percentage of the agricultural population".

Considering the Brazilian context, it is reasonable to assume that indicators "i" to "vi" are positively correlated with the degree of urbanization and the indicator "vii" is negatively correlated. Additionally, we estimated the (viii) "degree of urbanization of the municipality", i.e., the percentage of residents living in areas legally classified as urban, and the alternative (ix) "degree of urbanization" proposed by IBGE in a recently published report (IBGE, 2017).

DATA ANALYSIS

We analyzed the Urban Gradient Index through histograms and used box plots to compare it with the census tracts classification by IBGE. We also divided the results at the national level and at the level of the RMBH to check your adherence on a national and municipal extent. According to the 2010 Demographic Census (IBGE, 2010), the urban population of the RMBH corresponded to 97.6% of its population, with more than half of the 34 municipalities currently comprising the region having less than 10% of the population living in rural areas.

As with any other metropolitan region, it could be assumed to be an essentially urban area. However, this seems to be an oversimplification of a much more complex reality in face of the marked sociospatial heterogeneities that characterizes the RMBH (COSTA et al., 2013; CARVALHO et al., 2016; UMBELINO; DAVIS, 2015). To evaluate the consistency of the Urban Gradient Index and its comparability with more traditional metrics, a Pearson's correlation analysis was conducted at these two levels – Brazil and RMBH. Despite being conditioned by the available data, the basic principles of the Urban Gradient Index can be applied in different contexts and spatial extents.

RESULTS

SCREENING AND DEFINING THE VARIABLES THAT COMPOSE THE URBAN GRADIENT INDEX

After testing the initial variables (Section 3.2), we discarded "electricity" and "residents per household" because they did not properly discriminate between urban and rural sectors (s1 vs s8), as shown in Figure 1. Furthermore, the correlation analysis showed that the variables "water supply" and "garbage collection" were correlated above 70%. We kept the latter since it has a smaller standard deviation in urban areas (0.1 vs 0.2) (Table 1).

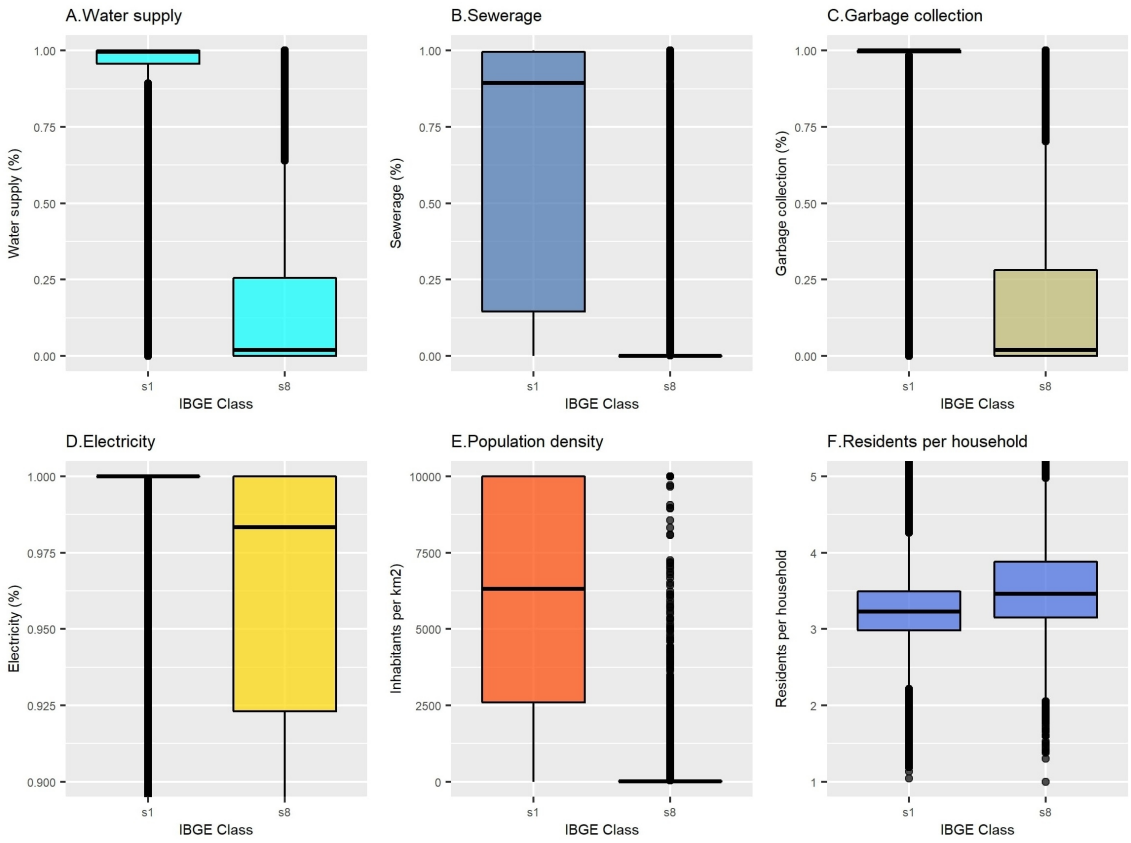

Figure 1 - Comparisons of selected variables regarding urban and rural census tracts (s1 vs. s8).

	Sewerage	Garbage collection	Population Density	Sta.Dev - urban tracts (s1).
Water supply	0.6	**0.74**	0.56	0.2
Sewerage		0.57	0.62	
Garbage collection			0.57	0.1

Bold: correlation > 70%

Table 1 - Correlation between potential Urban Gradient Index variables and standard deviation values in urban tracts*

DEFINITION AND DISTRIBUTION OF THE URBAN GRADIENT INDEX

After screening, we built the Urban Gradient Index, half weighted by urban infrastructure and half weighted by population density:

0.25*Sewerage + 0.25*Garbage collection + 0.50*population density (1)

The distribution of the Urban Gradient Index estimates (Figure 2) showed that, at the national level, the majority of census tracts received values near one (urban maximum) or zero (urban minimum); however, a considerable area of tracts were between those extremes. In the RMBH, presumably more urban than the country as a whole, the gradient is more consistent, with the majority of census tracts presenting values near one.

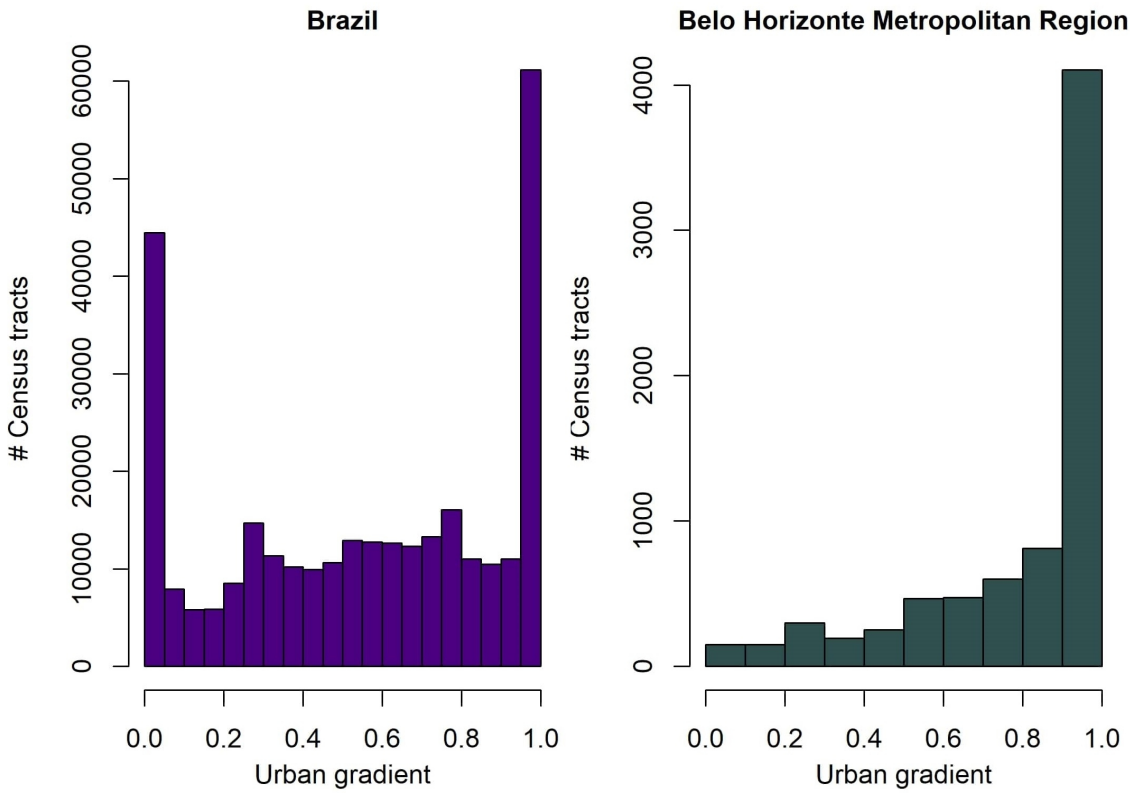

Figure 2 - Urban Gradient Index frequency at the level of Brazil and the RMBH

CONSISTENCY OF THE DISTRIBUTION OF THE URBAN GRADIENT INDEX

To verify the consistency with IBGE's classification of census tracts, the values of the Urban Gradient Index were grouped according to the categories s1 to s8. Because these categories use the legal framework (urban and non-urban areas) in addition to the "urban morphology" and population size, it is possible to order them from the "most urban" to the "most rural". Figure 3 shows how closely related the Urban Gradient Index is to IBGE's classification of census tracts, both in Brazil and the RMBH.

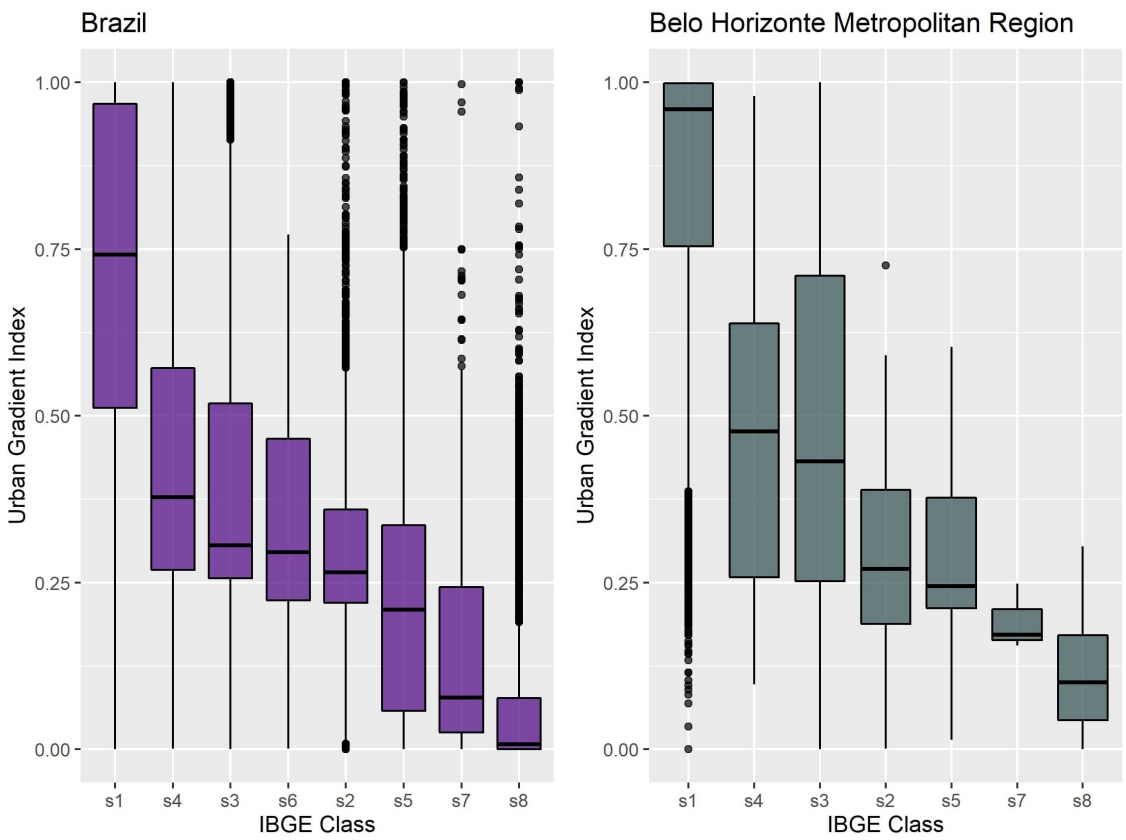

Figure 3 - Urban Gradient Index grouped by IBGE's census tract classes (Brazil and RMBH).

Correlation analyses show that the Urban Gradient Index has adherence to the selected urban indicators at the municipal level (Table 2). In most cases, the Urban Gradient Index shows greater correlation than the official measure of "degree of urbanization" and well above the alternative classification proposed by IBGE in 2017 (Table 2).

	HDI	*% Employed in agriculture*	*% Employed in industry*	*% Employed in services*	*Fertility rate*	*Pendular mobility*	*Bathrooms per inhabitant*
Brazil							
Degree of urbanization*	0.58	-0.82	0.47	0.65	-0.24	0.25	0.56
IBGE 2015 Classification	0.34	-0.67	0.38	0.45	-0.11	0.25	0.30
Study Classification	0.59	-0.72	0.49	0.52	-0.38	0.31	0.62
RMBH							
Degree of urbanization*	0.56	-0.82	0.27	0.62	-0.21	0.46	0.13
IBGE 2015 Classification	0.57	-0.89	0.29	0.65	-0.22	0.31	0.11
Study Classification	0.57	-0.75	0.13	0.61	-0.40	0.76	0.15

* Following official classification by the Brazilian Census Bureau (IBGE)

Table 2 - Correlation among urban classifications and urban indicators at municipal level.

A key advantage of the Urban Gradient Index is its applicability in intra-urban areas, i.e., within municipalities. Figure 4 shows an application of the Index to municipalities within the RMBH.

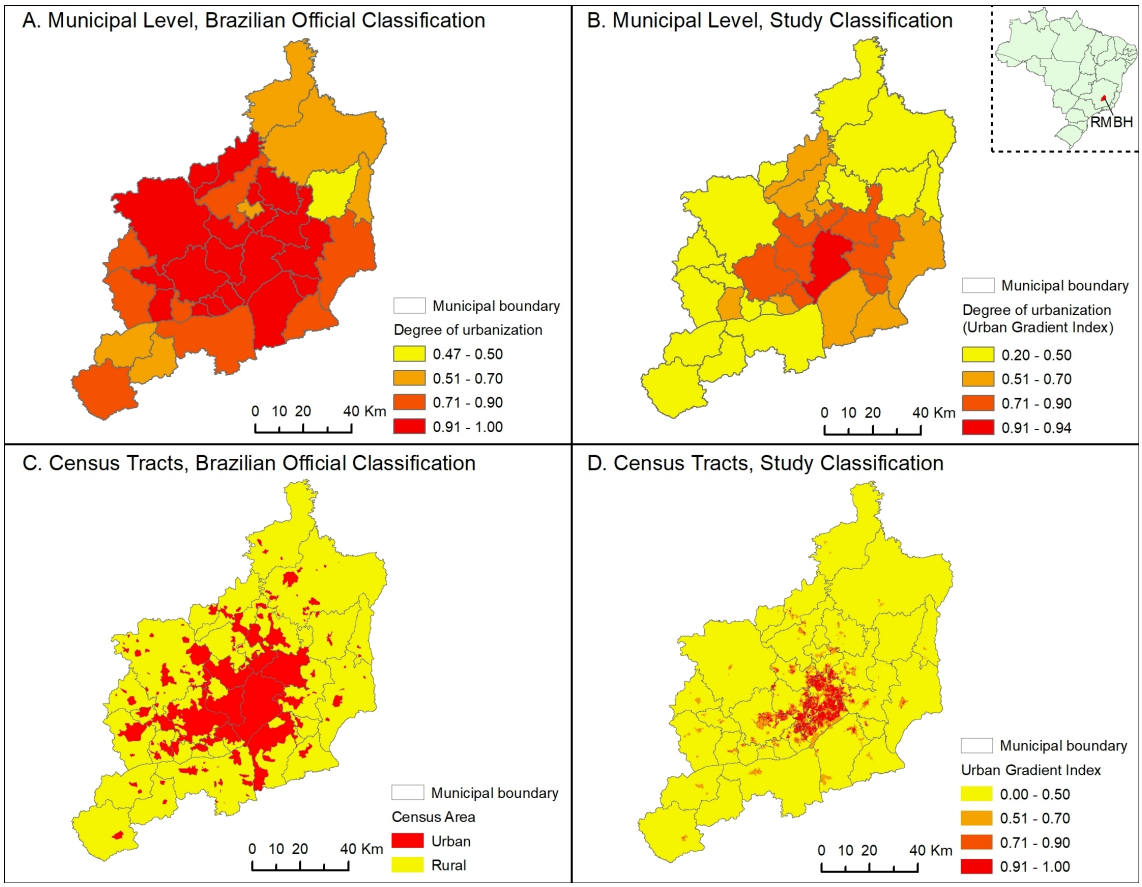

Figure 4 - IBGE's official urban-rural classification vs. Urban Gradient Index at the municipal and census tracts level in the RMBH

The spatial data containing the Urban Gradient index to census tract and aggregated by municipality are available on https://doi.org/10.5281/zenodo.4540710 and https://doi.org/10.5281/zenodo.4540714 respectively.

DISCUSSION

Our proposed classification was able to discriminate an urban-rural gradient that was consistent with several urbanization proxy indicators. The use of the IBGE database allowed the construction of a classification with homogeneous criteria, which can be applied at both municipal and intra-municipal levels. However, the conceptualization and measurement of "urbanization" is highly dependent on methodological choices and definitions. Classifications based on administrative criteria, such as in the Brazilian case, may not be sufficiently sensitive to reflect actual spatial urban features, such as high demographic density and the presence of infrastructure. To overcome this limitation, our Urban Gradient Index uses a territorial measurement of urban or rural that does not depend only on the clustering of urban or rural landscape elements, but also on the organization of the built-up space (such as infrastructure) and its correlation with population density.

Because the Urban Gradient Index reflects urban spatial features, it shows some methodological advantages. First, it is easily measurable, requiring only census data available for the whole country. Even in the absence of demographic censuses, it is possible to reproduce the index using household survey data of small areas (e.g., neighborhoods or census tracts). Furthermore, the index can be used in a multi-temporal perspective, as long as the spatial units are comparable over time (MACEDO; UMBELINO, 2010; 2016). The second methodological advantage is its potential application at multiple spatial extents. Data collection can involve any group of contiguous spatial aggregations (e.g., census

tracts, neighborhoods or river basins) without compromising the interpretation of the index, irrespective of the resolution and nature of the units of analysis. This flexibility helps minimize Modifiable Areal Unit Problem (MAUP) (OPENSHAW, 1984) effects and can thus be estimated from small areas and rearranged according to a given criterion that minimizes boundaries effects among territorial units. Another strategy involves grouping non-reducible territorial units – the households – according to the properties of the index components. Both alternatives do not apply to the traditional "degree of urbanization" because it is highly dependent upon ad hoc spatial classifications.

In comparing the Urban Gradient Index with the IBGE's eight categories of urban-rural census tracts (Figure 4), the Index adhered to the territorial classification, independently of spatial extent. It captures urban gradients among census tracts, as shown by its variance within each class (Figure 3). We observed this adherence both at the national level, as well as for the municipalities in the RMBH. This multi-extent approach is also important to verify if the Urban Gradient Index in small areas is consistent with the values observed at more aggregated levels, because associations between variables at the aggregate level do not necessarily represent associations at the individual level. For example, labeling the entire extent of the RMBH as "urban" creates an ecological and geographic fallacy because large portions of the RMBH have characteristics associated with rural areas (low demographic density, absence of equipment and services, large portions of the population working in agricultural activities etc.).

Finally, the greatest advantage of the index is shown in Figure 4D: the representation of a much more nuanced picture of settlement patterns, unveiling a spatial gradient between rural and urban (beyond the simple dichotomy depicted in figure 4B, for example). Figure 4D shows that many census tracts are less urban than shown by the official classification (Figure 4B), marked by discrete attributes instead of a continuum. This result opens the possibility of further investigations about the true nature of urban and spatial classifications.

Although innovative, our proposal is not without limitations. As pointed out by Champion and Hugo (2004), settlement systems are multidimensional and the adoption of a single scale from the most rural to the most urban may not be sufficient for several purposes. The urban gradient index deals with a wide diversity of settlements patterns in a unidimensional way, i.e., by simply quantifying how "urban" they are. The problem is that a place can be more urban than others in some aspects and more "rural" in others and a great diversity of settlement patterns can receive approximate values. Far from being a "one-size fits all" measure, the Urban gradient is a potentially useful way to formalize and operationalize the rural-urban continuum in order to refine the characterization of settlements beyond the rural-urban dichotomy, particularly in regional contexts (i.e. within a state or metropolitan region). In future works, new continuous measures can be used in conjunction with the urban gradient index to better qualify and differentiate settlement patterns in multiple spatial extensions.

CONCLUSION

The Urban Gradient Index uses national-level census data and allows multi-temporal and multi-spatial comparisons. It is replicable at multiple spatial extents, including intra-municipal areas, with multiple potential applications for urban planning, government management and academic studies. It uses simple, measurable and comprehensive variables and it can be replicated in other countries, even if not with the exact same variables. The index can differentiate heterogeneous settlement patterns with greater accuracy and reliability because it considers objective spatial (infrastructure) and population factors. In this way, it is especially useful in cases when a fine-tuning territorial focus and distinction between urban and rural features is needed to avoid masking the complex reality of settlements with precarious urban infrastructure and low population density (as in the case of Amazon and Northeast Brazil). As shown in our case study in the RMBH, it may reveal "hidden ruralities" that require specific policy interventions that traditional measures such as the "degree of urbanization" cannot unveil. It can also avoid "urbanization inflation" in some areas (such as in Amazônia and central Brazil).

We believe that the Urban Gradient Index facilitates improved spatial analysis on three fronts. The first refers to population projections. The official IBGE projections disregard nuances that urban and rural areas have concerning demographic behavior. They assume a uniform growth trend within

municipalities, disregarding the differential growth between urban and rural populations. In this sense, the estimates produced are useful at the municipality level but are not suitable for forecasting the social demand for public services. Second, the use of an index that is sensitive to urban infrastructure can contribute to public policies, especially those focused on socially vulnerable populations. This is because it allows comparisons with other indicators to establish priorities for structural actions in the territory, especially in situations of scarce public resources. For example, we believe the index can provide more efficient ways to analyze the association between urbanization patterns and threats from extreme weather events such as fires and floods, disease incidence (such as dengue and zika virus in Brazil, which are highly correlated with urban infrastructure and population density), and racial disparities (like in the USA and Brazil). Finally, studies that look for empirical evidence about urban and rural spaces, in general, lack information that differentiates those areas beyond the rural-urban dichotomy. In this sense, instead of using a dichotomous variable, the Urban Gradient Index can help to assess and visually represent urban and rural settlements in a much more nuanced way.

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