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SPATIAL AND ASPATIAL INDICATORS:

A COMPLEMENTARY APPROACH TO THE QUANTITATIVE ANALYSIS OF RESIDENTIAL SEGREGATION IN MANAGUA[1]

INDICADORES ESPACIALES Y NO ESPACIALES: UN ENFOQUE COMPLEMENTARIO PARA EL ANÁLISIS CUANTITATIVO DE LA SEGREGACIÓN RESIDENCIAL EN LA CIUDAD DE MANAGUA

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El polimorfismo de su concepto y la complejidad de sus múltiples dimensiones espaciales, hacen de la medición de la segregación un tema desafiante. A través de los años se han desarrollado enfoques metodológicos que han producido diversos indicadores para cuantificar el fenómeno. Por un lado, se hallan los indicadores tradicionales, criticados por las fallas que se les aducen, entre las que destaca su incapacidad para revelar la forma en que se distribuye espacialmente el fenómeno. Y, por otro lado, se encuentran los indicadores espaciales, creados a partir del desarrollo de la estadística espacial y la disponibilidad de softwares de Sistemas de Información Geográfica (SIG), a los cuales se les adjudica superioridad conceptual y operacional. Esto ha empujado a algunos investigadores latinoamericanos a proponer el abandono del uso de los indicadores tradicionales y recurrir exclusivamente a los indicadores considerados espaciales. No obstante, a través de este artículo se muestra cómo, desde un enfoque complementario, los indicadores espaciales y no espaciales pueden articularse para revelar las distintas dimensiones espaciales de la segregación residencial, y así disminuir las arbitrariedades en su medición, representación e interpretación, a la vez que se atiende la limitada disponibilidad de datos espaciales individuales que caracteriza a Latinoamérica. Los resultados del estudio de la segregación residencial socioeconómica de la ciudad de Managua, a través del Índice de Disimilitud y el Índice de Moran Global, exhiben que Managua se caracteriza por una segregación a pequeña escala y que el grupo más segregado, en términos de concentración y agrupamiento, es la población con estudios universitarios completos. Asimismo, demuestran que, si bien los indicadores espaciales buscan capturar la naturaleza inherentemente geográfica de la segregación residencial, su exclusiva utilización falla en atender la multidimensionalidad espacial del fenómeno y puede conducir a vacíos en su cuantificación.

Palabras clave: análisis espacial, segregación social, inequidad urbana, asimilación espacial, estadística y datos numéricos

The polymorphism of its concept, as well as the complexity of its multiple spatial dimensions, make the measurement of segregation a challenging subject. Which is why, over the years, methodological approaches have been developed, which have produced different indicators to quantify the phenomenon. On the one hand, there are the traditional indicators, which have been criticized for the flaws attributed to them, among which their inability to reveal the way in which the phenomenon is spatially distributed stands out. On the other hand, there are spatial indicators, created from the development of spatial statistics and the availability of Geographic Information System (GIS) software, which are believed to be conceptually and operationally superior. This has led some Latin American researchers to propose abandoning the use of traditional indicators altogether, and to exclusively use the indicators considered as spatial. However, this article shows how, from a complementary approach, spatial and aspatial indicators can be articulated to reveal the different spatial dimensions of residential segregation, and thus reduce arbitrariness in their measurement, representation, and interpretation. While, at the same time, it addresses the limited availability of individual spatial data that characterizes Latin America. The results of the study of socioeconomic residential segregation in Managua, through the Dissimilarity Index and the Global Moran´s Index, show that the city exhibits small-scale segregation, and that the most segregated group in terms of concentration and grouping is the population with a college degree. It also reveals that although spatial indicators seek to capture the inherently geographical nature of residential segregation, their exclusive use fails to address the spatial multidimensionality of the phenomenon and can lead to gaps in its quantification.

Keywords: spatial analysis, social segregation, urban inequality, spatial assimilation, statistics and numerical data

I. INTRODUCTION

In recent years, Latin America has seen a growing interest about conceptual and methodological issues related to the quantification of residential segregation. One of the most controversial statements has been the proposal to abandon the use of aspatial indicators because of their multiple flaws, and replace them with spatial indicators, given their estimated conceptual and operational superiority when it comes to measuring the phenomenon and its spatial patterns (Garrocho & Campos-Alanis, 2013). However, there have also been discussions about the urgency to introduce policy changes to manage census data in order to improve the quality of the studies in this and other fields, through instrumentation of a variety of simultaneous and non-exclusive solutions (Rodríguez, 2013); along with the need to address discrepancies that tend to appear in the analysis of the residential segregation dimensions, through complementary analytical approaches (Dominguez, 2017).

As a consequence, the purpose of this article is showing how spatial and aspatial indicators, from a complementary approach, can be articulated to reveal the different spatial dimensions of residential segregation, and thus reduce arbitrariness in the measurement, representation, and interpretation of the phenomenon, while addressing the Latin American reality regarding the management of individual spatial data and their limited availability.

For this purpose, the first step is to approach the challenges that the conceptualization and quantification of residential segregation present, and briefly introduce the city of Managua as a case study. Later, a methodological route is outlined which: i) uses information collected in the VIII Population and IV Housing Census of 2005; ii) considers the education variable broken down into two antagonistic social groups -illiterate population and population with completed tertiary education- as a single proxy variable of socioeconomic segmentation; and iii) proposes the use of two indicators -Global Moran's Index and Dissimilarity Index-, one spatial and another aspatial, to respectively study grouping and dissimilarity dimensions. In a third section, the results of the study are presented, which evidence that aspatial and spatial indicators reveal different results, as they show the different residential segregation spatial dimensions. However, they can be articulated to make progress towards a better understanding of the phenomenon. These results also allow detecting that this approach, due to its complementary nature, opens up the possibility not just to consider all residential segregation dimensions, but also to use the different available techniques and strategies, beyond those presented here. Finally, the main conclusions and bibliographical references of the literature consulted are presented.

II. THEORETICAL FRAMEWORK

It is sufficient just to note the broad distribution of the term "segregation" in the political, media and scientific discourse, to show its polysemy and ambiguity, as well as the difficulties there are for its use and measurement (Link, Valenzuela & Fuentes, 2015; Madoré, 2005). Because of this, it is important to distinguish different but complementary ways that are used to approach the concept of segregation, among which the following stand out: i) those that refer to differences within a collective, and the separation of the subjects into categories with a certain degree of hierarchical distinction (Rodríguez, 2001, p. 14); ii) those which refer to a spatial relationship or regional separation or proximity among people belonging to a same social group (Sabatini & Sierralta, 2006, p. 4); and iii) those which associate the phenomenon with a high social homogeneity and spatial concentration, that lead to the isolation of a group and that, according to Marcuse -as was cited in Sabatini & Rasse (2017)-, always imply some degree of imposition.

The aforementioned notions allude to an approximation to the phenomenon that addresses it in spatial, descriptive, and quantitative terms, to study the five spatial dimensions identified by Massey and Denton (1988): dissimilarity, exposure, concentration, centralization, and grouping. This work addresses two of them. From this approach, researchers from different parts of the world have made progress in the design of quantification methodologies, knowledge about the levels, trends, and determination of the phenomenon's spatial patterns.

In this context, the traditional or aspatial measurements -Dissimilarity Index, Isolation Index, among others- used over the last two decades to quantify segregation, have been criticized on having a "simplifying" nature, and on ignoring the way the phenomenon is spatially distributed (Yao, Wong, Bailey & Minton, 2019). However, as of the 1990s, the development of spatial statistics, and the availability of GIS software, allowed using spatial segregation indicators -Global Moran's Index and Local Moran's Index-, as an alternative to the acknowledged limitations. In the United States, researchers like Brown and Chung (2006) and Reardon et al. (2008) have made the call to focus attention towards segregation measurements that are space and scale sensitive -Spatial Information Theory Index and Spatial Segregation Profile-, although these have not been widely used, especially in Latin America, where public access to microdata is limited.

It is actually in Latin America where a growing interest about the conceptual and methodological problems of residential segregation quantification has been seen. One of the approaches that has been the most controversial, proposes abandoning the use of aspatial indicators due to their flaws, and replacing them with spatial indicators, given their estimated conceptual and operational superiority

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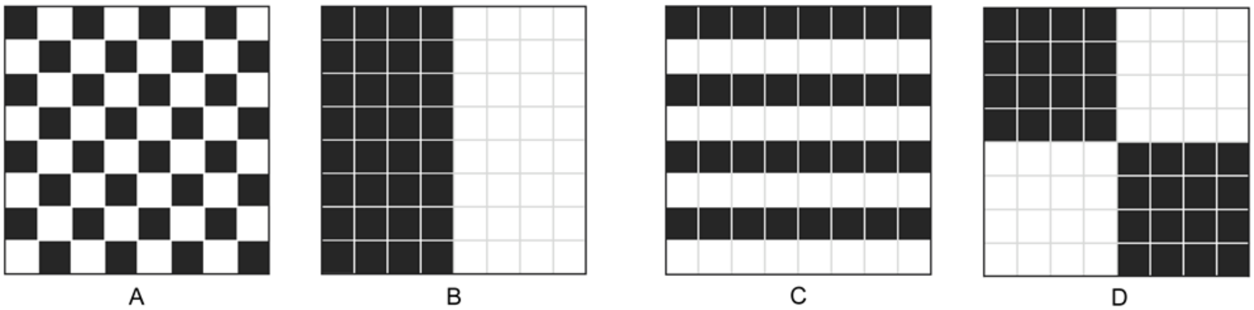

Figure 1. The chessboard problem. Source: Adapted from Garrocho & Campos-Alanis (2013, p. 276).

(Garrocho & Campos-Alanis, 2013). In addition, the urgency to introduce changes in census data management has been outlined, to improve the quality of the studies in this field, using the instrumentation of simultaneous and non-exclusive solutions (Rodríguez, 2013), and it has been proposed to address the discrepancies arising from the analysis of the residential segregation dimensions through complementarity focused analytical approaches (Domínguez, 2017; Linares, Velázquez, Mikkelsen & Celemin, 2016).

What is mentioned by Garrocho and Campos-Alanis (2013) and Ruiz-Tagle and López (2014) is interesting insomuch as they question the validity of approaches that are key in the debate, regarding the degree, the trends, and the pattern of Latin American segregation, whose base is the studies of Sabatini, Cáceres and Cerda (2001) for the main Chilean cities, which have echoed across the entire region. In particular, the former state that these approaches could be based on a measurement error associated to the use of aspatial indicators, and that the use of spatial indices would lead to different results.

It must be mentioned that, despite its limitations, and on there being other aspatial indicators, the Dissimilarity Index (DI) has become the main statistical measurement to quantify residential segregation. The first limitation is known as the "chessboard problem". Garrocho and Campos-Alanis (2013) exemplify it through a board where the squares represent spatial units as neighborhoods of a city, into which two population groups are distributed. On calculating the segregation indices using the classic board pattern (Figure 1, element A), certain results would be obtained. If the classic pattern were altered, moving all the black squares towards the middle of the board (Figure 1, element B), it would be expected to obtain different results that showed this new spatial distribution. However, on this being an aspatial indicator, it always generates the same results, without managing to distinguish between

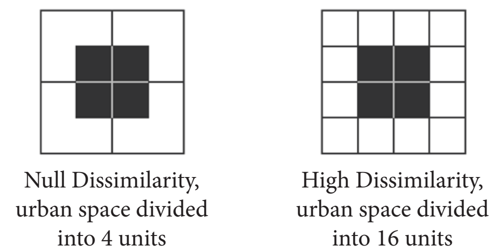

Figure 2. The modifiable areal unit problem. Source: Preparation by the Authors.

the classic pattern and any other spatial pattern (Figure 1, elements C and D) that may be formed (Garrocho & Campos-Alanis, 2013, p. 275-276).

The second limitation is known as the "modifiable areal unit problem" (MAUP). This was identified by White (1983), and consists of a variation of the DI, when the measurement area is modified. That is to say, that the smaller the measurement area is, the higher the index value. This problem is made evident in Figure 2: the spatial crowding of the homes represented by the black squares is strong at a microspatial level (Figure 2, element B), and weak if analyzed at a more aggregated level (Figure 2, element A). In this regard, Rodríguez (2013) indicates that the MAUP arises from the way census information is collected and published in spatial units whose limits are often non-existent in daily life.

Because of this, Garrocho and Campos-Alanis propose abandoning aspatial indicators and the absolute use of those they call genuinely spatial segregation indicators, like the Global Moran's Index (GMI), and the Local Moran's Index (LMI), which according to Ruiz-Tagle and López (2014), have shown "more reasonable results regarding the lack of spatiality of traditional indices" (p.34). Now, this proposal is

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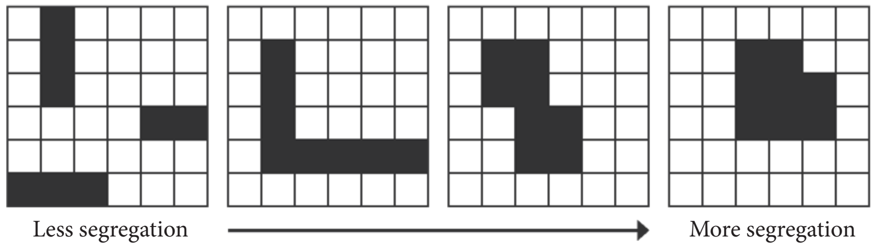

Figure 3. Segregation by grouping indices. Source: Ruiz-Tagle & López (2014, p. 34).

Figure 4. View of Managua from the Northern-Central Area. Source: Photograph by Álvaro Solis.

Figure 5. View of Xolotlán Lake from the Northern-Central Area of Managua. Source: Photograph by Álvaro Solis.

subject to three aspects: i) it omits that spatial indicators solely measure grouping (Figure 3); ii) it disregards that the capacity to quantify residential segregation is limited by existing aggregation units in the censuses (Rodrígez, 2013; Molinatti, 2021), which are also commonly used when working with spatial indicators; and iii) it ignores that segregation measures have been developed for the last two decades, which are sensitive to space and scale, whose use in Latin America would imply enabling public access to microdata.

On facing this scenario, and as is shown in the following section, this article suggests a way of working that seeks to show how, from a complementary approach, spatial and aspatial indicators can be articulated to reveal the different spatial dimensions of residential segregation, and to reduce the arbitrariness in their measurement and interpretation, while approaching the Latin American reality regarding the limited availability of individual spatial data.

III. METHODOLOGY

Although this article proposes, as has been said, a complementary approach to quantify residential segregation and its different spatial dimensions, which includes the use of aspatial and spatial indicators, the methodological path that is described below, only uses DI and GMI to study the grouping and dissimilarity dimensions, respectively. Despite this, it is suggested considering other residential segregation dimensions, as well as using the available techniques and strategies, such as: geographical information technologies for spatial analysis, graphical corrections, and spatial regressions among others.

The study was made in Managua, the Nicaraguan capital, inhabited by 28.9% of the population, which has a low density -38.51 inhabitants per hectare- compared to other Central American capital cities. It is characterized by a functional spread, the result of different factors, like the devastating earthquake of 1972, after which the State took control of property in the most affected area (historic hub), and opted to freeze its reconstruction. This led to a multiplying of neighborhoods around it and in the outskirts of the city, accentuating the disconnection of Xolotlán Lake with the rest of the city (Figure 5). Today Managua has a fragmented urban development, the result of flexible public management, where the actions of different real-estate and development agents have dominated (Figure 4).

To quantify socioeconomic residential segregation (SRS) in this case study, the information collected in the VIII Population and IV Housing Census carried out in 2005, was turned to, as this requires statistical representativity criteria. This shows a Managua that was divided into 5 district units (Figure 6), with a total extension of 267.17 km^2 and an estimated population of 937,489 inhabitants, spread over 618 neighborhoods and 23 districts. It is worth mentioning that, given the lack of census data referring to economic stratification, the SRS calculation was made using the census data available for public use. In this case, the education variable was used, broken down into two opposing social groups: the illiterate population and the population with complete tertiary education, as a single proxy variable of socioeconomic segmentation.

These decisions were based on the prevailing position in the residential segregation studies in the region, which usually use a single proxy variable of socioeconomic segmentation, such as poverty, education, or employment (Groisman & Suárez, 2010; Garín, Salvo & Bravo, 2009; Molinatti, Rojas & Peláez, 2016). At the same time, the great power of segmentation the education variable has in Latin American cities must be highlighted, inasmuch as it is capable of determining salary differentials and access to social protection, as well as linking it to the work division and the place occupied in the social structure (Molinatti ***et al***., 2016).

Meanwhile, the age of the census data can be considered as a methodological limitation, although this is common in Central America. El Salvador and Nicaragua are the countries with the oldest census data, from 2007 and 2005, respectively. However, it is essential to avoid methodological inhibition, which is like "a pronounced trend to confuse what one wishes to study with the series of methods suggested for this" (Mills, 1959, p. 69). In this sense, although there are no current data, those available are of a good quality and allow approaching the phenomenon being studied, through the indicators conceived for this purpose.

Aspatial indices versus spatial indices

Despite its limitations, the Dissimilarity Index (DI) is the one used most for quantifying residential segregation. It seeks to measure the under or overrepresentation of a social group in the spatial units into which an urban area is divided (Apparicio, Martori & Fournier, 2014). It is considered that a social group is segregated the more unequal its distribution in space is. The index varies between 0 and 1, and tends towards this second value when the social group appears more strongly overrepresented in some areas and underrepresented in others. Its formula (equation 1) shows the segregation understood as dissimilarity.

$$D = \frac{1}{2}\sum \left| \frac{ai}{A} - \frac{bi}{B} \right| \quad (1)$$

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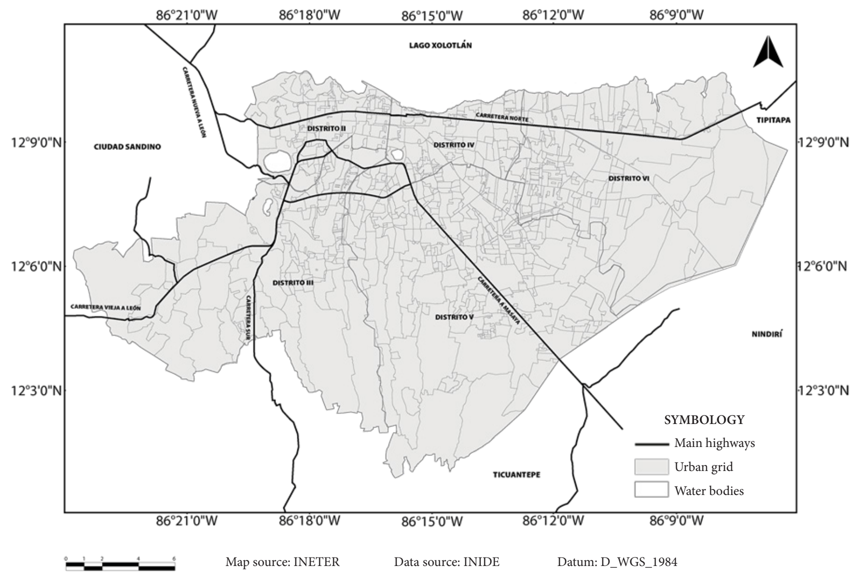


Figure 6. Outline of the study area. Source: Preparation by the Authors.

Where:
D: Dissimilarity Index
ai: Number of homes of a social group (illiterate population or with complete tertiary education) in area *i* (municipality, districts, and neighborhoods of Managua).
A: Total number of homes in the city of this social group.
bi: Number of homes not belonging to social group *a* in area *i*.
B: Total number of homes not belonging to the social group *a* in the city.

Ultimately, to avoid MAUP, the phenomenon was measured on different scales of analysis, using a solution proposed by Molinatti (2013) that considers two strategies. First, the census data were processed for the available segregations (municipality, district, neighborhood), from biggest to smallest. Second, a methodological correction was applied in the graphical analysis of the Dissimilarity Index values, represented graphically through a "diagonal curve". This refers to the expected reduction of the index, when the measurement area increases, and allows distinguishing between the expected effect on facing the change of scale and the segregation effect itself. As a curve above the straight line would indicate macro-segregation, a curve below it would reveal micro-segregation or small-scale segregation.

The Global Moran's Index (GMI) was used to quantify residential segregation understood as grouping. According to Ramírez and Falcón (as cited in Siabato & Guzmán-Manrique, 2019), the GMI constitutes one of the most widespread calculations to globally measure spatial autocorrelation (SA), whose essence is analyzing how a phenomenon varies through the geographical space and thus be able to determine spatial patterns, describe their behaviors, and understand the type of association there is between neighboring spatial units. The SA applied to this study can lead to three results: 1) the social group tends to segregate and group in uniform areas, in clusters of rich or poor population, which evidences the existence of a positive correlation (Figure 7, element A); 2) the spatial units under analysis are contiguous to others of dissimilar characteristics and the social group tends to be disperse (Figure 7, element B), indicating that the spatial autocorrelation is negative; and 3) the location of the spatial units under study behaves randomly and it is not possible to identify a defined behavior, so there is no spatial autocorrelation (Figure 7, element C).

Regarding GMI, it must be said that this arises from directly comparing the values of each unit of analysis with the global mean of the phenomenon under study. As a result, it does not constitute a univocal universal measurement of the behavior of the analysis units, but rather that it depends on the neighborhood criterion that is chosen (Siabato & Guzmán-Manrique, 2019). In this case, spatial units within 500 meters, from 0 to 4000 meters are considered as neighbors, as the interaction between these is the one that best describes the phenomenon. At the same time, this criterion allows identifying whether this index has MAUP or not. The results of the GMI are interpreted as follows: a) a value of close or equal to 0 indicates a random pattern; b) values below 0 indicate a disperse pattern; c) values above 0 exhibit a cluster type

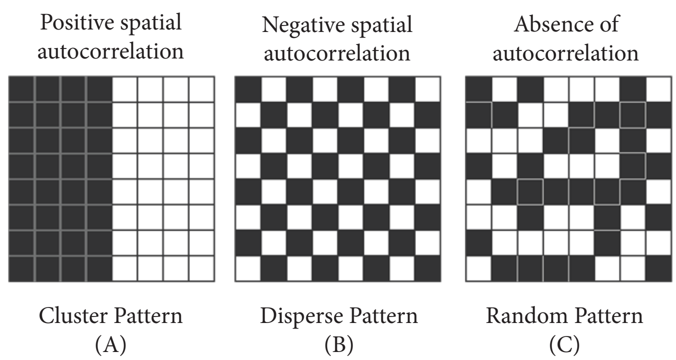
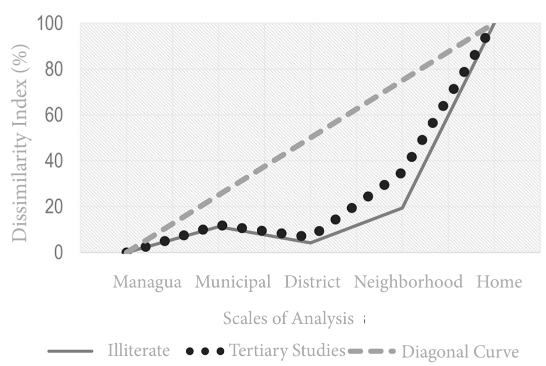


Figure 7. Spatial patterns and spatial autocorrelation. Source: Adapted from Siabato and Guzmán-Manrique (2019, p. 6).



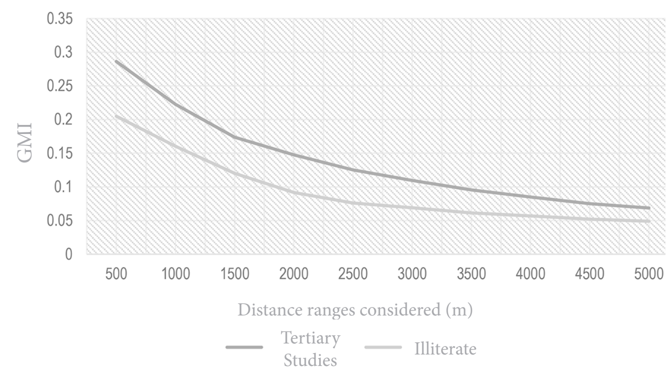


Figure 8. Comparison of DI with the methodological straight line, following scales of analysis for the city of Managua in 2005. Source: Preparation by the Authors.

Figure 9. Comparison of GMI for both social groups under study, following the distance ranges considered for Managua in 2005. Source: Preparation by the Authors.

pattern, which allows identifying whether there is a segregation pattern or not.

IV. RESULTS

The results of the DI show important differences depending on the scales of analysis considered (Figure 8). On municipality and district scales, the segregation understood as dissimilarity does not have high values. However, on a neighborhood scale, this increases for both groups. It is seen that 35.01% of the population with complete tertiary education, and 19.44% of the illiterate population would have to change residence to reach a more balanced distribution in the city. That is to say, that 1 in 3 people from the highest economic stratums would have to change residence to reduce the dissimilarity of this group. This shows that Managua is characterized by a small-scale segregation.

The GMI presented the following results: 1) the illiterate population shows grouping, although it has a low spatial correlation at 500 meters, and lower still at 2000 meters until becoming negligible. 2) The most segregated group by grouping is the population with complete tertiary education, particularly at 500 and 1000 meters, although the correlation becomes negligible as of 3500 meters. In other words, the data show that the lowest economic stratums do not form large clusters of poverty, both rather are found spread in localized neighborhoods, presenting a low segregation by grouping. Meanwhile, the higher stratum neighborhoods are much more grouped in the city, even generating high salary cones that avoid proximity with neighborhoods of other social groups. Just like in the previous index, it is left clear that the population with complete tertiary education is segregated on a small scale (Figure 9).

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In summary, the results obtained show that: 1) Managua is characterized for having a small-scale segregation, as both social groups under study are more concentrated and grouped at a neighborhood scale. 2) The most segregated group in terms of dissimilarity and grouping is the population with complete tertiary education. This also shows that, in Managua, social homogeneity of the space dominates within the neighborhood or in the sum total of some neighborhoods, but contrasts with the social diversity on greater spatial scales like the district or municipality. This spatial arrangement detected by both indicators is known as "small-scale segregation", and accounts for the reduction of the geographical scale of the phenomenon, marking a break from traditional Latin American segregation patterns (Sabatini, 2015). In Managua, this situation is associated to a disperse urbanization process, as well as to the evolution of the operation of the land and housing markets.

V. DISCUSSION

The results obtained allow, firstly, discussing about the limitations of aspatial indicators stated by Garrocho and Campos-Alanis (2013) and Ruiz-Tagle and López (214) as the main reasons to propose abandoning their use in the quantification of residential segregation.

In fact, the DI results show two empirical regularities of residential segregation studies: i) the population with complete tertiary education (highest economic stratum) is unequally distributed among the spatial units of the city and is concentrated more than the illiterate population in all scales of analysis; and, ii) the highest value of DI was obtained on the lowest scale of analysis considered (neighborhood), as the specialized literature describing the MAUP says (White, 1983). However, it must be mentioned that, both the DI and GMI results are revealing in this regard. In the case of the DI, the values did not fall on using a greater scale of analysis (Figure 8), which goes against the expected trend on the diagonal curve. While, on the contrary, the GMI did fall when the distance ranges considered for its analysis increased. This shows that regardless of the spatial pattern adopted, as the "chessboard problem" suggests, the intensity of segregation is different for DI and GMI. As can be seen, this result also questions the statements that assert the conceptual and operational superiority of the spatial indicators, and the advantages of their exclusive use for the quantification of the phenomenon (Garrocho & Campos-Alanis, 2013; Ruiz-Tagle & López, 2014).

Second, it is clear that spatial and aspatial indices measure different dimensions of the phenomenon, as the data show that the indices used coincide in one of the population groups under study, and differ in the other. This is why if, for example, the DI is compared for the population with complete tertiary education on a neighborhood scale (Figure 8) and the GMI at 500 meters (Figure 9), there will be a significant difference of more than 20 percent in the values obtained through the aspatial index that measures dissimilarity, compared to the spatial index used to measure the grouping. In this sense, it seems that empirically the same thing is not being quantified, because if this were true, the values obtained from the same indices would tend to be equal or similar, so the alternative proposed by Garrocho and Campos-Alanis (2013) and Ruiz-Tagle and López (2014), and the supposed advantage over the use of aspatial indicators, in reality is only another way of quantifying residential segregation, that fails to address the spatial multidimensionality of the phenomenon.

Finally, the results show the importance of opting for a complementary approach that considers the use of spatial and aspatial indicators as valid, and from which the results in this work would be read as follows: i) both social groups are concentrated and grouped with greater intensity on the neighborhood scale or at a homolog distance; ii) the illiterate population is concentrated and grouped with the same intensity; and, iii) the population with complete tertiary education is concentrated and grouped with greater intensity than the illiterate population on all the scales of analysis considered. Now, it is worth adding that this last group is concentrated more than it is grouped.

VI. CONCLUSIONS

The research presented here allows concluding that in Central America, access to updated census data without spatial aggregation, that can make the quantification of residential segregation possible using spatial indicators, is still complicated. For this reason, the use of measures that are truly sensitive to the space and scale for the study of the phenomenon would still be limited. As a result, it is key to address the flaws attributed to these aspatial indicators by using correction strategies, like those used in this study or other available ones, and thus also find methodological alternatives that, despite the limitations there are, make possible the study of urban phenomena like socioeconomic residential segregation.

Likewise, it must be understood that, although spatial indicators seek to capture the inherently geographical nature of residential segregation, its exclusive use fails to address the spatial multidimensionality of the phenomenon. In this sense, considering the spatial indices as the only valid ones, can lead to gaps or bias in their quantification. Meanwhile, working with aspatial and spatial indices from a complementary approach, can more broadly show the characteristics of the phenomenon for different social groups, as well as to offer more comprehensive readings that reduce the differences that the analysis of the spatial dimensions of the phenomenon usually generate, from any of their analytical approaches.

Finally, it is key to understand that the quantification of residential segregation, through approaches like that proposed in this article, allows evaluating the effects of actions promoted

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UN ENFOQUE COMPLEMENTARIO PARA EL ANÁLISIS CUANTITATIVO DE LA SEGREGACIÓN RESIDENCIAL EN LA CIUDAD DE MANAGUA
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by the State through local governments and the institutions set up to address the challenges of urban and regional development, which have the potential to increase or reduce residential segregation. Within this framework, it is pertinent that the progress in the understanding of contemporary spatial patterns of the phenomenon under study, can outline the need to improve the spatial distribution of the lowest economic stratums, for the sake of guaranteeing a more balanced distribution of the resources, opportunities, and benefits that the city offers through its residential environments.

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