ARTICLE IN PRESS

Journal of Urban Management xxx (xxxx) xxx

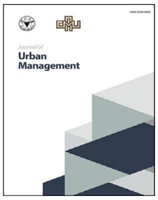
HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Journal of Urban Management

journal homepage: www.elsevier.com/locate/jum



Journal of Urban Management

Research Article

Characterizing landscape patterns in urban-rural interfaces

Paola Ortiz-Báez [a,c,*], Pablo Cabrera-Barona [b], Jan Bogaert [a]

[a] *Biodiversity and Landscape Unit. Gembloux Agro-Bio Tech. University of Liège, Belgium*
[b] *Latin American Faculty of Social Sciences (FLACSO), Ecuador*
[c] *Faculty of Architecture and Urbanism, Central University of Ecuador, Ecuador*

ARTICLE INFO

Keywords:
Urban-rural gradient
Landscape patterns
Landscape metrics
Urban expansion
Multivariate clustering

ABSTRACT

Due to new urbanization patterns, where cities' edges are becoming increasingly difficult to delimit, a better understanding of urban-rural gradients has become a key issue for urban planning. These interstitial territories are characterized for being highly heterogeneous, with hybrid and complex dynamics and -due to their landscape ambiguity and rapid transformation-frequently lack of clear regulations. Through calculation and analysis of landscape metrics in high resolution satellite images, this study proposes a novel and accurate method to identify urbanization patterns. It was applied to the urban-rural gradient of the Metropolitan District of Quito (MDQ), an Andean city. After analyzing five land use/land covers in six transects, results suggest that the MDQ presents patterns of urban diffusion and coalescence. The diffusion starts at the urban core and expand to rural parishes where some emerging traditional settlements merge, constituting a complex pattern of urbanization. Also, significant levels of fragmentation were identified for the vegetation cover in periurban areas, threatening the territory environmental sustainability. Finally, a multivariate cluster analysis was developed, evidencing five main tendencies of urbanization patterns. This knowledge can be particularly useful for urban planning in terms of reducing randomness in urban development processes. This paper proposes and tests an analytical approach which could be applied to other Latin-American cities, where urban expansion patterns remain unknown.

1. Introduction

The speed and pattern of cities' growth has changed in recent decades. For centuries cities grew slowly and following a compact configuration. However, technological innovations in information and communication, greater access to private motorization, the spread of the new neoliberal economic paradigm and globalization have transformed the structure of cities, producing new spatial morphologies that tend to be more dispersed (Harvey, 1989; Hidalgo et al., 2007; Inostroza et al., 2013; Newman & Kenworthy, 1996). In this scenario, the cities' edges are increasingly difficult to delimit, constituting urban-rural gradients highly heterogeneous, with hybrid and complex dynamics (Vizzari et al., 2018). Here, residential uses are mixed with agricultural production areas, industrial clusters, informal occupation areas, and new mega-infrastructures, among others (Soja, 2008).

Due to the diversity of this territory, various methodologies have been implemented to achieve greater understanding for planning and management. Gradient analysis, which identifies the urban-suburban-cultivated-managed-natural sequence (Forman & Godron, 1986), has been widely used to understand the process and effects of urbanization (Bogaert et al., 2015, pp. 59–69; Luck & Wu, 2002;

---

[*] Corresponding author. Biodiversity and Landscape Unit. Gembloux Agro-Bio Tech. University of Liège, Belgium.
E-mail address: rportiz@uce.edu.ec (P. Ortiz-Báez).

https://doi.org/10.1016/j.jum.2021.01.001
Received 19 September 2020; Received in revised form 22 November 2020; Accepted 15 January 2021

Please cite this article as: Ortiz-Báez, P. et al., Characterizing landscape patterns in urban-rural interfaces, Journal of Urban Management, https://doi.org/10.1016/j.jum.2021.01.001

Seress et al., 2014; Vanderhaegen & Canters, 2017; Vizzari & Sigura, 2015; Wadduwage et al., 2017; Weng, 2007). In some cases, relying on the use of transects (an imaginary linear trace that observes and describes a spatial sequence) as a tool to represent and systematize the urban-rural continuum (Hahs & McDonnell, 2006; Luck & Wu, 2002; Vanderhaegen & Canters, 2017; Wadduwage et al., 2017; Weng, 2007). In this sense, one of the main advantages of analyzing through continuous gradients is avoiding/reducing subjectivities when defining sample spots (Vizzari & Sigura, 2015).

Gradient diversity is characterized by the multiplicity of Land Use/Land Covers (LULCs) that interact within the same territory and which are frequently identify through various mechanisms of satellite and/or aerial photography interpretation (Antrop & Van Eetvelde, 2000; Inostroza et al., 2013; Kumar et al., 2018; Mejía, 2020). These LULCs, which according to landscape ecology can be recognize as "patches" (spatial units with homogeneous characteristics) or as "corridors" (linear elements that contribute to the connectivity of the landscape) (Subirós et al., 2006), have diverse spatial composition and configuration patterns, such as size, shape or connectivity (Liu & Weng, 2013). According to the pattern-process paradigm (Bogaert et al., 2015, pp. 59–69) there is a strong effect from these spatial patterns over ecological processes and vice versa, with subsequent environmental and socio-economic impacts (Hidalgo et al., 2007; Inostroza, 2017; Wadduwage et al., 2017). Particularly, the urban-rural interface is a fragile territory under these impacts, due to its ambiguity, lack of clear regulations and greater transformation speed (Bogaert et al., 2015, pp. 59–69; Vizzari & Sigura, 2015).

With 85% of its population living in cities, Latin America is the most urbanized region in the Global South (da Cunha & Jorge, 2009; Inostroza et al., 2013). In order to have a better comprehension of Latin America urbanization patterns, Borsdorf (2003) tested a series of models that describe the morphological and functional evolution of these cities, taking into account their historical, political and economic influences, from the colonial era to the present. Borsdorf describes the contemporary Latin American city as a fragmented and diffused area, composed of new functions that are currently located in the peripheries. The construction of new interurban highways has accelerated the access to peripheral areas, transforming them into attractive spaces for middle and upper classes occupation. Thus, territories that were previously considered distant and inaccessible have become the new main areas for dispersed urbanization, generating a mixed interface where fragments of lower, middle and upper class residences, along with new urban services, cohabit with agricultural and natural land uses.

The model proposed by Borsdorf (2003) has been recognized as a valuable contribution to knowledge about Latin American cities. However, this description remains general since, within the continent, there is a great diversity of cities with their own characteristics (Inostroza, 2017). This study seeks to delve into the finer facts and morphological details of the urban-rural gradient of the Metropolitan District of Quito (MDQ) in Ecuador, a territory that, despite sharing certain common conditions with the global pattern of contemporary urbanization, is characterized by its geographical, ecological, historical and socioeconomic specificities. Also, a territory where little is known about its urban expansion pattern and the interaction between its abiotic, biotic and human driven factors (Carrión & Erazo Espinosa, 2012; Municipio del Distrito Metropolitano de Quito, 2014). Therefore, the goal of this study is to identify landscape composition and configuration patterns of MDQ urban-rural interfaces, including a discussion of particular factors that have determined its differentiated urban expansion. It also aims to identify useful guidelines for effective land use planning in the MDQ. Finally, this paper proposes and tests an analytical approach which could be applied to other Latin-American urban areas, where the urban expansion pattern remains unknown.

2. Materials and methods

2.1. Study area, gradients and samples' definition

The MDQ is located on the Andes Mountain Range, a territory with a highly complex topography. However, this geomorphological feature has not been a limitation for its horizontal expansion. The MDQ is home to around 3 million people, distributed in 32 urban parishes and 33 rural parishes. Due to topographic factors, the rural parishes located at the north and west of the MDQ are paramount rural, some of them even covered by large areas of forests and where the Pichincha volcano is located. While the rural parishes located at the east of the DMQ are the ones dramatically facing the urban expansion of the city of Quito. In this area, new buildings are being constructed in increasingly more distant territories, now connected by new road infrastructures, occupying zones that previously were used for agricultural production or are ecological protection zones. Around 0.9 million people inhabit these periurban and rural areas within the MDQ (Carrión & Erazo Espinosa, 2012; Serrano Heredia & Duran, 2020; STHV, 2012).

We applied our analyses in 6 transects that were defined starting from the two main urban centralities towards the eastern rural parishes in 30°, 45° and 90° angles, covering the total extension of the eastern valleys from the north (valleys of Pomasqui and Calderon), center (valley of Tumbaco) and to the south (valleys of Los Chillos and Amaguaña). In order to observe the morphological characteristics of the urban-rural gradient on a very detailed scale, 1 square kilometer 64 samples (Wadduwage et al., 2017) were generated within the 6 transects (Fig. 1).

All transects are different in terms of abiotic (geomorphology, topography, etc.), biotic (ecosystem zones), administrative and demographic parameters. In fact, we can observe a great diversity of ecological zones, starting from very dry ecosystems such as the Low Montane Prickly Steppe up to Low Montane Humid Forests. Topographically this territory is located over the Andes mountain range and presents a great variability. Its urban core is located at 2.800 m above sea level (masl) and the lower eastern valleys, where urban expansion is now advancing, are located between 2.600 - 2.300 masl, while at the end of its eastern side the elevation goes back up to 4.800 masl. Finally, regarding its demographic features, it is relevant to mention that each MDQ rural parish has a traditional settlement core, known as *"cabecera parroquial"*. Many of them established in the colonial period.

Fig. 1. MDQ Location. Definition of the 6 study transects and 64 sample plots.

2.2. LULC identification

By observing and interpreting the ArcGIS 10.5 satellite image (basemap), five land use/land cover (LULC) were identified in a high-detail definition within each sample plot and then transformed into raster images (1 pixel = 1 m) (Fig. 2). The identified LULC classes were: *Built-up* (all artificial constructions including detached houses, high-rise buildings or sheds), *Road infrastructure* (including mega road infrastructure like highways and expressways and local roads), *Tree and Shrub Vegetation*, *Agriculture* (all recognizable plots with agricultural land production), and *Bare Soil and Grassland*. See Fig. 3.

2.3. Landscape metrics and gradient variations

Spatial composition and configuration patterns can be measured through landscape metrics (Bogaert et al., 2014; Sudhira et al., 2004; Wadduwage et al., 2017; Weng, 2007). In order to choose the more accurate metrics, the potential pattern variation of each LULC class was considered. As a result, a set of five metrics were selected, allowing us quantify the patches' area, density, dominance and isolation (Kumar et al., 2018; Liu & Weng, 2013). Using the FRAGSTAT 4.2.1 software, we calculated *Percentage of Landscape* (PLAND), *Patch Density* (PD), *Average Area* between all patches of a patch type (A_MN), *Larger Patch Index* (LPD) and *Average Euclidean Nearest-Neighbor Distance* (ENN_MN). See Table 1.

2.4. Assessment of landscape metrics

First, the Kruskal-Wallis test was applied to assess if landscape metrics' differences exist i) between gradients and ii) along the transects as we move away from the city center. Then, a multivariate lineal regression considering the Vegetation Percentage of Landscape as dependent variable was applied. We consider that the other landscape metrics of vegetation (such as patch density) and the landscape configurations of the other LULC could be influencing the amount of vegetation land cover. We chose as independent variables only the metrics that were found to have significant differences along the transects. After evaluating multicollinearity, some independent variables were removed for the regression model. The criteria for removing variables were first to remove the variables that originated the highest multicollinearities and, when a similarly high level of multicollinearity was identified between two variables, we prioritize the variable that was not an average (e.g. patch density over average area). Assumptions of normality and homoscedasticity were also evaluated. Finally, an analysis of normalized metrics variation along each transect was developed, in order to have a deeper understanding of landscape structure and its specificities.

2.5. Cluster analysis

Once we had assessed the main landscape patterns, a multivariate cluster analysis was developed in order to recognize samples' similarities/differences, regardless of the gradient or the distance to the city center. This analysis would allow us to identify, for example, if similar patterns could be generated in different abiotic and biotic conditions, or if all samples are evolving towards a common pattern. In this sense, this data could be very relevant for urban planning in terms of reducing randomness and observing tendencies of urban development patterns. We applied a hierarchical clustering analysis. This method was chosen since this bottom-up logarithm allowed us to test and select the better cluster fix-level. We developed the analysis considering the Built-up class as a proxy of urbanization intensity along the gradient. The variables PLAND, PD, A_MN and ENN_MN were standardized and analyzed under the Ward's-linkage method.

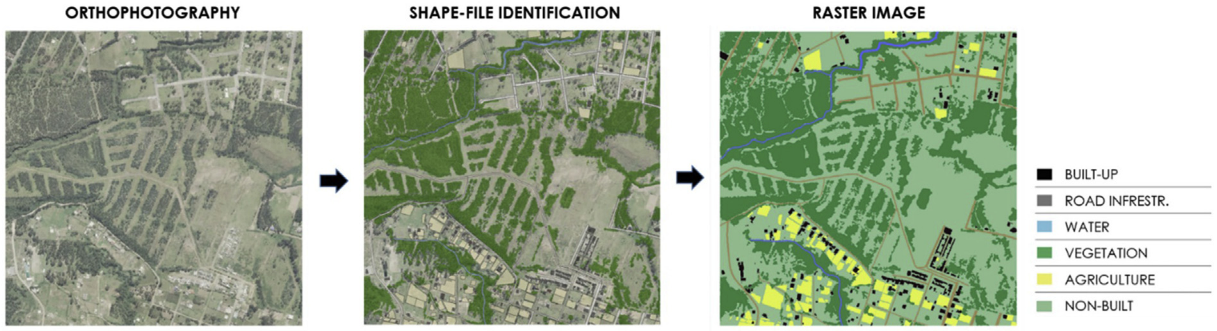


Fig. 2. Satellite interpretation process and construction of raster image with LULC.

1. BUILT-UP 2. ROAD INFRASTRUCTURE 3. TREE AND SHRUB VEGETATION 4. AGRICULTURE 5. BARE SOIL AND GRASSLAND

Fig. 3. Land use land covers (LULCs).

Table 1
Landscape metrics used in this study.

Name	Calculation Formula	Notes
Percentage of Landscape (PLAND)	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	P_i = proportion of the landscape occupied by patch type (class) i. a_{ij} = area (m2) of patch ij. A = total landscape area (m2).
Patch Density (PD)	$PD = \frac{n_i}{A}(10.000)(100)$	n_i = number of patches in the landscape of patch type (class) i. A = total landscape area (m2).
Average Area (A_MN)	$A\_MN = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10.000}\right)$	a_{ij} = area (m2) of patch ij. n_i = number of patches in the landscape of patch type (class) i.
Larger Patch Index (LPD)	$LPI = \frac{\max\limits_{j=1}(a_{ij})}{A}(100)$	a_{ij} = area (m2) of patch ij. A = total landscape area (m2).
Euclidean Nearest-Neighbor Distance (ENN_MN)	$ENN\_MN = \frac{\sum_{j=1}^{n} h_{ij}}{n'_i}$	h_{ij} = distance (m) from patch ij to nearest neighboring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center.

3. Results

3.1. Differences of landscape metric between gradients and along transects

Table 2 in general shows no significative differences in landscape metrics between the gradients of the study, except the cases of the metric patch density for the land cover built-up and the metric Euclidean nearest-neighbor distance for bare-soil. These results suggest a consistency of landscape transitions between all the gradients. In other words, we could say that the used gradients are suitable samples to represent the urban-rural transitions in the MDQ. Therefore, these gradients represent similar landscape features.

The results in Table 3 differ in comparison with the results in Table 2. The findings in Table 3 are striking. Most of the landscape metrics change between different distances to the city center. In the case of built-up, roads and vegetation, most of the changes in landscape metrics were significant. These results suggest that the landscape of urban and natural environments of the study area significantly change in the urban-rural gradients. Bare soil is the land cover that practically doesn't changes in its landscape structure, with the exception of patch density.

In this sense, landscape patterns have far more statistically significant differences along transects (as we move away from city-center) than between different gradients. These results show the great influence of distance to city centers into the spatial structure of the different LULCs. The results also suggest that the chosen gradients were a correct strategy for the applied sampling. The gradients are consistent references for the sampling.

3.2. Regression model results for the Vegetation Percentage of Landscape

Table 4 shows the regression coefficients and significance of the independent variables used in the regression model performed. The

Table 2
Kruskal-Wallis tests to assess differences of landscape metrics between gradients.

	PLAND	PD	LPI	A_MN	ENN
Built-up	0.201	0.019**	0.145	0.300	0.229
Roads	0.563	0.584	0.575	0.318	0.335
Vegetation	0.219	0.924	0.293	0.493	0.754
Agriculture	0.925	0.749	0.785	0.471	0.532
Bare-Soil	0.149	0.211	0.085	0.191	0.022**

Levels of confidence: *90%, **95%, ***99%.

Table 3
Kruskal-Wallis tests to assess differences of landscape metrics along transects (distance to the center).

	PLAND	PD	LPI	A_MN	ENN_MN
Built-up	0.000***	0.006***	0.020**	0.013**	0.000***
Roads	0.000***	0.006***	0.000***	0.036**	0.006***
Vegetation	0.040**	0.008***	0.024**	0.004***	0.281
Agriculture	0.005***	0.010***	0.019**	0.014**	0.056
Bare-Soil	0.673	0.003***	0.105	0.053	0.097

Levels of confidence: *90%, **95%, ***99%.

ANOVA significance of the model was 0,000, showing that the chosen independent variables are suitable factors to be used in the lineal model. The R2 of the model was 0.82. The Kolmogorov-Smirnov test for the residuals of the regression had a significance of 0.200 and the plot of standardized residuals and predicted values showed a random distribution, suggesting that the calculated model did not violate the assumptions of normality and homoscedasticity of residuals. The variables Road Infrastructure Percentage of Landscape (R_PLAND) and Agriculture Percentage of Landscape (A_PLAND) were found to be significant to explain Vegetation Percentage of Landscape (V_PLAND). In other words, the presence of roads and agricultural areas can influence the vegetation land cover of the study area, even more than Built-up elements. Understanding these relations could be particularly useful to support further assessments of urban expansion over natural areas.

3.2. Characterization of landscape structure along transects

By observing the metrics variation along each gradient and some relevant and more specific features were found. First, we observe that Vegetation PD tends to increase between km 9 and 21, especially in gradients 2,3,4 and 6, while LPI and A_MN tends to decrease. These patterns reflect higher levels of vegetation patch fragmentation, since they present on average small patch sizes and a higher number of patches. Geographically, this zone corresponds to periurban areas where built-up expansion is characterized for being more dispersed. Thus, we can detect that vegetation in periurban territories is particularly vulnerable to fragmentation processes. See Fig. 4. This can be related to the regression model results since road infrastructure and agricultural patches -both present in periurban territories-show to be potentially affecting the vegetation cover.

In Fig. 5, as expected, it can be observed that Built-up PLAND tends to decrease in all gradients as we advance away from the urban center. However, this decrease is not linear, it presents various increments which are directly associated with the presence of traditional rural settlements (*cabeceras parroquiales*). These were once in the outskirts of the city, but now are facing micro extension/conurbation processes. We also observed that Built-up PD decreases as we get closer to rural areas, but also in the urban cores due to fusion/aggregation of dense built typologies, and it increases in the middle of the gradients, showing higher levels of built dispersion. Similarly, Built-up A_MN increases in urban areas and where ancient *cabeceras parroquiales* are located, due to fusion/aggregation of denser typologies. Finally, distances between buildings (ENN_MN) tends to increase as we get closer to rural territories. Still, larger distances along with larger patch/building areas (A_MN), can be related to high-income class residences, as their houses are located in bigger plots with larger green areas between buildings (e.g. *Puembo,* 4th gradient, km 18). In contrast, smaller ENN distances reflect a completely different pattern of land occupation, which in many cases are related to lower-income class dwellings (e.g. *Calderon,* 5th gradient - Km18). See Fig. 6.

3.4. Cluster analysis

As result of a multivariate cluster analysis, standardizing the PLAND, PD, A_MN and ENN_MN variables for the Built-up class, a

Table 4
Regression considering Vegetation Percentage of Landscape as dependent variable. B (Built-up class), R (Road Infrastructure class), V (Vegetation class), A (Agriculture class), S (Bare soil class).

Metric	Coefficient	Significance
B_PD	−0.007	0.431
B_LPI	−4.415	0.161
R_PLAND	−3.462	0.004***
R_PD	0.146	0.581
R_A_MN	1.607	0.664
R_ ENN_MN	−0.010	0.729
V_PD	−0.006	0.179
A_PLAND	−0.925	0.001***
A_PD	0.061	0.144
A_LPI	1.335	0.165
S_PD	0.009	0.124

Levels of confidence: *90%, **95%, ***99%.

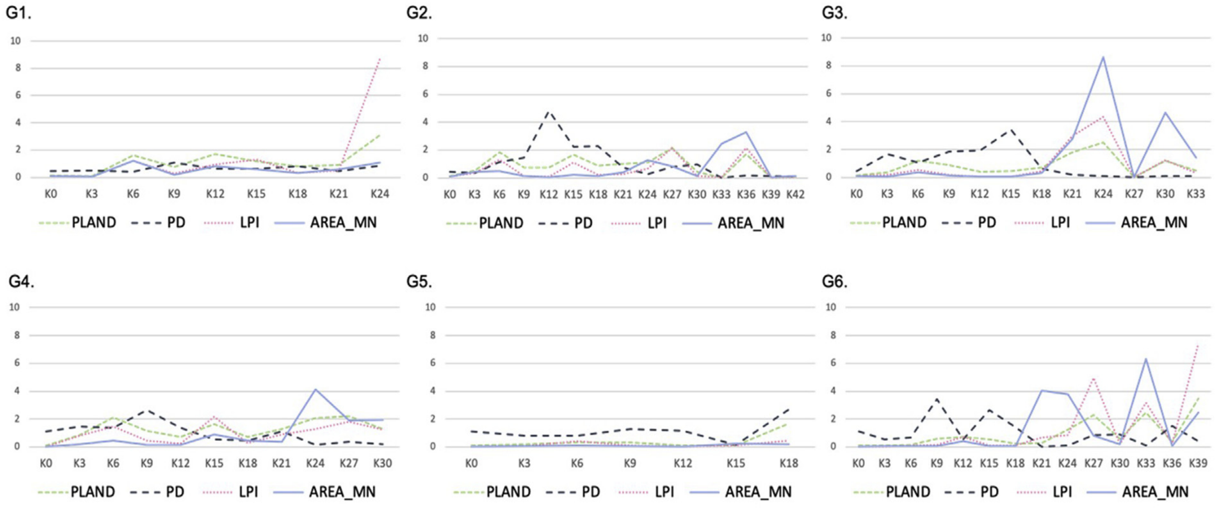


Fig. 4. Metrics variation for Vegetation cover along transects.

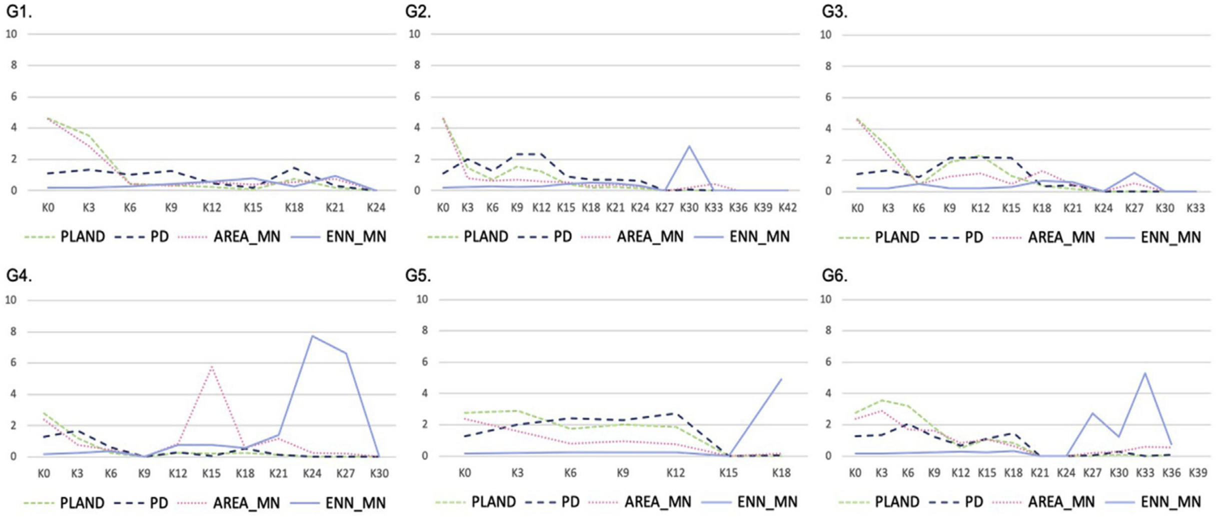


Fig. 5. Metrics variation for Built-up cover along transects.

dendrogram was obtained showing the association of five groups. The first cluster (C1) is formed by 27 samples. These are characterized by having a lower percentage of landscape (average 3.54%), fewer patches (average 222.5), average area of 0.015 ha and EEN medium-high average (16.6). Due to these characteristics, this cluster would seem to correspond to an area with very-low building density. Geographically, it is the less aggregated cluster and can be found indistinctly in the six gradients, starting from km 6 up to km 36. C2 contains 10 samples and is characterized by higher averages of PLAND (18.84%), higher PD (841.5) and lower ENN_MN (5.34). These patterns correspond to a medium dense territory. This cluster is located in a more concentrated zone, between km 3 and km 15, and it is present only in gradients 2, 3 and 5. C3 correspond to a built dense territory since it has the higher average PLAND (36.63%) and the lower EEN_MN (4.45). Its PD average is slightly lower than C2, probably due to fusion/aggregation of dense urban land occupation. Geographically, this cluster is concentrated between km 0 to 6, corresponding to urban samples. C4, on the other hand, could correspond to rural areas, as it shows the lower averages of PLAND (0.04%), PD (6.5) and A_MN (0.008ha) and the higher EEN (139.48). Finally, C5 is a cluster conformed by only one sample, which differs from C1 basically by the elevated average AREA (0.162ha) related to industrial structures.

Looking at Fig. 7, it can be noted that -in accordance with the Kruskal-Wallis test results-distance to city center influences the clustering location tendency. However, there are different levels of land occupation density that vary among gradients, regardless of the distance to the city. For example, all C2 samples are located only located in gradients 2, 3 and 5. This might be related to the aforementioned abiotic, biotic and human-driven specific conditions (such as the ecological zones, topography, pre-existent *cabeceras parroquiales* etc.).

Fig. 6. Left, km18 Gradient 4 (*Puembo*). **ENN:** 17.57m. Right, km18 Gradient 5 (*Calderón*). **ENN:** 5.02m.

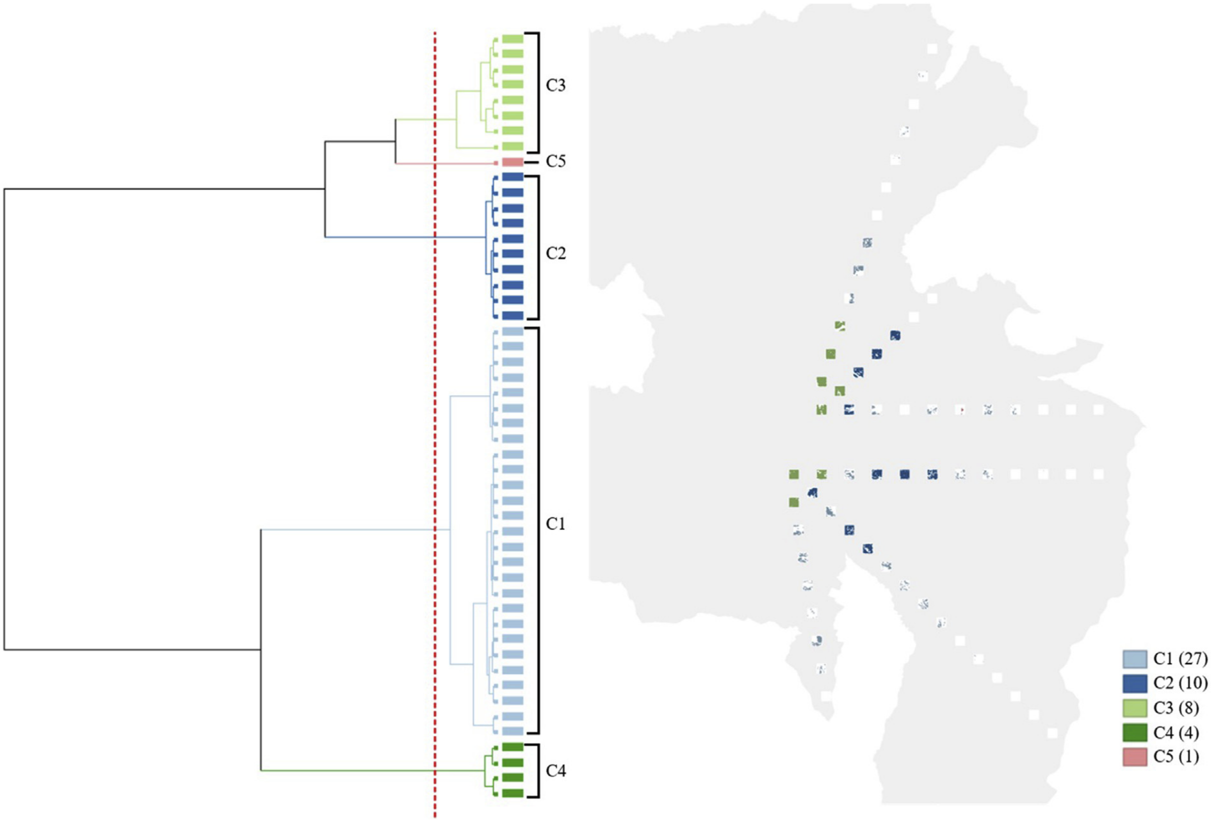


Fig. 7. Dendrogram and map of Built-up clusters.

4. Discussion

Recognizing new urbanization dynamics, an adequate planning and management of periurban territories has become a key issue for achieving a sustainable development (UN Habitat, 2013). Nevertheless, according to Geneletti et al. (2017) urban peripheries remain a marginal topic in research and sustainable planning approaches. Using landscape metrics calculation, this study provides novel and accurate data about interstitial territories within the MDQ urban-rural gradient, identifying composition and configuration patterns and their interactions. It has shown that, despite the strong influence that *distance to city center* has in shaping the urban-rural gradient, important particularities can be found among periurban territories within the same city. Frequently, when tackling periurban areas, they tend to be referred to as a generalized space (André et al., 2014; BID, 2015) and management and planning approaches can also remain general (Geneletti et al., 2017; La Rosa et al., 2017). Without question, periurban territories share common features as interstitial zones (Borsdorf, 2003; R. P. ; Ortiz et al., 2020) but this study has also shown that, while observing structural landscapes patterns, particular features ends up forming an extremely complex and diverse territory.

Satellite image interpretation at a finer scale and the calculation of landscape metrics for specific LULC has proven to be a methodology able to deliver accurate and detailed information, which can facilitate the design of appropriate land policies, more connected to local peculiarities. Transects have also been demonstrated to be a practical tool to tackle a wide territory in a very detailed scale. Nonetheless, the direction chosen to outline transects is a key decision in order to cover the landscape diversity, and it requires previous general knowledge about the territory. A hypothesis approach for each LULC allowed us to choose in a more precise manner the adequate metrics to identify the landscape composition and configuration. The most suitable metric to identify composition was PLAND, while the rest of the metrics allowed identifying the different characteristics of the spatial configuration. It is also remarkable that landscape metrics, which were originally designed to tackle research in ecological fields (Kumar et al., 2018; Liu & Weng, 2013; Seress et al., 2014; Subirós et al., 2006; Wadduwage et al., 2017), in this work have also allowed specific analysis of urban forms.

This study has shown that, despite the MDQ territory being surrounded and crossed by deep ravines and rivers, the urban fabric is still expanding over rural parishes, following a dispersed pattern in all gradients but the fifth. The obtained results are in line with a study about the urbanization process in Ecuador using night satellite images (Mejía, 2020) that shows defined trends of low-density urban dispersion over territories defined as rural. This dispersed pattern of expansion has been widely criticized for being an unsustainable model in terms of energy and environment (Hermida et al., 2015; Inostroza et al., 2013; Kasanko et al., 2006; P. ; Ortiz et al., 2019; Rueda, 2009). Our results have shown a significant percentage of Agricultural land use in territories threatened by urban expansion. Haller (2017) highlights the need for planners and policy makers to handle the risks associated to the loss of agricultural land in emerging periurban areas.

Other research has demonstrated that this dispersed pattern of urban expansion causes landscape fragmentation, threatening natural ecosystems' functioning (Kumar et al., 2018; Wadduwage et al., 2017). Particularly, our results have shown that Vegetation located in periurban areas in the proximity of the consolidated city (km 9 to 21), especially in gradients 2,3,4 and 6, presents higher levels of fragmentation, since its PLAND and A_MN decreases while its PD increases. This finding lends support to previous research. For instance, marked differences of forest density have been found between urbanized areas and preserved areas (Porter et al., 2001) and more dispersed vegetation patches are commonly found in urbanized areas (Kowe et al., 2020). The condition of natural vegetation fragmentation certainly has ecological implications, considering that the city of Quito is part of a more complex system. Stenhouse (2004) found that remnant vegetation in metropolitan areas is clearly affected by urbanized areas and vegetation fragmentation is one of the main problems of metropolitan natural areas. Correspondingly, our regression model has proven that roads' presence affects the vegetation LULC, probably due to fragmentation processes. It has also shown that agricultural areas significantly influence the vegetation cover. In this sense, various studies affirm that agriculture can be considered a main driver of landscape change, affecting natural ecosystems and biodiversity (Jeliazkov et al., 2016; Tilman et al., 2001; Vizzari et al., 2018). This study is a first step to understand the landscape composition and configuration patterns of the MDQ. In this sense, we consider it a priority to properly manage not only the natural reserves in the MDQ, but also urban and peri urban remnants of natural vegetation that are habitats for some species and ecological corridors for other species.

The role of parishes' main settlements (*cabeceras parroquiales*) has been a key driver in the patterns of MDQ urban expansion. For example, when analyzing Built-up PLAND, A_MN or PD, we can easily identify the presence or influence of these settlements, since outside the urbanized area, building peaks can be observed. According to Serrano Heredia and Duran (2020), the socio-spatial configuration of the MDQ has resulted in the production of new centralities in its periurban areas. These centralities correspond to *cabeceras parroquiales* that have been expanding and -in some cases-conurbating with the consolidated city. This can be easily observed (Fig. 5), for instance, in gradient 1, km 18, in the main settlement of *Amaguaña*, in gradient 3, km 12, in *Tumbaco*, or in gradient 6, km 18, in the *cabecera parroquial* of Pomasqui. Facing this scenario, urban planners and policy makers should analyze these particular structures for future city expansion, since these settlements would determine certain expansion-consolidation patterns.

La Rosa et al. (2017) affirms that peripheries are the outcome of physical, social, economic, institutional and cultural features as well as political decision-making at different scales. Accordingly, the conformation of the MDQ diverse peripheries could respond to different social, political processes and geographical settings. Achig (1983) refers to the recurrent social classes' segregation as a key determiner in the history of MDQ territorial conformation. Neighborhoods and sectors with better livability conditions tend to be grouped in determined zones, while others -that remain in highly precarious conditions-are excluded and grouped in other zones of the city (Carrión & Erazo Espinosa, 2012; Sabatini, 2003). By looking at the spatial patterns (Figs. 5 and 6), it can be inferred that this situation has been expanded and transposed to peripheral settlements. In this sense, we identified transects with high levels of building densification, which tend to be occupied by lower income population, while other transects showed households occupied by population with higher income which present a more dispersed spatial distribution. These first interpretations, based on the analysis of landscape characteristics, although they allow us to observe general spatial features, should be complemented with studies that address other economic and social logics.

Recognizing the landscape diversity and complexity within the DMQ urban-rural gradient, a clustering process could be a useful tool to identify territories with common characteristics and needs, allowing a more accurate management. The hierarchical cluster analysis developed, allowed us to clearly identify five groups within the urban-rural gradient. Due to their spatial patterns, they could be initially classify as urban (C3), periurban/rururban (C1, C2, C5) and rural (C4) (André et al., 2014; R. P. ; Ortiz et al., 2020). In general terms, distance to the city center influences the clustering pattern, however, important differences were identified among gradients. For example, only 3 of them concentrate all C2 samples. This is related to the aforementioned abiotic, biotic and human-driven specific conditions. In this study, the Built-up class was explored in the clustering analyses, demonstrating to be a good proxy in terms of urban expansion. However, analyzing other LULC in a future stage, could enrich the classification, generating even more specific typologies.

Finally our results suggest that the MDQ presents patterns of urban diffusion and coalescence (Dietzel et al., 2005). The diffusion starts at the urban core of the city of Quito, and urban areas expand to eastern rural parishes where some emerging urban zones merge, with the potential of scaling-up the urbanization process. A multi-peaked pattern was identified in the metric of percentage of landscape for Built-up and Vegetation covers. This finding indicates polycentric landscape patterns that reveal a heterogeneity that may be associated with the urban expansion: some emerging urban areas are intercalated with some agricultural or vegetation areas. This finding is consistent with previous findings of heterogeneity of landscape in terms of urban-rural gradients (Yu & Ng, 2007). Actually, an urbanization process can be very complex and an urban-rural distance alone could only support a partial understanding of this process (McDonnell et al., 1997). However, the diverse spatial metrics calculated in our study clearly reveal the complexity of the spatial patterns of urban-rural landscapes and identify local changes in land use patterns that are not usually considered in classical urban theories that are mainly based on social and economic assumptions (Yu & Ng, 2007).

5. Conclusions

The aim of this article was to have a better understanding of the urban-rural gradient of the MDQ, addressing its landscape composition and configuration patterns. Through high-detail LULC identification in satellite images and the calculation of landscape metrics, this study has demonstrated the great landscape diversity that exists within the MDQ periurban area. It has also detected and systematized specific characteristics, opportunities and vulnerabilities along rural parishes that are experiencing pressure for urban development. This data can be useful to planners and policy makers in order to lead more specific and accurate land regulations, since -nowadays- land policies in the MDQ tend to be quite generalist and, in terms of peripheral contexts, territorial strategies should be adjusted to particular local conditions and needs (Geneletti et al., 2017; La Rosa et al., 2017). This data can be useful to planners and policy makers in order to lead more specific and accurate land regulations, since -nowadays- land policies in the MDQ tend to be quite generalist and, in terms of peripheral contexts, territorial strategies should be adjusted to particular local conditions and needs (Geneletti et al., 2017; La Rosa et al., 2017). For example, policies related to natural areas protection could be reinforced in areas that have proven to be more vulnerable. This study has empirically showed the fragility of vegetation covers in specific periurban areas (e.g. parishes of Alangasí, Tumbaco, Tababela, San Antonio. Gradients 2,3,4 and 6). To stop the fragmentation of this land cover, it is essential to control the dispersed expansion in the most affected parishes as a mechanism to guarantee the conservation of vegetation and its multiple ecosystem services. Likewise, having specific policies for the protection of agricultural areas will allow, on the one hand, to guarantee the food sovereignty of the MDQ, but also protect the natural areas that are currently threatened by the relocation of agricultural land, as our regression model shown. Finally, recognizing the role of the cabeceras parroquiales in the expansion/consolidation of the urban area of the DMQ, it is essential that policy makers develop specific plans for those cabeceras parroquiales that still do not present an evident conurbation (Pintag, Checa, Yaruquí), preventing land occupation patterns that could generate greater environmental impacts.

This methodology has proven to be highly effective in terms of identifying landscape structure in the MDQ but it could also be replicated to other Latin American cities, where knowledge about urban peripheries -these hybrid and highly changing landscapes-is limited.

Declaration of competing interest

Please check the following as appropriate:

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.
This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.
The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript
The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

Acknowledgements

This research was funded by the Académie de recherche et d'enseignement supérieur (ARES), Belgium.

References

Achig, L. (1983). El proceso urbano de Quito. *Centro de Investigaciones CIUDAD*, 1–100.

André, M., Mahy, G., Lejeune, P., & Bogaert, J. (2014). Toward a synthesis of the concept and a definition of the zones in the urban-rural gradient | Vers une synthèse de la conception et une définition des zones dans le gradient urbain-rural. *Biotechnology, Agronomy, Society and Environment, 18*(1), 61–74. https://doi.org/10.1016/S0958-6946(03)00151-1

Antrop, M., & Van Eetvelde, V. (2000). Holistic aspects of suburban landscapes: Visual image interpretation and landscape metrics. *Landscape and Urban Planning, 50*(1–3), 43–58. https://doi.org/10.1016/S0169-2046(00)00079-7

BID. (2015). *Cuenca ciudad sostenible*. http://propone.net/cccv.ec/docs/cuenca-cuidad-sostenible.pdf.

Bogaert, J., Biloso, A., Vranken, I., & André, M. (2015). *Peri-urban dynamics : landscape ecology perspectives. Territoires Périurbains. Développement, Enjeux et Perspectives Dans Les Pays Du Sud* (pp. 59–69).

Bogaert, J., Vranken, I., & Andre, M. (2014). Biocultural landscapes. https://doi.org/10.1007/978-94-017-8941-7.

Borsdorf, A. (2003). Como modelar el desarrollo y la dinâmica de la ciudad latinoamericana. *Eure, XXIX*(86), 37–49. https://doi.org/10.4067/S0250-71612003008600002

Carrión, F., & Erazo Espinosa, J. (2012). La forma urbana de Quito: Una historia de centros y periferias*. *Bulletin de l'Institut Français d'études Andines, 41*(3), 503–522. https://doi.org/10.4000/bifea.361

da Cunha, J. M. P., & Jorge, R.-V. (2009). Crecimiento urbano Urban growth and population mobility in Latin America. *Revista Latinoamericana de Población, 3*(4–5), 27–64.

Dietzel, C., Herold, M., Hemphill, J. J., & Clarke, K. C. (2005). Spatio-temporal dynamics in California's Central Valley: Empirical links to urban theory. *International Journal of Geographical Information Science, 19*(2), 175–195. https://doi.org/10.1080/13658810410001713407

Forman, Richard, & Godron, Michel (1986). *Landscape ecology*. New York: Wiley.

Geneletti, D., La Rosa, D., Spyra, M., & Cortinovis, C. (2017). A review of approaches and challenges for sustainable planning in urban peripheries. *Landscape and Urban Planning, 165*, 231–243. https://doi.org/10.1016/j.landurbplan.2017.01.013

Habitat, U. N. (2013). State of the world's cities 2012/2013: Prosperity of cities. In *State of the world's cities 2012/2013: Prosperity of cities*. https://doi.org/10.4324/9780203756171

Hahs, A. K., & McDonnell, M. J. (2006). Selecting independent measures to quantify Melbourne's urban-rural gradient. *Landscape and Urban Planning, 78*(4), 435–448. https://doi.org/10.1016/j.landurbplan.2005.12.005

Haller, A. (2017). Urbanites, smallholders, and the quest for empathy: Prospects for collaborative planning in the periurban Shullcas Valley, Peru. *Landscape and Urban Planning, 165*, 220–230. https://doi.org/10.1016/j.landurbplan.2016.04.015

Harvey, D. (1989). The condition of postmodernity: An enquiry into the origins of cultural change. In *The condition of postmodernity: An enquiry into the origins of cultural change*. https://doi.org/10.2307/2072256

Hermida, M. A., Hermida, C., Cabrera, N., & Calle, C. (2015). La densidad urbana como variable de análisis de la ciudad . El caso de Cuenca , Ecuador. *Eure, 41*, 25–44.

Hidalgo, R., Borsdorf, A., & Sánchez, R. (2007). Hacia un nuevo tejido rurbano: Los megaproyectos de ciudades valladas en la periferia de Santiago de Chile. *Ciudad y Territorio - Estudios Territoriales, 14883*(151), 115.

Inostroza, L. (2017). Informal urban development in Latin American urban peripheries. Spatial assessment in Bogotá, Lima and Santiago de Chile. *Landscape and Urban Planning, 165*, 267–279. https://doi.org/10.1016/j.landurbplan.2016.03.021

Inostroza, L., Baur, R., & Csaplovics, E. (2013). Urban sprawl and fragmentation in Latin America: A dynamic quantification and characterization of spatial patterns. *Journal of Environmental Management, 115*, 87–97. https://doi.org/10.1016/j.jenvman.2012.11.007

Jeliazkov, A., Mimet, A., Chargé, R., Jiguet, F., Devictor, V., & Chiron, F. (2016). Impacts of agricultural intensification on bird communities: New insights from a multi-level and multi-facet approach of biodiversity. *Agriculture, Ecosystems & Environment, 216*, 9–22. https://doi.org/10.1016/j.agee.2015.09.017

Kasanko, M., Barredo, I., Lavalle, C., Mccormick, N., Demicheli, L., Sagris, V., & Brezger, A. (2006). Are European cities becoming dispersed ? *A comparative analysis of 15 European urban areas, 77*, 111–130. https://doi.org/10.1016/j.landurbplan.2005.02.003

Kowe, P., Mutanga, O., Odindi, J., & Dube, T. (2020). A quantitative framework for analysing long term spatial clustering and vegetation fragmentation in an urban landscape using multi-temporal landsat data. *International Journal of Applied Earth Observation and Geoinformation, 88*(February), Article 102057. https://doi.org/10.1016/j.jag.2020.102057

Kumar, M., Denis, D. M., Singh, S. K., Szabó, S., & Suryavanshi, S. (2018). Landscape metrics for assessment of land cover change and fragmentation of a heterogeneous watershed. *Remote Sensing Applications: Society and Environment, 10*(April), 224–233. https://doi.org/10.1016/j.rsase.2018.04.002

La Rosa, D., Geneletti, D., Spyra, M., & Albert, C. (2017). Special issue on sustainable planning approaches for urban peripheries. *Landscape and Urban Planning, 165*(May), 172–176. https://doi.org/10.1016/j.landurbplan.2017.04.004

Liu, H., & Weng, Q. (2013). Landscape metrics for analysing urbanization-induced land use and land cover changes. *Geocarto International, 28*(7), 582–593. https://doi.org/10.1080/10106049.2012.752530

Luck, M., & Wu, J. (2002). A gradient analysis of urban landscape pattern: A case study from the phoenix metropolitan region, Arizona, USA. *Landscape Ecology, 17*(4), 327–339. https://doi.org/10.1023/A:1020512723753

McDonnell, M. J., Pickett, S. T. A., Groffman, P., Bohlen, P., Pouyat, R. V., Zipperer, W. C., Parmelee, R. W., Carreiro, M. M., & Medley, K. (1997). Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystems, 1*(1), 21–36. https://doi.org/10.1023/A:1014359024275

Mejía, V. (2020). Morfología urbana y proceso de urbanización en Ecuador a través de la imagen satelital nocturna de la Tierra , 1992-2012. *Eure, 46*(138), 191–214.

Municipio del Distrito Metropolitano de Quito. (2014). *Ciudades del Buen Vivir, Quito hacia un modelo sustentable: Red Verde Urbana y Ecobarrios*.

Newman, P. W. G., & Kenworthy, J. R. (1996). The land use-transport connection: An overview. *Land Use Policy, 13*(1), 1–22. https://doi.org/10.1016/0264-8377(95)00027-5

Ortiz, R. P., Boisson, S., Torres, M., & Bogaert, J. (2020). Analysis OF the urban-rural gradient terminology and its imaginaries IN a Latin-AMERICAN context. *Theoretical and Empirical Researches in Urban Management, 15*(2), 81–98.

Ortiz, P., Pinto, V., Aguirre, M., Peláez, V., Paz, D., & Enríquez, D. (2019). *Recomendaciones de políticas urbanas para el uso y la gestión del suelo en Cuenca*.

Porter, E., Forschner, B., & Blair, R. (2001). Woody vegetation and canopy fragmentation along a forest-to-urban gradient. *Urban Ecosystems, 5*(2), 131–151. https://doi.org/10.1023/A:1022391721622

Rueda, S. (2009). *EL urbanismo ecológico: UN nuevo urbanismo para ABORDAR los retos de la sociedad actual* (Vols. 1–34).

Sabatini, F. (2003). La segregación social del espacio en las ciudades de América Latina. *Banco Interamericano de Desarrollo, 35*, 59–70. https://doi.org/10.4067/S0250-71612001008200002

Seress, G., Lipovits, Á., Bókony, V., & Czúni, L. (2014). Quantifying the urban gradient: A practical method for broad measurements. *Landscape and Urban Planning, 131*, 42–50. https://doi.org/10.1016/j.landurbplan.2014.07.010

Serrano Heredia, C. J., & Duran, G. (2020). Geografía de las nuevas centralidades en el periurbano de Quito: Un análisis de la evolución espacial en las parroquias Cumbayá-Tumbaco y San Antonio de Pichincha (2001-2010). *EURE (Santiago), 46*, 247–271.

Soja, E. W. (2008). Postmetrópolis. Estudios críticos sobre las ciudades y las regiones. https://doi.org/10.1017/CBO9781107415324.004.

Stenhouse, R. N. (2004). Fragmentation and internal disturbance of native vegetation reserves in the Perth metropolitan area, Western Australia. *Landscape and Urban Planning, 68*(4), 389–401. https://doi.org/10.1016/S0169-2046(03)00151-8

STHV. (2012). *Plan metropolitano de ORDENAMIENTO territorial*. ORDENANZA No 0171.

Subirós, J. V., Linde, D. V., Pascual, A. L., & Palom, A. R. (2006). Conceptos y métodos fundamentales en ecología del paisaje (landscape ecology). Una interpretación desde la geografía. *Documents d'Analisi Geografica, 48*, 151–166. https://doi.org/10.1007/BF00223681

Sudhira, H. S., Ramachandra, T. V., & Jagadish, K. S. (2004). Urban sprawl: Metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation, 5*(1), 29–39. https://doi.org/10.1016/j.jag.2003.08.002

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D., & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science, 292*(5515), 281–284. https://doi.org/10.1126/science.1057544

Vanderhaegen, S., & Canters, F. (2017). Mapping urban form and function at city block level using spatial metrics. *Landscape and Urban Planning, 167*(August), 399–409. https://doi.org/10.1016/j.landurbplan.2017.05.023

Vizzari, M., Hilal, M., Sigura, M., Antognelli, S., & Joly, D. (2018). Urban-rural-natural gradient analysis with CORINE data: An application to the metropolitan France. *Landscape and Urban Planning, 171*(November 2017), 18–29. https://doi.org/10.1016/j.landurbplan.2017.11.005

Vizzari, M., & Sigura, M. (2015). Landscape sequences along the urban-rural-natural gradient: A novel geospatial approach for identification and analysis. *Landscape and Urban Planning, 140*, 42–55. https://doi.org/10.1016/j.landurbplan.2015.04.001

Wadduwage, S., Millington, A., Crossman, N. D., & Sandhu, H. (2017). Agricultural land fragmentation at urban fringes: An application of urban-to-rural gradient analysis in adelaide. *Land, 6*(2), 28. https://doi.org/10.3390/land6020028

Weng, Y. C. (2007). Spatiotemporal changes of landscape pattern in response to urbanization. *Landscape and Urban Planning, 81*(4), 341–353. https://doi.org/10.1016/j.landurbplan.2007.01.009

Yu, X. J., & Ng, C. N. (2007). Spatial and temporal dynamics of urban sprawl along two urban–rural transects: A case study of guangzhou, China. *Landscape and Urban Planning, 79*(1), 96–109. https://doi.org/10.1016/j.landurbplan.2006.03.008