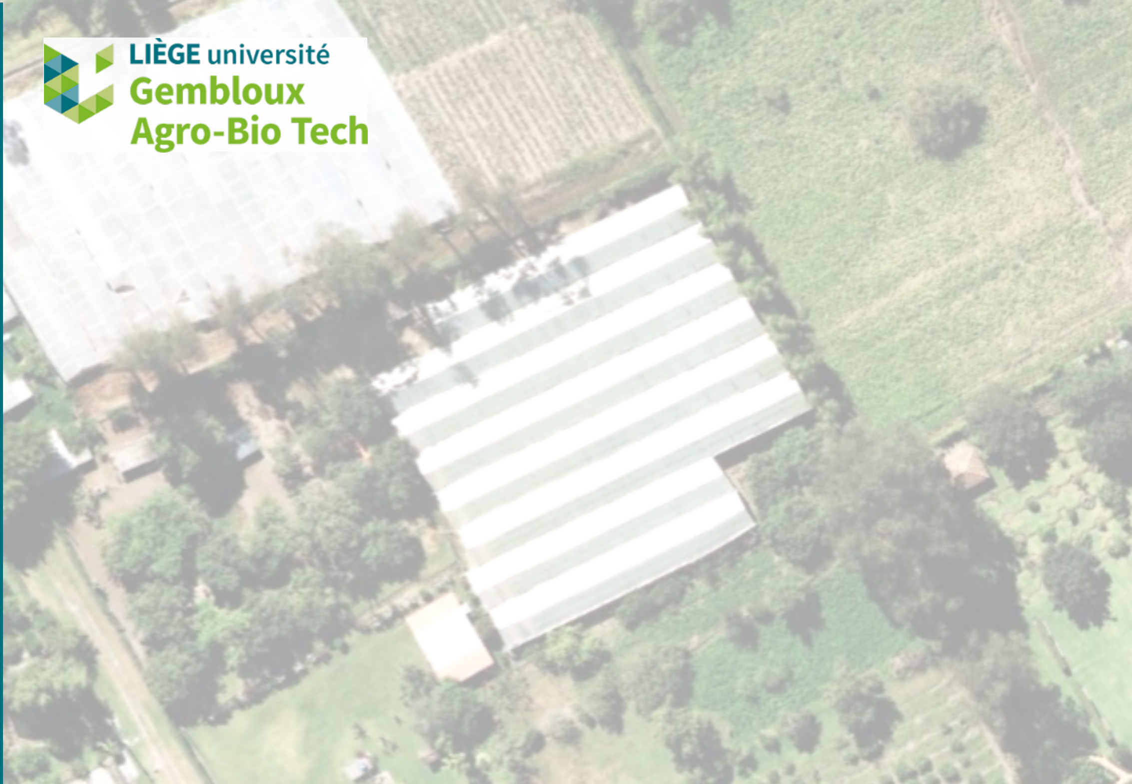

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CHARACTERIZATION OF PERI-URBAN TERRITORIES: PATTERNS AND DYNAMICS.

The case of the Metropolitan District of Quito, Ecuador

COMMUNAUTÉ FRANÇAISE DE BELGIQUE
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CHARACTERIZATION OF PERIURBAN TERRITORIES: PATTERNS AND DYNAMICS. The case of the Metropolitan District of Quito, Ecuador

Paola ORTIZ-BÁEZ

Dissertation originale présentée (ou essai présenté) en vue de l'obtention du grade de doctorat en sciences agronomiques et ingénierie biologique

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Abstract

In contexts of globalization, economic restructuring and information and communication revolution, the relocation of services in peripheries and new urban expansion patterns have dramatically altered periurban landscapes. Particularly, Latin American contemporary cities are facing a rapid urban dispersion which is mainly occurring in these zones. 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. Since these transitional spaces remain geographically and conceptually unclear, having a greater understanding of its landscape composition has become a key issue for territorial planning purposes.

Firstly, this contribution aims at establishing new precisions about the most recurrent terms used in the scientific literature to describe the urban-rural gradient in a Latin-American context. As methodology, in order to identify and systematize the most outstanding attributes for each term, a Citation Frequency Index has been calculated. Also a Sorensen Similarity Index has been developed to identify distinctions and synergies among terms, obtaining a wider understanding of these territories and its interactions. In this section we highlight the importance of specific studies that distinguish the conceptual nuances of terminology in each region and the realities and imaginaries they represent.

Then, as our case of study, the Metropolitan District of Quito (MDQ) urban-rural gradient, its landscape structure and its spatiotemporal transformations, were analyzed. Focusing in 1 square kilometer 64 samples based on high resolution satellite images, this research tested a novel and accurate method to identify urbanization patterns and its dynamic in the last decade. Here, various research methods were applied: landscape metrics calculation to undestand the landscape structure, a multivariate cluster analysis to recognize samples' similarities/differences, a transition matrix along with a stability index to analyze landscape composition change intensity, the Markov chains modelling technique as a land change tendency analysis, among others.

Results suggest that the MDQ presents patterns of urban diffusion and coalescence. The diffusion starts at the urban core and expands to rural parishes where some emerging traditional settlements merge, constituting a complex pattern of urbanization. Results also demonstrate that peri-urban areas show the highest landscape instability within the urban-rural gradient, although through a great diversity of land occupation typologies. Parsing LULCs independently, vegetation showed the greatest instability, which significantly alters ecosystems and their services, threatening the territory's environmental sustainability. Particularly, significant levels of fragmentation were identified in this LULC within the periurban areasSimilarly, the analyses identify

significant changes in agricultural coverages which highly are related to rural lots subdivision, evidencing the environmental fragility of these territories in transformation. On the other hand, the mega-road infrastructure that connects the city with the airport (located in the city outskirts), appears to be one of the most dramatic drivers of peri-urban transformation, evidencing the main role that these infrastructures have had in urban expansion. However, results show that there are other drivers such old historical settlements in the city outskirts or land price that are also strongly influencing periurbanization dynamics.

Finally, this research thesis proposes and tests an analytical approach which could be applied to other Latin-American cities, where urban expansion patterns remain unknown and where micro-scale policymaking should be a priority in scenarios of complex and highly heterogeneous peri-urbanization. This methodology is particularly useful for land-use planning policies since it provides precise knowledge about urbanization patterns and its main tendencies.

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List of acronyms

A_MN Average Area

ENN_MN Average Euclidean Nearest-Neighbor Distance

CFI Citation Frequency Index

LPI Larger Patch Index

LULC Land Use-Land Covers

MDQ Metropolitan District of Quito

PLAND Percentage of Landscape

PD Patch Density

PUGS Land use and management plan

SSI Sorensen Similarity Index

Chapter 1

General introduction

1.1 Theoretical Framework

1.1.1 Urban metamorphosis

The United Nations agency for human settlements (UN-Habitat) has declared the arrival of an "urban age" due to the rapid population growth in cities, on a planetary scale. The step towards this urban era has been a progressive process but with an exponential variation in the last decades. In fact, in 1950 there were two and a half billion people in the world, of whom 30% lived in cities. By 2000, of six billion people, 46% lived in cities and in 2017, of seven billion, 50% were urban population (ONU, 2019 en Bernal & Orcid, 2021). In this scenario, the shape and structure of cities have also changed. The morphology of urbanization is acquiring new and larger patterns, disintegrating the old distinction between urban and rural land (Brenner, 2013). To understand the current urban pattern --which is substantially different from the one that determined the city structure in previous phases-- it is necessary to explore history in aims of understanding how socioeconomic and technological aspects have shaped cities over time.

Several authors have analyzed this evolution from different perspectives. For example, the Newman & Kenworthy (1996) theoretical proposal looks at the history of cities in terms of transportation/land use. Based on that, the authors identify three major moments in urban form that are closely related to the evolution of transportation technologies. These three city models are presented in Figure 1.

The first figure represents the *Traditional walking city*, with high population densities (100-200 inhabitants/ha) and mixed uses, present until 1850 mainly in Europe. The second phase, which has been conceived as *Transit city* and refers to the cities that were established in the second half of the 19th century and the first decades of the 20th century. In this era, trains and trams allowed faster travel speeds and shaped a new spatial pattern. Trains generated sub-centers around their stations while the tram promoted a linear development that followed the routes of the existing road network. The cities could now spread from 20 to 30 km from the center depending on the systems they adapted, also generating a reduction in population density (50-100 inhabitants/ha). Most of the North American cities were built in this era and many maintain characteristics of this period.

Finally, the period that the authors have defined as the *Automobile city* began before the Second World War and was consolidated until the last years of the 20th century. The new transportation technology, the increasingly affordable motorized vehicles, is the primary shaper of this era. Here, low-density suburban housing expanded exponentially thanks to the new travel speeds and flexibility. The result has been the formation of cities with a dispersed spatial morphology, low density (10-20 inhabitants/ha) and with zoned and separated land uses. A city where the limits have become more diffuse.

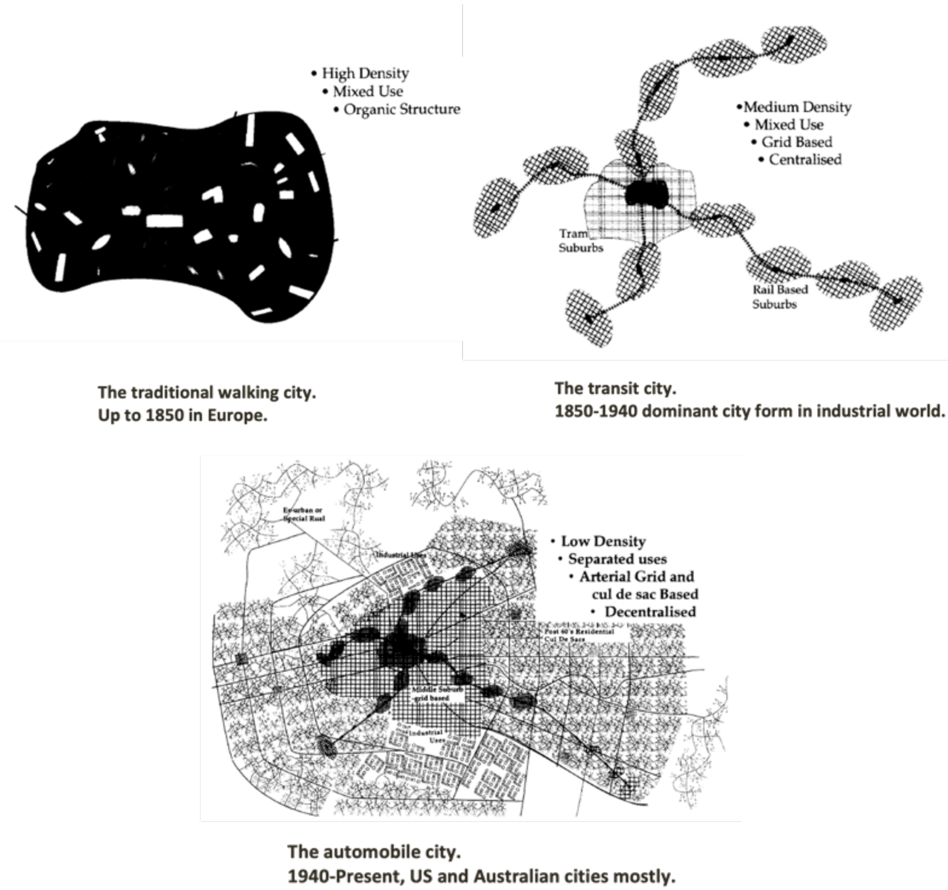


Figure 1. The evolution of the urban form in the United States based on transport systems.
Source: Newman & Kenworthy (1996)

On the other hand, Soja (2008) in his book Postmetropolis, also analyzes the metamorphosis of cities since the mid-18th century but focusing on the different geohistorical periods. This analysis is supported on a periodicity of the urban form which is related to the macroeconomic and cultural rhythms of capitalist development and its interaction with modernization. Considering cycles of approximately 50 years, the author identifies four periods of urban industrial capitalism. Each cycle begins with several decades of rapid economic growth in the most advanced industrial countries. Subsequently, these periods of economic boom reach their zenith in disruptive crises (generally related to accumulation constraints and capitalist profits) and are followed by periods of decelerated economic growth. Finally, these crises culminate in restructuring processes with the aim of initiating a new stage of accelerated economic. Briefly, the four periods are identified as follows:

The first cycle begins in the middle of the 19th century, called by Hobsbawn as the Age of Capital (1848-1878). This is a period of important economic expansion due to the consolidation of the Industrial Revolution in the cities, mainly of northwestern Europe. It was characterized as an initial phase of highly competitive free markets and strictly laissez-faire industrial capitalism. It reached its zenith in the early 1870s. Subsequently, several decades of restructuring and transition followed, where a new mode of capitalist development emerged. This second period was characterized by the rise of large corporations that reshaped competition and control over local and national economies. Free market competition was reduced through limited state intervention and the power of corporate monopolies. This new corporative-monopoly-imperialist mode of capitalist development would develop further at the beginning of the 20th century and would enter into a deep crisis during the Great Depression.

A third period, which lasted from the 1920s through the Great Depression to the end of World War II, has been closely associated with the names of Henry Ford and John Maynard Keynes. This different mode of capitalist development is built on the basis of large-scale production, mass consumption, and mass urbanization. It is based on an established social contract that linked big capital (symbolized in the automobile industry - Fordist), with the big national unions and a large state intervention in the economy in order to stimulate growth and maintain the expansion of social welfare (Keynesian proposal). This era of Fordist-Keynesian capitalist development entered into crisis at the end of the 1960s and -according to Soja's postulates- until the first decade of the present century it was still undergoing significant restructuring. This has led various theorists to describe the present era, the fourth one, as post-Fordist, post-Keynesian, post-industrial, post-modern.

Based on these periods, in the book *Postmodern Geographies*, Soja (1989) develops a series of cartography prototypes --mainly inspired by North American cities-- which illustrate the evolution of urban form in the period between 1820 and 1970 (Figure 2). These models represent the geohistorical process of urban space up to the emergence of the contemporary city as a product of the most recent restructuring wave.

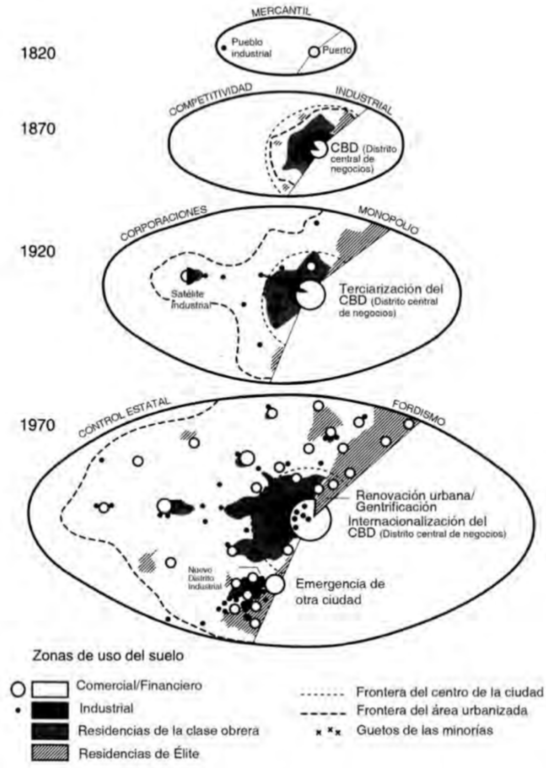


Figure 2. The evolution of urban form in the United States
Source: Soja, 1989, p.174.

The first graphic represents the small and compact mercantile city, with its dense mixture of residences of different social groups, grouped around a key place of exchange and commerce (port or central railway station). The industry is still located in a factory town outside the city, a place where power for the machinery is readily available. The poorer residential areas were also outside the city, in the form of ramshackle shelters. The second graph corresponds to a more intense model of a competitive, centralized and zoned industrial capitalist city. This took place from the late 1840s to the 1870s. But as in the mercantile city, the dynamics in this industrial/capitalist urban space would generate internal tensions and political discontent. The profound impoverishment of industrial workers and their dense residential concentration in the inner ring of the city, generated a growing mobilization and class consciousness. While, on the other hand, the affluent -- albeit reduced -- bourgeoisie had located themselves in garden suburbs outside the city.

During the last three decades of the 19th century, the classic industrial urban space was rethought in an effort to provide a new spatial solution to the problems of the industrial capitalist city. This generated a series of major restructurings, disguised as modernization and new developments. Thus, the third graph represents a monopolistic-corporate city, constituted in the period between 1870 and 1920. At this point, the evolution of the urban form becomes much more complex, to the extent that a greater diversity of specific geographies is generated. The classic urban space did not disappear, but its previously clearly defined and highly centralized structure began to disintegrate in various ways. In particular, a decentralization of factories, residences, offices, shops, public services, and other urban activities occurred. This not only spread the concentric zones outwards, in an uncontrolled process of suburbanization, but also made each existing zone less homogeneous. Likewise, urban space and life became increasingly fragmented, not only in terms of residential land use but also in patterns of local government, social class, race, and ethnic identity. On the other hand, an important recentralization of financial and banking activities also occurred in some cities (Chicago, NYC), which is evident in high-rise office buildings in the civic center and in the Central Business District. These new tenants assumed increasing responsibility for planning and regulating the expansion of urban space alongside local government officials. This agreement was accompanied by a significant return of the upper classes to residences located in the center of the city.

Finally, the last graph refers to the period between the Great Depression and the end of World War II. A new series of restructurings generated by economic crises once again reshaped the urban space. This process would extend many of the trends that had already become evident in the last period, but the cumulative effect would produce some significant changes. Backed by an alliance between big government (Keynesian), capital, and labor, the growth of large-scale production (Fordist), the rise of consumerism, and mass suburbanization led to an increasing sprawl of factories and workers. Thus arose the Fordist regional metropolis that was simultaneously urban and suburban. In this period, on the one hand, the suburban areas were consolidated extremely fragmented, in a large number of autonomous municipalities. On the other, there were battles for the center of the city, between those who aimed destroying and rebuilding everything versus those who sought a less invasive actions. According to Soja (2008), the crisis of this period uncovered the deep weakness and critical gaps in the urban theories and practices developed during the previous century. Although, most of the intensions in urban planning and development sought regularity and order, what really happened in the metropolises after this period was massive suburbanization, the rise of a car-based consumer culture, metropolitan political fragmentation, the decline of the inner city, further segregation, and ghettoization.

1.1.2 Postmetropolis, the contemporary city and its ubiquity

After the urban explosions in the 1960s, explained in the previous paragraphs, urban patterns developed in an increasingly complex ways. Castells (1977) used the term *la ville sauvage*, the wild city, to describe the new urban forms in North America and Europe during the post-war period. It has become a new unstable and volatile urban space, characterized by suburbanization on the one hand and metropolization on the other, in a world of new media and technologies. Since this wild city is being consolidated under new and more ethereal patterns and there is no specific term to describe this emerging urban space, Soja (2008) has chosen to call it *Postmetropolis,* as a process of deconstruction of the modern *metropolis*. This term aims to highlight the differences among contemporary urban regions and the modern metropolis consolidated in the mid-twentieth century. Thus, the prefix *post*, shows the transition between these two moments: the modern city and new post-modern patterns of urban life (Soja, 2003).

At this point, it is important to clarify that, although the conceptualization of Postmetropolis is mainly inspired by the unique urban experience of Los Angeles, the author recognizes that it also represents a "*particularly vivid example of a more general sea change in the very nature of contemporary urban life*" (Soja, 2003, p.2). It means that this phenomenon is happening not only in Los Angeles, but *"in varying degrees and, to be sure, unevenly developed over space and time, all over the world*" (Soja, 2003, p.2). Thus, Postmetropolis not only describes a specific pattern of new urban forms, but also refers to a postmodern era, which responds to new trends or processes in various fields.

To get closer to the notion of post-metropolis, Soja develops six discourses expanding these different aspects that are reshaping the current cities and their complex socio-spatial interactions. Globalization and the post-Fordist economic restructuring are presented as the most powerful processes that have caused the restructuring of the modern city. The second pair of discourses show the empirical consequences of these processes. The third refers to the restructuring of the urban form and the growth of cities, which Soja has called the *Exopolis*. "Exo" referring both to the growth of the city "outside" traditional urban cores and to the city that no longer offers the traditional qualities of citizenship. This is a discontinuous, fragmented and increasingly polycentric territory, with particular difficulty delineating its external borders. The fourth discourse refers to the increase in social inequalities, new types of social polarization and stratification within contemporary cities. Finally, the fifth and sixth discourses incur on the social response to the effects of urban restructuring. The fifth analyzes the rise of fortress-cities, surveillance technologies, and the substitution of police for polis. And the last discuss about the imaginary urban restructuring and the increasing hyperreality of daily life.

The diversity of aspects that are addressed in the discourses on the post-metropolis allow us to visualize how the transition between the modern metropolis and new socio-territorial forms is reaching a certain turning point or threshold. This does not mean that the modern city has disappeared or is completely displaced (not even in Los Angeles, the author affirms), but rather that the new urbanization and configuration processes have superimposed on the old ones. They have connected with them in increasingly complex ways and at different levels of intensity according to the process of each territory (Soja, 2003).

In the same line, and alluding this new city form, Chambers (1990) recognizes that something extraordinary has happened to the cities of the late 20th century, a change so radical that it renders the old ways of understanding the city and urban space totally anachronistic. He argues that the contemporary city seems to be less and less linked to its spatial specificity, diluting it as a point of reference, a place of memory or collective identity. Literally, in his book *"Border Dialogues: Journeys of Modernity"*, Chambers states:

> *"Whereas the earlier city constituted a discrete geographic, economic, political and social unit, easily identifiable in its radical separation from rural space, the contemporary western metropolis tends to bring that "elsewhere" into its own symbolic zone. The countryside and suburban residences of cities, connected by telephone, television, video, computer, and other branches of the mass media, increasingly constitute the locus of a shared and shaped world in a common way"* (Chambers, 1990, p. 53)

Along with Chambers, other current urban analysts have affirmed that the urban transformation of recent years could be the most dramatic in the history of an urbanization evolution, a process that has taken more than 10,000 years. In this line, Neil Brenner (2013) in his *"Thesis on Planetary Urbanization"* he affirms that, in recent years, the urban seems to have personified the very concept of diffuse. He affirms that the "urban" no longer presents any clarity in definition parameters, morphological coherence, or cartographic rigor. This term is used to refer to an unlimited range of contemporary socio-spatial processes and conditions. In the aforementioned thesis, Brenner cites Ash Amin and Nigel Thrift (2002) to describe the contemporary urban condition as follows:

> "*The city is everywhere and in everything. If the urbanized world is now a chain of metropolitan areas connected by communication places/corridors (airports and airlines, stations and railways, parking lots and highways, teleports, and information highways), What is left out? Perhaps the town, the village, the countryside? Maybe, but only partially. The traces of the city are in all these places as people who commute*

between home and work, and also in the form of tourists, telecommuting, media and urbanization of lifestyles. The traditional division between city and country has been destroyed" (Amin & Thrift, 2002, p.1).

Thus, the emerging form of widespread urbanization is consolidating a structure that, instead of concentrating on nodal points or circumscribing to delimited regions, is hyper-dispersed. It is increasingly more difficult to understand the territory through the traditional concepts related to urbanity, metropolitan areas, or the urban/rural binary scheme. The urbanization geographies, that were for a long time conceived in terms of densely concentrated populations and the built environments of cities, now pierce, traverse, and burst the boundaries and relationship between the urban and the rural (Brenner, 2013). The following satellite image of night lights clearly illustrates how the entire world is rapidly urbanizing, from Antarctica to the Amazon, as the spatial reach of urban-based cultures, societies and economies extends into all regions of the planet.

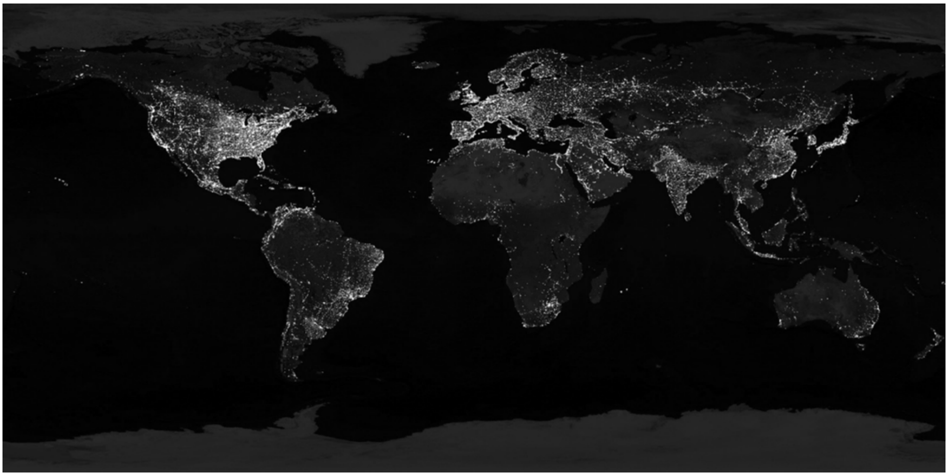


Figure 3. Night Lights
Source: Nasa, 20013

In this scenario, the old separation between an obvious "natural" exterior and an "artificial" urban interior is weakened and tends to collapse. *"The referents that once firmly separated the city from the countryside, the artificial from the natural, are now reproduced indiscriminately as signs and potential horizons within a common topography."* (Chambers, 1990, p. 53). In this sense, we can affirm that we no longer clearly know the extremes, borders, or limits of the contemporary city and thus, representing the city as a discrete geographical, economic, political, and social unit, rooted in its surroundings and in its hinterland, is more difficult than ever. To this Soja (2008) complements:

> *"The boundaries of the city are becoming more porous, hindering our ability to draw clear lines between what lies within the city, as opposed to what lies outside, between the city and the country, the residential areas of the suburbs and what is not city; between one city and another metropolitan region; between the natural and the artificial. What once clearly constituted "another place" for the city is now entering its enlarged symbolic zone. Between the real city and the imaginary city there is a growing confusion, which turns "the city" into both an imaginary or simulated reality and a real place."* (Soja, 2008, p.221,222)

Regarding the relationship of this new city and contemporary geohistorical and economic conditions, De Mattos states that the commodification of urban growth has also begun to transform under the effects of economic liberalization. In fact, although this tendency can be considered as congenital to capitalist urbanization, what is specific about the current evolution is that it is now having incomparably greater effects than it has ever achieved before. In contexts of planetary globalization, this model is causing substantial changes in the organization, functioning, morphology and landscape of the territory, with irreversible impacts (De Mattos, 2010). Already in 1972, Henry Lefebvre stated that we were beginning a process of "complete urbanization of society" where the difference between the urban and the rural began to become more complex. Thus, under a neoliberal capitalist development, the ubiquitous city is acquiring an articulating character of the globalization process and the flow of capital from the global financial market. In addition, ICTs (Information and Communication Technologies) have played a key role in altering the territory spatiotemporal understanding, that further disintegrates the concept of what is urban (Orellana et al., 2016).

Finally, we can affirm that this new transition towards the Postmetropolis --potentially extended to all regions of the planet-- seems to contain the entire world within itself, creating culturally heterogeneous urban spaces like never before. Thus, the Postmetropolis can be represented as a product of the intensification of globalization processes (Soja, 2008). However, it is extremely complex to achieve an effective understanding of this global(izing) city. Paradoxically, at the very moment when the urban seems to have acquired unprecedented strategic importance, the task of defining it has become almost impossible. As Brenner (2013) affirms: *"The apparent ubiquity of the contemporary urban condition prevents establishing precisions about it*" (p.45). Soja, (2008) complements this idea, stating that *"In the Post-Metropolis Age, it is increasingly difficult to 'escape the city', as the urban state and urbanism as a way of life are becoming virtually ubiquitous"* (p. 345).

We can conclude that, in the current scenario of economic liberation, globalization and expansion of ICTs, the challenge is to develop new ways of understanding (both in practical and theoretical terms) the new city models. In fact, it is fruitless to continue representing the contemporary city with traditional urban epistemologies.

1.1.3 The urban process in Latin America

Although with its own particularities, this region of the global south has also experienced an urban metamorphosis that has led to cities with complex characteristics. Its urbanization process is marked by transitions of exponential character. In demographic terms, between 1950 and 1970 there was a first transition, when the percentage of urbanization increased from 40% to 60%. This due to the natural growth rates on the one hand and, on the other, to the expulsion of the rural population, who gradually integrated into large urban centers. Between 1980 and 1990 there was a second important transition, with a percentage of the urban population that rose to 70%. Finally, a third demographic transition is recognized at the beginning of the century, with an increase to more than 80% of the population living in the main cities (Bernal & Orcid, 2021).

Similarly to the urban transition models proposed by Soja (1989), Borsdorf (2003) has developed a model applied to the Latin American reality and its geo-historical processes. Figure 4 shows a series of chorema that seek to explain the general structure for the Latin American city, organized into four moments of particular socioeconomic dynamics. These periods correspond to the colonial era (1820), the urbanization phase strongly influenced by European immigration (~1920), the urbanization phase marked by rural exodus and internal migration (~1970) and the contemporary city (~2000). Throughout these stages, the Latin American city changed from a very compact body to a sectoral perimeter. Subsequently to a polarized organism to end in a fragmented city. The Figure 4 shows the different socio-spatial elements, on the one hand, the distribution of social and economic classes (industry, trade and service infrastructure, airport, transit), but also elements of urban development (urban consolidation, social housing) and their evolution over time.

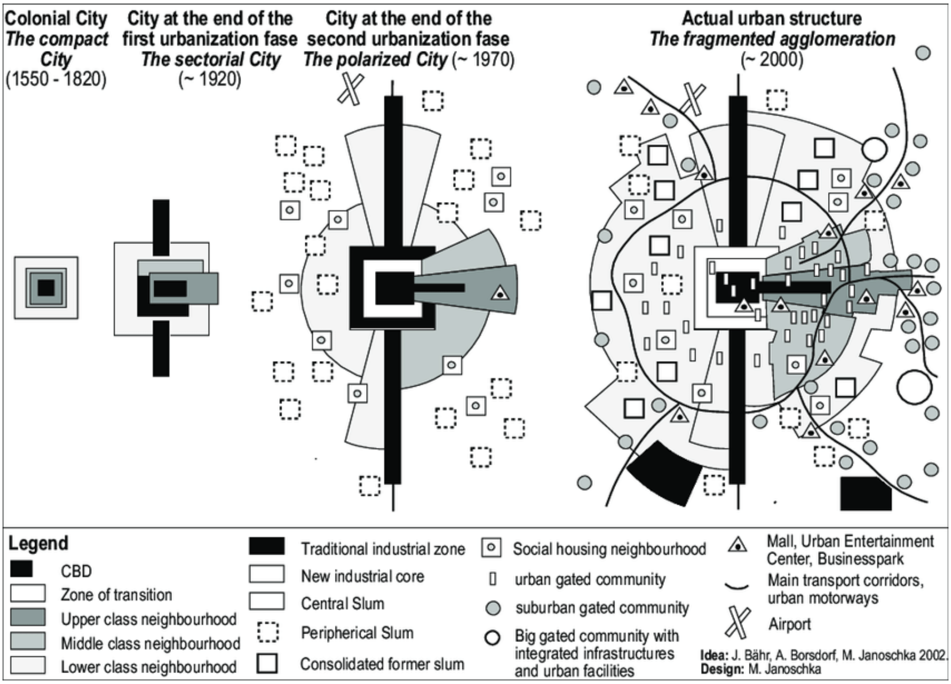


Figure 4. Model of the evolution of the Latin American City
Source: Borsdorf (2003)

The first scheme shows the model of the city around 1573, where the location, foundation, and planning of cities in the Spanish-American colonies was regulated by the "Ordinances of Discovery and Population". In this phase, the main square constituted both the center of each city (center of social life) and the key structure for the urban street system. The square also determined the social position of the citizens, based on the distance to it. In this sense, the characteristics of the colonial city in Latin America are the following: a strong centralization, a center-periphery social gradient, a slow development (mainly by natural growth), an economy based on the exploitation of natural resources, and a stable pre-industrial colonial society.

In the first decades of the 19th century, most of the Spanish colonies became independent and several cities received a significant migration of Europeans (merchants, industrialists, artisans and farmers). This political-economic change caused a reform in the urban structure. Firstly, there is evidence of a clear growth of the upper class, which were primarily located on the main boulevards. The development of the first industrial zones, located near the railway lines, is also observed. This development by zones or sectors breaks the circular structure of the colonial city, as can be seen in the second scheme.

Starting in 1920 --and in tune with the global trend-- a Keynesian economic policy was assumed within the region, and various spatial trends of previous periods intensified. Rapid industrialization around rail lines and highways increased growth in some sectors. The neighborhoods of the lower class and marginal groups expanded in the urban center in the form of "*cité*" in Chile or "*vecindad*" in Mexico. At the same time, peripheral slums (*barriadas, villas miserias*) were born, located in isolated lots outside the city. In this same stage, social housing neighborhoods were built on the urban periphery. On the other side of the city, the upper socioeconomic classes were moving further away from the city center, in the form of exclusive neighborhoods. Whit wide streets and extensive green areas, these were identified as "*barrio alto*" (high neighborhoods). Towards the end of this third stage, the first shopping malls appeared and quickly became centers of the growth of new luxury neighborhoods. In this period, the contrast between a rich city and a poor city intensified and polarization became the most important characteristic of the spatial structure, along with cell growth outside the urban perimeter.

Finally, the last phase that Borsdorf recognizes corresponds to what he calls the Fragmented City. In the fourth graph, it can be seen how the construction of new intra-urban highways facilitated accessibility, making peri-urban areas attractive to the middle and upper classes. This also allowed the formation of structures in the form of fragmented nodes outside the urban perimeter: cellular elements, such as upper-class gated communities, slums, and social housing. This fragmented pattern is characterized by a series of small-scale socio-spatial functions and elements, which are dispersed throughout the territory and (although without being integrated) are mixed. For example, luxury developments are located in very poor neighborhoods.

The geospatial description that Borsdorf develops through these urban models is in complete tune with the analyzes of Carlos de Mattos (2010), who --from a geo-historical perspective-- analyzes the Latin American urban condition. The author affirms that, since a growing number of countries of the "capitalist periphery" (Latin American) began to guide their public management processes based on Keynesian thought, major restructuring was promoted, accelerating industrialization and deepening economic-territorial integration. With the evolution of these processes there was a progressive intensification of internal migrations and growth in the rates of urbanization. This generated important changes in the territorial distribution of productive activities and the population. This is how, in just 30 years (between 1960 and 1990), the level of urbanization in Latin America went from 49.2 to 72%. Also, with the increase of new industries, which were mainly located in urban centers bordering the main city, an important process of suburbanization happened. The economic-territorial integration was also translated into a gradual spread of capitalist production towards the rural environment. This resulted in a substantial increase in migratory flows to the Latin American cities (De Mattos, 2010).

The aforementioned economic restructuring and its territorial impacts have achieved exponentially greater effects in recent years, altering the organization, functioning, morphology, and the landscape of Latin American cities. One of the especially visible changes is the increase in private real estate investment, incomparably higher than at any other time in the past. The modernizing spirit has had as a reference a neoliberal capitalist development model that advocates the establishment of favorable conditions for the private valorization of capital, giving new prominence to private capital (Castells, 1987; C. De Mattos, 2010). With the implementation of neoliberal policies, most Latin American cities are modifying their urban development policies to meet the growing need for housing. In this sense, the State's management of urban space gradually transformed from a rationalist approach to one of a business focused one (Cruz-Muñoz, 2021). In this context, the real estate market defines the rules of territorial organization, giving to real estate companies a central role in urbanization processes and subtracting the role of the public sector as manager and regulator. As Perahia, (2000) mentions, "*the city is extended by the action of real estate agents in an accelerated process of transformation of the dominant uses"*. On the other hand, this new development model increases informality and urban poverty since the marginal population is not the object of attention for real estate profit. Thus, social stratification is an additional layer to the spatial fragmentation.

Finally, with the transition towards the new millennium and in response to the location trends of families, factories and real estate market offers, Latin American cities have expanded their urbanized land generating a diffuse expansion. In this sense, the limits of the city have disappeared under a new urban form, almost ethereal and not always fully understood. Authors such as Aguilar (2002) define the contemporary Latin American city as a polycentric expansion that creates a pattern associated with networks, limits and borders that are difficult to define. Cruz-Muñoz (2021) , citing Lang (2003), alludes to the concept of edgeless cities. De Mattos (1998) on the other hand, defines it as an urban archipelago, very much in line with Borsdorf (2003) and the fragmented city.

Taking into account that this trend towards peri-urbanization would seem an inevitable process (since the demand for residential space continues to increase and the average income of Latin American families also tends to grow (De Mattos, 2010)), research on periurban territories has gained great relevance in recent decades. Disciplines such as geography, anthropology, economics, agronomy, sociology, or architecture have promoted theoretical debates and methodological contributions related to the social production of space, the incidence of actors, the convergence of various positions and profound socio-spatial transformations resulting from urban and periurban expansion (Ávila Sánchez, 2001; Barsky, 2005;

Bernal & Orcid, 2021; J. Frediani, 2009; Galindo & Delgado, 2006; Hernández-Flores et al., 2009; Hernández Flores, 2014; Serrano Heredia, 2017; Zulaica & Celemín, 2008). However, there is still a gap regarding the conception of these dynamic, complex, and full of contradictions territories, their relationship with natural environments and the potential impacts. Thus, the study of territorial transformations in urban-rural interfaces demands the knowledge of their multifarious dynamics, derived from particular interactions between society and nature.

1.1.4 Assessing urban expansion and the environmental impacts. Landscape ecology as a tool

In contexts of important geospatial changes, such as those explained in the previous chapters, understanding the characteristics of these transformations is a transcendental issue for land planning and management. There is a growing global consensus about the importance of understanding how the effects of human activities can unbalance natural ecosystems and generate a potential environmental crisis. Changes in land cover, caused by intensive and accelerated urbanization, are definitely one of the most severe forms of this ecosystems' alteration. In this regard, monitoring the spatiotemporal land cover transformation in urban and peri-urban environments, is a key effort to understanding the dynamics and the effects on these socioecological systems (Gallopín, 2003; Sánchez et al., 2010).

Landscape Ecology provides a conceptual framework and a methodology that allows analyzing this spatial dynamic from a transdisciplinary perspective, with contributions from geography and ecology (Subirós et al., 2006). The territorial vision and interpretation of this discipline is based on a structural approach, on the one hand, and functional on the other. Its fundamental hypothesis is based on the pattern/process paradigm. In this dialectical relationship, landscape patterns have the ability to condition the territorial functions/processes (ecological, economic, social) and the processes that occur in the landscape in turn modify spatial patterns (Bogaert et al., 2014; Matteucci, 2009). Thus, Landscape Ecology makes it possible to analyze the morphological patterns that determine a territory at a given moment (as well as its evolution over time) and this, at the same time, allows us to infer its incidence at a functional level. Therefore, we can affirm that this discipline focuses its attention on three basic characteristics of the landscape: structure, functionality and change (Forman & Grodon, 1986).

Methodologically, landscape ecology has adopted principles and concepts of ecology and applies them through geographic analysis (capable of showing the spatial, scalar, and temporal variability of the territory). In addition to its strong relationship with these two disciplines, Landscape Ecology entails an extreme complexity that is supported by the vision and interaction with other disciplines, as shown in the following Figure 5, based on Subirós et al. (2006).

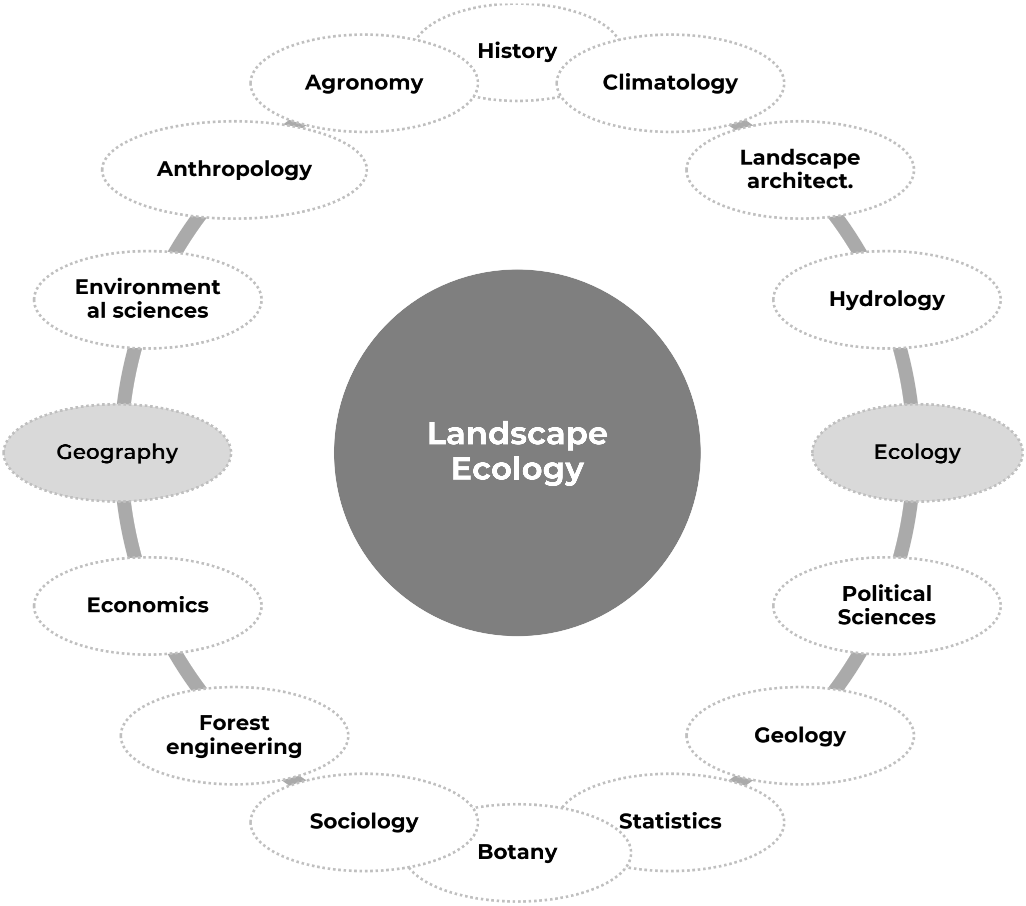


Figure 5. The complex diversity of disciplines that help shape landscape ecology and its holistic vocation.
Source. Subirós et al., 2006

The recognition of the pattern/process paradigm acquires particular importance when recognizing that the modification of spatial patterns -caused by human activities- can generate changes in the functioning of natural systems. And this -in turn- generates ecological alterations with social and economic effects in the long and medium term (Matteucci, 2009). This dialectical relationship is recognized by Hong et al. (2014) who claim that "*…landscape consequently represents an epistemic domain in which it is possible to observe a synthesis of the interactions between natural systems and human culture*". In particular, changes in land use caused by urbanization generate changes in the configuration of natural landscape, with effects on ecosystem services functioning (Costanza et al., 1997; Sánchez et al., 2010). Specifically, unplanned land cover change can lead to loss of ecosystem services such as: climate and temperature regulation, air purification, pollination, etc. Therefore, the understanding of this action-reaction has become a key issue for territorial planning (Lee et al., 2015).

For the analysis of territorial dynamics, in Landscape Ecology a series of concepts/elements have been defined that allow the interpretation and observation of its characteristics. The Mosaic, the base element, is delimited by the researcher based on the objectives of his work and is made up of a set of landscape elements. Three types of elements can be identified: patches, corridors, and matrix. Patches are singular spatial units that can have widely varying sizes, shapes, and edge types. A punctual patch introduced constitutes a perforation in the matrix. A patch can be natural or anthropic. The corridors, on the other hand, are elongated fragments that cross the mosaic and whose content differs from that of the neighboring elements. They can be natural (for example: watercourses, riverside or levee vegetation) or anthropic (communication routes, pipelines, power lines). Finally, the matrix constitutes the background of the mosaic, and it is the type of ecosystem within which patches and corridors are inserted. Some authors assign the matrix category to the dominant ecosystem in extension (Forman & Grodon, 1986; Matteucci, 2009; Subirós et al., 2006).

Specifically, the characteristics and transformations of the landscape can be evaluated through indicators known as landscape metrics. These reveal key aspects regarding the spatial structure of patches, matrix, or the landscape in general. These quantitative evaluations make it possible to understand, describe and interpret the different spatial phenomena, and with them, their effects on ecological or economic functions (Fan & Myint, 2014; Matteucci, 2009). For example, the area of the patches has a clear correlation with the diversity of species it can support. When there is a reduction in the patch, there is also a reduction in biodiversity called the area effect. According to various models, the decline in species is directly correlated with the decline in area. And the smaller the population size of a given species, the sooner it can drift the population toward 0 until its extinction (Subirós et al., 2006). This affectation to the population ends up affecting the ecological processes and the potential associated ecological services. Fragmentation is perhaps one of the main causes of patch size reduction, increased edge and number of patches, and loss of connectivity. All this is causing loss of biodiversity on a global scale (Otavo & Echeverría, 2017).

There are two key concepts that made up the very structure of landscape: the composition and the configuration of the landscape. Composition mainly refers to the number of patches present in the landscape, as well as their area and definition. While the landscape configuration refers to the spatial arrangement and the geometry of the patches (shapes, sizes, density and dispersion)(Bogaert et al., 2014). Landscape metrics provide numerical data specifically on the composition and configuration of landscapes: the proportion of each land cover and the shape of landscape elements. The selection of adequate metrics facilitates the morphological delineation and the optimal analysis of the territory, as well as the evaluation of changes over time and their ecological incidence (Xing & Meng, 2018). Additionally, landscape metrics allow the comparison between different landscape configurations at different moments in time and based on this, the definition of future scenarios. The results can help to interpret the situation (and its dynamics), both from an ecological point of view and from a socioeconomic perspective in a given cultural landscape (Subirós et al., 2006).

The combination of various metrics is essential for a correct interpretation of the morphological characteristics of landscapes and can be applied to the development of planning guides to reduce the loss of ecosystem services. Likewise, the combination of the quantitative results of the landscape structure with socioeconomic variables is key in territorial planning processes. This type of analysis can provide a more complete understanding of the relationship between ecological dynamics and anthropic activities in territories under transformation. These kinds of analysis are particularly important when analyzing the urban-rural gradient and periurban areas within it, since they often contain valuable protected biotopes such as forests, cultivated land, rivers, wetlands, and major streams. All of these deliver basic ecosystem services for urban residents (Lee et al., 2015).

Finally, it is key to mention that although Landscape Ecology and its analytical tools have been developed from an ecological perspective and have been applied mainly in research studies within this field, they have also started to be used more frequently used in studies with broader approaches (Xing & Meng, 2020). In particular, when analyzing periurban territories, there is an added value of considering the interaction of agricultural and natural covertures with anthropogenic covertures such as buildings and roads, since it is in these territories where there is the greater overlap of urban and rural land uses due to their interstitial character. This holistic and transdisciplinary vision of all the elements that integrate a territory are key for building sustainable strategies in territorial planning.

1.2 Research problem

1.2.1 Urban expansion in the Metropolitan District of Quito

The Metropolitan District of Quito (MDQ) is Ecuador's political capital. Surrounded by mountains, this city is located over the Andes at approximately 2.800 meters above sea level and crosses by the parallel 0.0. (Figure 6). This geographic location gives it a unique climatic condition, which is reflected in its wide diversity of climatic floors, ecosystem richness and natural resources (Figure 7). Among this diversity, we can identify the humid forests to the west of the urban area, shrubs and dry forests concentrated in the Guayllabamba basin, to the northeast. Also, humid shrubby vegetation, distributed towards the south of the MDQ and, finally, the presence of *"páramos"* -some of the highest in the world- that begin in the western mountain ranges. According to the classification system carried out by Nature Serve, the MDQ has 17 types of ecosystems, distributed in a total area of 423,074 ha. (Environmental Secretariat MDQ, 2016).

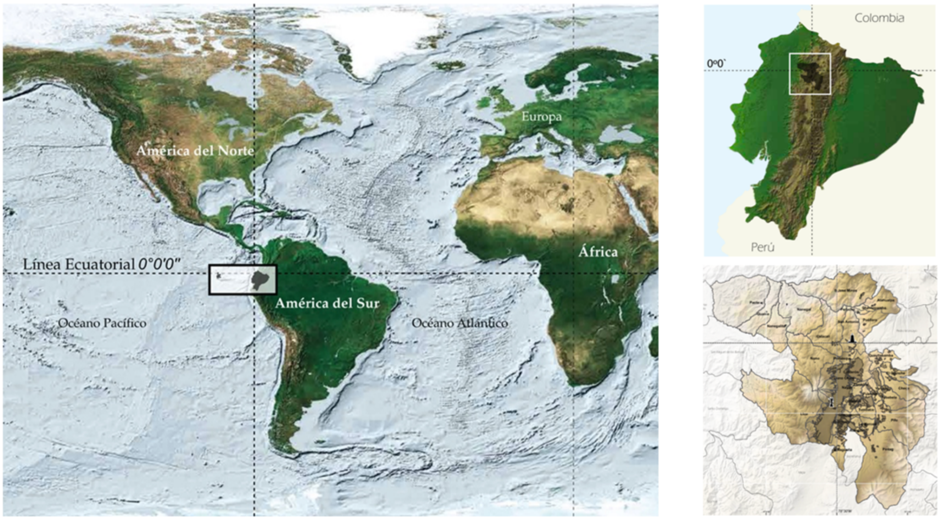


Figure 6. MDQ localization
Source: Environmental Secretariat MDQ, 2016

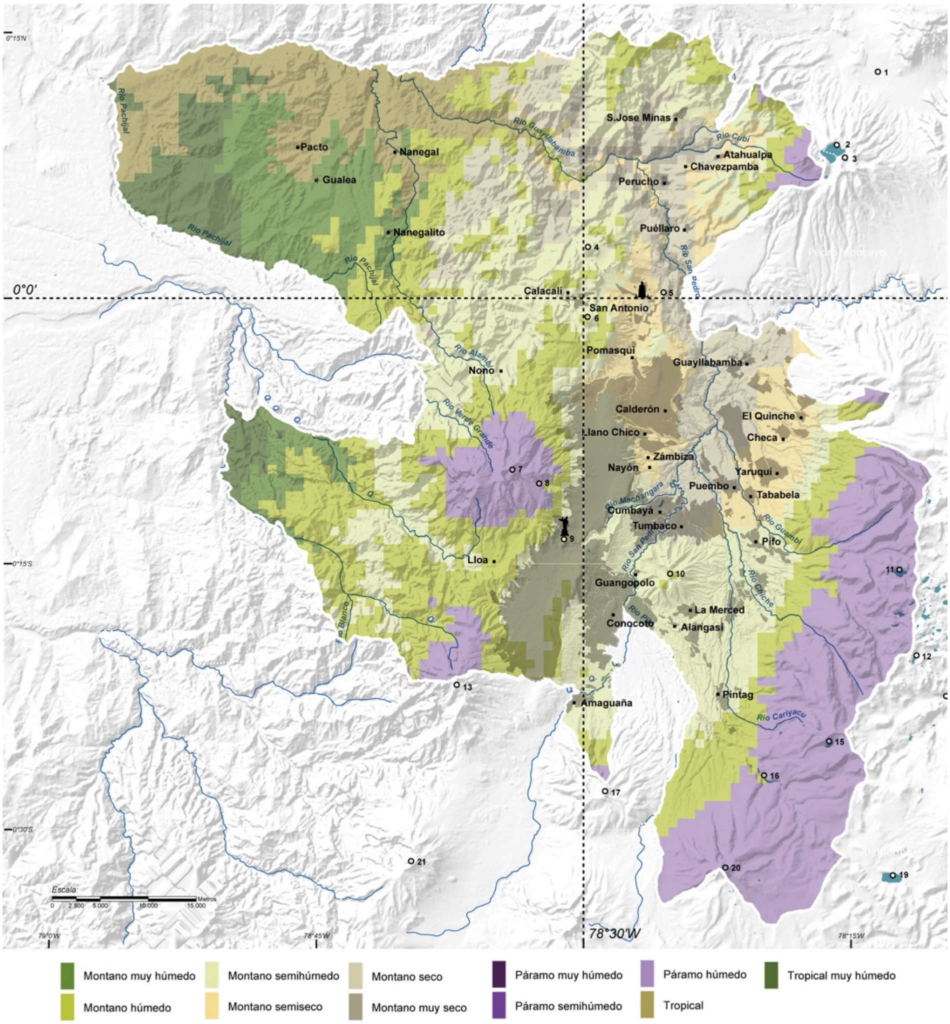


Figure 7. Climatic floors and diversity of ecosystems of the DMQ
Source: Environmental Secretariat MDQ, 2016

On the other hand, due to its privileged geographical location, which allows having the same number of hours in the day and night without much variation throughout the year, the MDQ has an agro-productive sector of local and national importance. In fact, in 21.2% of its territory different productive systems are established, which are located mainly in the eastern and northeastern zone of the consolidated urban area (Figure 8) (Environmental Secretariat MDQ, 2016). According to data obtained from the *Pacto Agroalimentario* (Agri-Food Pact), Quito's production supplies 26% of the city's food demand (Municipio del Distrito Metropolitano de Quito, 2021).

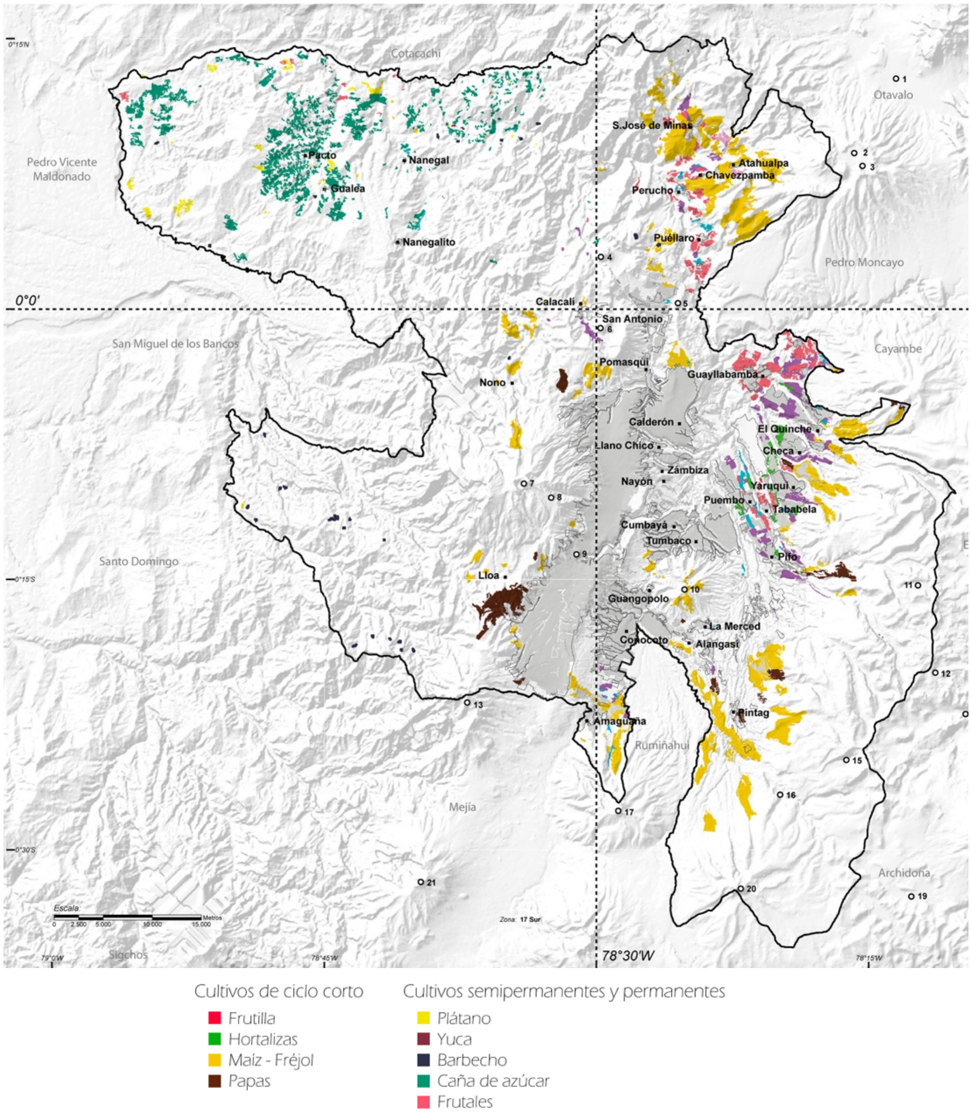


Figure 8. Types of crops in the DQM
Source: Environmental Secretariat MDQ, 2016

This productive and biodiverse territory has undergone important changes in the last years, mainly due to urban expansion. In sync with the Latin American trend, explained in previous chapters, the urban population of Ecuador doubled, starting in the second half of the 20th century. While in 1950 barely 28% of its inhabitants lived in cities, by 2010 67% had been located in cities (BID, 2015). The MDQ was one of the main destinations for the immigrant population due to its status as political-administrative capital and the dynamics and scale of its economy. Likewise, due to its regional, national, and international connectivity, the MDQ has become a hub for concentration of activities and a space for regional, national, and international articulation. Due to this condition, the population of the MDQ went from having approximately 220,000 inhabitants in 1950 to having 2,781,641 in 2020 (Dupérier et al., 2011; Municipio del Distrito Metropolitano de Quito, 2021).

This population growth has also been spatially reflected in the territorial extension of urbanized areas (Environmental Secretariat MDQ, 2016) and the pattern of growth has evolved in recent years. Since its foundation the city of Quito followed a compacted growth pattern marked through a clear north-south axis (probably due to its complex topography) (Carrión & Erazo Espinosa, 2012). However, after 2000 that pattern has started moving to the east side, toward the low valleys of the MDQ, following a dispersed pattern (Figure 9).

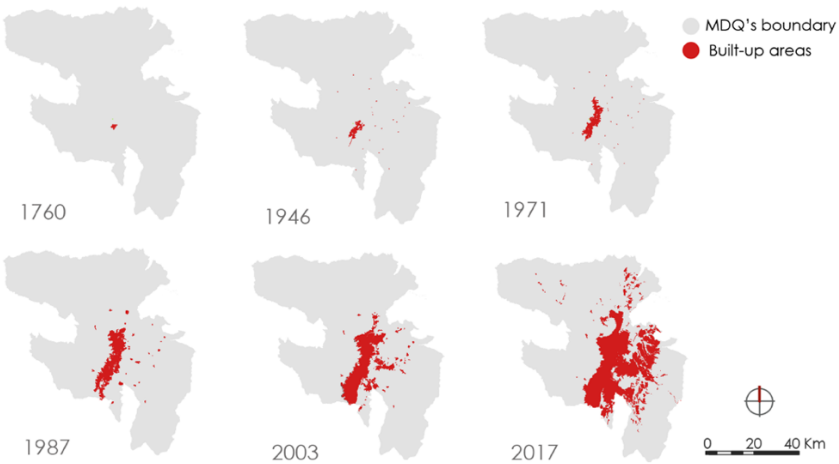


Figure 9. MDQ Location and evolution of built-up areas from 1760 to 2017.
Source: Municipio del Distrito Metropolitano de Quito (2017)

Administratively, the MDQ is organized into 65 "*parroquias*" (administrative units), 32 urban and 33 rural. 72% of the population lives in urban parishes and the remaining 28% in rural ones (Figure 10). However, only 6% of this last group is dedicated to productive activities (Municipio del Distrito Metropolitano de Quito, 2021). This means that at least 22% of the MDQ population lives in territories that are administratively considered rural but have urban-based forms of subsistence. This situation coincides with the reflections on the ubiquity of urban life and the obsolete conceptions between the urban versus the rural (Brenner, 2013). Thus, several settlements from previously rural areas and agricultural areas have progressively been incorporated - in a disjointed and dispersed way - to the urban land. This can be observed mainly in the eastern and northeastern valleys of Tumbaco-Cumbayá, Los Chillos, Calderón and Pomasqui-San Antonio de Pichincha.

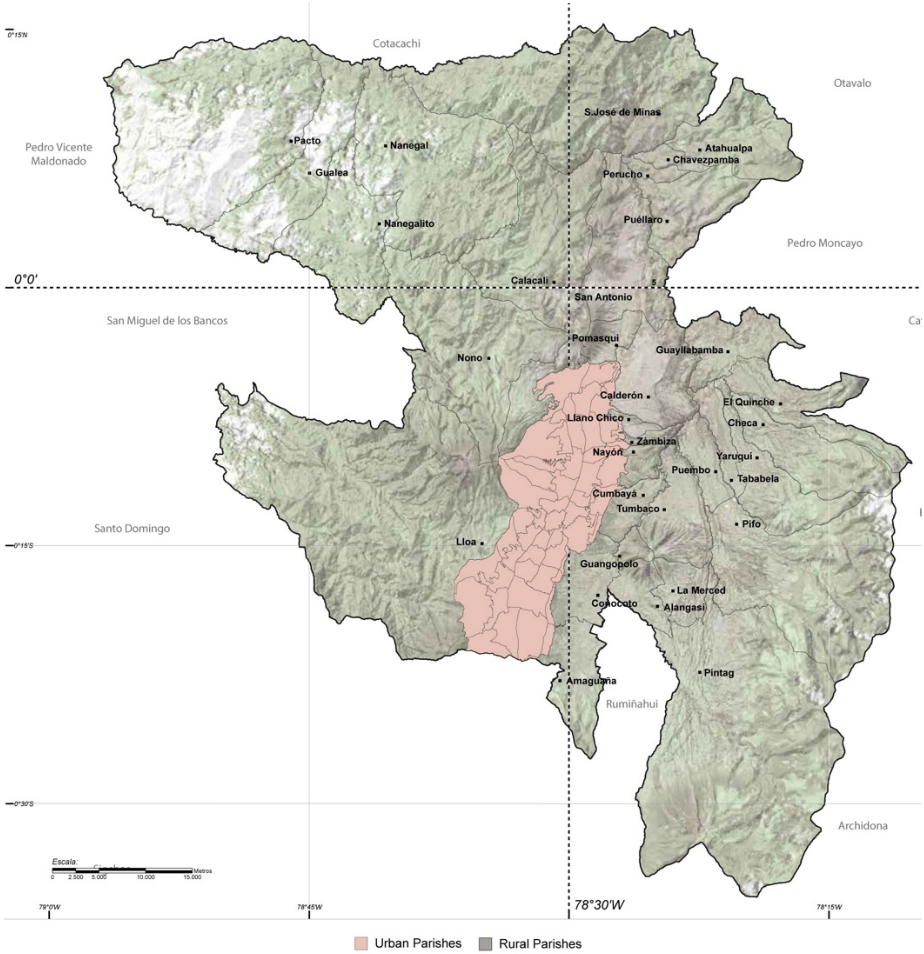


Figure 10. MDQ Administrative units. Urban a Rural Parishes
Source: Municipio del Distrito Metropolitano de Quito (2017)

As an additional aggravating circumstance to this expansion over rural territories, in 2013 the New International Airport of Quito (NIAQ) was inaugurated in one of the rural parishes to the east of the city (Figure 11). For the operation of this mega urban project, a set of highways were built connecting the airport with the city, which cross several rural parishes. These new road infrastructures facilitate accessibility to these peri-urban territories and this could accelerate the urbanization processes in the MDQ (Delgado, 2003). However, no impact assessments have been carried out on the intensity and speed of urbanization in peripheral territories, triggered by this type of infrastructure. In this sense, the urbanization of increasingly remote rural parishes reveals limited control over the urbanization trend in the MDQ, which is generating an expansive and diffuse periurbanization process.

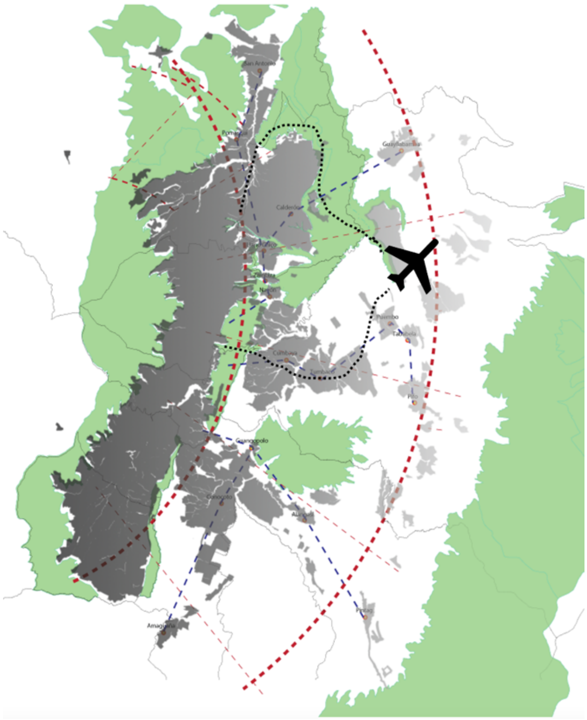


Figure 11. Urban expansion trend of the MDQ. Location of the new airport.

1.2.2 Peri-urban territories in the MDQ, an ambiguous space in territorial planning and management

Periurban territories can be essentially defined as an interface between urban and rural areas (Salazar, Díaz Mery, Mc-Intyre, & Foster Bonnette, 2014: 224). Due to the ambiguity regarding its compression and the speed of its transformation, the planning and management of the peri-urban area of the MDQ has been limited and the impacts of this dispersed growth can already be evidenced in the territory. The spatial discontinuity of the new urbanizations in different valleys, fragmented by geographical conditions, has generated limitations in the structuring of the local road network and in the provision of adequate transport services. Likewise, unplanned growth has limited the configuration of centralities, and the adequate provision of recreational, educational or health facilities. This generates a high dependence on the central city, which makes mobility and commutes even more complex. In addition, this disorderly growth generates limitations for the construction of adequate infrastructure for water management, sewerage, and waste collection, causing contamination of water channels. On the other hand, the fragility of agricultural land can be inferred since the productive soils of the eastern valleys are being destined for urban uses. However, the impact that urbanization has had on these soils in recent years has not been studied in detail. In general, the urbanization of rural territories and natural and protected areas represents a threat to the environmental sustainability of the territory. (Brenna, 2008; Environmental Secretariat MDQ, 2016; Municipio del Distrito Metropolitano de Quito, 2021; Serrano Heredia, 2017).

Despite these dynamics characteristic of peri-urban territories, current planning instruments continue to see the territory from an urban/rural dichotomous perspective. This can be observed, starting by the current Ley Orgánica de Ordenamiento Territorial, Uso y Gestión del Suelo (LOOTUGS) (Organic Law on Territorial Planning, Use and Land Management) that determines the setting of principles and general rules that govern the management of territories, at the national and local scale. In its article 17, the LOOTUGS determines that the classification of land will be limited to urban and rural. Also, this law determines that -based on its macro-guidelines- each municipality must prepare Development and Land Management Plans (PDOT) and Land Use and Management Plans (PUGS). These instruments outline each territorial components that determine land management, public and private land uses and the construction of buildings itself. Thus, the Article 17 also determines that the land classification (urban/rural), which is independent of the political-administrative allocation, will be applied both for the PDOT, PUGS, as well as for any complementary planning tool (Ministerio de Desarrollo Urbano y Vivienda, 2018).

In this sense, the management of MDQ periurban territories presents important limitations that can be evidenced even at its municipal plans themselves. Since the classification of land use continues to be limited to the urban/rural dichotomous vision, the highly complex dynamics of theses interstitial territories are left aside. These can be clearly seen in the Metropolitan Development and Territorial Planning Plan by 2033 and the current Land Use and Management Plan that continues to define all its actions, classifying them for urban land or rural land, ignoring that there is a gradient with much more complex dynamics (Image 12). Such is the confusion that, when observing in detail the urban-rural border of the MDQ, inconsistencies such as urban properties inserted and surrounded by rural properties and vice versa can be identified (Figure 13). These inconsistencies in territorial planning could favor speculation, the reduction of agricultural land or the informal occupation of protected areas.

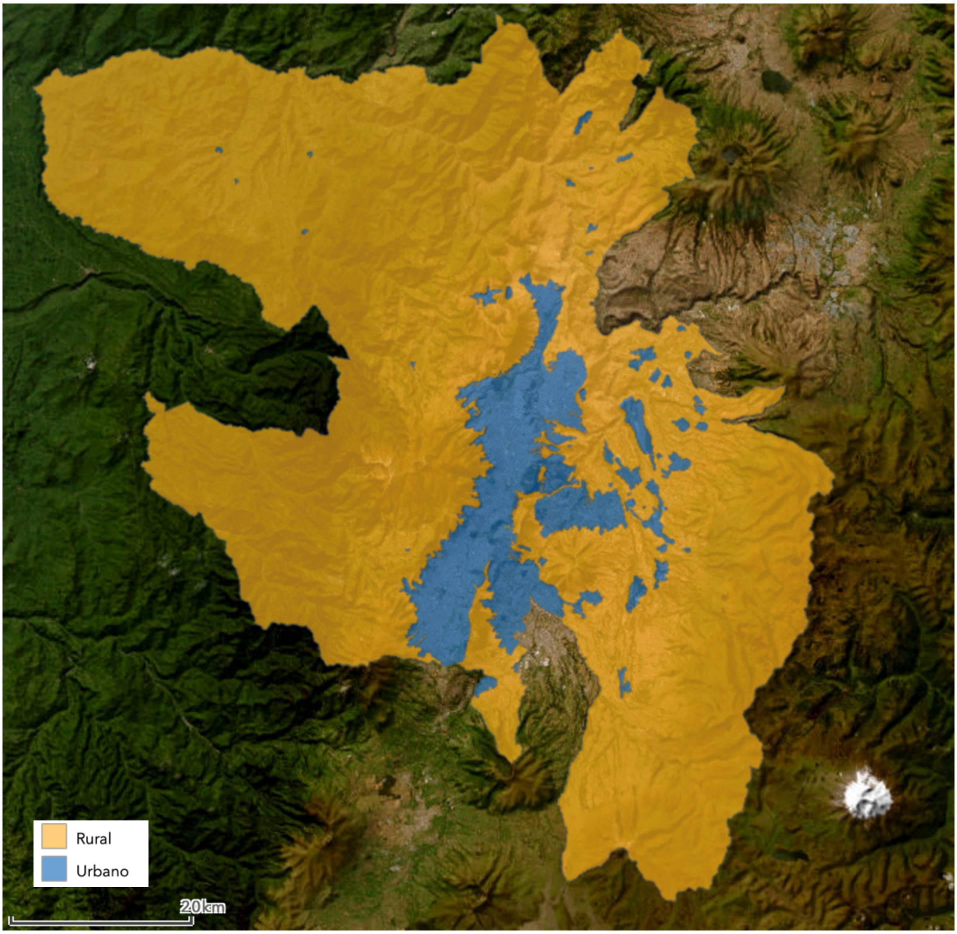


Figure 12. Current Land Use classification.
Source: https://pam.quito.gob.ec/tuciudadenlinea.aspx

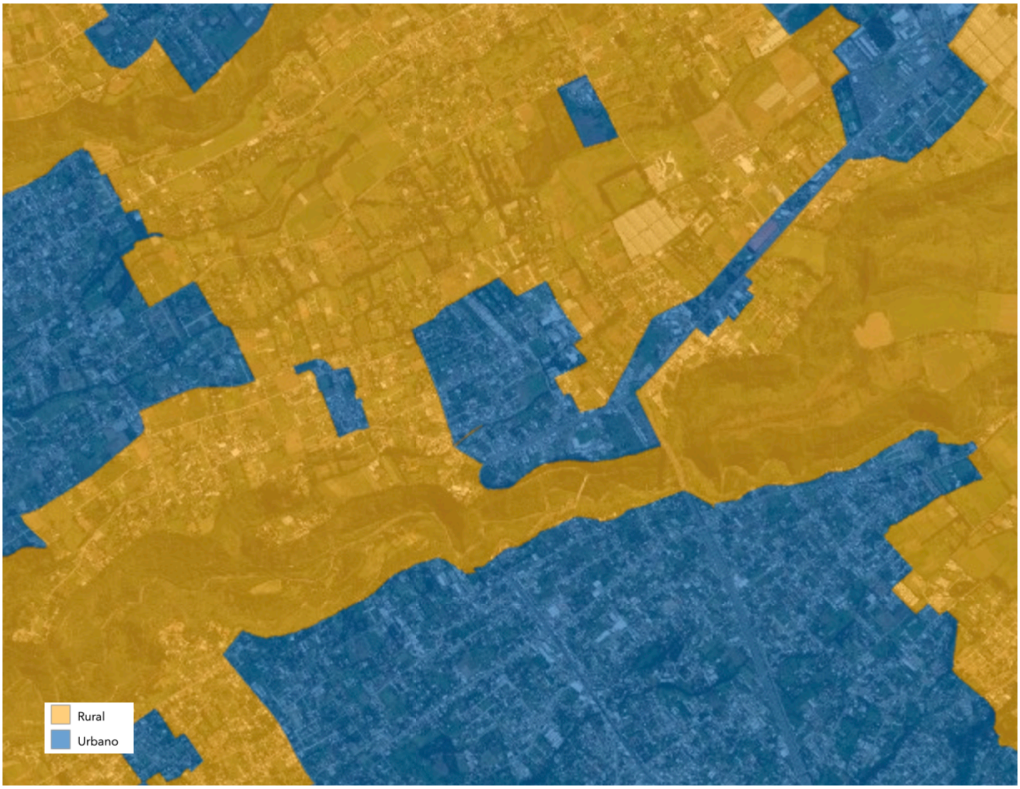


Figure 13. Zoom of the "boundary" among rural and urban territories of the MDQ, based on the official land classification.
Source: https://pam.quito.gob.ec/tuciudadenlinea.aspx

Finally, recognizing the diversity of ecosystems and climatic floors of the MDQ, in addition to the dynamics of their settlements, we can infer that there is a great diversity of morphological patterns within the periurban area. However, the detail of this diversity or the possible impacts that transformations due to urbanization may be causing in natural and agricultural ecosystems are unknown. This ambiguity regarding periurban territories limits the capacity for planning and territorial management. Despite all this, there is not much scientific work related to peri-urbanization growth patterns in the MDQ, neither its possible environmental impacts.

1.3 Research questions and thesis outline

1.3.1 Research questions and hypotheses

The main goal of this study was to identify the current landscape patterns in the MDQ periurban interfaces, as well as its evolution in the last years, in order to better understand urbanization tendencies. In addition, this study sought identifying the possible drivers that have determined each particular pattern of peri-urbanization, which is a key knowledge for future land use planning. In this context, the main research question was: **What is the current landscape pattern of the MDQ peri-urban area and how has the urban expansion process been in the last decade?**

The main hypothesis is that the MDQ easter valleys are undergoing important landscape transformation due to urbanization processes, with greater intensity in the periurban zones. Affirming that the concept of peri-urban area has a singular meaning in a Latin American context, the hypothesis sustains that these transformations within the MDQ periurban areas are altering landscape patterns of natural and anthropogenic covers in a particular way. Specifically, vegetation and agricultural covers are expected to experience more severe transformations, particularly affected by fragmentation processes, which threatens the environmental quality of the territory. Also, the implementation of new road infrastructures is expected to intensify territorial transformation in areas under their influence, generating differentiated rhythms of urbanization processes and singular patterns.

To answer the main research question and test the hypotheses, the following specific research questions were posed.

1. **How is the peri-urban area conceived in a Latin American context?**
   Testing the hypothesis that Periurban territories (as well as the other terminology related with the urban-rural gradient) has a different and a singular meaning in a Latin American context.

2. **How is the current landscape structure in the MDQ urban-rural gradient?**
   Testing the hypothesis that periurban areas the MDQ are very diverse in terms of landscape structure. The different variations respond to biotic, abiotic and socio-economic features, consolidating a very complex territory.

3. **How has landscape change in the last years, in terms of composition and configuration? And which are the drivers that are amplifying the MDQ urban expansion over periurban areas?**
   Testing the hypothesis that vegetation and agricultural covers are experiencing more severe transformations, particularly due to fragmentation processes. Also, testing the hypothesis that new road infrastructures along with land speculation can accelerate the rhythm of urban expansion.

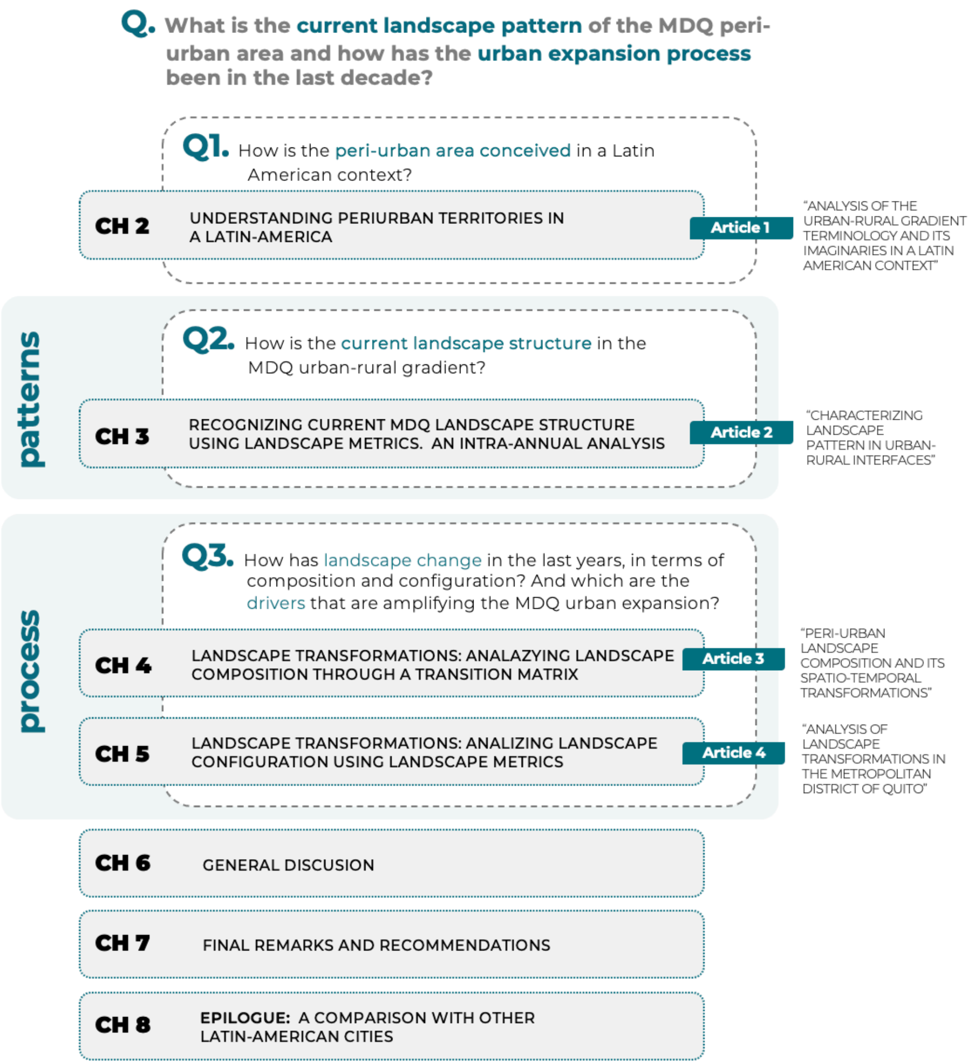
1.3.2 Specific research objectives and activities

The following Table presents the research objectives, which are based on the 3 specific research questions, as well as the specific activities to achieve each objective. The articles published from the different activities are also marked in the table.

Objectives	Activities	
O1: To analyze the different concepts to describe the urban-rural gradient in the Latin American context	**A1.1** Literature review	
	A1.2 Develop of a Citation Frequency Index	Article 1
O2: To recognize current landscape structure	**A2.1** Identify landscape covers	
	A2.2 Analyze landscape structure through metrics quantification	Article 2
O3: To analyze landscape change in terms of composition and configuration, and the possible drivers of that change	**A3.1** Identify landscape covers in both periods of analysis	
	A3.2 Identify changes over time	
	A3.3 Measure composition change based on a transition matrix and landscape stability index	Article 3
	A3.4 Analyze configuration change based on landscape metrics quantification	Article 4

1.3.3 Thesis outline

Based on the objectives described before, the thesis outline has been organized following the next schema:



The structure of the Chapters follows the schema as follows:

The **Chapter 2** develops new precisions about the most recurrent terms used in the scientific literature to describe the urban-rural gradient in a Latin-American context, particularly the terms Periurban area, Suburban area, Rurban area and Periphery. This first and general theoretical approach is a key stage to develop the following chapters, which will be analyzing the urban-rural gradient in the MDQ. Latin American perspective is addressed, recognizing the regional synergies due to our alike sociocultural condition. A Citation Frequency Index was used as main methodology, which allowed us to identify and systematize the main attributes for each terminology in order to define them in a clear way. Additionally, a Sorensen Similarity Index was calculated to identify distinctions and synergies among terms, obtaining a wider understanding of this territory and its interactions. Based on these findings, this chapter presents as a conclusion a scheme that illustrates the overall composition of the urban-rural gradient, based on the perceptions and imaginaries from Latin American authors and studies. Likewise, the conceptualization of the term peri-urban area (as well as the other terms) served as a conceptual basis that are applied throughout the entire study and the other articles that compose it.

Chapter 3 presents the first analyses applied to the case of study, the MDQ. In this chapter the current landscape pattern is addressed using as main methodology the calculation and analysis of landscape metrics. Here the definition of study transects, and the 1 square kilometer sixty-four sample polygons is developed. This will be the specific study sites through the whole thesis and the other articles as well. Also, the five land use/land covers (LULCs), applied through the entire study, are defined in this first chapter. Landscape structure was measured through five landscape metrics: 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. Based these results, a multivariate cluster analysis was developed, which allowed us to identify five main territorial patterns, that also coincide with the conceptualizations developed in chapter 2. This cluster classification is surely the main contribution of this chapter, which was also applied as a spatial reference in the following chapters.

The next two chapters continue analyzing the case of study, but this time including the dynamics of landscape transformation, that is, adding the time perspective. Particularly, **Chapter 4** focuses on Landscape Composition, while next one will address Landscape Configuration. As methodology, in this chapter a transition matrix and a stability index were developed to analyze landscape composition change intensity for each LULC independently, considering two year high resolution satellite images. The results allowed to clearly identify the land covers that have changed the most and its of level of instability. Also, taking a closer look at the more unstable samples (those that have changed the most for the total landscape) it was possible to identify a great diversity of urbanization patterns, which we propose organizing into four typologies, based on the most recurring configurations. Finally, applying the Cluster Classification (established in the previous chapter), we were able to quantify the transformation of each zone within the urban-rural gradient, highlighting the dynamism of the peri-urban territories over the others.

Following the territorial transformation analysis, **Chapter 5** analyses the MDQ spatiotemporal changes from a Landscape Configuration perspective. While composition perspective allowed us to understand how much landscape has change, configuration examines *how* it has spatially changed. Landscape metrics were the strategic tool to quantify specific patterns such as magnitude, dominance, isolation, or density. Specifically, we analyzed -for both years- the metrics: *Percentage of Landscape* (PLAND), *Patch Density* (PD), *Average Area* (A_MN), *Larger Patch Index* (LPI) and *Euclidean Nearest-Neighbor Distance* (ENN_MN). First, a *Wilcoxon Rank-Sum test* was performed to evaluate differences of landscape metrics between the two years of study, for each one of the LULC categories. Additionally, we calculated the *Kruskal-Wallis test* to assess if landscape metrics' differences exist along the transects as we move away from the city center. Finally, in order to have a more specific outlook of the pattern's transformation in each transect and sample independently, an analysis of *normalized metrics variation* (percentage of change comparing the two years) was developed. Finally, a Markov chains modelling technique was applied as a method to forecast the tendency of LULC's transformation in the following years.

Chapter 6 summarizes and discusses the main findings and the different synergies among all articles, with the aim to answer the main research question. It also presents a discussion on the drivers and built a schema showing the MDQ periurban spatial patterns, as a graphical conclusion of the main findings. Then, a section is developed confirming or rejecting the specific hypotheses raised. Finally, in this chapter, a brief discussion on all the methods is presented as well as some methodologic recommendations for future studies. As a general closure, in **Chapter 7** we discuss on the general challenges that the MDQ has, and we explore two scenarios of its future spatial metamorphosis. Then, we present a set of recommendations that can be particularly useful for the MDQ urban planning, highlighting how micro-scale policymaking should be a priority in scenarios of complex and highly heterogeneous peri-urbanization.

Finally, presented as an epilogue, in **Chapter 8** we propose comparing the MDQ results with other Latin American cases in order to envisage the urbanization trend within the region. In this sense this chapter reconnects with Chapter 2, presenting some insights that could be useful to other Latin American cities, where a similar urbanization processes are happening.

Chapter 2

Understanding periurban territories in a Latin-American context

PUBLISHED ARTICLE 1

"ANALYSIS OF THE URBAN-RURAL GRADIENT TERMINOLOGY AND ITS IMAGINARIES IN A LATIN AMERICAN CONTEXT"

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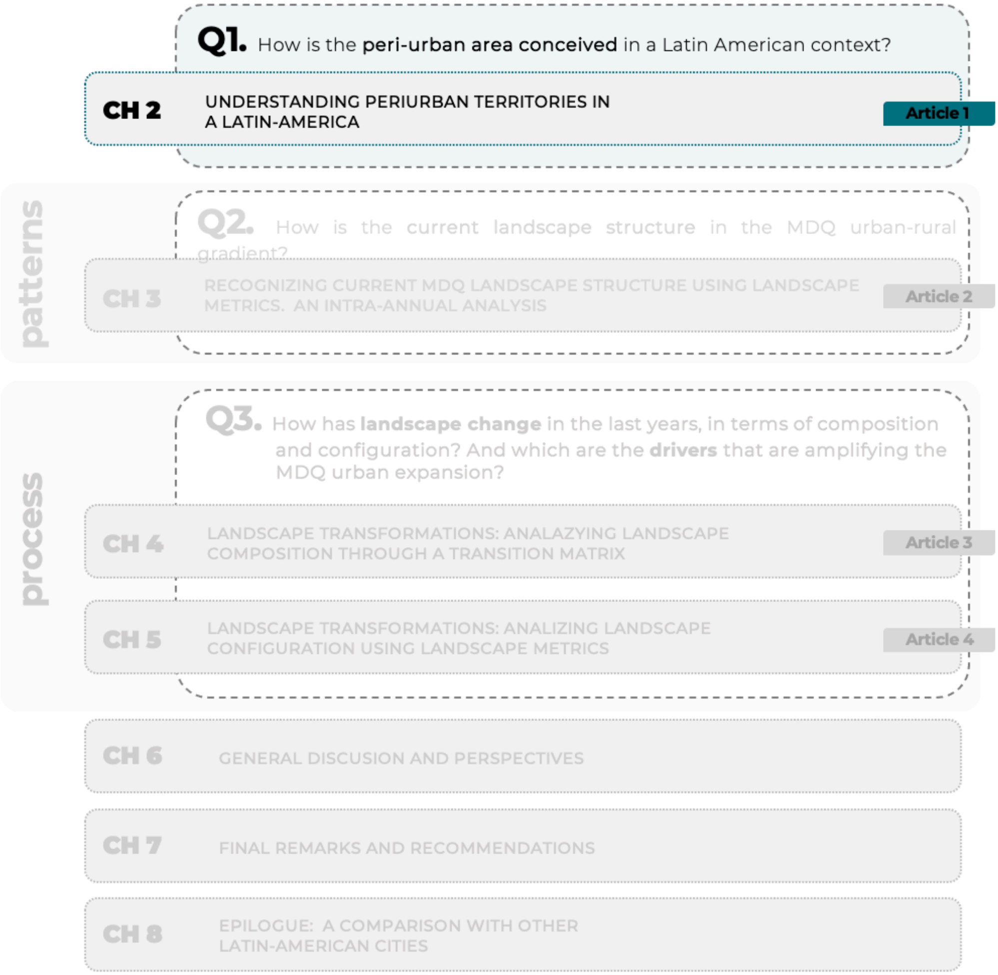
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Analysis of the urban-rural gradient terminology and its imaginaries in a Latin-American context

Abstract

Facing the new territorial configurations where the traditional binary conception of rural area versus urban area has become obsolete, this contribution aims at establishing new precisions about the most recurrent terms used in the scientific literature to describe the urban-rural gradient in a Latin-American context. As methodology, in order to identify and systematize the most outstanding attributes for each term, a Citation Frequency Index (CFI) has been calculated in 64 documents and 598 quotes. Additionally, the Sorensen Similarity Index (SSI) has been measured in order to identify distinctions and synergies among terms, obtaining a wider understanding of this territory and its interactions. A total of 50 attributes were identified and, based on them, the following precisions were formulated: "Rurban area" is a territory that, despite experiencing pressure for urban growth, is still strongly rooted to rural activities due to its proximity to the rural area. The terms "suburban area" and "periphery" are spatially located closer to the urban area; however, periphery is mainly associated with precariousness and informality, while a Latin-American suburb is constituted by large extensions of gated communities next to territories of poverty. Finally, the "periurban area" is essentially defined as an interface between urban and rural land, with highly heterogeneous uses and, due to its synergies with the other terms, it is recognized as a more extensive and encompassing territorial notion. This exercise highlights the importance of specific studies that distinguish the conceptual nuances of terminology in each region and the realities and imaginaries they represent.

Keywords: Citation Frequency Index; Periurban; Suburban; Rurban; Periphery.

1. New urbanization patterns

The magnitude and speed of anthropogenic influence on the worldwide ecosystems during the last decades, is an unprecedented event. Already in 1997, Vitousek et al., affirmed that more than a half of the earth's surface had been transformed by human activities, through new urban settlements and large agricultural and grazing areas. Consequently, the phenomenon of urbanization has become one of the greatest challenges for the coming decades, due to its high impact on the transformation and degradation of natural ecosystems. In 2008, the proportion of world's urban population exceeded the rural population for the first time. Despite several regions have still not reached that threshold, Latin America achieved 50% of urban population already in the seventies and nowadays, this tendency is still increasing, constituting a region essentially urban (United Nations, 2014).

Following this worldwide changes in urban-rural population ratio, the growth pattern of cities has also been transformed in recent years. In the contemporary patterns of urban settlements, a precise separation between the traditional notions of “countryside” and “city” is becoming more complex to delimit, and the city edge tends to disappear in a blurred interstitial territory (Borsdorf, 2003; Ligrone Fernández, 2016; Soja, 2008). For Chambers (1990), the traditional city -a metropolis- was established as a geographical unit, easily recognizable as distinct from the rural space. The contemporary city on the other hand or, what Soja (2008) has called "postmetropolis", is formed as a territory with new urbanization processes that restructure the modern metropolis. It is a new space where the urban-rural dichotomy tends to vanish into a gradient composed of residential areas, satellite cities, industrial clusters, new urban developments, informal occupation zones and agricultural production zones. It is a territory where the conception of an artificial interior (city) and a natural exterior (countryside) weakens in such way that it tends to fade (Chambers, 1990). This is particularly the case of megacities (a term used to describe the enormous size of these new human settlements), the foundation of metropolitan areas or the urban phenomenon of City-Regions (Mancheno & Terán, 2012). These transformations are occurring in a vertiginous speed and have an impact in an increasingly wider territory (Martner, 2016; Piorr et al., 2011; Seto et al., 2012).

2. Disentangling the urban-rural gradient terminology

Due to the hybrid condition (neither urban nor rural) of these new territorial configurations in anthropized areas, an extraordinary collection of terms (concepts) is currently used to describe them, such as periurban or suburban area. These terms, in some cases are used with ambiguity or as synonyms to describe similar areas and, in other cases, as terminology that seeks to capture the most outstanding features of these new territories within the urban-rural gradient.

Although sometimes two concepts may correspond to the same notion from a geographical point of view (for example, both periurban area and suburbs are in the outskirts of the city), there are certain historic, functional, and morphologic characteristics that are specific for each concept. For instance, a suburb in United States is not only an area in the outskirts of the city, but also a settlement shaped by the migration of a middle class in search of idealized areas with nature. Its expansion has been promoted by new access to private transport and it has particular morphological qualities: isolated and low-density houses with a front yard (Forsyth, 2012; Vaughan, 2015). Additionally, conceptual nuances can appear when terms are used in other geographical and socio-economic realities. Using the same example, the meaning of suburb in a Latin American context can be completely different to a suburb in United States. In fact, a "suburbio" refers a territory in the outskirts of the city that is usually associated with poverty, informality and lacking in infrastructure and services (J. Frediani, 2009; Hiernaux & Lindón, 2004; Serrano Heredia, 2017). At this point, it seems relevant to distinguish these regional particularities, embodied in terms that reflect specific realities, frequently opaque in a globalized world.

Since urban expansion areas have acquired new configurations, reflected in a highly region-dependent terminology, the general objective of this investigation is to achieve a more precise understanding of the urban-rural gradient through analyzing and clarifying the most frequent terms used to describe it, focusing specifically in the Latin American region. This study is composed of two parts: the first organizes and clarifies these various terms through a quantitative analysis of their most frequently quoted attributes in scientific literature. In the second part, similarities and synergies among terms are explored, in order to have a detailed and systemic understanding of the areas that integrate the urban-rural gradient. This work represents a first exercise and a sort of catalog for facilitating scientific dialogue in socio-territorial studies, by classifying, clarifying, and visualizing Latin American realities and their correlates in a technical and scientific language.

3. Methodological process: a bibliographical study

This bibliographic exploration was focusing exclusively on papers treating Latin American cases, that is, studies about cities within the region or articles written by Latin American authors describing their local context. The database of the Scientific Electronic Library (SciELO) was used, as it has a greater collection of Latin American scientific journals. The terms "periurban area", "rurban area", "suburban area" and "periphery", which are frequently used to describe the urban-rural gradient (André et al., 2014; Ávila Sánchez, 2009; Galindo & Delgado, 2006), were searched in the database to be analyzed. At this point, it is necessary to clarify that there are other terms associated with the urban-rural gradient, such as outlying district, expanded peripheries, fringe, and hinterland, among others. These terms were not considered in this study since, in some cases, they do not allow a literal translation into Spanish and therefore are not frequently used in Latin American literature. In other cases, despite the fact that they are Hispanic terms, they has been used by only one author (e.g. "Periferias Expandidas" (Adrián Guillermo Aguilar, 2002a)) so they cannot be consider as common terms. Due to the aforementioned reasons and their greater presence in the database, the four terms were identified in 64 references through a bibliographic search (see appendix A).

Table 1: List of attributes organized by category. These attributes were classified based on the main topic they address in order to highlight specific themes.

ATTRIBUTES
1. Fragmented and dispersed space
2. Concentric ring
3. Hybrid forms - complex spatial structures
4. New buildings
5. Low built density
6. Close to the city
7. Distant to the urban center
8. No defined limit
9. Advance of the urbanization along axes of exit of the city
10. Occupation and informal construction
11. Construction of gated communities for the elites
12. Construction of social interest housing
13. High landscape value
14. Dynamic and fast transformation
15. In process of consolidation
16. Persistence of highly rural activities
17. Functionally linked to the city
18. Daily commuting towards the urban center
19. Formation of new centralities
20. Heterogeneity in land uses
21. Growth focused on residential uses
22. New infrastructure and services
23. Lack of services
24. Interface between the countryside and the city (urban and rural activities)
25. New educational opportunities (relocation of the offer)
26. Lack of territorial planning policies
27. Environmental problems (fragile ecosystem)

28. Conflicts over the land (land use and tenure)
29. Conflicts over the tenure of water
30. Coexistence between different socioeconomic groups (precarious settlements next to gated communities for higher income population)
31. Territory as a benchmark for better quality of life
32. New actors and new forces (exogenous) build territory
33. Conservation of traditional social practices
34. Social isolation
35. Own social dynamics based on a sense of belonging (rooting)
36. Particular social and cultural changes (urban inhabitants that integrate into the rural)
37. Particular social and cultural changes (rural inhabitants that integrate into the city)
38. Ghetto / poverty
39. Decentralization of the industrial and commercial sectors
40. Labor precariousness
41. New jobs
42. Crisis in the agricultural sector (reduction)
43. Low land price
44. Land speculation
45. Stimulated by the flexibility of transportation
46. Pressure for urban growth
47. Land-use change
48. Resistance to change
49. Population growth due to immigration
50. Low population density

For the first part of the study, which consisted in identify the most frequently cited attributes (characteristic used to define each term), a list 50 attributes were identify from 598 quotes (see Table 1). This data was systematized in a matrix and the Citation Frequency Index (CFI) (%), proposed by André et al. (2014), was calculated. In this index, the values oscillate between 0 and 100%, being the attribute with the highest percentage the most quoted for each term. The equation of the CFI is the following:

$$CFI_{at} = 100 \times f_{at} / n_t$$

Where a is the attribute by which the index is being calculated, t is the term analyzed (periurban, suburban, rurban or periphery), f_{at} is the number of citations of the attribute a for the term t and n is the number of total citations used to describe one term. In this study, a "citation" is a phrase or short paragraph, analyzed by the authors, in which a term is defined or a specific attribute is described.

For example, in order to calculate the CFI of the attribute "fragmented and scattered space" (a) for the "periurban area" (t), the number of citations referring to this attribute were quantified (f_{at} =19) and divided for the total number of citations of all attributes for that term (n = 339). Through it, a CFI of 5.6% was obtained.

The attributes with greater frequency were considered the most characteristic for each term. Therefore, in order to understand the essential notion of each term, the 50% of the most outstanding attributes for each term were those taking into account, as they represent the most distinctive conceptual characteristics of each zone.

In a second part of the study, which consists in exploring similarities and synergies among terms, the Sorensen Index was calculated. This index enables to identify similarities, emphasizing the presence of the same element in different groups (Gebrehiwot et al., 2019; Noukeu et al., 2019). This is particularly important for this research since, in several occasions, one attribute could be associated to more than one term. For example, the attribute "Fragmented and dispersed space" was used to describe both the periurban and the suburban area (Ávila Sánchez, 2009; J. Frediani, 2010). Identifying these similarities would allow acquiring a more detailed understanding on how these terms are perceived and the possible correlations among them, within the gradient.

4. Results

4.1. Overview

From the bibliographic search, 64 articles were analyzed. Most of them, 21 to be precise, were written in a Mexican context, followed by the Argentine production (20). The rest corresponds to academic research carried out in Ecuador (5), Brazil (3), Chile (3), Colombia (2), Bolivia (1), Uruguay (1) and several with a regional approach (8). The oldest reference included dates from 1993, considering that in Latin America the rural exodus that generated the explosive urban growth was particularly determinant up to 1990 (Da Cunha et al., 2009).

Out of a total of 64 articles and 598 quotes, the term Periurban area was the most mentioned in a total of 48 articles and in 339 quotes, followed by the term periphery which was mentioned in 23 articles (113 quotes), suburban area in 14 articles (76 quotes) and rurban area in 12 articles (70 quotes).

Several authors mentioned more than one concept in the same article. In some cases, clearly defining the specific characteristics of each term. For example in Frediani (2009):

"*The suburbanization (...) is an expansion that extends in the form of an oil stain with the access of the middle and working classes to individual housing and that will explode with the access of the same classes to the ownership of the automobile. This suburbanization will not be rural, but an invasion of rural spaces by the city, which will include the conservation of some elements, such as the green of the trees, the small gardens and existing parks*" (p. 105). "*This situation makes the periurban area have a high degree of interest because it is a very dynamic and heterogeneous environment, as well as because environmental fragility and imbalances in the relationship between society and nature occur in it. In this geographical space large equipment and industries, landfills, slums, caves, closed urbanizations, etc. coexist in a complex way*" (p. 111)

However, in other cases, mixing the concepts as if they were the same space:

"*In the first instance, the analyzed models are similar to each other because they contain a booming peripheral space, in which the periurban area has gained accessibility through road infrastructure and increased use of the automobile, allowing suburbanization far from the center by high social strata and easy center-periphery accessibility*" (Serrano Heredia, 2017: 52).

Table 2: Citation Frequency Index (50% of the most cited attributes).

Periurban area	
Attribute	CFI%
Interface between field and city	8.26
Pressure for urban growth	7.08
Fragmented and scattered space	5.60
Dynamic and fast transformation	5.31
Coexistence between different socioeconomic groups	4.72
Environmental problems (fragile ecosystem)	4.72
Population growth due to immigration	4.42
Crisis in the agricultural sector (reduction)	3.54
Particular social and cultural changes (rural inhabitants who integrate into the city)	3.24
New infrastructure and services	2.95
Heterogeneity in land uses	2.65
Hybrid forms - complex spatial structures	2.36
Persistence of mainly rural activities	2.36
Growth focused on residential uses	2.36
Lack of services	2.36
Occupation and informal construction	2.36
Construction of gated communities	2.36
Decentralization of the industrial-commercial sectors	2.36
Distant to the urban center	2.06
Stimulated by the flexibility of transportation	2.06
Conflicts over the land tenure	2.06
Land speculation (real estate)	2.06
New buildings	1.47
Lack of territorial planning policies	1.47

Rurban area	
Attribute	CFI%
Persistence of mainly rural activities	12.86
New infrastructure and services	10.00
Own social dynamics based on a sense of belonging (rooting)	10.00
Resistance to change	7.14
Particular social and cultural changes (urban inhabitants that integrates rural)	7.14
Interface between field and city	5.71
Pressure due to urban growth	5.71
Low built density	4.29
Distant to the urban center	4.29
Growth focused on residential uses	4.29
Conservation of traditional social practices	2.86
Environmental effects (fragile ecosystem)	2.86
High landscape value	2.86

Suburban area	
Attribute	CFI%
Coexistence of different socioeconomic groups	7.89
Territory as a benchmark for quality of life	7.89
(Ghettos in) poverty	7.89
Close to the city	6.58
Stimulated by the flexibility of transportation	6.58
Lack of services	6.58
Construction of gated communities for elites	6.58
Fragmented and scattered space	5.26
Daily commuting towards the urban	5.26
Occupation and informal construction	3.95
Growth focused on residential uses	3.95
New infrastructure and services	3.95
Pressure for urban growth	3.95

Periphery	
Attribute	CFI%
(Ghettos in) poverty	10.62
Occupation and informal construction	9.73
Lack of services	8.85
Land speculation	6.19
Growth focused on residential uses	5.31
Coexistence of different socioeconomic groups	5.31
Pressure for urban growth	4.42
Concentric ring	3.54
Close to the city	3.54
New infrastructure and services	3.54
Gated communities for elites	3.54
Social isolation	3.54
Labor precariousness	3.54

4.2. First part: Analysis of the Citation Frequency Index

The results of the CFI are presented in Table 2. The attributes with highest percentages are the most quoted and, therefore, those that embody the most representative characteristics of each term, according to the perception of Latin American authors.

Based on the 50% attributes with highest percentage, the periurban area is conceived as an interface between the countryside and the city, that is, a place where urban dynamics cohabite with rural ones (CFI: 8.26). This territory is under constant pressure due to the exogenous growth of the urban area (7.08). It is characterized as a fragmented and dispersed space (5.60) with hybrid forms and complex spatial structures (2.36). Here, new housing projects (2.36) are next to areas for agricultural activities (2.36), industrial zones and new commercial developments (2.36). It means that there is a high heterogeneity in land uses (2.65). It is also a territory in a dynamic process of transformation, both towards its edges and inside (5.31) even though it is distant from the urban center (2.06). Within it, different socio-economic groups coexist (4.72): precarious or informal settlements (2.36) with lack of services (2.36) but also gated communities for high-income groups (2.36). The presence of non-compatible uses, as well as the reduction of forests and natural covers, has caused a deterioration of its ecosystems, damages, and environmental degradation (4.72). Its population profile responds to a migratory phenomenon (4.42) that comes from two sources: i) the exodus of the urban population to the countryside in search of a better quality of life, facilitated by the access to private transport (2.06); and ii) the migration from the countryside to the city, related -among other things- to the agricultural sector crisis (3.54). This double entry of population with practices that respond to two opposite realities –rural versus city life- generates a series of social and cultural dynamics that are exclusive to this territory (3.24), as well as conflicts over the use and tenure of the land (2.06). Finally, along with the construction of new buildings (1.47), new road infrastructure and urban services and facilities have been implemented (2.95). However, they are not always articulated to a clear territorial policy (1.47) but rather to opportunistic land speculation (2.06).

The suburban area or suburbs are characterized for having different socioeconomic strata (CFI: 7.89). Exactly with the same frequency of citation, the authors describe this territory with two attributes that would seem contradictory: some describe it as a place where people migrate in search of a better quality of life, idealizing it as a more healthy, quiet space surrounded by nature (7.89); while others describe it as a territory with highly impoverished settlements (7.89). These two scenarios, although dissimilar, are in synchrony with its first attribute: coexistence of different socioeconomic groups. The suburban territory is also characterized as an area geographically close to the city (6.58) and its development has been greatly enhanced by the recent and accelerated access to private motorization (6.58), generating permanent commuting to and from the urban center (5.26). In relation to its -partial- condition of poverty, informal settlements are usually located within it (3.95) with lack of basic services (6.58). On the other hand, the new morphological pattern of development of the middle and upper classes, responds to a private urbanization model, enclosed and isolated, provided with a perimeter wall and a single guarded access (6.58). Finally, this territory is characterized for being a fragmented and dispersed space (5.26), essentially residential (3.95) and in process of consolidating due to the implementation of new services and road infrastructure (3.95). All of these as a result of urban expansion (3.95).

The rurban area is characterized by the persistence of rural landscapes and activities (12.86), although, in a context of a globalized world, new urban forms start to appear in this territory. For example, the spread of new urban services and road infrastructure (10.00). However, the rurban territory is strongly based on a sense of belonging or rooting of its inhabitants (10.00). It is a territory that resists changes (7.14) and that conserves traditional social practices (2.86). Despite it is under pressure due to urban development (5.71), the rurban area is characterized by having its own dynamics that responds to particular social and cultural changes (7.14), due to its condition of interface between the countryside and the city (5.71). Morphologically, it is characterized as a settlement of low building density (4.29), with a growth focused on residential uses (4.29) and with a high landscape value (2.86). However, it is being increasingly more exposed to new environmental problems and is recognized as a fragile ecosystem (2.86). Unlike the periphery or the suburban zone, the rurban area is recognized as a space far from the city (4.29).

Finally, the term periphery, which literally means “the outer edge of an area”, in Latin America is usually associated with ghettos or slums, highly poor (10.62). It is formed by informal settlements and their constructions (9.73), with precarious or nonexistent basic services (8.85). In spite of this, in recent years and with increasing intensity, these territories have been the subject of speculation, driven by the logic of the land market (6.19) due to its privileged position of proximity to the city (3.54). This speculation is accompanied by the construction of new infrastructure and services (3.54) for new residential developments (5.31). These last characteristics triggers a double socio-territorial condition (5.31): precarious neighborhoods next to new condominiums for inhabitants with a different socioeconomic condition (3.54). Despite this, the marginality image of the periphery prevails, since its condition is also strongly associated with job insecurity (3.54) and with the social isolation of its inhabitants (3.54). Finally, its main changes are resulting from the urban expansion (4.42) which morphologically is expanding as a concentric ring (3.54).

5.3 Second part: Distinctions and synergies

The previous paragraphs seek to highlight the most outstanding characteristics of each term; however, even as each term represents an independent idea, there are synergies among all of them. In order to identify the level of correlation between these terms, the Sorensen Similarity Index has been calculated (Table 3).

Table 3: Sorensen Similarity Index. This diagonal matrix shows the number (upper cells) and the percentage (lower cells) of common attributes between terms.

	Periurban	Suburban	Rurban	Periphery
Periurban	**24**	9	7	11
Suburban	48.6 %	**13**	3	10
Rurban	37.8 %	23.1 %	**13**	3
Periphery	55.0 %	69.0 %	20.7 %	**16**

Periphery and suburban area are the terms with the greater percentage of similarity (69%), which means that more than half of their outstanding attributes are the same. Geographically, both are the only terms that emphasize being close to the city. They also match in being spaces with poverty, informal occupation, and precarious services. This description causes a negative perception of these two territories. However, considering the weighting detail of their attributes, periphery is a more pejorative notion since its three more frequent attributes are poverty, informality, and lack of services; and it has attributes related to social isolation and precariousness labor. While the suburban imaginary has a double burden: in addition to its condition of poverty, it is also conceived as a territory for the recent migration of the middle class in search of better quality of life.

On the other side, the rurban area is the term more distinguished from the others. It has a similarity of only 23.1% with the suburban area and 20.7% with the periphery. Its most outstanding characteristics are related to the permanence of activities and rural dynamics and the conservation of traditional social practices. All these describe a territory that is resisting the change, due to its particular social condition based on a sense of territorial rootedness.

Finally, what is more outstanding from the notion of periurban area, is that it is the term with highest similarities within the other three territories; to be precise, it shares 48.6% of its most outstanding attributes with the suburban area, 37.8% with the rurban area and 55% with the periphery.

5. Summary and discussion

Although some ambiguity is evident in the use of terms in the literature, recognizing the most distinctive characteristics through the Citation Frequency Index, has allowed clarifying and refining each terminology with more precision, from a Latin-American perspective. It can be summarized that: the rurban area stands out as a territory that still resist the predatory logic of urbanization. Although it is a territory that experiences strong pressure due to urban growth, and its inhabitants live functionally connected to the city, it stills maintaining rural logics, practices and landscapes (Ávila Sánchez, 2009; Cacivio & Ringuelet, 2012; Nates Cruz, 2008; Otero Macuacé & Gomez Sanchez, 2014; A. Salazar et al., 2014; Sereno et al., 2010).

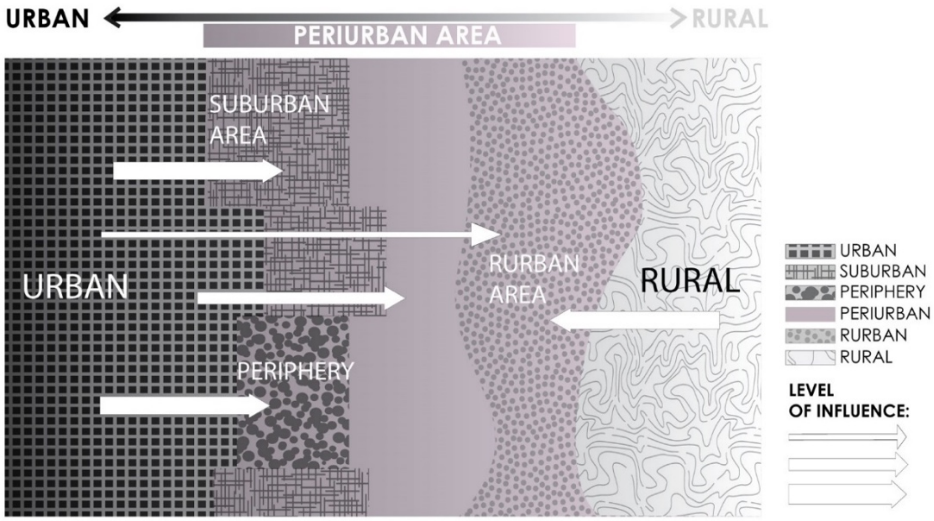
On the other hand, the suburban area and the periphery share socio-territorial phenomena strongly influenced by their proximity to the city (Delgado Campos, 2003; Durán et al., 2016; J. Frediani, 2010; Hiernaux & Lindón, 2004; Martner, 2016). However, the term "periphery" carries an unquestionably more negative appraisement in the social imaginary because of its association with poverty, precariousness, marginality, exclusion and informality (Adrián G Aguilar & López, 2016; Cacivio & Ringuelet, 2012; Carrión & Erazo Espinosa, 2012; Domínguez Aguilar, 2017; J. Hernández & Vieyra, 2010; Hidalgo et al., 2007; Ringuelet, 2008). While the most outstanding attribute of the suburban area is the interaction of both realities: impoverished territories next to gated communities built for middle and upper classes. Both cases are essentially residential (Calleja & Bolán, 1993; Delgado Campos, 2003; Durán et al., 2016; J. Frediani, 2009; Inostroza, 2017).

Finally, the periurban territory is characterized for having highly heterogeneous uses and for being under a strong pressure because of urban growth. It is essentially defined as an interface between urban and rural areas. Due to its multiple coincidences with the other terms, based in the Sorensen Index results, it would seem to be a much more general and extensive notion, able of containing the others. In fact, several articles insert the other terms within this apparently larger space: the periurban. "It is also understood the external area of this strip, or rurban zone, as the external limit of the periurban, where the urban-rural continuity shows a predominance of the rural area although with some characteristics of the city" (Sereno & Santarelli Serer, 2012: 43). “Any place around the city is a periurban area, but not anyplace is a rurban area; the latter is located around the city where the mentioned transformations are lodged with the new rurality" (Salazar, Díaz Mery, Mc-Intyre, & Foster Bonnette, 2014: 224).

Based on the above synthesis, the following scheme is proposed to illustrate the overall composition of the urban-rural gradient, based on the perceptions and imaginaries from Latin American authors and studies (Figure 1).

The main contribution of this research in relation to a previous study about the terminology in the urban-rural gradient from a multi-regional approach (André et al., 2014) is the recognition of the peculiarities of the Latin American reality and its imaginaries. Indeed, important divergences can be identified while comparing these two studies. The first notable difference is that the term "periphery" does not appear in the multi-regional study; therefore, it seems that these territories, strongly associated with precariousness, are spatial imaginary distinctive for the Latin American region. Likewise, the terms suburban and periurban area, in the study of André et al., are defined as the same notion, where the only difference is the language of origin (if it comes from a francophone context it is defined as periurban area). Both are defined as a territory where: "i) the built-up areas are not dominant, ii) where there is no explicit zoning of uses and iii) where there isn't exclusively agricultural or forestry uses" (p.66). However, in Latin America, when analyzing the zoning, it can be notes that these two concepts are very different: the periurban territory is highly heterogeneous (residential, industrial, commercial, and agricultural) while the suburb has an explicit zoning: mainly residential.

Figure 1: Graphical scheme of the urban-rural gradient. Based on the CFI and the Sorensen Index. This graphic proposes a scheme of the spatial location of the different studied territories and their relation among each other. The width of the arrows shows the level of influence from the urban or rural area to a specific territory.



6. Conclusions

This exercise highlights the importance of specific studies that distinguish the conceptual nuances of terminology in each region, and the realities and imaginaries they represent. It is necessary to overcome univocity, that is, the idea that there are unique conceptions, valid for everyone and everywhere. On the contrary, it is necessary to recognize the diversity of the realities abstracted in different concepts, avoiding that any territorial particularity will become invisible. It would be wrong for academics, policy makers or city planners to propose territorial management strategies based on generalized concepts, since this could result in projects and guidelines disconnected to the specific needs of each place.

After these first results, it seems essential to verify and validate these theoretical-symbolic notions in a specific territory. Greater distinctions or similarities could appear between cities and countries within the region. As well, further studies approaching other regions could also enrich the discussion about contemporary urbanization patterns. Finally, a relevant challenge for future studies would be, not only to understand the status quo of these new territorial configurations, but also to recognize and measure their possible social, environmental, and economic impacts, which represent the main concern about the contemporary patterns of urbanization in Latin America.

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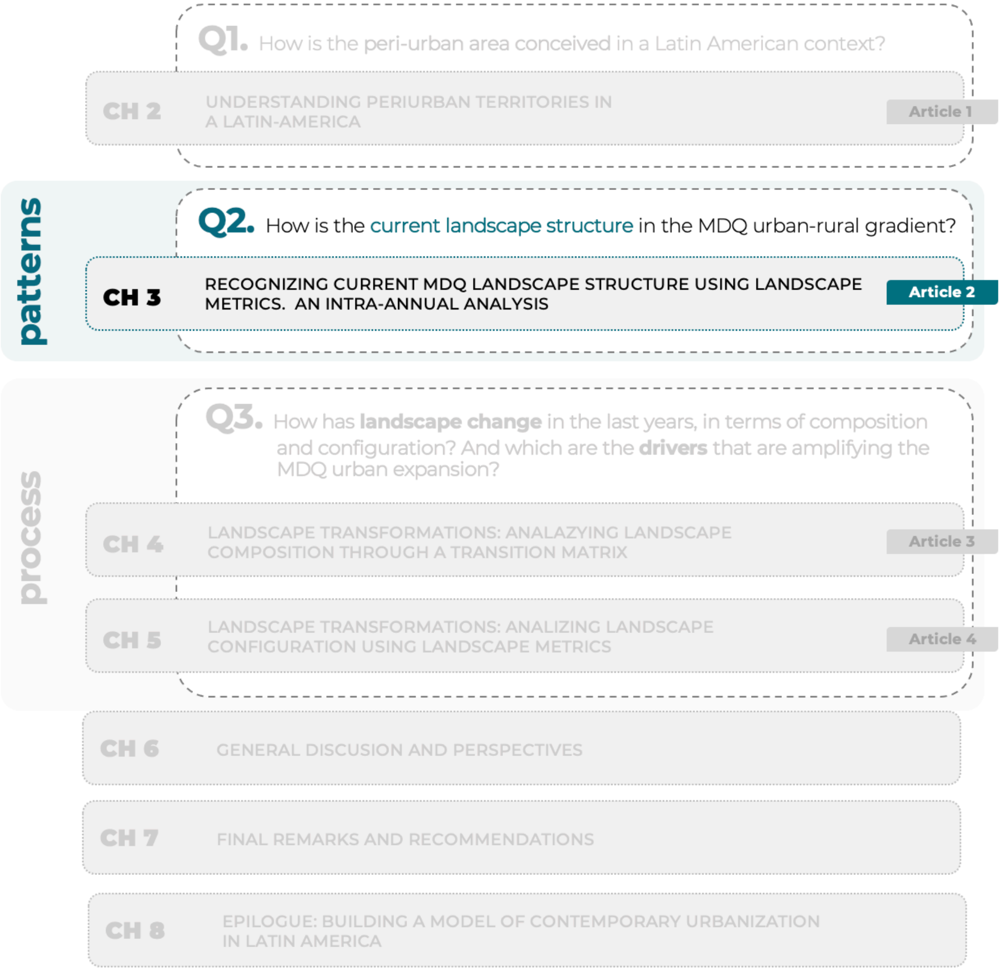
Chapter 3

Recognizing current landscape structure in the Metropolitan District of Quito using landscape metrics

PUBLISHED ARTICLE 2.

CHARACTERIZING LANDSCAPE PATTERN IN URBAN-RURAL INTERFACES

Paola Ortiz-Báez, Pablo Cabrera-Barona & Jan Bogaert (2021). Journal of Urban Management. Volume 10, Issue 1, Pages 46-56, ISSN 2226-5856


Q1. How is the peri-urban area conceived in a Latin American context?
CH 2
UNDERSTANDING PERIURBAN TERRITORIES IN A LATIN-AMERICA
Article 1
patterns
Q2. How is the current landscape structure in the MDQ urban-rural gradient?
CH 3
RECOGNIZING CURRENT MDQ LANDSCAPE STRUCTURE USING LANDSCAPE METRICS. AN INTRA-ANNUAL ANALYSIS
Article 2
process
Q3. How has landscape change in the last years, in terms of composition and configuration? And which are the drivers that are amplifying the MDQ urban expansion?
CH 4
LANDSCAPE TRANSFORMATIONS: ANALAZYING LANDSCAPE COMPOSITION THROUGH A TRANSITION MATRIX
Article 3
CH 5
LANDSCAPE TRANSFORMATIONS: ANALIZING LANDSCAPE CONFIGURATION USING LANDSCAPE METRICS
Article 4
CH 6
GENERAL DISCUSION AND PERSPECTIVES
CH 7
FINAL REMARKS AND RECOMMENDATIONS
CH 8
EPILOGUE: BUILDING A MODEL OF CONTEMPORARY URBANIZATION IN LATIN AMERICA

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Research Article

Characterizing landscape patterns in urban-rural interfaces

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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; 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

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Characterizing Landscape Patterns in Urban-Rural Interfaces

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.

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

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).

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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 (H. Liu & Weng, 2013). According to the pattern-process paradigm (Bogaert et al., 2015) 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; Vizzari & Sigura, 2015).

With 85% of its population living in cities, Latin America is the most urbanized region in the Global South (J. M. P. 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. Around 0.9 million people inhabit the periurban and rural areas of the MDQ. Nowadays, new buildings are being constructed in increasingly more distant peripheral territories, now connected by new road infrastructures, occupying zones that previously were used for agricultural production or are ecological protection zones (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 rural territory 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). These valleys are territories where urban expansion is dramatically advancing, due to topographic factors: on the western side the Pichincha volcano is located (Municipio del Distrito Metropolitano de Quito, 2014). 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 (Figure 1).

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

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 meters 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.

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) (Figure 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 Figure 3.

Figure 2. Land Use Land Covers (LULCs)

Figure 3. Satellite interpretation process and construction of raster image with LULC.

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; H. 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.

Table 4: Landscape metrics used in this study.

Name	Calculation Formula	Notes
Percentage of Landscape (PLAND)	$\text{PLAND} = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	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)	$LPI = \frac{\max_{j=1}(a_{ij})}{A}(100)$	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.

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.

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.

Table 5: 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 6: 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%

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 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.

Table 7: 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%

3.3 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 Figure 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 figure 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 figure 6.

Figure 4. Metrics variation for Vegetation cover along transects.

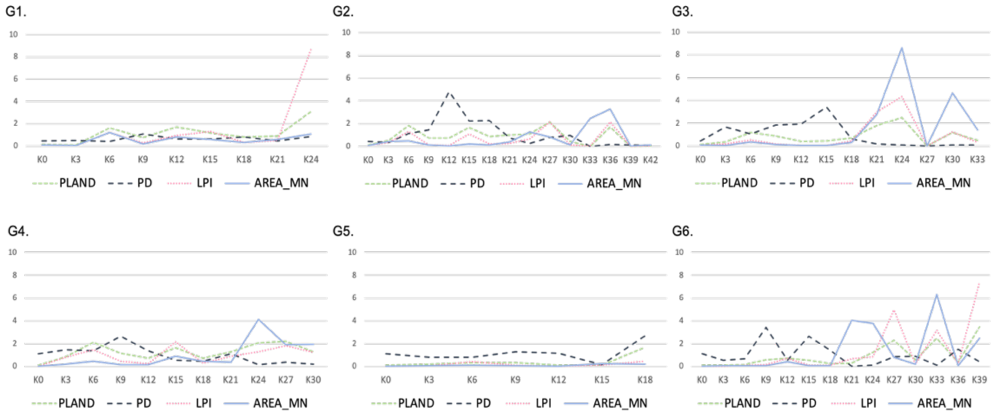


Figure 5. Metrics variation for Built-up cover along transects.

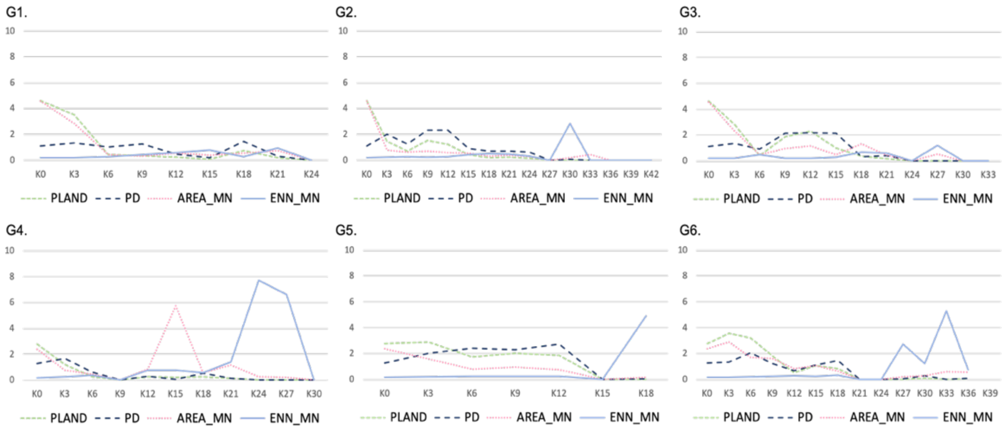


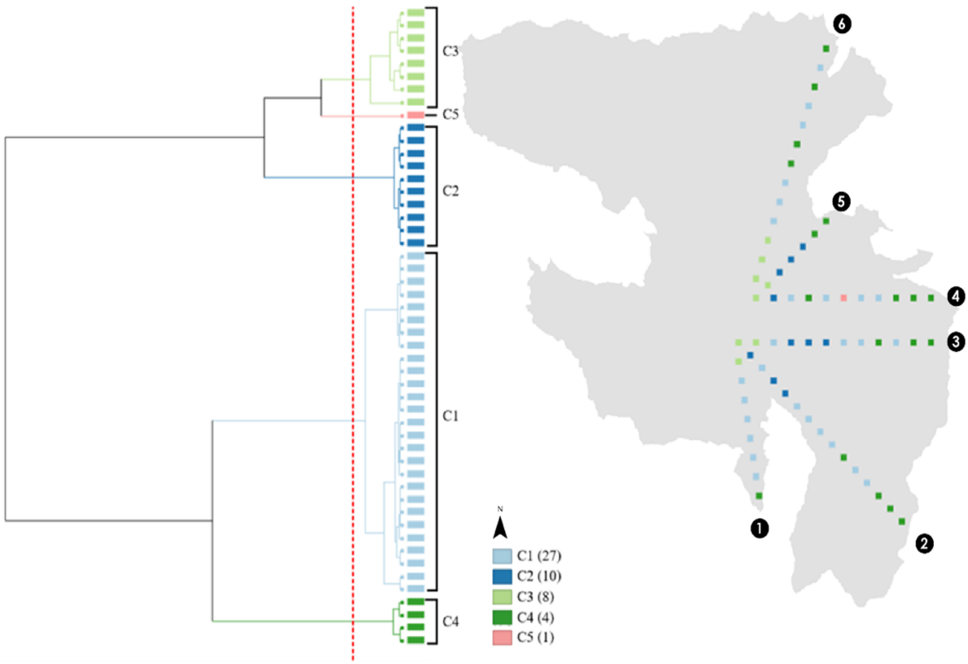
Figure 6. Left, km18 Gradient 4 (Puembo). ENN: 17.57m. Right, km18 Gradient 5 (Calderón). ENN: 5.02m

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 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 Figure 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.).

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



The ratio of between to total sum of squares: 0.844916

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; H. 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 & 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 (Figure 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 (Figures 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 MDQ 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). Finally, this methodology has proven to be highly effective in terms of identifying landscape structure and could also be replicated to other Latin American cities, where knowledge about urban peripheries -these hybrid and highly changing landscapes- is limited.

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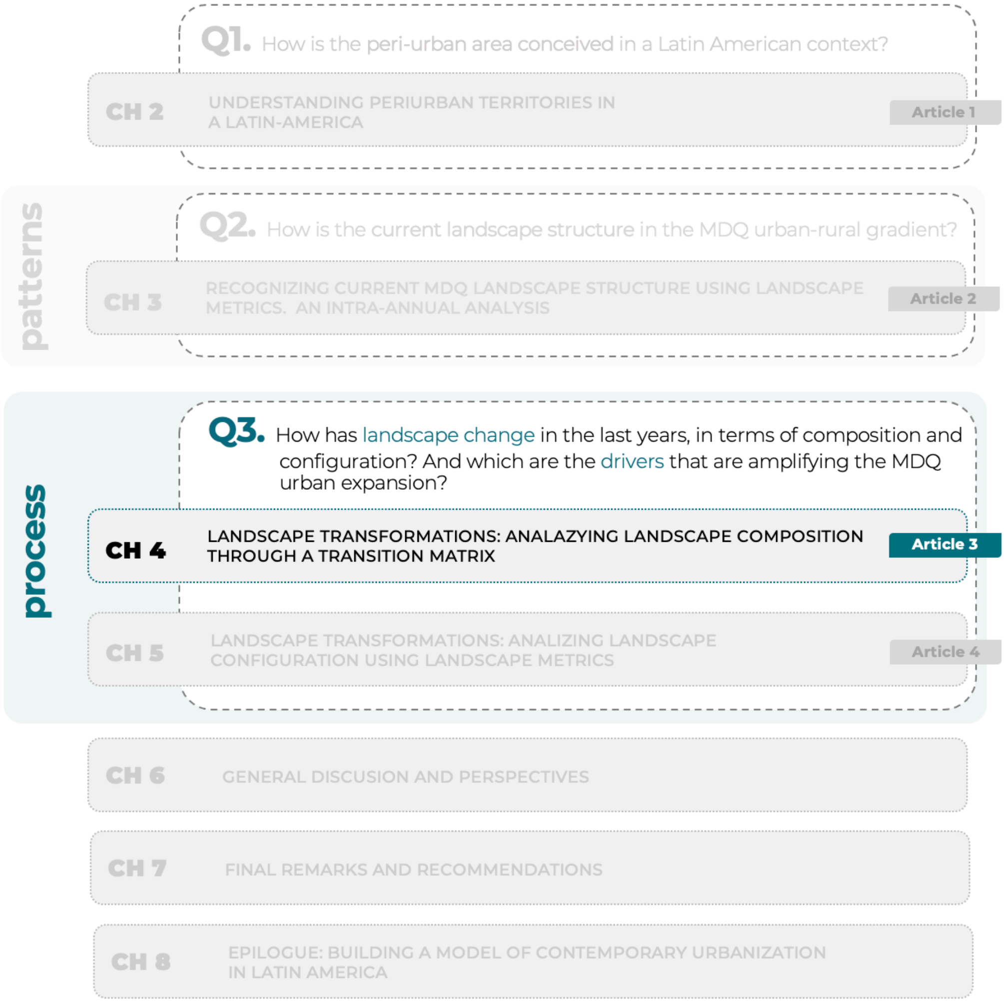
Chapter 4

Landscape transformations: analyzing landscape composition through a transition matrix

PUBLISHED ARTICLE 3.

ANALYSIS OF PERI-URBAN LANDSCAPE COMPOSITION AND ITS SPATIO-TEMPORAL TRANSFORMATIONS. THE CASE OF THE METROPOLITAN DISTRICT OF QUITO.

Ortiz-Báez, P., Freire, M. J., & Bogaert, J. (2023). Analysis of peri-urban landscape composition and its spatio-temporal transformations: the case of the Metropolitan District of Quito. *Journal of Architecture and Urbanism*, *47*(1), 1–11. https://doi.org/10.3846/jau.2023.16968


Q1. How is the peri-urban area conceived in a Latin American context?
CH 2
UNDERSTANDING PERIURBAN TERRITORIES IN A LATIN-AMERICA
Article 1
patterns
Q2. How is the current landscape structure in the MDQ urban-rural gradient?
CH 3
RECOGNIZING CURRENT MDQ LANDSCAPE STRUCTURE USING LANDSCAPE METRICS. AN INTRA-ANNUAL ANALYSIS
Article 2
process
Q3. How has landscape change in the last years, in terms of composition and configuration? And which are the drivers that are amplifying the MDQ urban expansion?
CH 4
LANDSCAPE TRANSFORMATIONS: ANALAZYING LANDSCAPE COMPOSITION THROUGH A TRANSITION MATRIX
Article 3
CH 5
LANDSCAPE TRANSFORMATIONS: ANALIZING LANDSCAPE CONFIGURATION USING LANDSCAPE METRICS
Article 4
CH 6
GENERAL DISCUSION AND PERSPECTIVES
CH 7
FINAL REMARKS AND RECOMMENDATIONS
CH 8
EPILOGUE: BUILDING A MODEL OF CONTEMPORARY URBANIZATION IN LATIN AMERICA

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ANALYSIS OF PERI-URBAN LANDSCAPE COMPOSITION AND ITS SPATIO-TEMPORAL TRANSFORMATIONS: THE CASE OF THE METROPOLITAN DISTRICT OF QUITO

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Abstract. Latin American contemporary cities are facing a rapidly urban dispersion which is mainly occurring in peri-urban zones. Since these transitional spaces remain geographically and conceptually unclear, having a greater understanding of its landscape composition has become a key issue for territorial planning purposes. In this article, the Metropolitan District of Quito urban-rural gradient landscape composition and its spatiotemporal transformations are analysed. Using satellite images of very high resolution of two periods, five Land Use-Land Covers (LULC) were identified in sixty-four sample polygons. Based on that, a transition matrix and a stability index were developed to analyse landscape composition change intensity. Results demonstrate that peri-urban areas show the highest landscape instability, although through a great diversity of land occupation typologies. The four dominant typologies are analysed. Parsing LULCs independently, vegetation showed the greatest instability, which significantly alters ecosystems and their services. On the other hand, mega-road infrastructure appears to be one of the most dramatic drivers of peri-urban transformation, since samples crossed by new highways experienced the greatest landscape transformation on average. Finally, this methodology and insights could be extrapolated to other Latin American cities, where micro-scale policymaking should be a priority in scenarios of complex and highly heterogeneous peri-urbanization.

Keywords: landscape composition, periurban areas, transition matrix, landscape stability index.

Introduction

During the past century, the world's urban population has rapidly increased, drastically transforming landscapes around the planet. Latin America is one of the most urbanized regions in the world, with approximately 80% of the region's total population living in cities. Despite the slowdown in population growth, Latin America faces a myriad of problems related to the spatial dispersion of its cities. This growth is mainly characterized by the quick appearance of new residential areas, new informal neighborhoods, shopping centers and industrial zones, all of which have expanded built space with low population density (ONU-Habitat, 2012).

This rapid urban expansion is mainly occurring in peri-urban zones, which is particularly challenging since these transitional spaces remain geographically and conceptually unclear. Peri-urban zones encompass both urban and rural activities and frequently undergo unplanned and chaotic transformation processes (Gonçalves et al., 2017; Ortiz Báez et al., 2020; Vergés et al., 2008). Although peri-urban areas have become a key issue for many cities, there remains a lack of studies on peri-urban growth patterns in Latin America. Most of the existing studies look at urbanization processes in the global West, while research that analyzes landscape patterns in Latin American cities remain scarce (Cruz-Muñoz, 2021).

Landscape is spatially, structurally and functionally dynamic, and it's the result of complex interactions between biophysics and socio-economic factors (Vergés et al., 2008). When cities expand into peri-urban areas, landscapes that were originally natural or agricultural lands become residential, commercial, or industrial. Accordingly to Forman and Grodon (1986) there is an "anthropization gradient" which includes five steps: natural, managed, cultivated, suburban, and urban landscapes. This transformation can bring important environmental challenges like ecosystem degradation, biodiversity damage, decline of natural recourses, as well as loss of ecosystem services, agricultural land and food supply, among

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Analysis of peri-urban landscape composition and its spatiotemporal transformations

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In Latin American cities in particular, the land market has been poorly regulated and developed. Therefore, many governments have opted for neoliberal policies in order to meet the enormous need for housing. Thus the rules of land use planning and the growth of cities is defined largely by the "liberation of the land market", where real estate agents not only maximize their profits, but also take the leading role in urbanization processes (Cruz-Muñoz, 2021; Perahia, 2009). This free-market policy has been a central driving force behind land speculation and urban dispersion.

In this context, the study of landscape patterns and transformations has become a crucial task of urban and environmental research (Bogaert et al., 2014; Pérez-Hugalde et al., 2011). Since landscape change depends on various processes and factors, many studies have applied multi-temporal landscape composition analysis to understand the magnitude and characteristics of these changes (Czekajlo et al., 2021; Huang et al., 2012; Vega et al., 2007). A transition matrix has shown to be a practical method to quantify landscape change, analyzing two diachronic land cover maps (Huang et al., 2012; Liu et al., 2021). Likewise, the urban-rural gradient is a technique that has proven to be useful for understanding how urbanization changes ecological patterns across the landscape (Hahs & McDonnell, 2006; Vizzari & Sigura, 2015). Recognizing the territory as a continuum, this technique has been widely used to assess how anthropogenic influence gradually modifies the structure and functions of ecosystems (Yu & Ng, 2007). This study manages to integrate, in a novel way, the gradients paradigm and their spatial transition with a temporal transition.

The aim of this paper is to analyze the last decade of landscape change in the Metropolitan District of Quito (MDQ) -- the city with the fastest population growth in Ecuador -- with a particular focus on the urban expansion areas. Our hypothesis is that the easter valleys of the MDQ are undergoing important landscape transformation processes, with greater intensity in the peri-urban zones. These changes alter landscape patterns of natural and anthropogenic covers differently. Particularly, in urbanization scenarios, vegetation and agricultural covers are expected to experience more severe transformations, threatening the environmental quality of the territory. Also, the implementation of new road mega-infrastructures is expected to intensify territorial transformation in gradients that are crossed by them and its areas of influence. Finally, we believe that insights from our study of changing landscape composition in the MDQ can provide important lessons for other Latin American urban contexts which are undergoing similar dynamics, in terms of infrastructure development and processes of urbanization.

Methodology

1.1 ***Study Area***

Located at 2,800 meters above sea level, the MDQ is the administrative capital of Ecuador. Due to its political and economic dynamism, it has become an important node of national and international migration. Despite its complex topography within the Andes Mountain range, this has not hindered urbanization, which has been occurring in an accelerated and dispersed way (Figure 1) (MDMQ, 2017). Historically, urban growth largely occurred on a north-south axis due to topographic limits in other directions. In this first stage, this north-south growth was mainly motivated by private interests that urbanized the land through the model of citadel[1]. Growth was led by middle and upper classes, who were looking for a new residential location outside the overcrowded historic center (Freire Silva, 2015). Simultaneously, in the absence of social housing projects, many people informally occupied land near urban areas, initiating an expansion of the city towards the slopes and near peripheries.

In the last few decades, a much more intensive growth has occurred, overflowing the urban tissue outside the city limits. It could be explained by the fact that Quito has experienced a greater population growth motivated by international and internal migratory processes. It is estimated that the population has doubled in less than three decades, going from 1,409,845 inhabitants in 1990 to 2,781,641 in 2020 (Municipio del Distrito Metropolitano de Quito, 2021). This growth has also been reflected spatially in the city itself, which has approximately tripled its urban expansion, accentuating a dispersed growth towards peri-urban areas, especially toward the east (Figure 2). It has generated mobility difficulties, more expensive infrastructure and services, and large extensions of vacant land in between (Municipio del Distrito Metropolitano de Quito, 2018).

During this period, land use management plans have allowed modifications in peri-urban territories, for example changes in land use from agricultural to residential because of pressure from real estate companies. In other cases, due to informal land occupation that are later regularized by the municipality. This has consolidated a polarized peri-urban territory. Both self-constructed settlements and real estate projects in the form of gated communities have expanded to the nearby valleys. Further, the construction of the new airport in the eastern outskirts of the city and the accompanying road infrastructure has stimulated real-estate and speculative sectors to start urbanizing this entire eastern strip, characterized by having natural ecosystems and cultivated areas (Carrión, 2015; Environmental Secretariat MDQ, 2016). Many of the urbanization processes in this peri-urban area remain unregulated by local government, leading to disorganized urban growth (Municipio del Distrito Metropolitano de Quito, 2021). Finally, due the speed of this transformation, very little is known about the current peri-urban landscape in terms of its spatial composition, its transformation tendency, and the potential impacts on its pre-existing natural ecosystems.

[1] A Citadel describes the urbanization of small parts of territory with an urban tissue of similar characteristics in terms of block shapes and sizes, parcel dimensions and in some cases also of buildings, which are not necessarily in coordination with other citadels or neighboring tissues. These urbanizations allocated a percentage of the parcel for green and recreational areas.

Figure 1. Aerial image of the MDQ, the upper and lower valleys and its complex topography.
Source: Correa, Felipe. Line in the Andes. Editorial: Harvard Graduate School of Design. 2013.

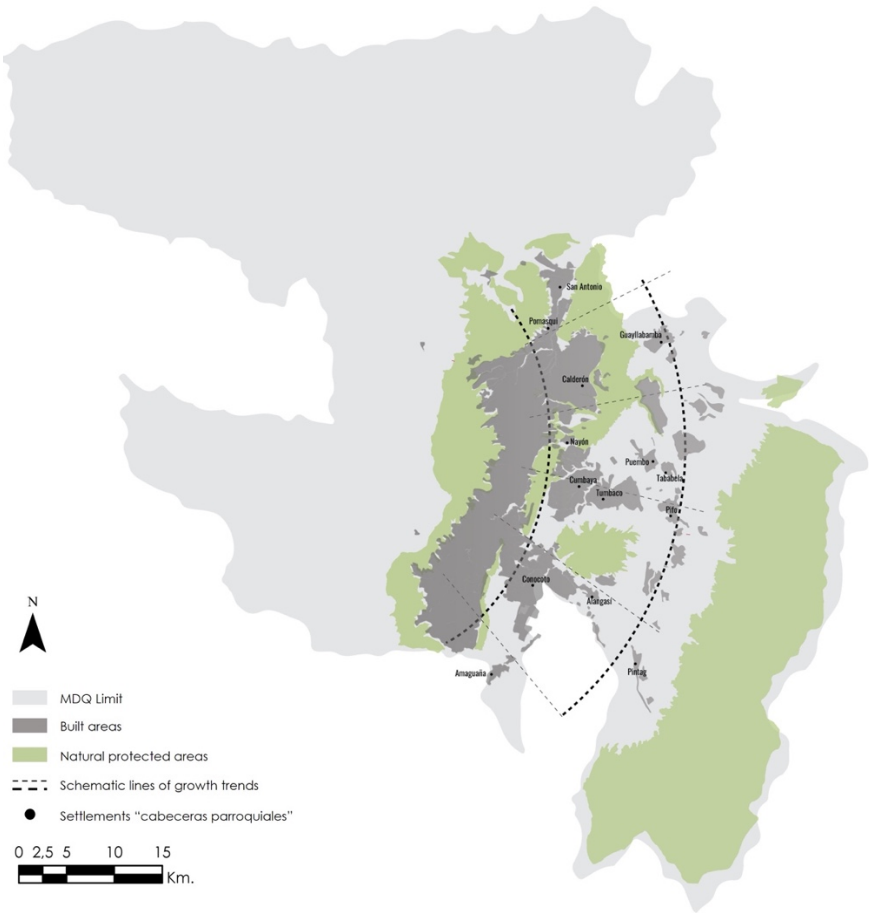

Figure 2. Metropolitan District of Quito grow tendency over the peri-urban eastern valleys. Source: By the authors

1.2 *Definition of transects, samples and LULCs*

To analyze the extension and diversity of the MDQ urban-rural gradient, six transects were defined, based on a previous publication by Ortiz-Báez et al. (2021)[2]. The transects start in the two main urban centralities and move toward the rural areas, covering the

[2] This article analyzes the structure of the 2017 landscape through calculating landscape metrics.

eastern valleys from the northeast to the southeast. The transects are traced following mathematical angles. Sixty-four sample polygons, of one square kilometer, were defined within the transects (Figure 3). In each polygon, 5 Land Use-Land Covers (LULC) were identified through visual identification using the very high resolution (1 pixel = 1 m2) satellite images of 2010 and 2017 (Figure 4). The LULC classes include 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 (which includes all arboreal and shrubby foliage present in the different MDQ's ecological zones: from Low Montane Prickly Steppe up to Low Montane Humid Forests), agriculture (all recognizable plots with agricultural land production), and bare soil and grassland (Figure 5).

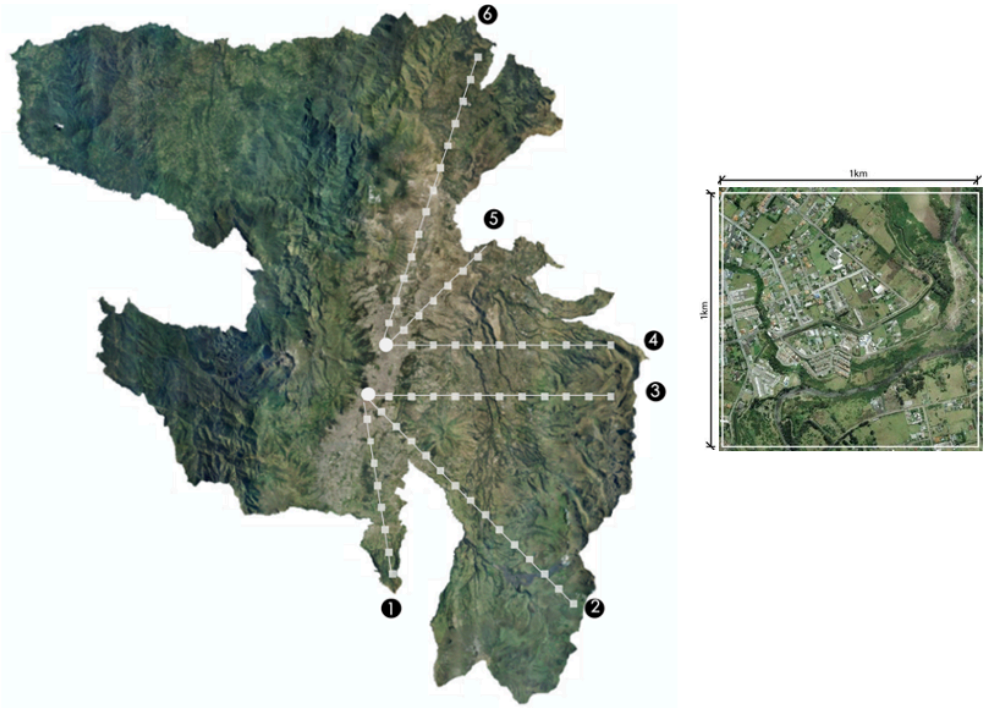

Figure 3. Definition of transects and sample size.
Source: By the authors

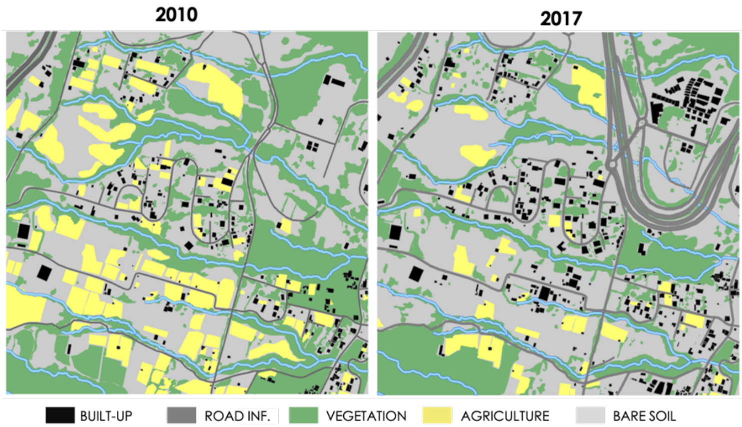

Figure 4. Example of one sample LULC identification for years 2010 and 2017.
Source: By the authors

Figure 5. Visual identification of Land Use Land Covers
Source: By the authors

1.3 MDQ's urban, peri-urban, rurban and rural areas

In Ortiz-Báez et al's study (2021), a multivariate cluster analysis was presented based on landscape structure patterns (patch density, mean area, Euclidean nearest neighbor, among others) for the 64 samples. In the same article, a Kruskal-Wallis statistical test was developed demonstrating that landscape patterns have more statistically significant differences as samples move away from city-center. Both analyses confirmed that the chosen gradients are an adequate strategy for the applied sampling and the clustering classification. Five groups were identified: urban (C3), rurban[3] (C1), peri-urban (C2), industrial (C5) and rural (C4). Figure 6 displays the cluster dendrogram and the map with the five-group classification, which will be used as a reference for this analysis.

[3] According to (R. P. Ortiz et al., 2020), the rurban zone can be defined as the external strip or limit within the periurban area, where the urban-rural continuity shows a predominance of the rural area although with some urban features.

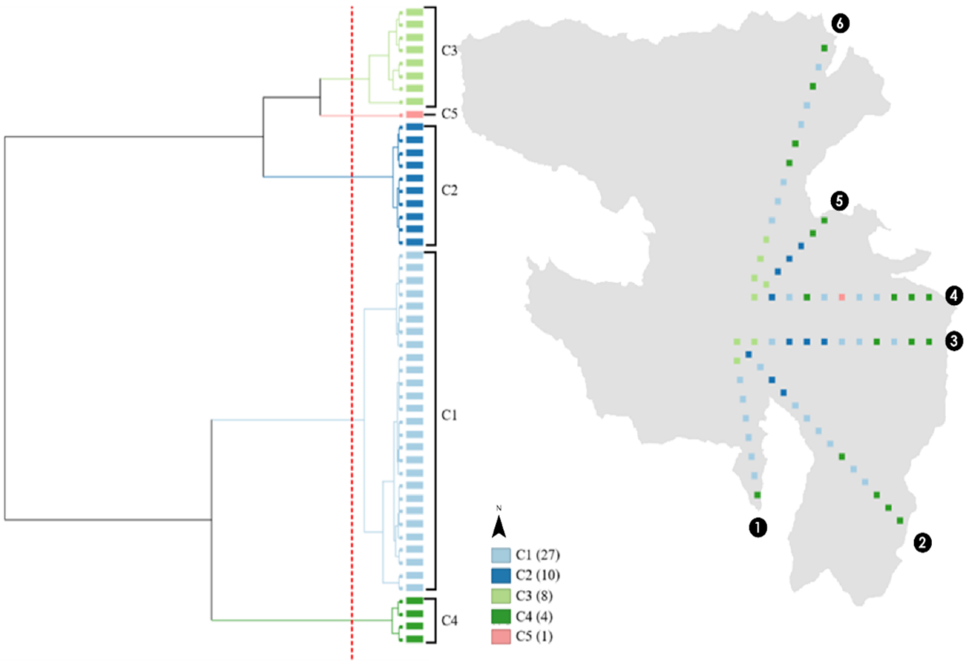

Figure 6. Cluster classification that defines urban, periurban, rurban and rural samples in the MDQ.
Source: (Ortiz-Báez et al., 2021)

1.4 Transition matrix and landscape stability index

A transition matrix methodology was used to analyze changes in landscape composition[4]. This methodology allowed us to overlay various LULC maps and generate a database that demonstrate which areas have remained the same and which have changed to another cover type within a specific time period. The matrix also shows the proportion (area) of every type of change (Camacho-Sanabria et al. 2015; Huang et al. 2012; Vergés et al. 2008). In Table 1, the rows show the proportion of land cover types at the initial time point, and the columns show the proportion of land cover types at the subsequent time point. Thereby, the values on the diagonal reflect those areas or proportions that did not change, while the values outside the diagonal show the proportions of land cover change between time point one and time point 2.

[4] In landscape analysis, composition refers to the number of patch types or LULCs in the landscape, their area and their definition (Bogaert et al., 2014).

Table 1. Transition matrix
Source: By the authors

		Time 2				
		LULC 1	**LULC 2**	**LULC 3**	**LULC 4**	**LULC n**
Time 1	**LULC 1**	$\mathbf{L_{11}}$	L_{21}	L_{31}	L_{41}	L_{n1}
	LULC 2	L_{12}	$\mathbf{L_{22}}$	L_{32}	L_{42}	L_{n2}
	LULC 3	L_{13}	L_{23}	$\mathbf{L_{33}}$	L_{43}	L_{n3}
	LULC 4	L_{14}	L_{24}	L_{34}	$\mathbf{L_{44}}$	L_{n4}
	LULC n	L_{1n}	L_{2n}	L_{3n}	L_{4n}	$\mathbf{L_{nn}}$

When the values on the diagonal are high comparatively to the "outside values," it indicates that landscape has been less dynamic, or more stable. On the other hand, an instable landscape will present higher values on the outside cells than on the diagonal. Based on that, we can calculate a landscape stability index (Bogaert et al., 2014), dividing the sum of all the values of the diagonal by the sum of all the outer values (Equation 1). Values closer to zero indicate that the landscape has been very unstable, while higher values indicate that the landscape has been more stable. This stability calculation can also be performed for each LULC independently, considering only the row and column of that LULC.

$$S = \frac{\sum_{i=1}^{n} Lii}{\sum_{i=1\ j=1}^{n} Lij} \quad (1)$$

where Lij ($i \neq j$), shown in the denominator and corresponding to the "outside values," indicates the proportion of land use that experienced a transition from LULC i to LULC j between time 1 and time 2 and n is the total number of LULC. The diagonal entries, shown in the numerator, Lii, indicate the proportion of land use that did not change.

A transition matrix was built for each of the 64 samples, and a stability index was calculated, both for each LULC and for each sample total landscape. We then created a set of maps that were categorized in 4 ranges, based on the stability change intensity: Highly unstable ($x<1$), unstable ($1<x<5$), stable ($x>5$) and highly stable ($x>10$). This analysis is presented in section 2.1 and 2.2. Additionally, an average stability index was calculated for each gradient and cluster (section 2.3)

Results

1.5 *LULC stability index*

In Figure 7, we observe the spatial results of the stability index of each LULC independently. Table 2 systematizes these results by showing the percentages of the four instability ranges (Highly Stable (HS), Stable (S), Unstable (U) and Highly Unstable (HU)) for every cluster and LULC. The results show that the most unstable clusters are C1 and C2, which correspond to rurban and peri-urban areas. Adding ranges U and HU, C1 presents 81.5%, 70.4% and 88.9% for the Built-up, Vegetation and Agriculture LULCs respectively. While for C2, the same LULCs represent 80%, 100% and 90% respectively. Regarding on the Road infrastructure cover, a greater instability can be observed for C1, since -adding the HU and U ranges- reaches 48.1%, while in C2 there is greater stability with a HS range of 70%.

On the other hand, the C3 cluster -- that corresponds to the urban area -- present a higher stability in the coverages of Built-up (100%) and Road Infrastructure (75%), when adding the S and HS ranges. However, when observing the vegetation and agriculture LULCs, they present high values of instability as adding the U and HU ranges they reach 75% and 72.5% respectively. Finally, regarding the rural (C4) and industrial (C5) clusters, a great instability for the vegetation cover can also be highlighted, with 55.6% and 100% respectively, adding the HU and U ranges.

Table 2. Stability Index
Source: By the authors

	BUILT-UP					ROAD INFRASTRUCTURE					VEGETATION					AGRICULTURE				
	HS %	S %	U %	HU %	ND %	HS %	S %	U %	HU %	ND %	HS %	S %	U %	HU %	ND %	HS %	S %	U %	HU %	ND %
C1	3,7	7,4	55,6	25,9	7,4	48,1	3,7	33,3	14,8	0,0	14,8	11,1	55,6	14,8	3,7	3,7	0,0	55,6	33,3	7,4
C2	10,0	10,0	80,0	0,0	0,0	70,0	0,0	20,0	10,0	0,0	0,0	0,0	30,0	70,0	0,0	0,0	0,0	40,0	50,0	10,0
C3	75,0	25,0	0,0	0,0	0,0	75,0	0,0	25,0	0,0	0,0	0,0	25,0	62,5	12,5	0,0	12,5	12,5	12,5	12,5	50,0
C4	0,0	0,0	11,1	0,0	88,9	33,3	5,6	11,1	5,6	44,4	27,8	16,7	38,9	16,7	0,0	5,6	0,0	5,6	5,6	83,3
C5	0,0	0,0	0,0	100	0,0	0,0	0,0	100	0,0	0,0	0,0	0,0	0,0	100	0,0	0,0	0,0	0,0	0,0	100

Note. C1 (Rurban Cluster), C2 (Peri-urban Cluster), C3 (Urban Cluster), C4 (Rural Cluster), C5 (Industrial Cluster) / HS (High Stable range), S (Stable range), U (Unstable range), HU (Highly Unstable range), ND (No data).

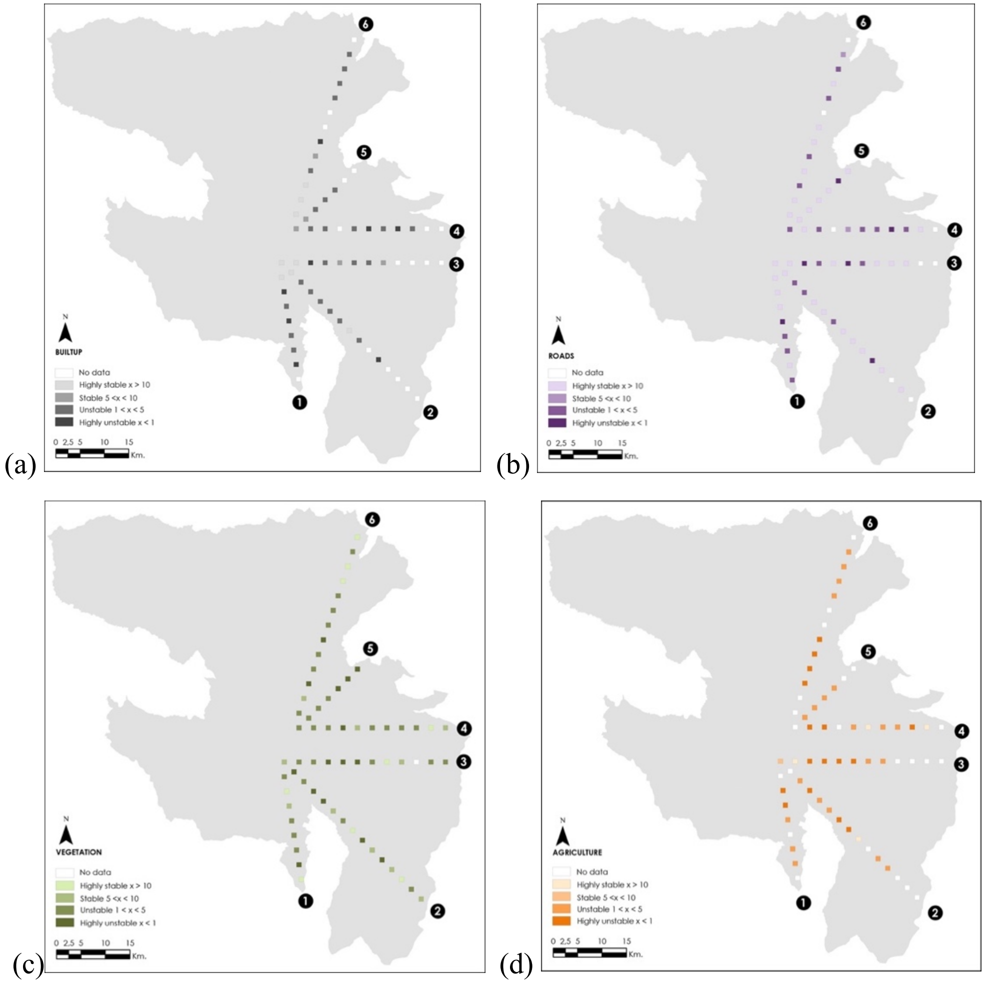

Figure 7. Stability Index by independent LULC. a) Built-up, b) Road Infrastructure, c) Vegetation, and d) Agriculture
Source: By the authors

1.6 *Total landscape stability*

Figure 8 shows the results of the total landscape stability index, which considers LULCs' dynamism on average. Samples of high instability (x<1) were not found in this analysis. However, we can observe that unstable samples are concentrated mainly in gradients 1 through 4 in the peri-urban area. These zones correspond to *parroquias rurales* (rural administrative areas) of *Conocoto-Amaguaña* (Gradient 1), *La Armenia-*

Alangasí (Gradient 2), *Cumbayá-Tumbaco-Pifo* (Gradient 3) and *Puembo-Yaruquí* (Gradient 4). For gradients 5 and 6, we observed a more detached pattern for unstable samples. These dynamic spots include *Guayllabamba* (Gradient 5) and *San José de Minas* (Gradient 6). On the other hand, stable samples are concentrated in the peri-urban area of gradients 4, and 6. These zones correspond to *Nayón-Tababela* and *Pomasqui* respectively. Finally, highly stable samples are mainly located near the urban center and in the distant rural areas. Then they show a dispersed and random pattern throughout the territory.

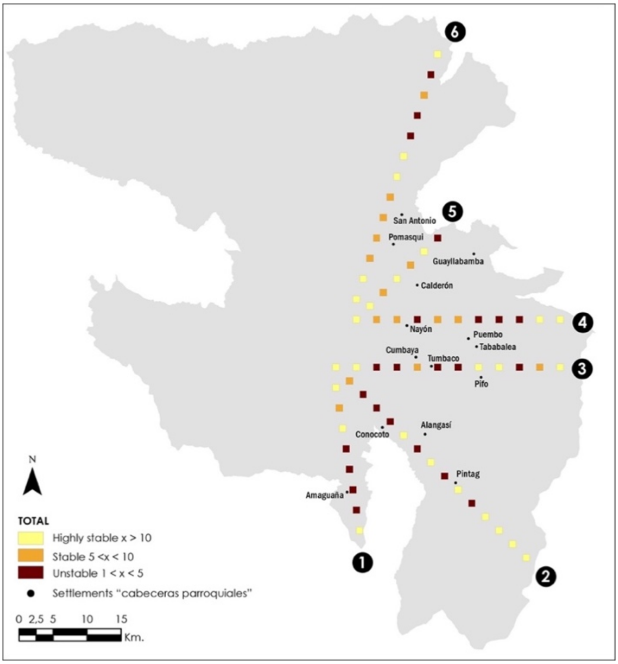

Figure 8. Total landscape stability index
Source: By the authors

Taking a closer look at the unstable samples -- those that have changed the most for the total landscape -- we identified a great diversity of urbanization patterns, which we propose organizing into four typologies, based on the most recurring configurations. The first typology was identified by detached and isolated houses developed by high-income classes in rurban areas, largely around large green areas such as gardens (Figure 9a. *Yaruquí*. Gradient 4). The second typology, also in rurban areas, can be identified by the subdivision of land into smaller parcels with low-density housing projects (Figure 9b. *Amaguaña*. Gradient 1). The third typology corresponds to gated communities marketed toward middle (Figure 9c. *Armenia*. Gradient 2) and high-income classes (Figure 9c. *Puembo.* Gradient 4). This typology is basically a set of monofunctional residences enclosed within a peripheral wall. Gated communities are currently the main focus of key real estate players in the region. Finally, the fourth category is identified by a more intensive self-construction process, mainly developed for low- and middle low-income classes (Figure 9d. *Alangasí.* Gradient 2). This last typology is frequently built within the context of land tenure irregularities, without municipal permits, and sometimes in precarious areas such as ravines or slopes.

These four typologies reveal the great diversity of urban expansion processes in the MDQ peri-urban and rurban areas, all of which have an aggregate effect on landscape instability.

a)  b) 

c)  d) 

Figure 9. Urbanization Patterns Typologies. a) Large parcels with isolated buildings surrounded by green area. Residence in Yaruquí. Gradient 4. b) Smaller parcels with low-density buildings. Residence in Amaguaña. Gradient 1. c) Gated communities target middle-

(left - Residences in Armenia, Gradient 2) and high-income classes (right - Residences in Puembo. Gradient 4). d) Self-construction housing developed mainly for the low- and middle-low-income classes. Residences in Alangasí. Gradient 2. Source: Google Earth

*1.7 **Gradient and cluster stability index***

Table 3 shows the stability index for the six gradients. We can see that Gradient 3 has experienced the most change, which could be related to the construction of the *"Ruta Viva,"* the main road infrastructure that connects the city of Quito with the new airport. This route was inaugurated in 2014 and has connected various peripheral territories with the city center. Various real-estate projects have since been implemented along the *Ruta Viva* and into the surrounding areas.

Table 4 shows the average stability index for each one of the five clusters previously describe in Section 1.3. Results show that clusters C1 and C2, classified as peri-urban and rurban, are the most instable, while Cluster 3, classified as urban, is the most stable.

Table 3. Gradient's stability index. Source: By the authors

	Total landscape Stability Index
Gradient 1	5,741
Gradient 2	6,242
Gradient 3	3,890
Gradient 4	5,009
Gradient 5	6,907
Gradient 6	6,435

Table 4. Cluster's stability index
Source: By the authors

	Total landscape Stability Index
Cluster 1	4,578
Cluster 2	4,493
Cluster 3	17,204
Cluster 4	5,061
Cluster 5	7,665

Discussion and conclusions

Our results demonstrate that the eastern valleys of the MDQ's landscape is undergoing heterogeneous transformation processes ranging from medium to high intensity, depending on the LULC. In general terms, we can affirm that rurban and peri-urban areas (clusters C1 and C2) present the greatest instability in most of the LULCs. Spatially analyzing the Stability Index for each LULC there are some findings to highlight. Although the main concentration of the S and HS samples for the *built-up cover,* is in close proximity to the urban centralities, a few stable samples are also located in the peri-urban areas following a scattered pattern. These coincide with the old traditional rural settlements (*cabeceras parroquiales*) that were once located in the outskirts of the city. Regarding the *roads cover*, highly stable samples are dominant throughout the entire territory. The north urban centrality is an exception, due to the new roads that were built as part of the new Metro project. On the other hand, a concentration of unstable and highly unstable samples can be identified in gradients 1,3 and 4. In the first case, the new road infrastructure is related to new housing developments built in previously rural contexts. In the other two cases, it mainly corresponds to highways built to connect the new airport. When looking at the *vegetation cover,* only 9 of the total 64 samples are classified as high stable, while there is a clear dominance of unstable and highly unstable samples. This confirms that vegetation is the coverage type that has undergone the most dramatic changes during this period. According to Ortiz-Báez et al. (2021), the MDQ is experiencing a reduction and fragmentation of its vegetation cover, which results in a significant threat to the territory's environmental quality. Our results corroborate and highlight the magnitude of vegetation lost caused by dispersed urbanization. Finally, looking at the *agricultural cover,* results are striking since only 4 samples are classified as highly stable and 1 as stable, while throughout the territory samples were largely classified as experiencing instability and high instability. This clearly shows that areas that used to have agricultural vocation, currently are undergoing significant changes due to urbanization.

Regarding the total landscape, rurban and peri-urban areas also show the highest rates of landscape instability, while the areas closest to the urban center are the most stable. Based on the diffusion-coalescence theory (Chakraborty et al., 2021; Duany et al., 2011; Estoque & Murayama, 2015), we can see that the MDQ's urbanization tends toward a diffuse, axial and isolated expansion pattern, rather than an "infill" pattern (Inostroza et al., 2013). Several studies have found that dispersed urban sprawl can present negative environmental and social impacts, such as: demand for new and expensive infrastructure for low-density neighborhoods, reduction and fragmentation of natural areas, low accessibility to services, facilities and public spaces, high dependence on fossil fuel since the mobility model focuses on the private vehicle, and spatial segregation, among others (Hermida et al., 2015; R. P. Ortiz et al., 2020; Reis et al., 2016; Rueda, 2009).

It is likely that the conceptual ambiguity of peri-urban territories -- where the urban-rural border dissolves into a diversity of uses -- and its speed of transformation, may be affecting the planning and control of urban expansion in these territories (Bogaert et al., 2015; R. P. Ortiz et al., 2020). For samples with landscape instability, we could observe heterogeneous land occupation patterns: detached and isolated houses developed by high-income classes, gated communities, low-density housing projects, and self-construction projects. Although this identification is based mainly in satellite and field observations, it reflects consistency with other relevant literature. For example, the text "Quito Vision 2040" written by the Municipality of Quito presents a diagnosis of the city's growth problems based on the interpretation of urban structure and the same typologies are recognized (Municipio del Distrito Metropolitano de Quito, 2018). According to ONU-Habitat (2012) these settlement patterns can be viewed through two main models of housing acquisition, either through the formal or informal/illegal market. The detached houses, gated communities, and low-density housing projects all fall within the formal market, while the self-construction processes fall into the informal/illegal market. In these zones, there is still a lack of urban equipment and services due to the deficiency of government-led social housing projects. Both settlement patterns are defined by the lack of clear regulations, which allows for a free-market governance of land that favors speculators (Carrión, 2015). This raises an urgent need for territorial planning based on spatial justice.

In addition, these newly urbanized areas are structured around the separation of functions (low-density residences, commercial/educational clusters, and large circulation routes), with the resulting abandonment of another public spaces, such as streets, squares, and parks. This turns the city into a space to transit and not to live (J. C. Frediani, 2013; Perahia, 2009). For example, gated communities wall off residential and communal spaces (such as roads, gardens, and parks), leading to the disappearance of life in public spaces in their immediate surroundings and the disintegration of neighborhoods (Guamán Guagalango, 2021; Roitman, 2003).

The construction of mega-road infrastructure appears to be one of the most dramatic drivers of landscape transformation. Results have shown that Gradient 3, which is crossed by the recent *"Ruta Viva"* highway (inaugurated in 2014 and built to facilitate the access to the city's new airport and two new shopping centers), is the gradient that has experienced the greatest landscape transformation on average. In fact, several studies have described road infrastructure as of the main "urban expanders" (Bayón Jiménez, 2016; Delgado Campos, 2003). In Borsdorf's study (2003), they identify highways (linear structures) as accelerators of a centrifugal growth of the urban tissue in contemporary Latin American cities. Along with road infrastructure, the location of new urban facilities (educational, health, leisure) can also be identified throughout the peri-urban territory. Borsdorf (2003) describes them as nodes that make this territory more attractive.

On another hand, our results confirm that vegetation cover is one of the land types that has changed the most in this period of time. Natural areas offer important socioeconomic and ecological values to territories (Kowe et al., 2020) and their reduction or fragmentation -- due to urbanization processes -- threatens the quality of life of its inhabitants. Evidence has shown that diffuse urban expansion, such as that in the MDQ, significantly alters ecological patterns and processes, affecting ecosystems and their services (Estoque & Murayama, 2015; Lee et al., 2015; Seto et al., 2012; Shrestha et al., 2012). Along with the vegetation cover, agricultural land has also shown significant instability due to extensive nearby urbanization processes, which push the agricultural frontier further away. This urbanization of agricultural land can have various effects, including more fossil fuel emissions to transport agricultural products to city markets and increasing fragility of food sovereignty of the MDQ (Clavijo Palacios & Cuvi, 2017).

The establishment of protected areas and strict regulations for their adequate protection, have proven to play a key role in the conservation of natural areas. In this study, the few samples that demonstrate vegetation landscape high stability coincide with the location of protected areas, such as the *Cayambe Coca* National Park (a fundamental area for the MDQ water supply) or the *Epiclachima* urban forest. We argue that protection policies should be strengthened not only for natural parks, but also for agricultural production land and small natural remnants, such as streams, ravines, and slopes, in areas with the greatest urbanization pressure. Due to its location over the Andes Mountain range, the MDQ is crossed by hundreds of streams and ravines, whose protection must be guaranteed due to their important role in natural drainage of soil and flood protection, among other things. Landscape structure and topography should be the key deciding factors in planning and controlling urban expansion, rather than the interests of the real-estate market.

In conclusion, analyzing these spatiotemporal transformations allows us to understand the trends and intensity of change in the landscape and, based on that, be able to take better decisions on territorial planning and management. In this sense, these results complement previous findings related with landscape structure (Ortiz-Báez et al. 2021), specifying the land covers and MDQ zones that are most sensitive to change. Based on these results, we can also affirm that micro-scale planning is urgent and necessary in the MDQ. The current large-scale planning tends to gloss over the heterogeneous dynamics in peri-urban landscape transformation. Planning must be complemented with management and control instruments to avoid land speculation and the construction of individual and disjointed projects that destroy the social and environmental fabric. We hope that our methods and conclusions can be applied and extrapolated to other Latin

American cities, and that we can find more opportunities for regional-level policymaking around sustainable land use.

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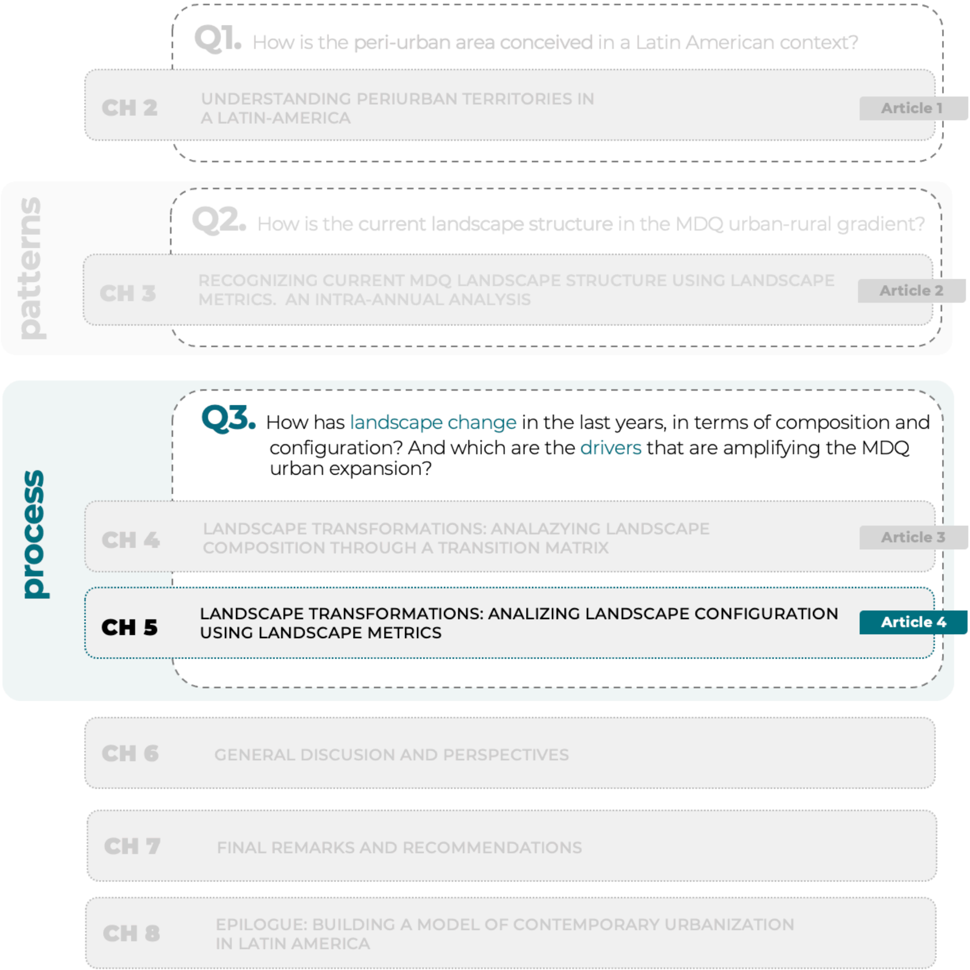
Chapter 5

Landscape transformations: analyzing landscape configuration through landscape metrics

PUBLISHED ARTICLE 4.

ANALYSIS OF LANDSCAPE TRANSFORMATIONS IN THE METROPOLITAN DISTRICT OF QUITO.

Paola Ortiz-Báez, Pablo Cabrera-Barona & Jan Bogaert (2022). Journal of Urban and Regional Analysis 14–2. Pages 243–264. https://doi.org/10.37043/JURA.2022.14.2.4


Q1. How is the peri-urban area conceived in a Latin American context?
CH 2
UNDERSTANDING PERIURBAN TERRITORIES IN A LATIN-AMERICA
Article 1
patterns
Q2. How is the current landscape structure in the MDQ urban-rural gradient?
CH 3
RECOGNIZING CURRENT MDQ LANDSCAPE STRUCTURE USING LANDSCAPE METRICS. AN INTRA-ANNUAL ANALYSIS
Article 2
process
Q3. How has landscape change in the last years, in terms of composition and configuration? And which are the drivers that are amplifying the MDQ urban expansion?
CH 4
LANDSCAPE TRANSFORMATIONS: ANALAZYING LANDSCAPE COMPOSITION THROUGH A TRANSITION MATRIX
Article 3
CH 5
LANDSCAPE TRANSFORMATIONS: ANALIZING LANDSCAPE CONFIGURATION USING LANDSCAPE METRICS
Article 4
CH 6
GENERAL DISCUSION AND PERSPECTIVES
CH 7
FINAL REMARKS AND RECOMMENDATIONS
CH 8
EPILOGUE: BUILDING A MODEL OF CONTEMPORARY URBANIZATION IN LATIN AMERICA

Journal of Urban and Regional Analysis 14–2 (2022): 243–264, https://doi.org/10.37043/JURA.2022.14.2.4

ANALYSIS OF LANDSCAPE TRANSFORMATIONS IN THE URBAN-RURAL GRADIENT OF THE METROPOLITAN DISTRICT OF QUITO

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Keywords:

urban-rural gradient; landscape metrics; spatiotemporal analyses; Latin-American urbanisation

Abstract: The relocation of services in the peripheries and the new urban expansion patterns have dramatically altered the periurban landscapes. However, due to its transformation speed, there is limited knowledge regarding the spatiotemporal changes of these interstitial territories. By calculating landscape metrics in high resolution satellite images, this research analyses spatiotemporal transformations in the Metropolitan District of Quito urban-rural gradient, testing a novel and accurate method to identify urbanisation tendencies. The results evidence the main role that new road infrastructures have had in urban expansion. Also, the analyses reveal significant changes in agricultural coverages (related to the subdivision of rural lots) and the processes of vegetation fragmentation, evidencing the environmental fragility of these territories in transformation. Finally, the Markov chains modelling technique was applied, exploring the landscape change probabilities in the following years. This methodology can be particularly useful in land-use planning policies since it provides precise knowledge about the main tendencies of urbanisation.

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Analysis of landscape transformations in the urban-rural gradient of the Metropolitan District of Quito

Abstract:

In contexts of globalization, economic restructuring and information and communication revolution, the relocation of services in peripheries and new urban expansion patterns have drastically altered periurban landscapes. However, due to its transformation speed, there is limited knowledge regarding spatiotemporal changes of these interstitial territories. Calculating landscape metrics in high resolution satellite images, this research analyses spatiotemporal transformations in the Metropolitan District of Quito urban-rural gradient, testing a novel and accurate method to identify urbanization tendencies. Results evidence the main role that new road-infrastructures have had in urban expansion. Also, the analyses identify significant changes in agricultural coverages (related to rural lots subdivision) and processes of vegetation fragmentation, evidencing the environmental fragility of these territories in transformation. Finally, the Markov chains modelling technique was applied, exploring landscape change probabilities in following years. This methodology can be particularly useful in land-use planning policies since it provides precise knowledge about urbanization main tendencies.

Keywords: *urban-rural gradient, landscape metrics, spatiotemporal analyses, Latin-American urbanization.*

1. Introduction

During the past century, the urban world's population has rapidly increased, drastically transforming landscapes around the planet. Furthermore, the limits of the entity known as "city" have tended to be diluted, forming territories with *urban* attributes but expanding in an unlimited and diffuse pattern. According to De Mattos (2016), this metamorphosis of the city happens as a result of financial globalization, economic restructuring (deindustrialization and neoliberal development) and the information and communication revolution. This has resulted in the relocation of urban services in the peripheries, which are increasingly better connected by new road infrastructure and the increased access to private motorization. Similarly, Borsdorf (2003) associates the dispersed pattern of contemporary cities with the increase of new interurban highways and the relocation of artifacts of globalization, such as malls, airports, industrial and technological platforms in areas that were previously mainly rural.

This expansion model has particularly promoted the localization of new residential units for elite classes in the peripheries (Smith, 1996; UN Habitat, 2013). In Latin-America these units are typically gated communities (J. C. Frediani, 2013; Hidalgo et al., 2007), and sometimes they adjoin pre-existent informal settlements, showing complex patterns of socioeconomic segregation (J. M. P. da Cunha & Jorge, 2009; Durán et al., 2016; R. P. Ortiz et al., 2020). These new residential units are also characterized for their low building density and monofunctional activities, representing an antagonistic model to the central and compact city (Albarracin, 2017; Serrano Heredia & Duran, 2020). In this sense, the functional fragmentation of the urban structure, the unequal provision of services, and the lack of connectivity complicates the spatial mismatch between residents of peripheral areas and their places of employment. Their need to commute to workplaces generates a saturation of road infrastructures, increasing the levels of vehicular pollution and travel times (Ávila Sánchez, 2001; Cruz-Muñoz, 2021).

Furthermore, the expansion of human activities over rural and natural territories alters landscape structure, affecting this socio-ecological system (Gallopín, 2003). From an ecological perspective, landscape composition and configuration determines the capacity to provide, manage and sustain the quality of resources indispensable for human life (Inkoom et al., 2018; Lee et al., 2015; Vizzari & Sigura, 2015). One of the most severe impacts in landscape structure has been fragmentation, either due to land covers' subdivision, conversion from native to designed covers or development in a non-contiguous pattern. As Shrestha et al., (2012) state, fragmentation can significantly alter ecological functions and processes, reducing habitat and wildlife corridors, decreasing agricultural and forest productivity and, finally, affecting ecosystem services.

In this sense, quantifying landscape structures facilitates a better understanding of the urban-rural conditions of a territory, land use patterns, and the transformation of land use through time. The quantification of the landscape structure is also useful for evaluating the ability of the landscape to perform ecological functions and processes, and monitoring the provision of ecosystem services (Inkoom et al., 2018). Landscape metrics have been widely used for measuring landscape composition and configuration and evaluating landscape mosaics (Antrop & Van Eetvelde, 2000; Buyantuyev et al., 2010; Fan & Myint, 2014; Lee et al., 2015; H. Liu & Weng, 2013; Solon, 2009). Although landscape metrics were originally developed from an ecological perspective, they are more and more frequently used in studies with broader approaches (Xing & Meng, 2020) and have shown to be useful for sustainable strategies in territorial planning (Lee et al., 2015; Vizzari & Sigura, 2015; Weng, 2007). Finally, since landscape change is a dynamic process and the direction and magnitude can vary depending on each environment, analyzing the urban-rural gradient has shown to be a useful tool to capture and analyze spatiotemporal complexity of urban dynamics (Shrestha et al., 2012; Wadduwage et al., 2017; Yu & Ng, 2007).

Several authors have developed theories in order to understand and characterize the complexity of these interstitial territories. Concepts such as *"exopolis"* (Soja, 2008), *"fragmented city"* (Borsdorf, 2003) or *"postborder* city"(Leclerc & Dear, 2003) have been explored, presenting valuable but generalized approximations. Although the limitless expansion of contemporary cities is a common phenomenon, the specific spatial patterns of this development and its rhythm of transformation may vary between regions, countries and their particular environments. In this article, the transformation of the spatial patterns in the Metropolitan District of Quito (MDQ) is analyzed. This metropolitan area has shown the fastest urban population growth in the Ecuadorian context in the last years, and the city of Quito (the urban area of MDQ) spatially tends to follow a dispersed and fragmented pattern (Serrano Heredia & Duran, 2020; STHV, 2012). However, there is a lack of research regarding the patterns and spatiotemporal transformation along the urban-rural gradients of the city. The goal of this research is to quantify the last decade transformation of MDQ urban-rural landscape patterns, and forecast the probabilities of future tendencies of land cover changes. Our hypothesis is that, due to its current pattern of expansion, natural and agricultural covers are being particularly affected by fragmentation processes. However, these impacts have dissimilar levels of intensity depending on the infrastructure and other urban services implemented -differently- in various sectors of the MDQ periurban area. In this sense, we also present a discussion about the main drivers of these spatiotemporal changes and formulate some recommendations focused on territorial planning. Research on the landscape dynamics is particularly important for sustainable development and the results for the MDQ could give key information for the formulation of development policies and planning strategies in the long term. Furthermore, the analysis of changes of MDQ urban-rural landscapes, can contribute to a better understanding of the urban expansion of Latin American metropolitan areas, considering that Latin America is a continent facing a rapid urbanization process in a context of extreme inequality.

2. Methods

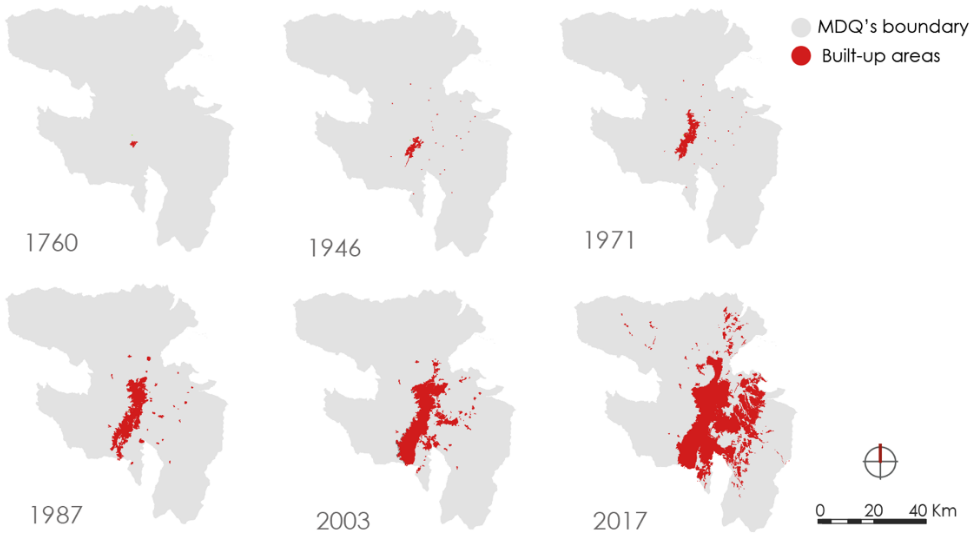
2.1 Study area

The MDQ is located in the Andes region, and is administratively organized into 65 parishes, 32 urban and 33 rural (Figure 1). This metropolitan area encompasses the city of Quito, the Ecuadorian political-administrative capital. The MDQ economic dynamism and its national and international connectivity constitutes an important attractor node of people and activities. In the last decade, its population has increased from 2’239.191 in 2010 to 3’059.097 in 2020, according to the Environmental Secretariat MDQ (2016), and currently is the most populous city in Ecuador. Due to its marked altitudinal variation (500 to 4.780 meters above sea level) and its complex topography the MDQ has more than 15 types of ecosystems, presenting great biodiversity along its climatic floors, rivers and streams (Environmental Secretariat MDQ, 2016).

Since the Spanish foundation of Quito in 1532 until the end of the decade of 1990, the city grew following a clear north-south longitudinal axis, which topographically corresponds to the plateau located between the Pichincha volcano and the eastern valleys of the district. However, in recent years the urban limits have overgrown, moving towards the eastern valleys, which are experiencing an accelerated transformation in relation to the gradual growth of the upper plateau (Figure 2) (MDMQ, 2017). This phenomenon may have also been influenced by the location of the new International Airport of Quito (Mariscal Sucre Airport), inaugurated in 2012 and located in Tababela, one of the rural parishes of the MDQ in the eastern valleys. This new urban expansion zone is in permanent transformation and, depending on ecological and socioeconomic conditions, this expansion can present diverse characteristics.

Figure 1. MDQ Location
Source: Gobierno Abierto (2021)

Figure 2. MDQ Location and evolution of built-up areas from 1760 to 2017.
Source: Municipio del Distrito Metropolitano de Quito (2017)



2.2 Definition of transects and study samples

Based on the previous study of Ortiz-Báez et al. (2021) and in order to cover the extension and diversity of the MDQ periurban expansion in a very detailed scale, six transects were defined. These transects started from two urban centralities[5] and move towards eastern rural parishes in 10°, 45° and 90° angles, covering the whole expansion area from the north to the south, allowing us to have a wide perspective of the complexity of the MDQ urban-rural gradient but avoiding eventual underlying patterns (Figure 3). Within the transects, a total of 64 sample polygons of 1 square kilometer each (Wadduwage et al., 2017) were defined in order to identify Land Use-Land Covers (LULC) in a very high resolution (1 pixel = 1 m2) through visual identification of satellite images[6] and confirmed by field visits (Figure 4a). 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.

[5] The MDQ has two main urban centralities: one is the old "historical center" where central and local government offices are located (locations related to related political-administrative activities). The second centrality is the "modern center" (central business district) where the most important economic activities (public and private) are located.

[6] ESRI World Imaginery Source

See Figure 4b. Satellite images from two years, 2010 and 2017, were analyzed and systemized in order evaluate spatiotemporal transformations (Figure 5).

Figure 3. Transects and samples definition. The figure presents the location of the 6 transects and the 64 samples as well as the dimension and scale of one of the samples.

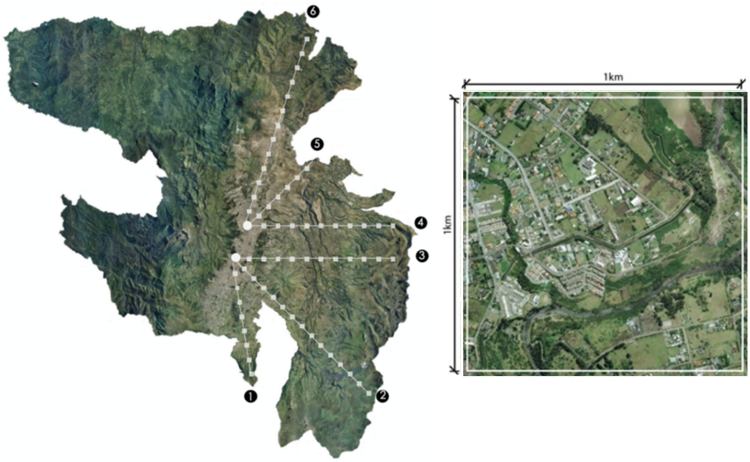


Figure 4. Satellite interpretation process and construction of raster image with LULC. Land Use Land Covers (LULCs).

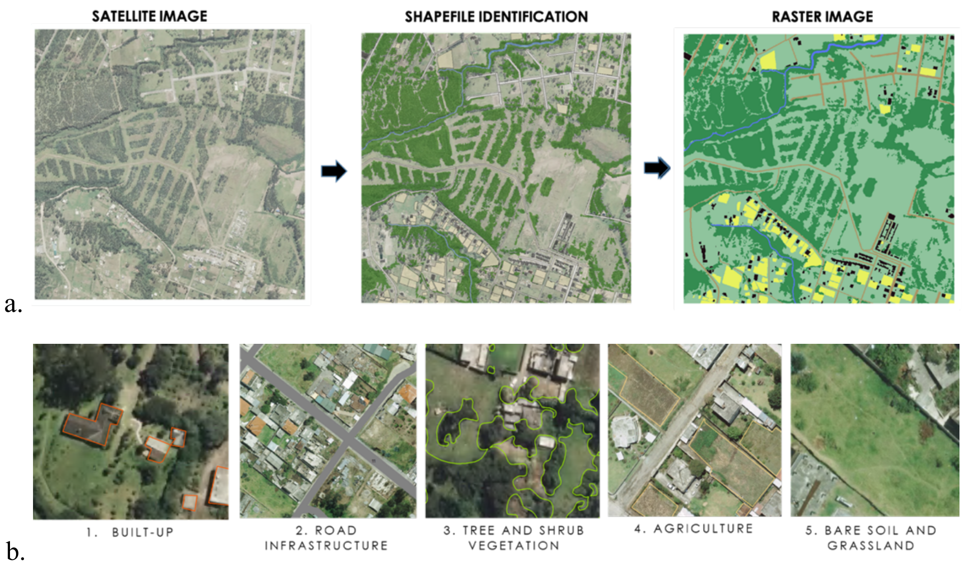


Figure 5. Example of one sample raster images LULC identification for years 2010 and 2017.

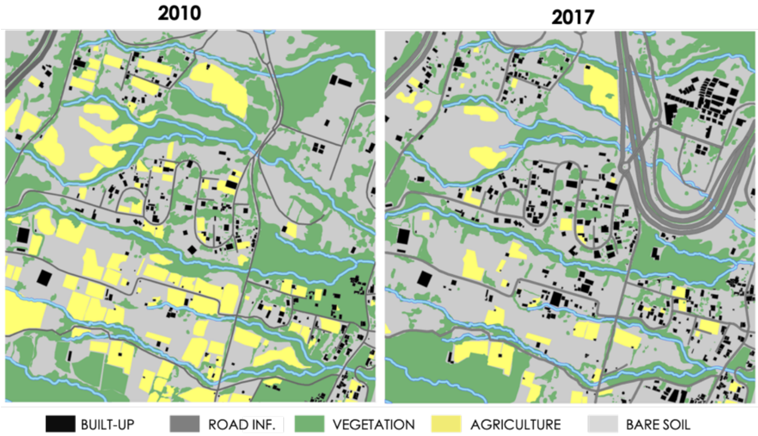


Table 8. Landscape metrics and their calculation formula.

Name	Description	Calculation Formula	Notes
Percentage of Landscape (PLAND)	PLAND equals the sum of the areas (m2) of all patches of the corresponding patch type, divided by total landscape area (m2), multiplied by 100 (to convert to a percentage)	$\text{PLAND} = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	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 equals the number of patches of the corresponding patch type divided by total landscape area (m2), multiplied by 10,000 and 100 (to convert to 100 hectares).	$PD = \frac{n_i}{A}(10.000)(100)$	n_i = number of patches in the landscape of patch type (class) i. A = total landscape area (m2).
Average Area (A_MN)	A_MN equals the sum of the areas (m2) of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to covert to hectares)	$A\_MN = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10.000}\right)$	a_{ij} = area (m2) of patch ij. n_i = number of patches in the landscape of patch type (class) i.
Larger Patch Index (LPI)	LPI equals the area (m2) of the largest patch of the corresponding patch type divided by total landscape area (m2), multiplied by 100	$LPI = \frac{\max_{j=1}(a_{ij})}{A}(100)$	a_{ij} = area (m2) of patch ij. A = total landscape area (m2).

	(to convert to a percentage)		
Euclidean Nearest-Neighbor Distance (ENN_MN)	ENN equals the sum of the distance (m) to the nearest neighboring patch of the same type, based on shortest cell center-cell center distance, divided by the number of patches of the same type.	$ENN\_MN = \frac{\sum_{j=1}^{n} h_{ij}}{n'_i}$	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.

2.3 Landscape metrics calculation

Since there is a strong effect of patterns over processes (Bogaert et al., 2015) landscape metrics have shown to be a strategic tool to quantify specific spatial patterns such as area, density, dominance, diversity, and isolation, among others (Kumar et al., 2018; H. Liu & Weng, 2013; Shrestha et al., 2012). In order to prove our spatiotemporal hypotheses, five metrics were calculated using the software FRAGSTAT 4.2.1. Specifically: i) *Percentage of Landscape* (PLAND), ii) *Patch Density* (PD), iii) *Average Area* (A_MN), iv) *Larger Patch Index* (LPI) which represents the area of the largest patch and is an indicator of spatial dominance, and v) *Euclidean Nearest-Neighbor Distance* (ENN_MN) which calculates the average distance between two patches, showing levels of isolation (See Table 1).

2.4 Assessment of landscape metrics

First, a *Wilcoxon Rank-Sum test* was performed to evaluate differences of landscape metrics between the two years of study, for each one of the LULC categories. This test is also known as the Mann Whitney Wilcoxon test, and is a non-parametric statistic applied to evaluate whether two paired samples are statistically different. In the present research, we are evaluating the differences in landscape metrics between 2010 and 2017 of the same LULC class (e.g., Built-up). In this sense, we are analyzing two paired samples: the same LULC class for 2010 and 2017. The null hypothesis of the test is having differences between the pair members equal to zero. Additionally, we calculated the *Kruskal-Wallis test* to assess if landscape metrics´ differences exist along the transects as we move away from the city center. This test of also known as One Factor ANOVA of Kruskal-Wallis for k samples. The test variables were the landscape metrics, and the grouping variable was the kilometrage categories (nominal variable).

Thus, with this test we evaluated whether statistically significant differences of landscape metrics values exist between the different kilometrages for all the transects of the study area. The null hypothesis of the Kruskal-Wallis test is having the same distribution of the landscape metrics values between all the kilometrage categories. This analysis was separately applied for the two years of the study. Finally, in order to have a more specific outlook of the pattern's transformation in each transect and sample independently, an analysis of *normalized metrics variation* (percentage of change comparing the two years) was developed.

2.5 Land change transition probability

The Markov chains modelling technique was applied, as a method to forecast the tendency of LULC's transformation in the MDQ urban-rural gradient. This tool has shown to be one of the most effective in quantitative simulations and has been widely applied in land use change evolution studies (E. R. da Cunha et al., 2021; Guan et al., 2011; Mansour et al., 2020; Rahnama, 2021; Wang et al., 2021). This technique is a stochastic model based on computing a probability matrix of transition and randomly simulates changing covers, calculating rates of all possible transitions between various land covers. Markov chains analysis describes land cover changes from one period to another and predicts future tendencies of change (E. R. da Cunha et al., 2021; Mansour et al., 2020; Rahnama, 2021). Using the software Idrisi 17.0 a Markovian transition estimation was developed for year 2024.

3. Results

3.1 General results

The general LULC transformation between 2010 and 2017 is presented in Table 2. The Vegetation cover shows the greatest reduction in this time period, with -2,23%, followed by Bare-soil and Agriculture covers with -1,57% and -1,29 respectively. On the other hand, the covers that show an increase are Built-up and Roads, confirming that this study area is undergoing transformations due to urban expansion. The Built-up cover shows the highest net percentage of increment, with 12,43%, followed by Road infrastructure with 9,09%.

Table 2. LULC general changes between 2010 and 2017

	2010		2017		2010-2017 Changes
	Area (Ha)	% of total area	Area (Ha)	% of total area	% of change
Built-up	515,7	8,1	579,8	9,1	12,43
Road	374,9	5,9	409,0	6,4	9,09
Vegetation	1392,0	21,7	1360,9	21,3	-2,23
Agriculture	571,9	8,9	564,5	8,8	-1,29
Bare-soil	3459,8	54,1	3405,5	53,2	-1,57

3.2 Differences of landscape metrics between the two years

When comparing differences of metrics between years, interesting outcomes were obtained. Regarding the land cover of built-up, results are striking: significant differences or changes were identified for all the metrics, with 99% of confidence for PLAND, PD, LPI and A_MN, and 95% of confidence for ENN_MN, showing that the quantity and spatial structure of built-up land use has had an important dynamic and changed through the time. These results also suggest an advance of urban frontier between the two years considered. Furthermore, in the case of the category of roads, significant changes were identified for the metrics PLAND and LPI. In the case of the agricultural cover, there is a statistically significant difference (90% of confidence) of the metric percentage of landscape (PLAND) between 2000 and 2017 (Table 3).

Table 3. Wilcoxon test comparing metrics between 2010 and 2017 for each land use-land cover considered

	PLAND	PD	LPI	A_MN	ENN_MN
Built-up	0.000***	0.005***	0.001***	0.000***	0.029**
Roads	0.006***	0.928	0.016**	0.929	0.995
Vegetation	0.646	0.531	0.760	0.695	0.335
Agriculture	0.080*	0.464	0.347	0.343	0.791
Bare-soil	0.206	0.414	0.127	0.792	0.321

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

Note: The calculated landscape metrics are Percentage of Landscape (PLAND), Patch Density (PD), Average Area (A_MN), Larger Patch Index (LPI) and Euclidean Nearest-Neighbour Distance (ENN_MN).

3.3 Differences on landscape metrics along transects.

Results of Table 4 show that, for the two years of study, statistically significant differences (95% and 99% of confidence) in all the landscape metrics along transects, were identified for the LULC classes of Built-up ad Roads. For the metric LPI, Vegetation and Agriculture did not change for the year 2010, while for the year 2017 these LULC classes experienced significant differences (95% of confidence) along transects. PD in Agriculture did not change in 2010, while significantly changed (99% of confidence) in the year 2017, showing greater dynamics in this last period. In 2010, Bare-Soil only changed along transects in PD and LPI, and in 2017, only changed in PD along transects.

Table 4. Kruskal-Wallis test results to assessing differences of landscape metrics along transects (distance to the center) for 2010 and 2017.

2010	PLAND	PD	LPI	A_MN	ENN_MN
Built-up	0.000***	0.006***	0.005***	0.006***	0.000***
Roads	0.000***	0.018**	0.001***	0.048**	0.008***
Vegetation	0.036**	0.027**	0.051	0.005***	0.245
Agriculture	0.046**	0.061	0.080	0.023**	0.099
Bare-Soil	0.722	0.007***	0.031**	0.084	0.063

2017	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%

Note: The calculated landscape metrics are Percentage of Landscape (PLAND), Patch Density (PD), Average Area (A_MN), Larger Patch Index (LPI) and Euclidean Nearest-Neighbour Distance (ENN_MN).

3.4 Analysis of landscape structure temporal variation along transects.

Observing the percentage of change between the two years along each gradient, some relevant and more specific features were found. For the Agriculture cover, when comparing the PLAND variation between the two years, this land cover tends to be reduced in most samples, especially in those closest to the urban center (Figure 6). However, there are some peaks where an increase in the percentage of agricultural land is observed; these coincide with sectors with strong agricultural potential such as Puéllaro, Pifo or Cotogchoa. On the other hand, the agriculture cover tends to reduce its AREA_MN and LPI in almost all samples, regardless of their distance to the urban center. This shows a tendency of plots fragmentation as a result of land use change from rural to urban (where lots can be smaller).

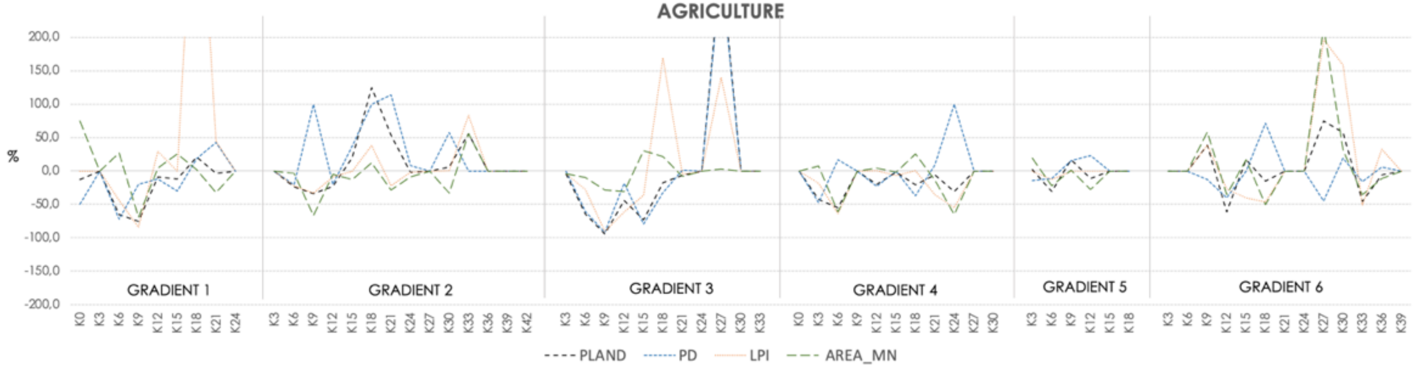
When observing the Vegetation cover and the metrics temporal variation, processes of fragmentation can be identified in various sites. This can be deduced, on the one hand, for the reduction of the patches mean area (A_MN) and the larger patch index (LPI), and on the other hand, due to the increase of number of patches (PD) at the same spot (Figure 7). This is particularly evident in the Kilometer 24 in gradient 2 (Conocoto) and at the beginning of gradients 3 (Cumbayá), 4 (Nayón) and 5 (Pomasqui). If we compare all these samples with the PLAND of the Built-up cover (Figure 8) we can confirm that all these sectors present a high building increment in the period of time analyzed.

When analyzing the temporal variation of PLAND for the Built-up cover (Figure 8), we can see that there is an overall tendency to increase buildings in all the gradients, although at different levels of intensity and distances from the urban center. The highest intensity of built-up growth tends to match the location of traditional rural settlements (cabeceras parroquiales) situated in the periurban area. On the other hand, when analyzing the temporal variation for the ENN_MN for the Built-up cover, in most samples the distances tend to be reduced. This shows that there is a general propensity to densification and agglomeration through all the urban-rural gradient in the MDQ.

Finally, when comparing the Built-up PLAND variation with the Roads PLAND variation (Figure 9), we can observe a tendency of a correspondence with the increment of roads and the increment of buildings in all gradients. In fact, applying the Spearman test[7], a correlation coefficient of 0.34 and a p value of 0.005 were found, which indicates a 34% strength of association between the two variables, this association is positive (directly proportional) and highly significant (99% confidence). However, what happens in gradient 5 is striking, since there is a significant increase in buildings but without an important increase in roads. Additionally, it is important to mention that the highest growth point of Built-up (Gradient 3, Kilometer 9) coincides with the intersection of the highway named Ruta Viva, which was built to connect the city of Quito with the new international airport.

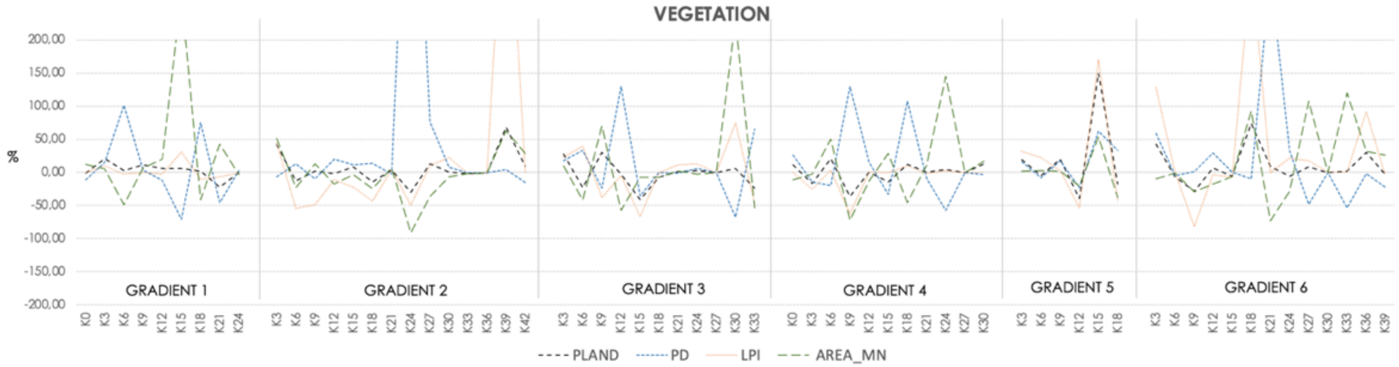
[7] The normality of the variables was evaluated using the Kolmogorov-Smirnov test. It was found that the variables do not follow a normal distribution, so it was decided to apply Spearman's correlation.

Figure 6. Metrics percentage of change for Agriculture cover along gradients



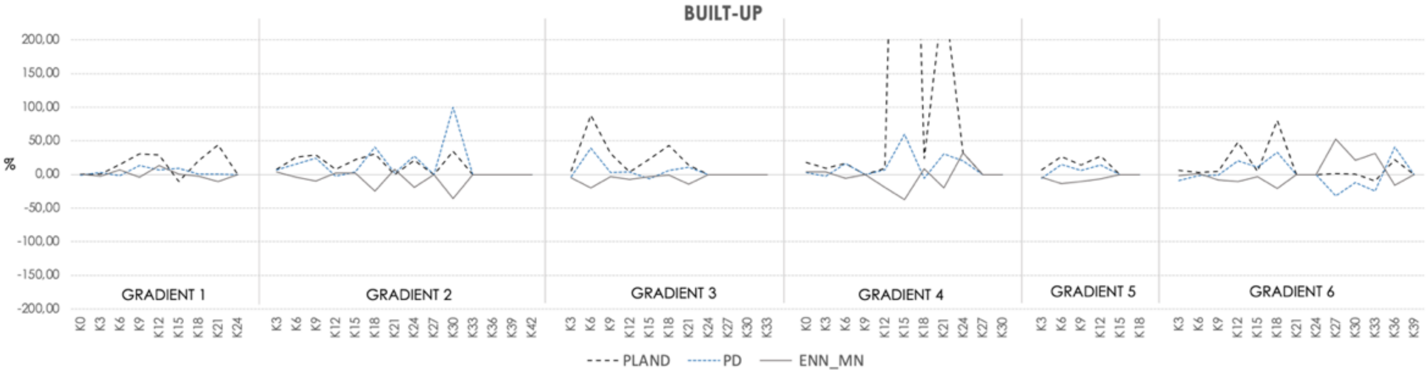
Note: K refers to Kilometers away from the urban center. The presented landscape metrics are Percentage of Landscape (PLAND), Patch Density (PD), Larger Patch Index (LPI) and Average Area (A_MN).

Figure 7. Metrics percentage of change for Vegetation cover along gradients



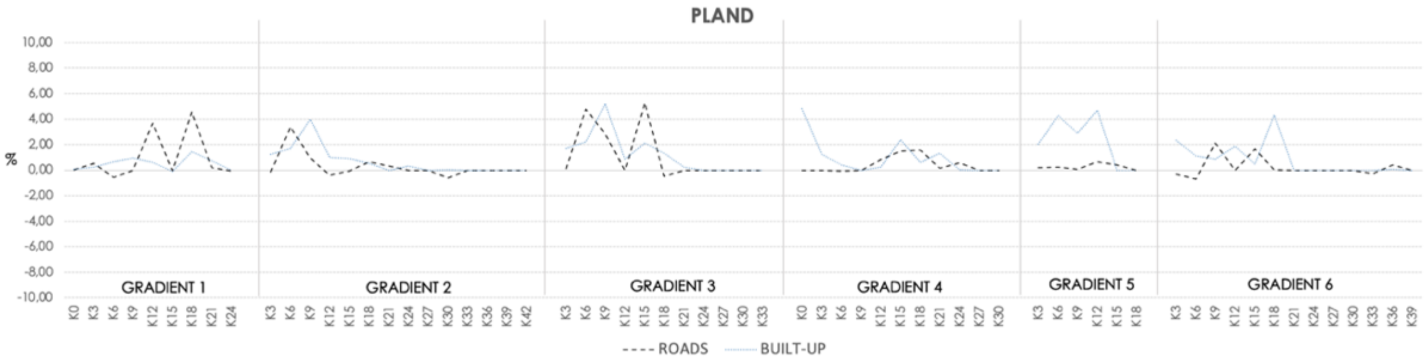
Note: K refers to Kilometers away from the urban center. The presented landscape metrics are Percentage of Landscape (PLAND), Patch Density (PD), Larger Patch Index (LPI) and Average Area (A_MN).

Figure 8. Metrics percentage of change for Built-up cover along gradients



Note: K refers to Kilometers away from the urban center. The presented landscape metrics are Percentage of Landscape (PLAND), Patch Density (PD) and Euclidean Nearest-Neighbor Distance (ENN_MN).

Figure 9. Comparison of temporal variation of PLAND between Roads and Built-up covers.



Note: K refers to Kilometers away from the urban center. The presented landscape metric is Percentage of Landscape (PLAND).

3.5 Land change transition probability matrix

In the Markov transition probability matrix (Table 5), the higher values can be identified on the diagonal, which means that the highest probability is that coverages will remain stable in the same class until 2024. Regarding the probabilities of change, based on previous transformations 2010-2017, there is a probability of 0.02 that vegetation covers will become roads and a probability of 0.15 of becoming bare-soil. There is also a probability of 0.21 that agriculture covers will become bare-soil. Finally, the probability of bare-soil becoming vegetation is 0.08, in built-up is 0.03 and in agriculture is 0.06.

Table 5. Transition probability matrix between 2010 and 2017 for predicting the LULC transformation in 2024

	Vegetation	Built-up	Roads	Agriculture	Bare-soil
Vegetation	**0.8094**	0.0078	0.0201	0.0038	0.1565
Built-up	0.0012	**0.9628**	0.0049	0.0004	0.0030
Roads	0.0043	0.0035	**0.9550**	0.0007	0.0035
Agriculture	0.0174	0.0137	0.0048	**0.7251**	0.2178
Bare-soil	0.0819	0.0318	0.0138	0.0552	**0.8162**

4. Discussion

In a previous research, currently landscape patterns in the MDQ urban-rural gradient have been addressed (Ortiz-Báez et al., 2021). However, analyzing the spatiotemporal dynamics in the last years has allowed us to have a more precise understanding of the transformation trends that will determine the territorial development in the coming years. The analysis of the temporal variation in various landscape metrics, enables a richer visualization of landscape composition and configuration, and their transformation tendency. Additionally, the use of transects and the detailed scale of the samples allowed us to make a very meticulous and detailed assessment of landscape features along transects, without losing the general perspective of the MDQ, which facilitates the analyses of territorial diversity within the urban-rural gradient.

Land use change in the MDQ is a key topic, since its demographic development has evolved significantly since the decade of 1970 and with greater intensity in recent years, but particularly because its physical urban tissue has shown to be expanding in an accelerated and intensive way. There are important socioecological implications in this expansion tendency. On the one hand, there are several impacts on natural and agricultural areas that are not always perceptible but are threatening the territorial environmental sustainability. And, on the other hand, new urban peripheral settlements are producing socioeconomic problems such as the proliferation of low density gated communities or the concentration of poverty settlements in peripheral areas (Herrero Olarte, 2021; Municipio del Distrito Metropolitano de Quito, 2014; Sabatini, 2003; Serrano Heredia & Duran, 2020) .

Our results provide clear evidence of significant changes in the Built-up cover, in all landscape metrics between the two years of study, which confirms the urban expansion of the city of Quito towards the eastern valleys of the MDQ. In these valleys are located some parishes that administratively are considered rural (e.g., Cumbayá, Tumbaco, Conocoto), but that have become practically urban in structure and in function. These territories, that were previously considered distant and inaccessible, have become the new areas of dispersed urbanization. However, this process of urban expansion is no linear, it presents various peaks which can be observed in the PLAND variation. These peaks are directly associated with the presence of traditional rural settlements (cabeceras parroquiales) which were once in the outskirts of the city, but now are facing micro extension/conurbation processes (Ortiz-Báez et al. 2021). Since these settlements are geographically separated, we can confirm a fragmented urbanization pattern in the MDQ periurban areas.

Furthermore, the significant change of Roads´ PLAND between 2010 and 2017 is also indicative of the landscape functionality driven urban expansion: the development of roads that connect the city of Quito with the eastern rural parishes. In this way, the statistical analyses of the transects suggested high variation of landscape metrics for the Built-up and Roads LULC classes, which provides important evidence of landscape dynamics involving rural transformation to urban. Also, the analysis of the Euclidean Nearest Neighbor (ENN_MN) metric 2010-2017 variation, evidences a tendency towards building densification along all gradients. Various authors have affirmed that new road infrastructure tends to accelerate urban expansion (Adrián Guillermo Aguilar, 2002b; Borsdorf, 2003; Serrano Heredia & Duran, 2020). This hypothesis can be confirmed in the MDQ case since the Roads and Built-up PLAND increases in parallel. Also, the higher Built-up increment occurs in the samples crossed by the new highways that connect the central city with the new International Airport of Quito, opened in 2012. At this point, it is worth asking if the municipal planning of these mega road-infrastructures foresaw the impact they would have on urban expansion. Along with the impact of new road infrastructure on urban expansion, the diffuse pattern and the lack of efficient public transport in periurban areas, increases the dependency on private motorization. In fact, in the MDQ the private automotive fleet has increase in 7% in the last years (MDMQ, 2017) and the daily commuting from the rural valleys of Cumbayá, Tumbaco and Los Chillos to the city center has increased from 40.000 in 2008 to

140.000 in 2019 (La Hora, 2019; Núñez et al., 2015). This not only affects traffic congestion and travel times, but has important environmental effects: in the MDQ, 56% of the carbon footprint is caused by emissions from transport vehicle emissions (MDMQ, 2017).

Despite the fact that new road infrastructure has demonstrated to be a main driver of urban expansion as mentioned above, this study presents a particular case that deserves to be discussed from a socioeconomic perspective. Gradient 5, which correspond to the rural parish of Calderón, shows one of the most pronounced increases in buildings in the period 2010-2017. However, this parish does not have a direct influence of new road infrastructure during that period of time. In this case, the noticeable urban intensification would be associated with other drivers. Informal building growth has been one of the main challenges of urban expansion in the MDQ. Speculation and high land prices in central parishes have led to informal and deregulated occupation of nearby rural parishes (Guerrero Miranda, 2011). This is the case of Calderón, where until 2010, 90% of its settlements were illegal (PMOT, 2010). Evidence has shown Irregular growth processes lack infrastructure, facilities, economic opportunities and basic services affect the price of land (Cabrera & Plaza, 2016; Weku et al., 2019). Currently, Calderón has one of the lowest land prices on the market, which makes it an attractive place for the migration of low socioeconomic classes. On another hand, facing the high density of the parish, the local government has made efforts to provide new urban services and facilities such as the 2015 inaugurated Calderón Hospital among others, making the parish more attractive for new migrants. Furthermore, in the studied period of time, private agents have also seen an opportunity to promote real estate projects focused on middle and low economies, which are focused in guaranteeing housing but not always an adequate urban context. Thus, the mix of these factors: irregular growth, low land prices, new social services, and speculation in the real estate market with a focus on the middle and lower classes, appear to be accelerators of urban expansion in the parish of Calderón. This development pattern seems to be recurrent in Latin-American realities. According to Frediani (2009), the diffuse city in Latin-America presents enclaves of poverty in its peripheries, which also present accelerated rates of expansion. This is consistent with the study of Herrero Olarte (2021) for the city of Quito, where it is stated that there is a direct relationship between multidimensional poverty and the distance to the city centrality.

Regarding the environmental implications, in the 2010-2017 period, Agriculture and Vegetation covers significantly varied along transects, suggesting modification of the ecological systems during the last years. This statistical evidence corresponds with other transformations in the territory, such as the alterations of rural livelihoods due to development of new highways connecting the city to the Airport. Regarding to the Agriculture cover, the analysis confirms that it has been reduced in the last decade and, according to the Markov's probability matrix, it tends to be reduced even more in the following years. This is particularly critical, since the area where the urban tissue is expanding, is also the area with more concentration of soil with agricultural vocation in the MDQ (Environmental Secretariat MDQ, 2016). Another relevant finding is the reduction of the Patch Mean Area (A_MN) and the Larger Patch Index (LPI), revealing a tendency of plots' fragmentation which can be a result of land use change from rural to urban. Indeed, despite the metropolitan land use regulation, in which rural land use has particular restrictions in order to protect it (such as a minimum lot size), there are several regulatory and legal gaps that continue allowing the division of lots. One of them is the legal tool of "acciones y derechos" (shares and rights) in which a percentage of the property can be sold without legally changing the plot size, but this allows the new owner to change to use within its percentage of land. Another frequently used legal mechanism, especially by real estate companies, is the "horizontal property", where a dwelling unit is sold as a percentage share within a large lot. The latter is the most common method to implement gated communities and it has started to be used more frequently (Instituto Metropolitano de Planificación Urbana et al., 2018). In this scenario, agricultural practices may tend to weaken even further, considering that by 2014 only 5% of the population living in rural parishes was engaged in agricultural production which has an socioeconomic impact (Environmental Secretariat MDQ, 2016).

Finally, regarding the Vegetation cover, after analyzing the metrics 2010-2017 variation, processes of fragmentation were identified in various sites. This can be inferred due to the reduction of the Patch Mean Area (A_MN) and the Larger Patch Index (LPI), while there is an increment of Number of Patches (PD). Fragmentation is one of the major environmental concerns, due to its effects on ecological functions and processes which can result on the damage of natural habitats, the reduction of ecosystem services and consequently of the effect on basic human needs (Kumar et al., 2018; Shrestha et al., 2012). The sites that present the most evident processes of fragmentation match areas with higher increase in Built-up covers. Observing the Built-up ENN_Mean metric, we can also relate these areas with "medium to low" density patterns of built expansion, related for example with the accelerated suburban sprawl in the parishes of Cumbayá, Nayón and Conocoto. According to Shrestha et al. (2012), low-density developments contribute to increase the level of land fragmentation and they typically happen on the urban-rural fringe.

5. Conclusions

The MDQ is undergoing a process of intensive urban expansion towards its eastern valleys. However, the level and patterns of transformation are different between gradients and along gradients, showing the diversity within this periurban territory. The calculation of landscape metrics has proven to be an effective tool to assess the spatial patterns of these territorial transformations and identify such diversity, and can be a key tool to formulate and implement land use planning policies with an environmental and socioeconomic perspective.

There are important socioecological implications in this expansion pattern. The implementation on new road infrastructure appears to be one of the major factors accelerating urbanization, since there is a correspondence between the increase of roads and buildings in the studied time period. This is particularly evident with the Ruta Viva highway, built to connect the new airport of Quito and where one of the highest levels of increase in buildings were found. However, as a result of the diversity of patterns and processes in the periurban area of the MDQ, the particular case of the parish of Calderón stands out, where -unlike the rest of the study areas- there has been a significant increase in buildings without a corresponding increase in roads. Other socioeconomic drivers, such as informal settlements, low land price, new public investment and low class-focused real estate speculation seems to explain the accelerated urban growth of this rural parish. The variety of dynamics within the MDQ evidence the complexity of the urbanization phenomenon, where specific plans should be part of the agenda. Calderón's urban development model is a recurrent pattern in Latin-American diffuse cities, where enclaves of poverty in the peripheries are growing rapidly.

Finally, our analysis demonstrates the vulnerability of the natural and agricultural ecosystems in the MDQ. The tendency of Agriculture PLAND, A_MN and LPI reduction, as well as the increment of fragmentation processes in the Vegetation cover, show the fragility of the territorial environmental sustainability. The results of this study can be a key input for the formulation of more specific policies for the conservation and recovery of ecosystems affected by these accelerated and little-known processes of urban expansion.

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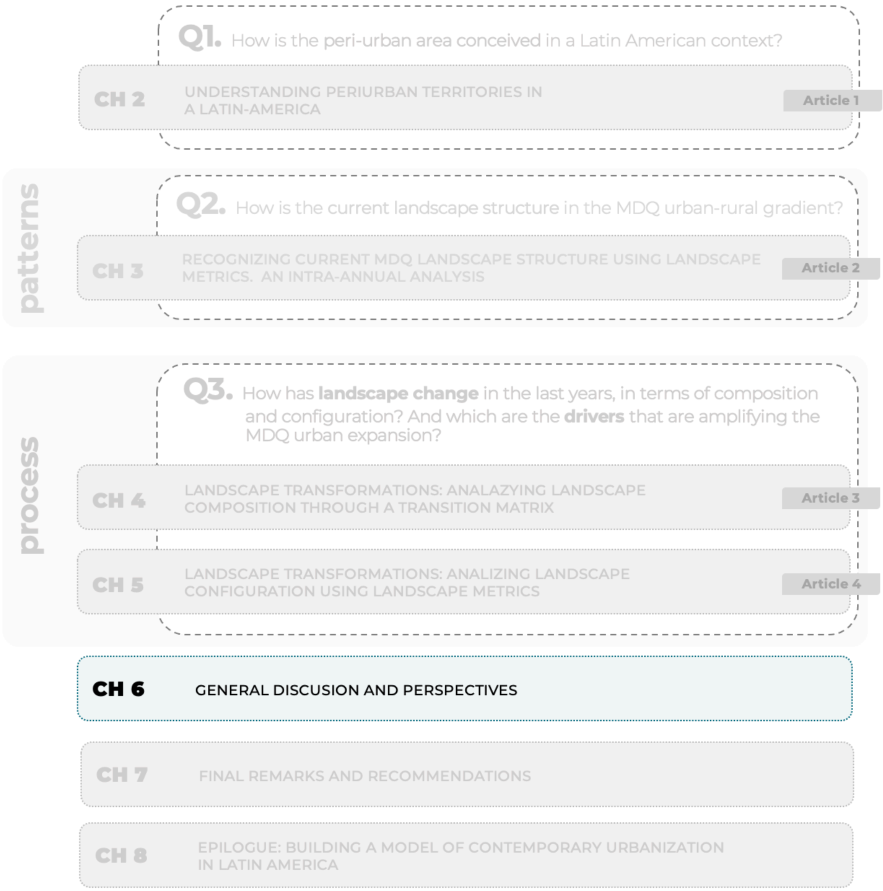
Chapter 6

General discussion & perspectives



6.1 Answering the research question

This study provides novel and accurate data that allows answering the following research question: **What is the current landscape pattern of the MDQ peri-urban area and how has the urban expansion process been in the last decade?** By identifying and analyzing its landscape structure and by measuring its spatiotemporal transformations, we have achieved a wider understanding of MDQ urbanization evolution and comprehension of the landscape patterns in its periurban interfaces. Based on these results, we were also able to explore some of the drivers that could have determined the particular patterns and dynamics of periurbanization and explore the MDQ main tendencies of territorial change.

The following sections summarizes the main findings and their interpretation. Here, the specific characteristics and dynamics of diverse land covertures along the urban-rural gradient are systemized, focusing particularly in periurban areas experiencing pressure for urban development. Also, there is a discussion on the main drivers that could be triggering and accelerating these spatiotemporal changes. All this with the aim of answering our research question.

6.1.1. Main results and interpretation

Through the development of different analyzes (high-detail Land Use Land Covers identification, landscape metrics calculation, multivariate clustering classification, landscape stability index evaluation and transition probability matrix definition, among others) the following relevant findings have been identified.

About the expansion pattern: diffusion/coalescence and polycentrism

When analyzing landscape structure, it can be affirmed that this territorial transformation has mainly followed a dispersed and fragmented pattern. These results coincide with the study about the urbanization process developed for the entire Ecuadorian territory, in which -through night satellite images analyzes- a trend of low-density urban dispersion over territories defined as rural is confirmed (Mejía, 2020). Specifically, our results show an urbanization process that tends to follow a diffuse, axial, and isolated expansion pattern towards its eastern low valleys. Diffuse expansion due to the reduction of the building density in the new areas of periurban expansion, axial expansion associated with growth in the proximities of road infrastructures and isolated expansion related to the discontinuity on the built-up element along the urban-rural gradient.

Regarding the intensity of change, although the MDQ territory is surrounded and crossed by deep ravines and rivers, the urban fabric is still expanding over rural and natural areas, ranging from medium to high intensity. Distance to city center has shown to have statistically the stronger influence in the urbanization process, however, different levels of change intensity have been identified it the different LULCs within the urban-rural gradient. Specifically, from the four territories clearly identified through the hierarchical cluster analysis (urban, rural, periurban and rurban areas), the last two present the greatest dynamism, generally, and in most of the LULCs. Particularly, in the analysis of the Stability Index presented in Chapter 4 (Table 2), we observe how the higher percentages of instability and high instability for the Built-up, Roads, Vegetation and Agriculture LULCs, correspond to the Periurban and Rurban areas. While, in the case of the urban cluster, the same Built-up and Road LULCs remain mainly highly stable. This suggest that the main territorial transformations in the MDQ are less an "infill" process (urban densification[8]) but rather an external/peripheral one.

Our results also suggest that the MDQ presents patterns of urban diffusion and coalescence (Chakraborty et al., 2021; Dietzel et al., 2005; Duany et al., 2011; Estoque & Murayama, 2015). 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, although in some cases following a discontinuous pattern, but with the potential of scaling-up the urbanization process. As mentioned above, the urban center has been statistically shown to have the greatest influence on the current expansion of the DMQ. In this sense, the regional morphology of the urban environment can be considered a product of the centrifugal forces that have historically emanated from the dominant central city. However, the dispersed, low-density, polycentric, and highly dynamic pattern of peri-urban territories is leading us towards "exopolization" (Soja, 2008). This is accompanied by the decentralization of services and industries, the promotion of new business centers and the intensive promotion and speculation of increasingly remote housing in the eastern valleys of the MDQ. In this scenario, the new centralities in the peri-urban begin to present both centripetal and centrifugal forces towards their own surroundings. Thus, growth in the peri-urban area is decentering and recentering -at the same time- the metropolitan landscape, beginning an irreversible process of deconstruction of the predominant monocentric pattern.

In line with the previous paragraph, our findings support a new polycentric pattern. For example, in Chapter 3, when observing the clusters map, a discontinuous pattern of

[8] Densification at ground level, because the raster image does not allow to reflect the densification in height, which is also a phenomenon that is happening in the MDQ.

the cluster groups can be easily identified. For example, samples that are classified as denser periurban areas are located further away than samples classified as rurban area. Similarly, rural samples are located closer to the city center than other samples classified as periurban area. This shows not only a discontinuous urban expansion but sustains the hypothesis of polycentrism within the MDQ urban-rural gradient. In the same chapter, when observing the metrics variation along gradients, although -in general terms- there is a tendency of built PLAND, AREA_MN and PD reduction as we get further away from the city center, there are several points where there is an increase in these landscape metrics across all transects. In fact, on several occasions, higher peaks are observed at points further from the center. In terms of landscape, these peaks locate the new centralities that are emerging in areas outside the traditional city. These peaks are also identified in Chapter 5, when observing the temporal variation of PLAND for the Built-up cover. These results confirm the intrinsic dynamism of this external centralities, sustaining the polycentrism hypothesis.

The results also suggest landscape heterogeneity: some emerging urban areas are intercalated with some agricultural or natural areas. Although periurban territories share common features by being interstitial zones, important particularities were found when analyzing the different LULCs and transects in terms landscape composition and configuration, as well as in terms of transformation speed and intensity. These particular features end up forming an extremely complex and diverse territory. The following paragraphs describe these particularities.

About the built-up elements

Our results provide clear evidence of significant changes in the Built-up cover, which confirms a process of urban expansion towards the eastern valleys of the MDQ. In these valleys is where MDQ rural parishes (administrative unities) are located. However, due to the intense transformation they are experiencing, many areas within these parishes have become practically urban in terms of landscape structure and in function. It is important to mention that, despite that distance to the urban center has proven to have the stronger influence on the intensity of built-up expansion, our results on current landscape structure show that this influence is no linear. This can be clearly observed in the Built-up PLAND and ENN_MN variation, which presents various peaks that represent spots with more presence and density of buildings. These peaks are directly associated with the presence of *cabeceras parroquiales* (traditional rural settlements) which were once in the outskirts of the city, but now are facing micro extension/conurbation processes. Also, when analyzing the stability index for the Built-up cover although on average the periurban area is the most unstable zone within the urban-rural gradient, some stable samples were identified within it. They correspond to these traditional rural settlements which follow a scattered configuration, confirming a fragmented urbanization pattern. On the other hand, while observing landscape transformations, the ENN_MN metric 2010-2017 variation evidences a tendency towards building densification in the whole territory. It means that, although the urbanization process has historically responded to a dispersed pattern (as mentioned in previous paragraphs), currently there is a tendency towards a greater building density. Some denser peaks are still remained, but the general trend is greater densification throughout the whole periurban area.

When observing (by satellite images and field verification) those areas with higher landscape instability, very heterogeneous build occupation patterns were identified. Among the most representative, there are detached and isolated houses developed by high-income classes, gated communities for high and middle-income classes, mainly promoted by the real estate market. There are also informal self-construction projects. According to ONU-Habitat (2012) in Latin-America there are two main models of housing acquisition, either through the formal or the informal/illegal market. Speculation and high land prices in central parishes have led to informal and deregulated occupation of nearby rural parishes (Guerrero Miranda, 2011). This can be clearly seen in Calderón -the parish that shows on of the most intensive building growth- where 90% of its settlements are considered illegal (PMOT, 2010). Finally, although it is less frequent than the previous typologies, it is important to mention that in recent years building projects have begun to be built at heights (4 to 6 floors) within the periurban area. Many of these have been built after data collection in 2017. However, when observing the analysis samples at present, the increase of this new building typology can be confirmed.

Besides the great diversity of these typologies, it is important to mention their spatial segregation. According to Achig (1983) social classes' segregation has been a key determiner in the history of Quito territorial conformation. Here, neighborhoods and urban 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). In our analysis about spatial patterns, the results show that this situation has been expanded and transposed also to peripheral settlements. Thus, we could clearly identify transects with higher levels of building densification, which tend to be more occupied by lower income population (Calderón), while other transects that have more households occupied by population of higher income, tend to present a more dispersed spatial distribution (Puembo). Thus, although there are micro-segregations within the parishes, there seems to be a tendency towards macro-segregation by sectors within all peri-urban areas. These segregation processes may be related -among other things- to the quality of the infrastructures of each parish. As Graham & Marvin (2001) state, infrastructural devices are more and more being used to separate places and people. In this sense, the -high speed- *Ruta Viva* road infrastructure, is connecting the riches parishes in a "premium network" that has better and faster access to the central city services and to the new peripheral "premium services" located in the same periurban parishes.

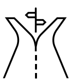
About the Agricultural LULC

Other relevant findings are related to agricultural land within the periurban area and how threatened it is due to urban expansion. According to the stability index results, agricultural covers were largely classified as experiencing instability and high instability. This clearly shows that areas that used to have agricultural vocation are currently undergoing significant changes due to extensive nearby urbanization processes, which push the agricultural frontier further away. Also, according to the Markov's probability matrix, they will tend to be reduced even more in the following years. This is particularly critical, since the area where the urban tissue is expanding, is also the area with more concentration of soil with agricultural vocation in the MDQ (Environmental Secretariat MDQ, 2016). On the hand, the reduction of the Patch Mean Area (A_MN) and the Larger Patch Index (LPI), are revealing a tendency of plots' fragmentation which can be a result of land use change from rural to urban. Indeed, despite the metropolitan land use regulation, in which rural land use has particular restrictions in order to protect it (such as a minimum lot size), there are several regulatory and legal gaps that continue allowing the division of lots. "*Acciones y derechos*" (shares and rights) and the "horizontal property" are the two more common legal tools in which the property size can be altered. The second is the most frequent method to implement gated communities and it has started to be used more frequently (Instituto Metropolitano de Planificación Urbana et al., 2018). In this scenario, agricultural practices may tend to weaken even further, considering that by 2014 only 5% of the population living in rural parishes was engaged in agricultural production (Environmental Secretariat MDQ, 2016). The loss of agricultural land can have various effects, including more fossil fuel emissions to transport agricultural products to city markets and increasing fragility of food sovereignty of the MDQ (Clavijo Palacios & Cuvi, 2017).

About the vegetation LULC

According to our findings, when looking at the dynamics and the stability index we observe that there is a clear dominance of unstable and highly unstable samples in the vegetation cover. This confirms that vegetation is the coverage type that has undergone the most dramatic changes in the last years. This is critical since this cover instability is something present not only in the dynamic periurban and rurban territories but also in urban areas. In addition, when analyzing the metrics spatiotemporal variation, processes of fragmentation were also identified in various sites throughout the entire periurban area. This can be inferred due to the reduction of the A_MN and the LPI, while there is an increment of Number of Patches (PD). Fragmentation is one of the major environmental concerns, due to its effects on ecological functions and processes which can result on the damage of natural habitats, the reduction of ecosystem services and consequently of the effect on basic human needs (Kumar et al., 2018; Shrestha et al., 2012). According to Shrestha et al. (2012), low-density developments contribute to increase the level of fragmentation and they typically happen on the urban-rural fringe. The condition of natural vegetation fragmentation certainly has ecological implications, considering that the city of Quito is part of a complex system, also with various ecological zones and attributes. Finally, our results have also shown that the transformation from a natural ecosystem to an urban settlement, first undergoes a transformation from natural to agricultural. Thus, in the regression model it was found 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 foremost natural ecosystems and biodiversity ant then facilitating the urbanization processes (Jeliazkov et al., 2016; Tilman et al., 2001; Vizzari et al., 2018).

6.1.2 Discussion about periurbanization main drivers



Road Infrastructure

The construction of road infrastructure appears to be one of the most dramatic drivers of landscape transformation. Results have shown that the areas crossed by the "Ruta Viva" highway (inaugurated in 2014 to facilitate the access to the city's new airport and two new shopping centers) are those that has experienced the greatest landscape transformation on average. In fact, when observing the PLAND metric temporal variation, Roads and Built-up covertures increase in parallel. However, this could also be related to those road infrastructures developed as part of new real estate residential projects on areas that were previously rural. On the other hand, our regression model has proven that roads' presence mainly affects natural and vegetation covertures, generating fragmentation processes. All this harmonizes with literature, since several studies have described road infrastructure as main "urban expanders" (Bayón Jiménez, 2016; Delgado Campos, 2003) and various authors have affirmed that they tends to accelerate urban expansion (Adrián Guillermo Aguilar, 2002b; Borsdorf, 2003; Serrano Heredia & Duran, 2020).

Cabeceras parroquiales / pre-existing settlements

In the MDQ case, the presence of old traditional rural settlements (*cabeceras parroquiales*) has demonstrated to be a key driver its urban expansion. As mentioned before, we could observe in the Built-up PLAND variation that the urbanization pattern is not linear but presents various peaks that coincide with these peripherical settlements. Also, when observing the temporal variation, we identified that the highest intensity of built-up growth within periurban areas tends to match these settlements, confirming the micro extension/conurbation processes. According to Serrano Heredia & Duran (2020), the socio-spatial configuration of the MDQ has resulted in the production of new centralities in its periurban areas. These centralities are associated to these *cabeceras parroquiales* that have been expanding around themselves and -in some cases- conurbating with the consolidated city.

New facilities in periurban areas

We have identified that the implementation of new urban facilities (educational, health, leisure) within the peri-urban territory, seem to work as an urban accelerator. We were able to infer this when analyzing the rural parish of Calderón that -without presenting the construction of an important road infrastructure in the period of analysis- shows one of the most pronounced increases of buildings in the same period. One of the aspects that explains this intensive growth could be the provision of new services (hospital, market, mall) that make the parish more attractive for new urban immigrants. Borsdorf (2003) describes these new facilities as nodes that make a territory more attractive.

Land price

Evidence has proved that high land prices in central urban areas have led to informal and deregulated occupation of nearby rural parishes (Guerrero Miranda, 2011). In addition, in a kind of vicious circle, irregular growth processes -that lack infrastructure, facilities, economic opportunities and basic services- affect the price of land (Cabrera & Plaza, 2016; Weku et al., 2019). In this case of study, it can be observed that the parish of Calderón has one of the lowest land prices, which makes it an attractive and accessible place for the immigration of the lowest socioeconomic classes. This could explain partly the significant increase in built coverage that Calderón experienced during the analysis period.

Real estate market

Based on the dominant typologies observed by satellite images and by field verification, it can also be inferred that speculative real estate projects have accelerated the peri-urbanization process in the MDQ. Real estate projects mainly in the form of gated communities (and recently in the form of high buildings), have expanded importantly towards rural parishes. While looking at those areas that have change the most, according to the stability index, and their most recurring spatial configurations, we have clearly identified this typology promoted by the real-estate market for middle and high socioeconomic groups. In addition, private agents have also seen an opportunity to promote real estate projects focused on low economies, focused in guaranteeing cheap housing (because of the low land price in peripheral areas) but not always an adequate urban context. This can be clearly observed in the case of Calderón.

Weak urban management and legal gaps

As we mention before, we have identified weak urban management and control mechanisms and legal gaps that are facilitating land use change even above the intentions of general territorial plans. Particularly, the "acciones y derechos" and "*horizontal property*" legal tools. In Brenna's study (2008) about Land Use Management for the MDQ, the author recognizes that the current planification processes (which is developed in wide-ranging urban growth plans) are limiting the management and engagement capabilities of other stakeholders, including the local inhabitants. Exploring periurban territories, Brenna states that "*the combination of limited participation and resources has resulted in a lack of programs for those rural and natural areas that face increasing pressures of urbanization*" (p.83).

6.2 DMQ periurban spatial patterns schema

As a summary of the main findings of the case of study, the following schema shows the MDQ peri-urban spatial patterns and their main dynamics. Here, five main elements are diagrammed: (1) the most important infrastructures, (2) the built-up structures (understood as the macro-tendencies the entire urban-rural gradient), (3) the natural elements (including the agricultural land), (4) the built typologies (highlighting the most predominant forms of land occupation); and finally, (5) several symbols that seek to express the main territorial dynamics.

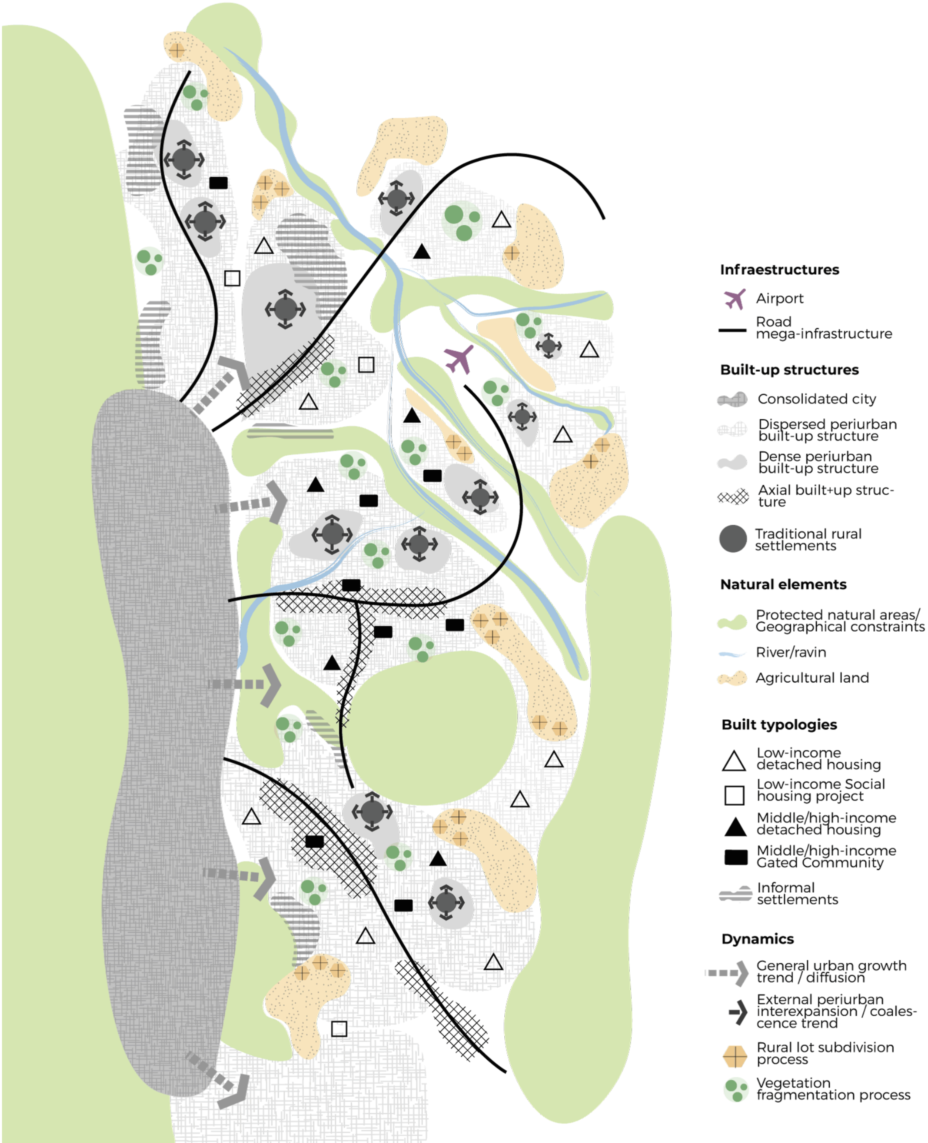


Figure 14. Schema of the current spatial patterns of the peri-urban area. Based on the Metropolitan District of Quito.

Regarding the infrastructures, the aim has been to represent both the new airport, located in the rural parish of Tababela and the main road infrastructure that connect the traditional city to the eastern valleys and to the airport as well. As shown in the scheme, road infrastructures have been and continue to be one of the main drivers of both dispersed expansion and axial expansion. Thus, in relation to the built-up structures, the axial built-up structure can be clearly observed around these main road infrastructures. The consolidated city stands out on the western side, like an elongated unit. This is largely due to geographical constraints: the flanks of the Pichincha volcano to the west and the *Auqui* hill to the east. In the lower east valleys, where the periurban area is located, both Dense and Dispersed built-up structures can be observed (along with the -already mentioned- Axial built-up structure). The dense built-up structures are located basically around the pre-existent traditional rural settlements or *"cabeceras parroquiales"*.

In the group of natural elements, we can identify the protected natural areas (which has also work as a geographical constraints). These correspond both to the remnants of forest on the flank of Pichincha, the *Auqui* and *Ilaló* hills, the Cayambe-Coca protected area as well as to green buffers around rivers and streams. As can be seen, these geographical constraints have significantly determined the geography of the periurban areas and the expansion of its built-up structures. In this category, the areas where the main reserves of agricultural land are located are also diagrammed.

Regarding the built-up typologies, five of the predominant forms of land occupation are presented, considering socioeconomical conditions. These are: Low-income detached housing, Low-income social housing projects, Middle/high-income detached housing, Middle/high-income gated community, and Informal settlements. As can be seen, these typologies are randomly located throughout the peri-urban area. However, as explained in previous paragraphs, in the MDQ periurban territory it has been possible to observe patterns of macro-segregation where certain parishes concentrate a greater number of settlements for the middle/high-income population, while others concentrate more settlements for low income. Thus, it can be seen, how the east-central zone concentrates a greater number of typologies for the middle/high-income class (both detached and gated communities) while the northeast and north-south valleys present a greater mix of typologies by socioeconomic class.

Regarding the dynamics, two types of arrows seek to represent, on the one hand, the general urban growth trend which starts -as a centrifugal force- from the central city towards the peripheries. But, on the other hand, the new centrifugal forces that start from the new external centralities located in the peri-urban areas (cabeceras parroquiales) and that are generating an intrinsic dynamic towards their own surroundings (mainly conforming periurban dense built-up structures). Finally, two additional symbols locate specific dynamics, related to the subdivision of rural lots and vegetation fragmentation processes. These are found mainly in the adjacent areas to the built structures (dense or dispersed).

6.3 Confirming or rejecting the hypotheses

Based on the previous results, we can confirm our hypotheses as follows:

1. The first hypothesis suggested that Periurban territories (as well as the other terminology related with the urban-rural gradient) has a different and a singular meaning in a Latin American context. We could confirm that, although in a previous study about the terminology in the urban-rural gradient from a multi-regional approach (André et al., 2014) the terms suburban and periurban area are defined as the same notion, where the only difference is the language of origin. In Latin America, on the other hand, when analyzing the zoning, it can be notes that these two concepts are very different: the periurban territory recognized as highly heterogeneous (residential, industrial, commercial, and agricultural) while the suburb has an explicit zoning: mainly residential. Other notable difference is that the term "periphery" does not appear in the multi-regional study; therefore, it seems that these territories, strongly associated with precariousness, are spatial imaginary distinctive for the Latin American region. This corresponds to the informal construction patterns that were identified in various sectors in our study area.

2. The second hypothesis, related to the current landscape structure in the MDQ periurban areas, is also confirmed since our result have demonstrated that these areas are very diverse in terms of landscape structure. As explained in the previous section, very heterogeneous occupation patterns were identified, among detached and isolated houses, gated communities, low-density housing projects, informal self-construction projects, etc. All these typologies, are also interconnected with agricultural and natural landscapes, consolidating a very diverse and complex territory from a biotic, abiotic, and socioeconomic perspective.

3. Finally, the first part of the third hypothesis can be confirmed since vegetation and agricultural covers are those experiencing the more severe transformations, particularly due to fragmentation processes. However, the second part of the hypothesis (related to how new road infrastructures along with land speculation can accelerate the rhythm of urban expansion) can be partially confirmed. Our results have demonstrated that there are other drivers (such as new facilities, old historical settlements in the city outskirts, real estate speculation, illegal/informal settlements, land price, or natural-agricultural land use change) that have a similar important influence in periurbanization dynamics.

6.4 Brief discussion on the methods

This doctoral thesis has applied several methodologies and software in order respond the research question. The following paragraphs analyze the main successes and limitations of the different methods applied.

Satellite image interpretation at a very finer scale (1 pixel = 1 m) for identifying specific Land Use Land Covers (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. There is a limitation specifically in the recognition of the agricultural cover, since -depending on the production cycle- in some cases it can be identified as bare soil. Comparison with images from different periods, along with field verifications, can help reduce inaccuracy in this case.

The definition of transects and sample polygons, has proved to be a clever solution when analyzing large territorial extensions. Indeed, transects seems to be the most practical tool when approaching the urban-rural gradient and to analyze a wide territory in a very detailed scale. Additionally, the use of transects and the detailed scale of the samples allowed us to make a very meticulous and detailed assessment of landscape features, without losing the general perspective of the MDQ. 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.

Landscape metrics calculation was the chosen methodology to analyze landscape structure. A hypothesis approach for each LULC allowed us to choose in a more precise manner the adequate metric to identify landscape composition and configuration. Particularly, the most suitable metric to identify composition was Percentage of Landscape, while the other selected metrics (Patch Density, Average Area, Larger Patch Index and Euclidean Nearest-Neighbor Distance) allowed us identifying other characteristics of the spatial configuration. We calculate the selected metrics using the software FRAGSTAT 4.2.1. At these point, it is remarkable that landscape metrics - which were originally designed to tackle research in ecological fields- (Kumar et al., 2018; H. Liu & Weng, 2013; Seress et al., 2014; Subirós et al., 2006; Wadduwage et al., 2017), in this work have also allowed us to explore specific patterns of urban forms.

A multivariate cluster analysis was developed in order to recognize samples' similarities/differences, regardless of the transect or the distance to the city center. This analysis allowed us to identify how similar patterns could be generated in different abiotic and biotic conditions. In this sense, this analysis was key in terms of reducing randomness and observing tendencies of urban development patterns. In fact, the results of this clustering became the spatial basis for several subsequent analyzes. We applied a hierarchical clustering analysis using the software GeoDa 1.18. 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 Built-up variables PLAND, PD, A_MN and ENN_MN were standardized and analyzed under the Ward's-linkage method. However, although the Built-up class demonstrated to be a good proxy, analyzing other LULC in future stages, could enrich the classification, generating even more specific typologies.

When analyzing territorial transformation, a **Transition Matrix and a Stability Index** have proven to be an effective tool to assess landscape composition change intensity, both for each LULC independently and for the total landscape. The results allowed us to identify those land covers that have changed the most and -specially- its levels of instability in a very systematized way. These two methods, along with the analysis of the temporal variation in various landscape metrics, enables a richer visualization of landscape composition and configuration, and their transformation tendency.

Finally, regarding land change tendency analysis, the **Markov chains modelling technique** has shown to be one of the most effective in quantitative simulations and has been widely applied in land use change evolution studies (E. R. da Cunha et al., 2021; Guan et al., 2011; Mansour et al., 2020; Rahnama, 2021; Wang et al., 2021). This technique is a stochastic model based on computing a probability matrix of transition and randomly simulates changing covers, calculating rates of all possible transitions between various land covers. Markov chains analysis describes land cover changes from one period to another and predicts future tendencies of change (E. R. da Cunha et al., 2021; Mansour et al., 2020; Rahnama, 2021). We used the software Idrisi 17.0 and its Markovian transition estimation. These models also make it possible to spatially observe the trend of change. However, since the study object was not a unified territory, but rather a group of samples along transects, this spatial exercise did not meet the characteristics to spatially model the transformation trend. It is also important to mention that, when we analyze the 2010-2017 Transition Probability Matrix that predicts LULCs' transformation, some suspicious results are observed, for example, the probability of Road Infrastructure and Built-up becoming vegetation or Agriculture becoming natural vegetation. These potential errors may be related to LULCs' misclassification, one of the methodological limitations that we have already explained in the second paragraph of this section. In this sense, its necessary to address this data from a critical point of view. Despite this, the statistical results allow us to have a general idea of the trend of change in the MDQ and are useful data for territorial planning.

6.4.1 Methodological recommendations for future stages

It is important recognizing that administrative territorial units (artificially established by local governments) do not necessarily reflect accurately the existing social and territorial phenomena. In this sense, although our study was based on the MDQ administrative limits --mainly due to data access-- it would be suitable analyzing landscape structure beyond these imaginary edges. For example, it would be key to include the Rumiñahui canton that, even though it's off administrative limits, it shares spatial and functional dynamics with the MDQ.

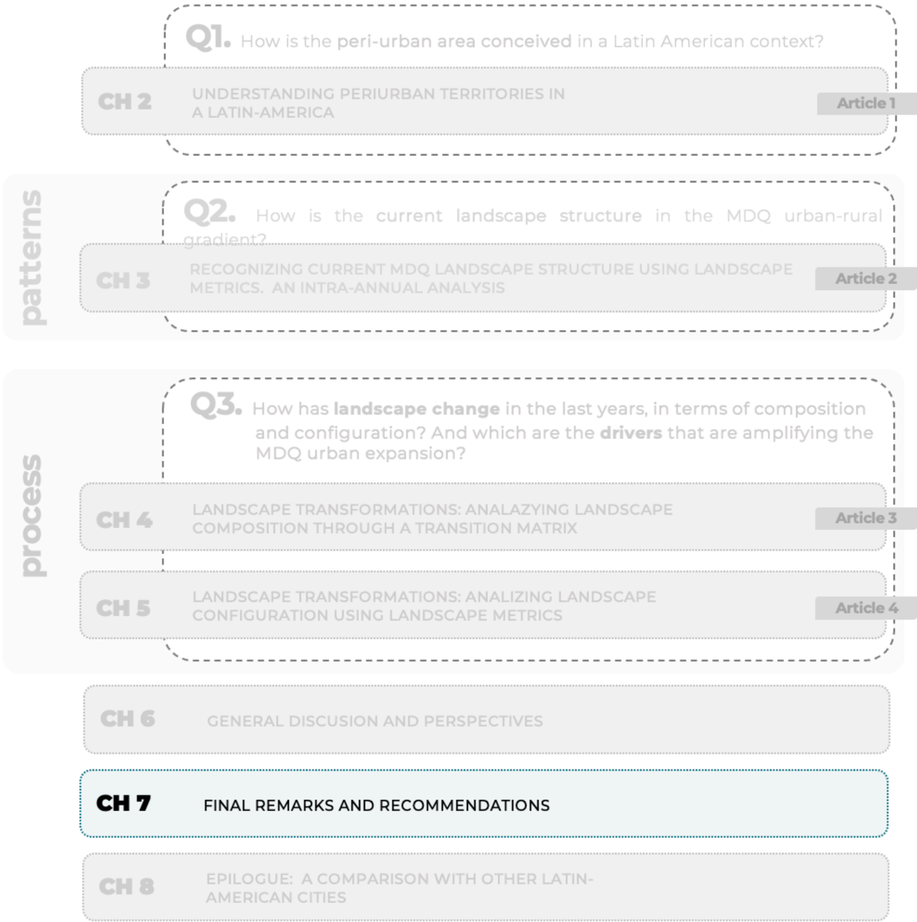
Despite the fact that the study is strongly based on a planimetric analysis of raster images (as the main input in the analysis of the landscape structure), in the development of the results various aspects related to territorial altimetry were considered, including the climatic floors and the main natural constraints. However, a more focused analysis on the characteristics and topographic conditions could enrich the interpretation of the results. For example, the topography can be a determining factor in the typologies of agricultural plantations or in the conservation level of natural areas. Likewise, it could condition the intensity of buildings' construction or the development of road infrastructures.

It would be also recommendable complementing this study by tackling a sociological approach that explores the daily practices and perception of periurban dynamics at the level of the subjects, including their socioeconomic and cultural imaginaries, as counterpart to the spatial perspective.

Finally, in Chapter 2, after exploring the terminology to understand these interstitial territories, it was concluded -among other things- that the difference between Periurban and Suburban areas are specifically functional: the periurban territory is highly heterogeneous (residential, industrial, commercial, and agricultural) while the suburb has an explicit zoning: mainly residential. In this sense, we highlight the importance of the functional approach for a holistic territorial understanding. Thus, we highly recommend for future research, the development of complementary studies related to mixed land use analysis, mobility patters (including daily travels, walkability), among others.

Chapter 7

Final remarks & recommendations



7.1 The current urban process of the MDQ: a scenario full of challenges

This study has demonstrated that the city of Quito is rapidly expanding over its eastern valleys following mainly a dispersed pattern. This model of urban expansion represents a challenge for planning processes and for building an adequate habitat for the population and its natural environment. Indeed, there is plenty evidence that this expansive model can bring negative environmental and social impacts (Bogaert et al., 2015; Hermida et al., 2015; Hidalgo et al., 2007; Inostroza, 2017; Reis et al., 2016; Rueda, 2009; Vizzari & Sigura, 2015; Wadduwage et al., 2017). Additionally, since the costs of urbanization and the provision of basic infrastructure and services for a suitable habitat increases, the capacities of local governments become insufficient (Cruz-Muñoz, 2021).

Specifically, regarding the environmental dimension, we can affirm that both agricultural and natural covertures that surround urban areas are under great pressure to change and to the detriment of its quality. However, their conservation is particularly important since they provide essential ecosystem services and are key elements on mitigating the effects of climate change (Inkoom et al., 2018; Kumar et al., 2018; Lee et al., 2015). However, the current urban expansion is threatening the quality of these areas, exposing the territories to environmental fragility[9], and potentially losing the well-being of the population. Reflecting on the nature/settlement's relationship is particularly important within periurban territories, since is here where both worlds coexist intertwined. However, the dichotomous and obsolete urban/rural perspective (imperatively present in territorial planification) difficult and limit an adequate management of these interstitial spaces since, generally, it gives priority to new urban/anthropogenic uses, to the detriment of natural areas.

From a social perspective, the model of urban expansion brings other specific challenges. On the one hand, the dominant presence of gated communities evidence has shown that it leads to the disappearance of life in public spaces in their immediate surroundings and to the disintegration of neighborhoods (Guamán Guagalango, 2021; Roitman, 2003). This turns the city into a space to transit and not to live (J. C. Frediani, 2013; Perahia, 2009). However, a common mistake in our region is to conceive the habitat only as the house by itself, without considering the urban context as an integral element (Cruz-Muñoz, 2021). As Mauricio Hernández (2008) stated "*public space is as necessary as private space for the development of urban societies*" (p.111). In this

[9] This environmental fragility refers to the degree of sensitivity of habitats, communities, and species due to territorial changes. The degree of fragility is determined based on external anthropogenic threats and the vulnerability of the species and the landscape according to each ecosystem, productive agricultural zones or protected zones and protective forests.

context, gated communities has become an object of high profitability for the capital of the real estate businesses, contributing to the proliferation of new modalities of urban fragmentation specially in periurban areas (Bernal & Orcid, 2021). This is particularly critical when the logic of the real-estate housing market (the profit maximization) is one of the primary drivers of new urban expansion. In these scenarios, the city tends to grow responding only to the greater profitability of real estate projects, where real estate companies are not always concerned with providing urban conditions that improve the quality of urban/periurban life (Cruz-Muñoz, 2021; C. De Mattos, 2010; Hidalgo et al., 2007).

On the other hand, with informal housing (other typology present in the periurban area) residential socio-spatial segregation increases and territorial inequality is exacerbated (Muñoz & Ramos, 2022; Perahia, 2000; Sabatini, 2003). Since these informal buildings are erected without regard to construction or regulatory standards, lacking of basic infrastructure services, and provide owners no property rights, the level of vulnerability of low-income residents is increased (Goytia et al., 2023). It is also critical that, located in the peripheries, they lack access to job and educational opportunities and -in free market scenarios- real estate companies do not consider this population group as a potential group to offer alternative facilities (Cruz-Muñoz, 2021).

Another challenge is that low densities, as results of these disperse patterns of land occupation, makes an adequate public transport system unfeasible, generating a territory highly dependent on private transport. In fact, in the MDQ the private automotive fleet has exponentially increase in the last years (MDMQ, 2017) and the daily commuting from the rural valleys of Cumbayá, Tumbaco and Los Chillos to the city center has increased from 40.000 in 2008 to 140.000 in 2019 (La Hora, 2019; Núñez et al., 2015). Urban dispersion not only increases the costs of new infrastructure, but increases distances, time, and costs of traveling from residences to work, study and other leisure activities. At this point, it is important to mention that mobility is experienced differently according to socioeconomic levels. In fact, the population with less income must spend more time traveling as a result of deficient transport systems which impoverishes them even more. Finally, the high dependency on private motorization also brings important environmental effects: in the MDQ, 56% of the carbon footprint is caused by emissions from transport vehicle emissions (MDMQ, 2017).

7.2 Spatial metamorphosis scenarios for the MDQ

With the aim of exploring alternative solutions for the aforementioned challenges, in the following section, future scenarios for the spatial metamorphosis in the MDQ are discussed. Specifically, two scenarios are confronted: one that responds to the current transformation trend and an alternative scenario that explores a more compact, decentralized, and connected pattern. The exploration of these scenarios is built on the basis of the results obtained and summarized in the "MDQ periurban spatial patterns schema" (section 6.2) and in correspondence with the analyses on landscape structure temporal variations.

Actual scenario: current trend

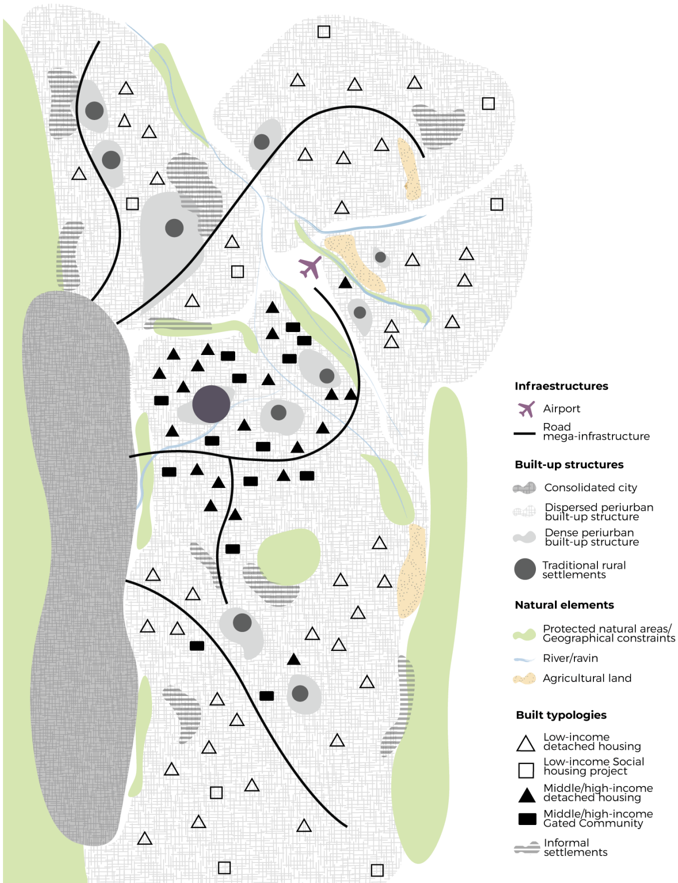


Figure 15. Current MDQ metamorphosis scenario

This scenario, which maintains the current trend, tends towards the formation of a dispersed and low-density territory, which extends towards a very diffuse boundary.

Due to the cost of implementing an efficient public transportation system in these highly dispersed and low-density territories, the use of private motorized transportation continues to be the dominant mobility model. The central city continues to concentrate the majority of activities, services, and job opportunities, so there is a great dependence on commuting to the upper western valley. The environmental and time costs due to long trips to the center increase, as well as traffic jams at the few access points to the central city. These negative impacts affect those who travel by private vehicle as much as they are immersed in highways clogged with traffic. But also, to those who travel by public transport, for long hours and sometimes, with the need to make several transfers which increases the cost of transport and time.

The traditional settlements that are located in the peri-urban area continue to consolidate as external centralities. However, the levels of development are uneven. There are "cabeceras parroquiales" that are of greater interest to private capital and therefore receive greater investment in terms of services and opportunities. This sustains and increases patterns of macro-segregation, with territories better equipped for inhabitants with greater economic resources. The new inhabitants who relocate to the areas of influence of these parishes acquire homes within gated communities, following patterns of dispersed land occupation, where cars are the main means of transportation and where public space is not built.

Due to the highly dispersed pattern of land occupation, the fragmentation and reduction of natural areas increases. Forests are cut down and ravines are filled to move forward with the construction of new buildings, where the profit logic of the real estate market rules. Likewise, promoted by the real estate market, agricultural plots are divided up and urbanized in increasingly distant territories. Thus, productive areas tend to disappear or move towards protected natural areas. All of this causes, in the long term, the loss of essential ecosystem services for the MDQ.

Something particularly critical about this scenario is that it not only responds to the observed dispersion trend but would happen even if current land use policies are followed. In Salazar's study (2020) (that simulates the urban tissue expansion by 2050 for the whole DMQ and its surrounding cantons, considering both demographic dispersion and the regulated scenario), it is shown that in both cases there is a tendency towards fragmented dispersion. In fact, in the regulated scenario urban expansion is 2% greater than in the trend without intervention.

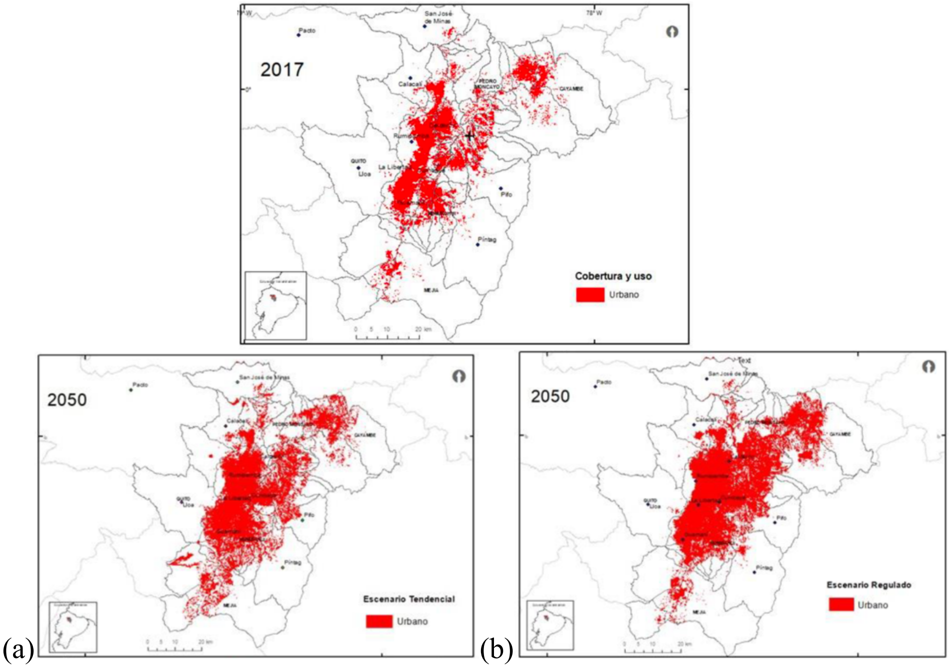


Figure 16. Urban expansion from 2017 to 2050, (a) trend scenario and (b) regulated scenario. **Source:** (E. Salazar, 2020)

Alternative scenario: a decentralized, equitable, compact and connected city

In this alternative scenario, a pattern almost opposite to the trend is explored. In a similar way to the previous scenario, in this one a process of decentralization of opportunities and services occurs towards the periurban “cabeceras parroquiales”, but with a more equitable distribution. That is, preventing certain territories from being better equipped than others. To this end, public intervention is essential to reduce the biases inherent to capital's interest in its own profits. The traditional center of the city continues to function with its essential services (economic and administrative), but by decentralizing job opportunities and various services, such a marked monocentric dependence is reduced.

To address low-density urban dispersion, "in fill" development is first promoted within urban limits, in areas that already have all the services and that are not occupied due to the high costs of land price or for real estate speculation. As for periurban areas, a more compact occupation is promoted around the new centralities. These new, more compact development areas would allow, on the one hand, less dependence on travel by motorized vehicles, increasing walkability and non-motorized mobility (bicycle and others). On the other hand, the concentration of buildings would allow the implementation of a more efficient public transportation system, with better frequencies and less expensive. This public transport network could connect these centralities and their immediate surroundings not only with the central city but with each other.

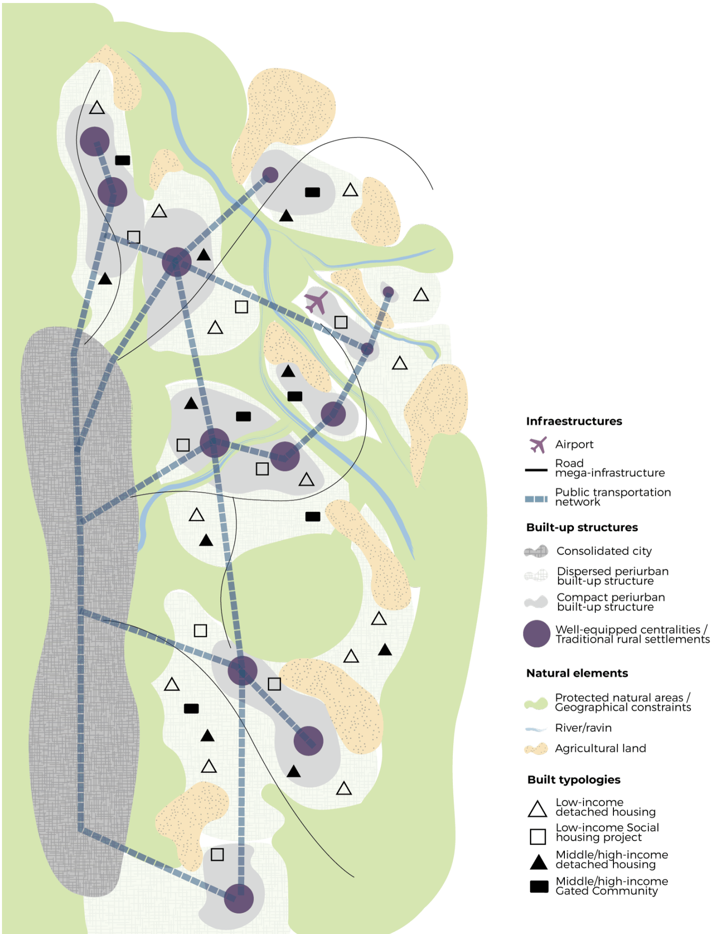


Figure 17. Alternative DMQ metamorphosis scenario

These sets of nuclei that function autonomously -although articulated- outside the central city, seem to be one of the attributes that differentiates peri-urban territories from the traditional city. The disparity with the descriptions of the Fragmented City of Borsdorf (2003) or the Postmetropolis of Soja (2008) is that instead following a dispersed and disarticulated pattern, these compact nodes could function in an articulated manner with an optimal public transportation system. Not only with large road infrastructures that benefit some and segregate others.

In this alternative scenario, along with achieving a more equitable distribution of services within the new centralities, macro-segregation could be reduced by facilitating the mixed location of different socioeconomic groups. For example, social housing quotas could be included in areas that have tended to have greater capital gains and not just segregate them to peripheral areas lacking services. At this point, the importance of public intervention for the development of this time of initiatives is highlighted again.

Finally, by limiting diffuse and low-density dispersion, a greater number of green areas and conservation zones would be protected, by reducing fragmentation. Likewise, a greater number of agricultural production areas could be conserved. This is key, since these land uses are particularly differentiating and constitutive of periurban territories.

7.3 Other specific recommendations for land management and planning

It is likely that the conceptual ambiguity of periurban territories (where the urban-rural border dissolves into a diversity of uses) and its transformation speed, may be affecting the capabilities of planning and control of these territories. However, this research's findings have brought various insights than can be useful to planners and policy makers in the MDQ regarding this periurban areas specifically. And in conexion with the alternative scenario previously discussed.

- First of all, it is key to develop more specific and accurate land regulations and tools, since nowadays, land policies in the MDQ tend to be quite generalist and -in terms of periurban contexts- territorial strategies should be adjusted to particular local conditions and needs. This could start by rethinking the traditional urban/rural land classification and recognizing the presence of interstices that do not fit into any of these categories. The separated treatment of urban and rural spaces often favors urban planning in periurban areas, to the detriment of rural and natural areas.

- Based on our results, we can also affirm that micro-scale planning is urgent and necessary in the MDQ. The current large-scale planning tends to gloss over the heterogeneous dynamics in peri-urban landscape transformation.

- Facing the overwhelming evidence of the influence of transport infrastructures on the urban expansion it is imminent to evaluate how other highways (such as the next phase of the "*Ruta Viva"* over the parish of Puembo) will affect the speed of the urban fabric expansion. This could alter the intentions of the current Land Use and Management Plan (PUGs) to stop the enlargement of the city.

- Planning must be complemented with stronger management and control instruments to avoid land speculation and the construction of individual and disjointed projects that tends to destroy the preexistent natural ecosystems and the agroecosystems. There is a particular need to handle the risks associated to the loss of agricultural land in the emerging periurban areas.

- Likewise, it is essential to strengthen the planning instruments that promote sustainable development through the protection of natural resources, guaranteeing the provision of ecosystem services from the natural heritage of the city. Also, taking action to mitigate the effects of climate change by promoting environmental resilience. In this sense, the establishment of protected areas and strict regulations for their adequate protection, have proven to play a key role in the conservation of natural areas. In our study, the few samples that demonstrate vegetation landscape high stability coincide with the location of protected areas, such as the *Cayambe Coca* National Park (a fundamental area for the MDQ water supply) or the *Epiclachima* urban forest.

- Also, protection policies should be strengthened not only for natural parks, but for small natural remnants, such as streams, ravines, and slopes, in areas with the greatest urbanization pressure. Due to its location over the Andes Mountain range, the MDQ is crossed by hundreds of streams and ravines, whose protection must be guaranteed due to their important role in natural drainage of soil and flood protection. Landscape structure and topography should be the key deciding factors in planning and controlling urban expansion.

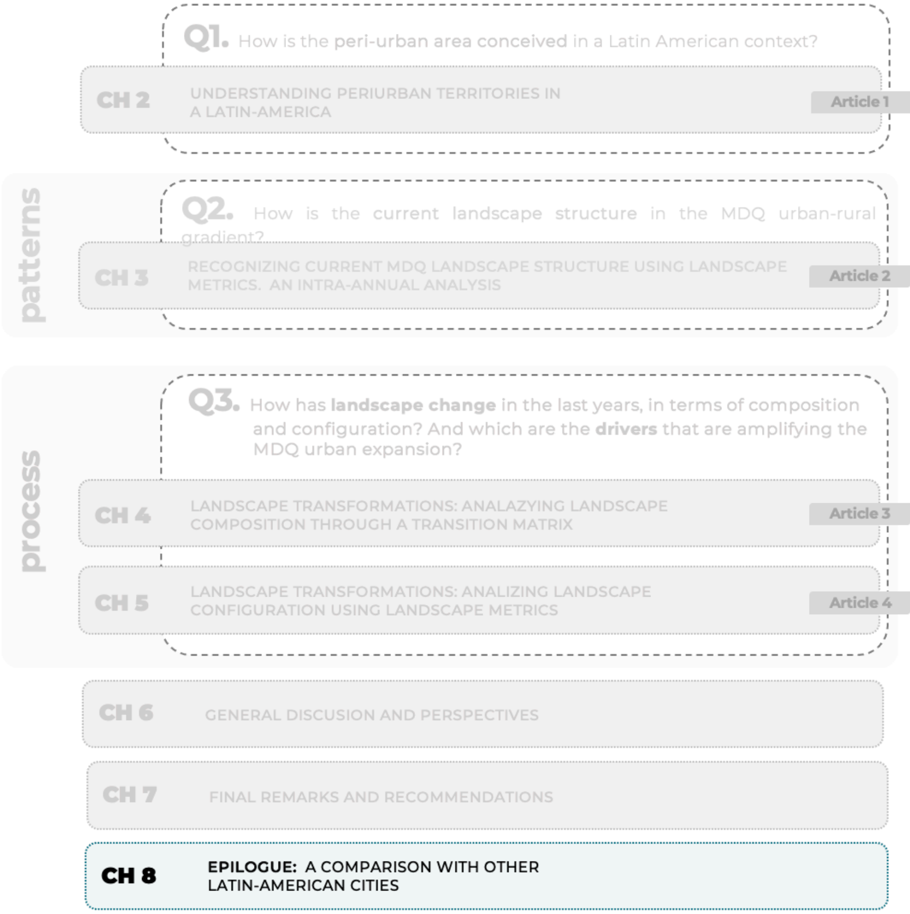
- In the particular case of regulating informal urban expansion (although it is a more complex challenge that covers not only peri-urban territories), in this case it would be key regulating the land price in order to provide affordable opportunities within vacant already urbanized land.

- It is key to devise instruments capable of ensuring urbanized areas, where inhabitants' well-being is the main engine of development rather than the profits of a group of real estate companies. Thus, it is necessary to find mechanisms to set limits to real estate interests that, like an unstoppable force, are shaping peri-urban territories lacking quality public space. The characteristics of public space and the daily activities that are carried out in there, are decisive in achieving an inclusive city model.

- Finally, the existing land use regulations seem to be incompatible with current speed of urban population inflows. The this is surely one of the biggest challenges for policymakers in developing countries. Actively involving all stakeholders and enhancing the collaboration across institutions at all scales, according to Brenna (2008) could help improve MDQ periurban land management. It requires integrating resources and responsibilities regardless administrative boundaries while involve local actors.

Chapter 8

Epilogue: Comparing the MDQ case with other Latin-American cities



8.1 A comparison with other Latin-American cities

We consider that the insights from our study about the MDQ urbanization process and the landscape patterns in its interstitial territories, can provide important inputs, reflections, and perspectives from and for other Latin-American cities that are undergoing similar dynamics in terms of socio-spatial development. In Chapter 2, we addressed periurban territories from a regional point of view, and we were able to identify common correlates from a bibliographic exploration. In this sense, this work explores a novel discussion about contemporary urbanization pattern in Latin-America that could facilitate dialogue in regional socio-territorial studies. To achieve this, in the following sections we present a discussion about common/distinct elements with regard to urbanization processes in various Latin-American cities, based in 34 secondary sources that address contemporary urban patterns in several cities within the region.

8.1.1 What are common elements with regard to urbanization among the MDQ and the other cities within the region?

Synergies in terms of the expansion pattern

Although in Latin America there is a great variety of urban formations, such as cities of colonial origin, planned cities with specific purposes (Brasilia for example), coastal cities, Andean cities, cities created for productive, commercial, or military reasons, etc., a contemporary common pattern has been identified pointing to a dispersed, low-density growth which is consolidating rapidly (J. Frediani, 2009; ONU-Habitat, 2012). This has been demonstrated by several studies that have been carried out in recent years. For example, in the article of Inostroza et al. (2013) new urban developments in 10 Latin-American cities are explored, taking into consideration their built-up area, density, and spatial configuration. Based on that, the authors identify three trends of urban development: infill (growth inside the urban limit), axial (growth along road infrastructures) and isolated (growth spatially disconnected). The results show that although all studied cities still growing on their infill areas, the expansion into axial and isolated patterns is more prominent demonstrating a general trend towards a dispersed pattern or urban sprawl. This is also confirmed by Silva Lovera (2015) who affirms that "*Urban sprawl in South America is an ongoing process supported by policies traditionally adjusted to promote outer expansions defined by housing demand*". Cruz-Muñoz (2021), in her study about urban expansion in three Latin American megacities, found that -on average- urban density has dropped from 117 hab./ha in 1990 to 85.7 hab./ha in 2010, due to the increase of hundreds of square kilometers of intensive dispersion of urban land. In these scenarios of great urban sprawl, the lack of definition between urban and rural has become a common issue in the cities within the region (Terraza et al., 2016).

Along with the low density spatial dispersion, fragmentation is also a spatial pattern common among contemporary Latin-American cities. For example, Inostroza (2017) affirms that periurbanization in the cities of Lima, Bogotá and Santiago is following a spatial model that corresponds to a discontinuous structure of settlements that generates a fragmented and disrupted territory. Other studies also confirm this spatial condition for the case of Lima (Inostroza et al., 2013; Ioris, 2012), Buenos Aires (Fernández, 2016; J. Frediani, 2010; Ringuelet, 2008), Mar de Plata (Daga et al., 2015; Zulaica & Celemín, 2008), Montevideo (Ligrone Fernández, 2016), Cuenca (BID, 2015), Santiago (Cáceres Seguel, 2015) and México City (Cruz-Muñoz & Isunza, 2017).

It is important to mention that, although there are differentiated levels and intensities of expansion, there is a general tendency to follow this expanded and fragmented pattern of periurbanization. The city of Santiago de Chile, for example, has experienced an expansive growth in the last 20 years, adding approximately 1,300 ha per year of urban land and following a strong dynamic towards the periphery. While the city of Bogotá shows an smaller average of urban expansion of only 317 ha per year (Inostroza et al., 2013). This last case is similar to the city of Buenos Aires that presents a greater compactness in relation to other megacities within the region, such as Mexico City or Sao Pablo (Cruz-Muñoz, 2021). However, when analyzing its rate of expansion, it is evident that it is not long before it will acquire a highly dispersed and fragmented pattern like that of the other cities (Goytia et al., 2023). In this sense, according to De Mattos (2010) this general phenomena of metropolization can be observed not only in the largest metropolises (Sao Paulo, Mexico City, Buenos Aires, Rio de Janeiro, Lima, Caracas, Bogotá, Santiago de Chile, etc.), but also in some smaller cities such as Belo Horizonte, Cali, Panama City, Concepción, Córdoba, Guadalajara, La Paz, Medellín, Monterrey, Montevideo, among others.

Patterns of new constructions in periurban areas

Regarding the patterns of built-up elements in this diffuse periurban territory, several peculiarities of the region can be mentioned, which are related with its great diversity of socio-territorial characteristics. The first are the enclaves of poverty in the peripheries, which appears as a phenomenon common to all Latin-American cities. According to De Mattos (2010), it has been possible to observe in the entire region displacements of the lower income sectors towards the urban periphery, where the price of land is lower. In the periurban area of Mexico City, for example, a growing proportion of vulnerable homes lacking basic services has been identified (Cruz-

Muñoz, 2021). In fact, a significant number of its peripheral delegations have presented a very low level of social development, even below 25% (Adrián G Aguilar & López, 2016). Similarly, the study of Bernal & Orcid (2021) also identifies an accelerated process of urban expansion with little or no access to basic social services in the periphery of El Alto. In Buenos Aires, according to Goytia et al. (2023) the "*villas miseria*" (slum) have proliferated in the less expensive urban periphery, where there is little to no infrastructure, with poor environmental quality, along river banks or on floodplains. In Mar de la Plata, also an important appearance of precarious settlements is also highlighted, whose growth is mainly related to migration from nearby agricultural areas (Daga et al., 2015). Likewise, Inostroza (2017) identifies precarious housing sectors in the periphery of Bogotá along the Bogotá River which is mainly occupied by rural immigrants. Here, periurban areas become habitats of poverty whose inhabitants do not have access to the benefits of the city, given the deficiency of the material conditions of infrastructure and services (Cruz-Muñoz & Isunza, 2017). This "peripheralization of poverty" is directly associated with informal housing processes (Adrián G Aguilar & López, 2016). This phenomenon of informality has been clearly identified in the cities of Cuenca (BID, 2015), Buenos Aires (located mainly towards the southern part of the city) (J. Frediani, 2010; Goytia et al., 2023), Lima (Muñoz & Ramos, 2022), Bogotá (Inostroza, 2017) and México City (Adrián G Aguilar & López, 2016; Pradilla Cobos, 2015).

The other side of the coin corresponds to the location of the middle and upper classes in periurban areas in the form of single-family, isolated, and low-density homes, and in the form of gated communities. This last pattern of occupation has been increasing exponentially in several cities in the region. An emblematic case is the Buenos Aires peri-urban, where various housing complexes have proliferated in the form of isolated and gated settlements, promoting spatial fragmentation (Cruz-Muñoz, 2021). Although these were initially developed as "country clubs" intended for weekend residence, they were eventually consolidated as gated communities for permanent residence (Pírez, 2016). In fact, the predominant typology within the Metropolitan Region of Buenos Aires -in the year 2000- was the private neighborhood, constituting 57% of the total urbanizations. These are mainly located in the north of the peri-urban area (J. Frediani, 2010). This model of occupation has also been identified in other cities such as Mar de Plata (Daga et al., 2015), Santiago de Chile, where they are recognized as large fenced cities (Hidalgo et al., 2007) or Mexico City, where -in its northern periphery- there are massive gated complexes in zones completely isolated from the urban area (Cruz-Muñoz, 2021). These two contrasting worlds exist side by side in Latin American peri-urban territories (Goytia et al., 2023). Thus, cities continue expanding under a situation of extreme inequality and high levels of social segregation (Inostroza, 2017) and situations of micro-fragmentation are identified, where "*a street, or a wall, can separate a high-level gated community from a precarious popular settlement*" (Pírez, 2016, p.112).

Intensive loss of agricultural plots

Urban growth on productive land would also seem to be a common pattern in the cities of the region. Although there are fewer specific studies in this regard, some authors have recognized this problem as one of the negative impacts of contemporary peri-urbanization. For example, in the case of Mexico City, Cruz-Muñoz & Isunza (2017) identified that agricultural producers that are located in the urban proximities (increasingly impoverished in scenarios where rural life has become less profitable) have started selling large lots of productive land to real estate companies for the construction of large housing complexes. And despite recognizing the importance of agri-food systems in peri-urban areas for the sustainability of the city, real estate projects continue to expand on the most important reserves of agricultural land (Bernal & Orcid, 2021; Méndez-Lemus et al., 2017; Ringuelet, 2008). The latter affects not only productive land but also the agricultural livelihoods (*ejidos*) of local residents. In fact, the Mexican territory has over more than 30,000 community-based land tenure, mainly ejidos, which are under particular danger because urbanization (Méndez-Lemus et al., 2017).

A similar problem has been identified for the city of Buenos Aires where urban expansion is consuming productive land, compromising the maintenance of land productivity that supports local horticulture and supplies a good part of the city's fruit and vegetable market (Fernández, 2016). This, in turn, expands the agricultural frontier that -in search of new productive lands- consumes new natural soils (Barsky, 2005). In the case of the city of Cuenca, the IDB (2015) identified that the condominiums that -just like in Quito- are built under the horizontal property regime have favored the legal path to lot subdivision in rural areas. In the city of Santiago de Chile, legal tools have also been promoted to facilitate the division of agricultural land. In particular, the Decree Law 3,516 that promoted *"parcelas de agrado"* have allowed the subdivision of at least 156.251 agricultural properties in scenarios of high speculation (Hidalgo et al., 2007).

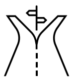
Reduction and fragmentation of natural areas

The diffuse peri-urbanization in the cities of the region has also hindered a coordinated relationship between natural areas and new areas of expansion, to the detriment of spaces of ecological value (Terraza et al., 2016). In the case of Bogotá, for example, Bernal & Orcid (2021) affirm that urban growth has advanced directed towards areas of ecological importance, causing profound environmental damage in mountainous areas, wetlands and "*madreviejas*". The study of Ramírez (2009) particularly recognizes eight periurban areas in Bogotá where there is a complex web of interactions between new uses and preexisting natural resources, that have brought major environmental conflicts. Likewise, Neira Acosta (2016) affirms that this excessive growth of the city of Bogotá has significantly decreased areas of pasture, stubble and forests in percentages equivalent to those of the increase in urban area.

In the case of Buenos Aires, nature has also been subordinated in scenarios of intense urban expansion. Lands with environmental restrictions, especially wetlands, have been used for the construction of large projects that have altered natural conditions, water flows, and aquifer recharges (Pírez, 2016). Particularly, in the periurban areas of Buenos Aires, fragments of areas of great natural value have been identified, especially in the deltaic-pampas ecotone, where grasslands and riverside jungle can be observed. They provide important ecological functions such as biodiversity refuge, water cycling, hydrological regulation, and nutrient recycling. However, they are currently threatened by the trend of land use change towards low density urbanization (Fernández, 2016). Likewise, Bernal & Orcid (2021) recognize how in Mexico City the effects of urbanization in areas of ecological importance have been deepened in the last years. Finally, in the case of Mar de Plata, along with the clear substitution of natural ecosystems and subsequent loss of biodiversity, soil negative effects have been identified due to erosion and contamination from fertilizers (Daga et al., 2015; Zulaica et al., 2012).

8.1.2 Are the same drivers responsible of the patterns and dynamics observed?

In the following paragraphs we discuss on the drivers that are triggering or intensifying urban expansion and that were found common in several Latin-American cities.



Road Infrastructure

A first common driver, which is mentioned in 12 of 34 articles, is transportation infrastructure which has shown playing a central role in landscape transformation in several cities within the region. For example, in the case of Buenos Aires, the opening of new highways has shown to encourage the expansion of a new residential suburbs. This peripheral expansion has been designed mainly for middle and high income groups with access to private vehicles. In fact, these complexes are particularly located over the large highways in the peri-urban area of Greater Buenos Aires (Fernández, 2016; ONU-Habitat, 2012; Pírez, 2016). As an empirical example, Frediani (2010) affirms that the construction of gated communities in the southern area of the city has been induced by the construction of the *Buenos Aires-La Plata* highway and the expansion of *Ruta 2*. Likewise, the expansion of Ciudad de Plata has advanced mainly towards the coastal sector and along the most important road communication axes (Daga et al., 2015; Zulaica et al., 2012). In Bogotá, the expansion of the airport and the construction of perimeter highways have increased the expansion of the city (Ramírez, 2009), just like in the MDQ. In other Ecuadorian city, Cuenca, satellite images show that urban sprawl is following clearly the road network (BID, 2015). Finally, Cáceres Seguel (2015) affirms that periurban expansion in Santiago de Chile is associated with the new mobility conditions generated from the development of private highways such as *Autopista del Sol, Radial Nor-Oriente, or Costanera Norte.* He affirms that "*the binomial relation car-road has definitively freed the inhabitant from searching urban density as a fundamental criterion to define his relationship with the city.*" In this sense, in the study of Inostroza et al. (2013) -developed for 10 Latin-American cities-, higher levels of dispersion were correlated with higher motorization rates. The authors affirm that "*vehicles availability is playing an important role in the sprawling trends which Latin American cities are facing*".

Pre-existing settlements

Regarding pre-existing settlements outside the urban limit and its connection with urban expansion, in the ONU-Habitat (2012) document --that analyzes the regional urban sprawl state-- it is mentioned how large cities tend to physically absorb other population settlements generating a process of conurbation. In the case of Sao Paulo, Cruz-Muñoz (2021) identifies these external settlements as elements that importantly affect the compactness index of the city. Contrasting, the study of Cáceres Seguel (2015) about peri-urbanization in Santiago de Chile, affirms that in these territories new centralities are emerging in isolation from the pre-existing traditional peri-urban nuclei. In fact, the author affirms that new isolated and autonomous residential nuclei are being formed, which instead of seeking proximity to historic peri-urban localities (*Colina* or *Lampa*) seek better accessibility to the main metropolis through highways. This last case differs greatly from the MDQ case, where findings have shown that there is also a key process of centrifugal growth from these traditional settlements. However, the Santiago case once again confirms that road infrastructures not only transform mobility conditions but also alter the very DNA of the metropolis.

Informal land occupation

Illegal/informal land occupation has proven to be another of the main drivers of expansion beyond urban limits and is a recurring phenomenon in Latin America. In fact, it is the most mentioned in the literature analyzed for this section in 13 articles out of

34. Inostroza (2017) affirms that *"Informality has been called a key driver of metropolitan expansion, especially in Latin America*" (p.268). And this form of urban growth is not minor, according to ONU Habitat (2003), approximately 14% of Latin American population lives in informal conditions. Examples of how illegal occupation defines peri-urban growth can be identified in several cities in the region. For example, the city of Lima is a paradigm of informal settlements in Latin America, translated into massive peripheral expansion (Muñoz & Ramos, 2022). In 2004, the *"barriadas"* (Lima's informal settlements) reached 43.4% of the metropolitan population, that was more than 3.5 million people (Ioris, 2012). Currently, the majority these settlements are located in peripheral areas (Sakay et al., 2011). In Buenos Aires, the invasion of vacant land has been a dominant trend in the formation of new peripheral neighborhoods. In many cases, these are located on environmentally unsuitable land, mainly in in the interstices occupied by river basins (Fernández, 2016). Currently, more than 1800 informal neighborhoods have been identified in Buenos Aires (Goytia et al., 2023). Furthermore, informality is the main form of access to land in the metropolitan region of Buenos Aires, where of every 100 new inhabitants, 60 are located in informal settlements (J. Frediani, 2010). In Bogotá, spontaneous settlements are also observed in areas that were not planned for residential uses but that are being consolidated by purchase processes from land traffickers, or by land invasions. These settlements, generally peripheral, lack public services or road infrastructure. They are also usually in areas of high environmental risk, especially landslides (Bernal & Orcid, 2021; Ramírez, 2009). In Mexico City, the irregular occupation of land and the self-construction of homes is a notable aspect in its peri-urban area, which presents a marked deficit in public services (Adrián G Aguilar & López, 2016; Pradilla Cobos, 2015). Irregular settlements in the city of Montevideo also show a marked location tendency over periurban areas (ONU-Habitat, 2012).

Land Price

Another driver that is mentioned in at least eight studies, is land price. De Mattos (2010) affirms that, in most regional cases, land prince tends to decrease as distance from core areas increases (especially in certain directions) while continuing to rise in higher income central areas. This has caused, on the one hand, a progressive emptying of the central areas and, on the other, an expansion towards the more economically accessible peripheries. This can be clearly observed in the case of the Metropolitan Zone of the Valley of Mexico where the population is expelled from the central areas due to real estate reproduction and the correlative rise in land prices and property taxes (Pradilla Cobos, 2015). ONU-Habitat (2012) recognizes that the price of land tends to disperse the expansion of the city, since land ready for use remains vacant while waiting for a better price, generating a false scarcity of land. This results in the need to expand the city to ever more remote areas. In Cuenca, for example, the increase in the cost of urban land prices has resulted in a scarce supply of affordable lots for the low/middle income population and has caused an expansion of the city towards the cheaper and farer periphery (BID, 2015). Ioris (2012) affirms that in the case of Lima, due to the limited number of affordable housings in the central city, the most vulnerable groups move toward an "illegal city" located around the central city. On another hand, in the case of Buenos Aires it can be seen that the low price of peripheral land has allowed high profitability in commercial developments. The latter have occupied land even beyond seventy kilometers from the historic center, generating high profitability (Pírez, 2016).

Real estate market

With the same weight as road infrastructures (12 of 34 articles), the influence of the real-estate market appears as one of the drivers of urban expansion. ONU-Habitat (2012) sustains that, within the Latin-American region, real estate development mechanisms have largely determined the location and characteristics of urban expansions. In this sense, the speculation of real estate companies -in their search for higher profits- have incorporated new land into the city with their construction projects. Thus, the territorial structuring of the peripheries is directly linked to the logic of the real-estate market and the maximization of profits. In other words, the peripheral expansion is largely explained by real estate developments. This has happened with greater intensity since the entry of neoliberal policies, where the majority of Latin American nations modified their urban development and management policies towards a strongly entrepreneurial vision (Cruz-Muñoz, 2021; C. De Mattos, 2010). Silva Lovera (2015), regarding this has stated that "*urban sprawl is understood as an outcome of neoliberal policies, where the planning process follows market trends*". There are multiple examples of the influence of the real estate sector in various cities in the region. In Buenos Aires, for example, Bernal & Orcid (2021) affirm that private sector real estate projects became a fundamental factor for the spatial expansion of the city, mainly under the closed neighborhood model. In a complementary way, Pírez (2016) affirms that, in Buenos Aires, the tendency to strengthen the mercantile and neoliberal processes, consolidated suburbanization. Thus, any urbanization process has been subordinated to the decisions of private actors regarding the new land incorporation or the implementation of infrastructures. Santiago de Chile is another emblematic case of real-estate market power in urban expansion. Hidalgo et al. (2007) affirmed that metropolitan expansion trends are mainly marked by the design of large real estate projects. Thus, the image of the Santiago peri-urban area as a business opportunity explains the purchase of agricultural lots by real estate groups, who -with absolute freedom- redefine functional contents of these territories (Cáceres Seguel, 2015). Likewise, in the city of Manizales, Nates Cruz (2008) affirms that the purchase of rural land by real estate companies has been the first local trigger of the phenomenon of peri-urban expansion. In the case of Bogotá, Bernal & Orcid (2021) affirm that the production of peripheries operates under a real-estate market logic, where private promoters act -with the state entities approval- to promote formal urban expansion. Finally, in Mexico City, evidence has shown that urban sprawl tends to expand into areas relevant to the profitability of real estate projects and all this under the consent of a weakened government (Cruz-Muñoz & Isunza, 2017; Pradilla Cobos, 2015).

Weak urban management

One last driver that has been identified within the cities of the region, and which is strongly linked to the last point, is weak urban management and legal gaps. ONU-Habitat (2012) recognizes that in Latin America developers have had sufficient legal and political power to obtain land use authorizations according to their discretion. And, on the other hand, legal frameworks for planning are usually very weak or lack the political will to implement them. This opens a huge window for urban expansion that responds to private and isolated interests, seeking their own profit. Several authors have identified these legal gaps and inconsistencies in the land use planning instruments of cities within the region. A first example is the case of Montevideo, where its Departmental Guidelines have proven to be general and incongruous, making it impossible to achieve an adequate development in interstitial territories. Specifically, under this planning tool and due to pressure from certain groups thousands of hectares of productive rural land have been classified with the category "potentially transformable" into urban or suburban land. This has caused great speculation regarding its real estate value and has generated subdivisions and isolated and disjointed urbanizations on rural land (Ligrone Fernández, 2016). Another example is the change in article 55 of the General Urban Planning and Construction Law of the city of Santiago de Chile in 2003, which allowed the construction of housing under 1,000 UF (social housing range) in areas outside the urban limit. This has triggered new patterns of urban expansion over rural area (Cáceres Seguel, 2015). Likewise, the so-called “Priority Urban Development Areas” (AUDP) were promoted for ther rural localities of Colina, Lampa and Batuco as a legal instrument to accommodate single-family housing projects for the middle class. These areas have welcomed residents from Santiago and surely have played an urban expander role (Hidalgo et al., 2007). Finally, in the city of Cuenca -as in the case of the MDQ- the "horizontal property" legal form has become a key gap that favors subdivisions in essentially rural lots (BID, 2015).

8.1.3 What particularities have been identified in these Latin-American cities that do not coincide with the case of the MDQ?

All the topics discussed in the previous paragraphs are fully consistent with the findings in the MDQ. However, some relevant issues have been identified for other cities that are not evident in the MDQ case. An issue that has been mentioned recurrently in various cities, is the influence of social housing projects as a significant element in periurban expansion. In fact, Inostroza (2017) affirms that social housing has been a key engine of formal urban expansion at the edge of the Latin American cities. For example, in Mexico City, subsidized social housing mega-projects are located mainly in the cheapest peripheries, especially the most distant, poorly connected, and poorly served (ONU-Habitat, 2012; Pradilla Cobos, 2015). Similarly, the price of land in Santiago has defined the periurbanization process of social housing (Hidalgo et al., 2007). In fact, during 2001, 85% of the lots purchased by the regional government of Santiago to build social projects were concentrated in three peri-urban communes (Cáceres Seguel, 2015). In the case of Bogotá, the National Housing Fund and the Popular Housing Fund promoted various citadels for the expansion of the city on land with a rural vocation. In this context, the allocation of subsidies has had a constant increase between 2000 and 2013, incrementing processes of periurbanization (Bernal & Orcid, 2021). Although in the case of the MDQ, social housing projects have been promoted in the periphery, they do not seem to have the same intensity as in other cities. In fact, they did not appear in any of the sample polygons analyzed for this study.

On the other hand, regarding informal housing as regional condition, the Chilean case appears an exception due to its long-standing policy of subsidies and eradication of slums. This policy occurred in an aggressive capitalist context where housing is one more market niche supported by the State and has been highly criticized (Silva Lovera, 2015). However, there is overall agreement that informality is drastically lower in Chile than in the rest of Latin America (Inostroza, 2017). Something particular in the case of Buenos Aires is that the greatest demographic weight of urban expansion has been identified on the railway axes (Fernández, 2016). This is unique and not applicable for other cities, such as the MDQ, which do not have a working commuter rail system. Another particular issue mentioned in the case of Bogotá, is how the employment subcenters have been determinant in the intensity level of urban expansion (Lozano et al., 2021)

Finally, an aspect that is mentioned in a general way for the cities of the region and that, due to the methodological nature of this study, could not be identified --but that is worth mentioning-- is the preference of families as a driver of urban growth. On the one hand, the average income increase has tended to rise the capacity of residential area per family, and this has generated a drop in urban density. On the other hand, the strong preference for single-family housing, where possible equipped with green spaces, would seem to be one of the factors with the greatest incidence in peri-urbanization. One last factor has been the change in the urban family composition, which tends to form smaller nuclei, influencing an increase in demand for new types of housing, mainly single-family homes. Consequently, it can be affirmed that the set of strategies and locational decisions of the families can be considered as one of the central components of the processes of urban expansion. In fact, as Carlos De Mattos (2010) affirms, "*peri-urbanization is above all the result of the voluntary choice of a multitude of actors who decide to settle outside the morphological agglomerations*" (p.261).

8.1.4 Final remarks on the Latin-American urbanization process within the global urban condition.

In a world that tends to globalization, it is worth asking if focusing on a specific region is useful or pertinent. In this sense, it is necessary to recognize that although the globalization process generates global networks that influence urban structures, it has also been observed that it also has the capacity to accentuate local and/or regional particularities (Borsdorf, 2003).

It is a fact that economic restructuring, globalization and the increase in information and communication technologies are transforming cities on a global scale. As mentioned in the introductory chapter, the economic restructuring strongly established in the 1990s in all the countries of the region, have generated a morphological and landscape functional reorganization of Latin-American cities. These transformations resemble those that are taking place in other regions of the world, specifically a diffuse urban sprawl, with unclear boundaries, polycentric and increasingly ubiquitous (Aguilár & Ward, 2003; Borsdorf, 2003; Cruz-Muñoz, 2021; C. De Mattos, 2010; Newman & Kenworthy, 1996; Perahia, 2009; Soja, 2008). Based on the MDQ findings and the regional comparison, we can affirm that many of the factors that have influenced in this territorial metamorphosis can only be explained in a context that respond to a dynamic of globalized neoliberal economic accumulation. According to De Mattos (2010) *"the explosive intensification of connectivity, mobility and the consequent compression of the space-time relationship, the configuration and continuous expansion of a world space for accumulation... ...are playing a decisive role in this evolution towards a new urban form"* (p. 276). And as a globalized phenomenon, it is applicable to all Latin-American cities despite their singularities.

Then, what could be the particularities or socio-spatial specificities of the Latin-America cities in a globalized reality? After this comparative exploration socio-economic inequality and segregation would seem to be a common and prominent attribute among the cities of the region. In fact, according to data from the Economic Commission for Latin America and the Caribbean (ECLAC), Latin America is the most unequal region on the planet. This condition becomes palpable in a spatial dimension, where processes of micro and macro segregation can be observed in their urban and periurban territories.

On the other hand, high rates of informality also characterize Latin American cities. In this sense, and although informality may seem like a negative attribute, according to Arce (2016) these high rates of self-construction (the informal city) and social struggle (for the right to the city) have made the inhabitants of Latin American cities much more involved in "making the city". These perspectives could help reveal specific socio-spatial conditions and raise awareness about main the urban challenges but also about the cities' opportunities and its potential, as well as the particular cultural heritage of each region. The identification of these specificities is surely the most solid way to achieve management and planning appropriate to each reality and thus build more sustainable and equitable cities.

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ANNEXES

APPENDIX A: List of articles analyzed to calculate the CFI.

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