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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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others (Czekajlo et al., 2021; Estoque & Murayama, 2015; Vergés et al., 2008). Poorly planned urban expansion can also bring economic and social impacts that affect quality of life (Estoque & Murayama, 2015). Some of these landscape changes are facilitated by territorial and administrative management decisions, while others are shaped by specific social, political and economic forces that dictate land use and prices (Vergés et al., 2008).

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.

1. 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) (Municipio del Distrito Metropolitano de Quito [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

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)

[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.

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 (MDMQ, 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 (MDMQ, 2018).

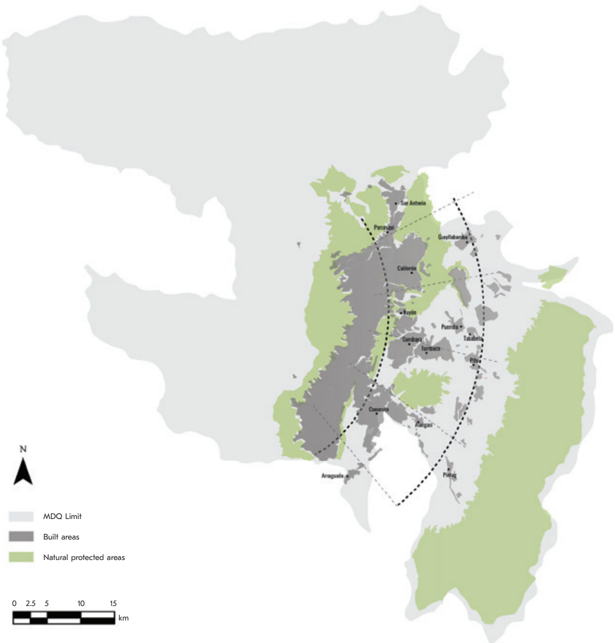


Figure 2. Metropolitan District of Quito grow tendency over the peri-urban eastern valleys (source: by the authors)

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 (MDMQ, 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.

1.2. 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 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 m^2) satellite images

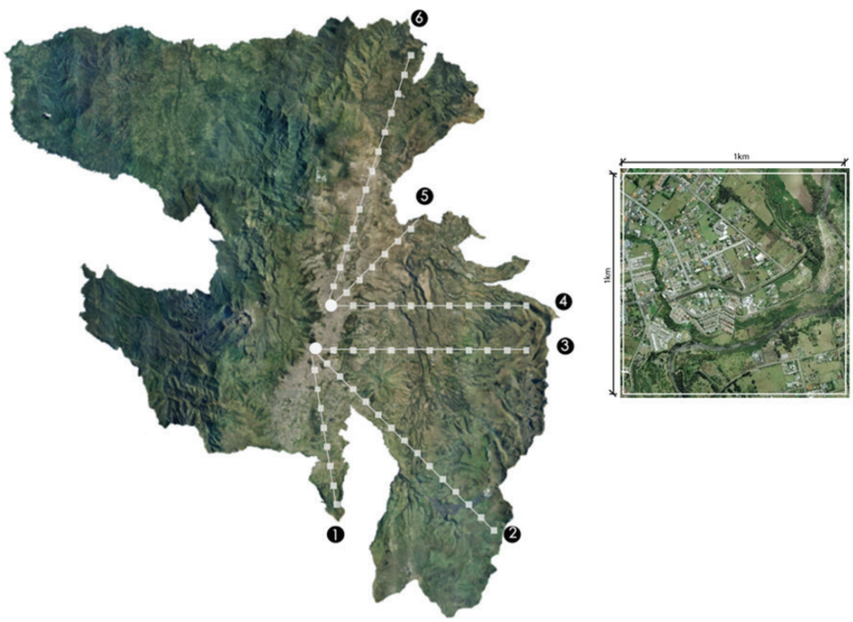


Figure 3. Definition of transects and sample size (source: by the authors)

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

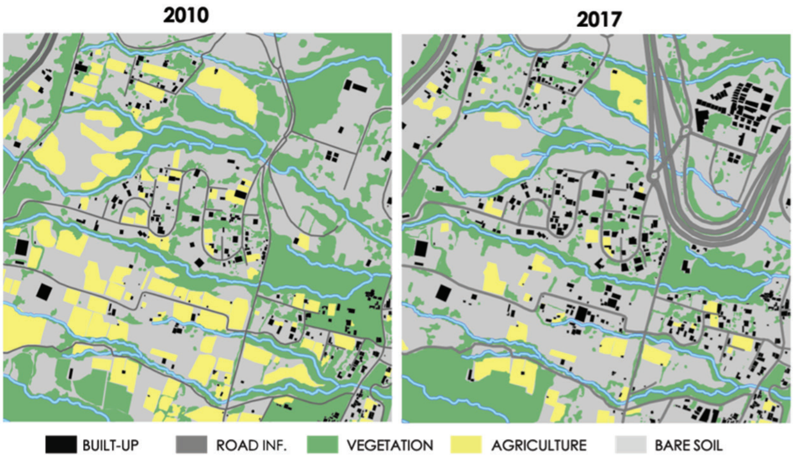


Figure 4. Example of one sample LULC identification for years 2010 and 2017 (source: by the authors)

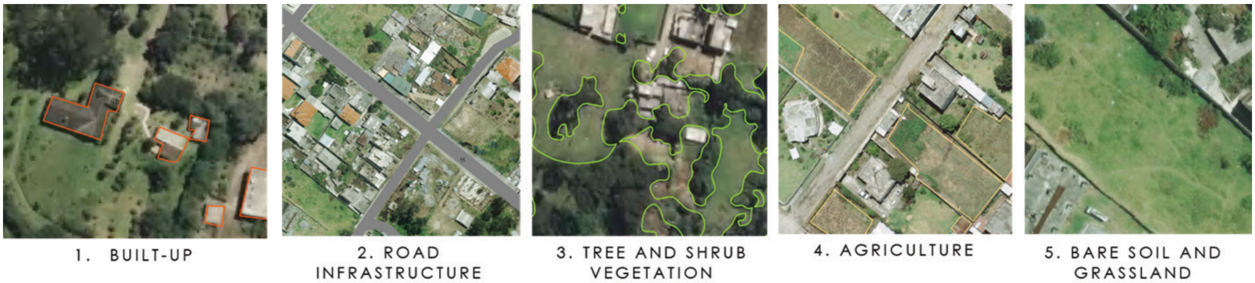


Figure 5. Visual identification of Land Use Land Covers (source: by the authors)

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).

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),

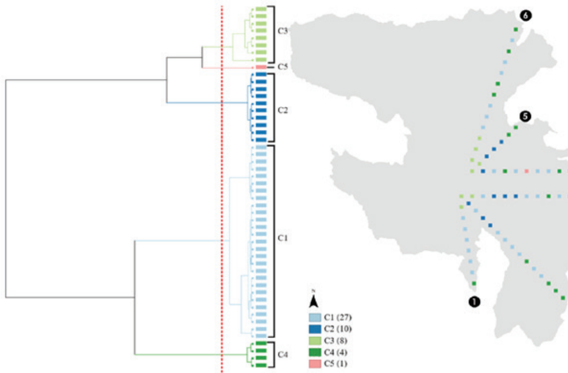


Figure 6. Cluster classification that defines urban, periurban, rurban and rural samples in the MDQ (source: Ortiz-Báez et al., 2021)

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 (Ortiz Báez 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.

1.4. Transition matrix and landscape stability

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 (Table 1).

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).

2. Results

2.1. 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%.

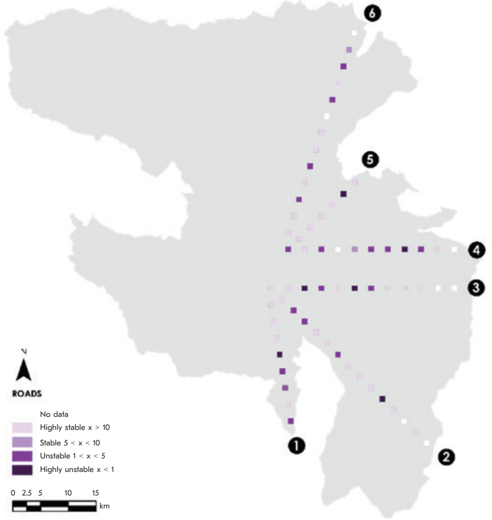
On the other hand, the C3 cluster – that corresponds to the urban area – present a higher stability in the coverages of Built-up (100%) and Road Infrastructure (75%), when adding the S and HS ranges. However, when observing the vegetation and agriculture LULCs, they present high values of instability 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 1. Transition matrix (source: by the authors)

		Time 2				
		LULC 1	LULC 2	LULC 3	LULC 4	LULC n
Time 1	LULC 1	L_{11}	L_{21}	L_{21}	L_{21}	L_{21}
	LULC 2	L_{21}	L_{22}	L_{21}	L_{21}	L_{21}
	LULC 3	L_{21}	L_{21}	L_{33}	L_{21}	L_{21}
	LULC 4	L_{21}	L_{21}	L_{21}	L_{44}	L_{21}
	LULC n	L_{21}	L_{21}	L_{21}	L_{21}	L_{nn}

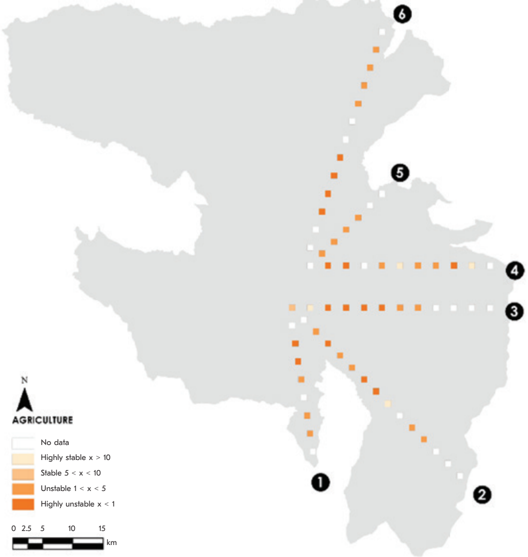
[4] In landscape analysis, composition refers to the number of patch types or LULCs in the landscape, their area and their definition (Bogaert et al., 2014).

a)



b)

c)



d)

Figure 7. Stability index by independent LULC: a) Built-up, b) Road infrastructure, c) Vegetation, and d) Agriculture (source: by the authors)

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).

2.2. 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.

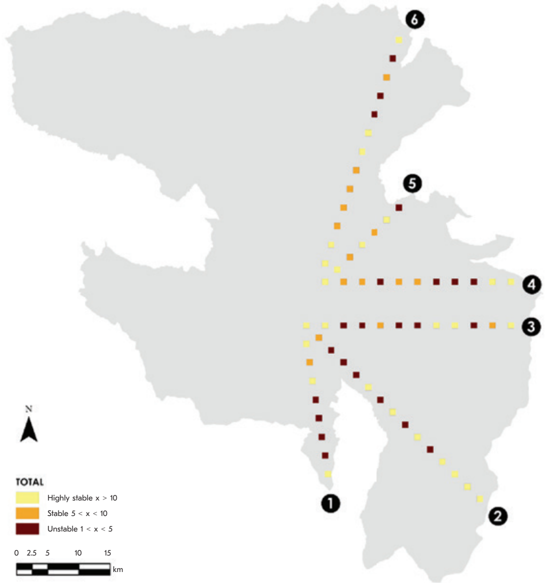


Figure 8. Total landscape stability index (source: by the authors)

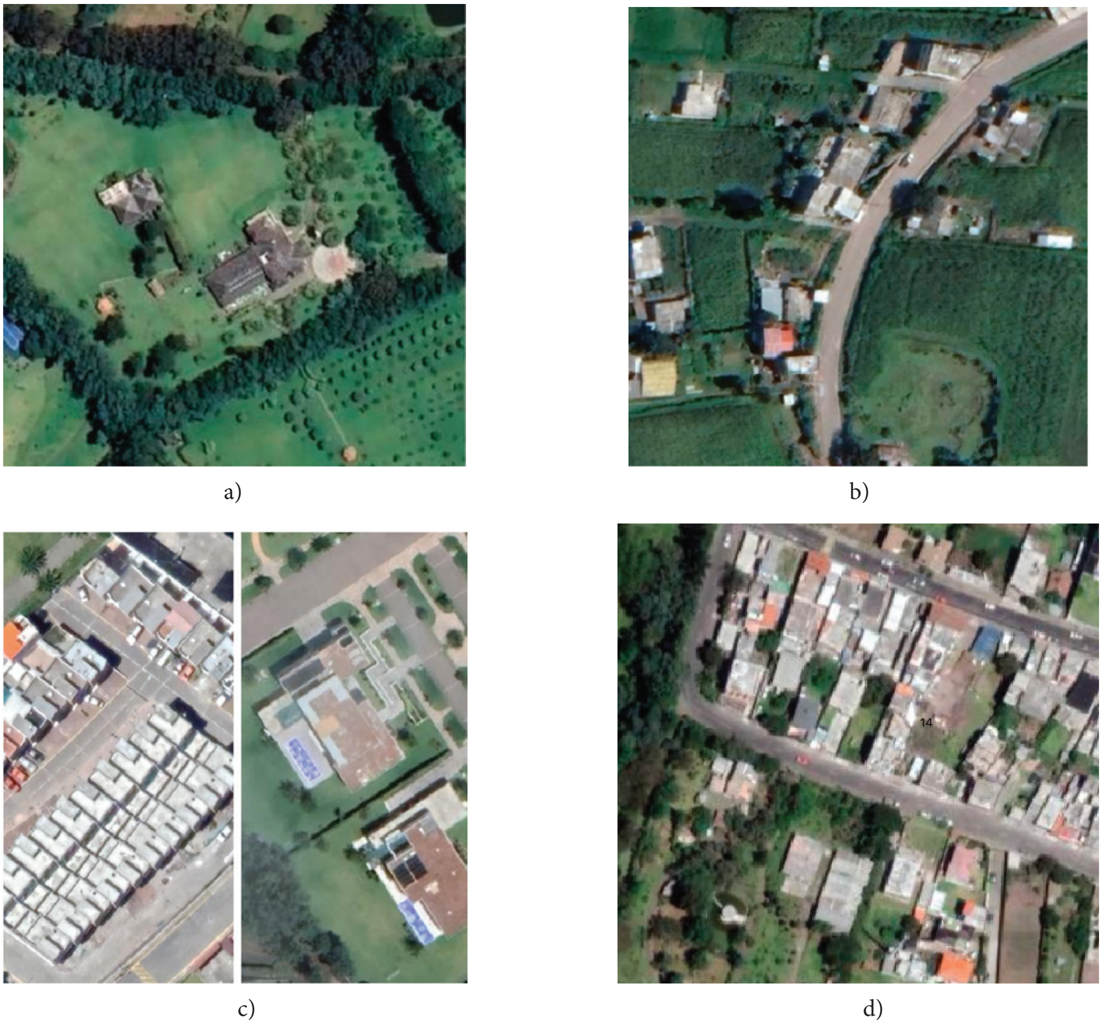


Figure 9. Urbanization patterns typologies: a) Large parcels with isolated buildings surrounded by green area. Residence in Yaruquí. Gradient 4, b) Smaller parcels with low-density buildings. Residence in Amaguaña. Gradient 1, c) Gated communities target middle- (left – Residences in Armenia, Gradient 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, 2017)

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.

2.3. 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

Conclusions and discussion

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; Ortiz Báez 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; Ortiz Báez 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 (MDMQ, 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 (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, 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 DMQ (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 policy-making around sustainable land use.

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Author contributions

POB conceived the study and was responsible for the design and development of the data analysis. POB and MJF were responsible for data collection and analysis. POB and MJF were responsible for data interpretation. POB and MJF wrote the first draft of the article. JB was responsible of the theoretical review.

Disclosure statement

Authors declare don't have any competing financial, professional, or personal interests from other parties.

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Notations

Abbreviations

LULC – Land Use-Land Covers;

MDQ – Metropolitan District of Quito.