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LAND COVER CHANGES IN COFFEE CULTURAL LANDSCAPES OF PEREIRA (COLOMBIA) BETWEEN 1997 AND 2014

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ABSTRACT. Understanding how and what land cover changes and transitions have occurred in a territory is crucial to planning and managing high-demand surfaces. At the landscape level, the challenge is determining the allocation and management of various land cover options. Therefore, for natural resources planning and management, a study characterizing and analysing the territory of interest should be included. This work aimed to analyse the changes and land cover patterns in the city of Pereira, Colombia, within the framework of the Colombian Coffee Cultural Landscape. The evaluated period was between 1997 and 2014, and a Geographic Information System, ENVI 4.8 programme and QGIS programme were used for multitemporal analysis. To describe the land cover transitions, two temporal moments were analysed with Landsat satellite images: one moment was for the year 1997, which was taken in August (Landsat 5), and the other moment was for the year 2014, which was taken in July (Landsat 8). At level 1 of CORINE (Coordination of information on the environment), the areas of land cover corresponding to agricultural areas, forests and semi-natural areas decreased most in the analysis period, while artificial surfaces increased. At level 3, the cover with the greatest decrease in territory was coffee crops, which showed a negative annual loss rate of -3.97%, followed by permanent crops (-2.67%). The continuous and discontinuous urban fabric showed the greatest growth with a positive annual rate of 4.14%. In conclusion, the land cover that lost the most territory was coffee crop, mainly due to political-economic factors, such as the dissolution of the International Coffee Agreement and the National Federation of Coffee Growers that discouraged coffee cultivation and permanent crops. Likewise, sociocultural factors, such as smallholder farmers have guided the changes in land cover and have stimulated productive styles to adapt and remain, increasing heterogeneous agricultural areas.

Cambios en la cubierta del suelo en los paisajes culturales del café (Colombia) entre 1997 y 2014

RESUMEN. Comprender cómo y qué cambios y transiciones de las cubiertas del suelo se han dado en un territorio es clave para la planificación y gestión de las superficies con alta demanda. A nivel del paisaje, el desafío es cómo decidir la asignación y gestión de opciones de coberturas del terreno. Por lo tanto, para la planificación y manejo de los recursos naturales se debe incluir un estudio de caracterización y análisis del territorio. Este trabajo tiene como objetivo analizar los cambios y los patrones de cubierta del suelo en la ciudad de Pereira, Colombia, en el marco del Paisaje Cultural Cafetero de Colombia. El período evaluado se estableció entre 1997 y 2014, se trabajó con Sistemas de Información Geográfica y se emplearon los programas ENVI 4.8 y QGIS para el análisis multitemporal. Para describir las transiciones de coberturas, se propuso un análisis en dos momentos con imágenes del satélite Landsat, una para el año 1997 tomada en agosto (Landsat 5) y la otra para el año 2014 del mes de Julio (Landsat 8). Se encontró en el primer nivel de Corine que las cubiertas de territorios agrícolas, bosques y áreas seminaturales fueron las áreas que porcentualmente más han disminuido en el período de análisis mientras que han aumentado las zonas artificales; también se halló para el tercer nivel de Corine que la cubierta que más territorio ha cedido fueron los cultivos de café con una tasa negativa por año de -3,97%, seguido de los cultivos permanentes (-2,67%); mientras que, el tejido urbano continuo y discontinuo presentó el mayor crecimiento con una tasa positiva por año de 4,14%. En conclusión, la cubierta del suelo que más perdió territorio fue el cultivo de café, principalmente por factores político-económicos, como la disolución del Convenio Internacional del Café y la Federación Nacional de Cafeteros que desestimularon el cultivo de café y los cultivos permanentes. Así mismo, factores socioculturales, como el minifundio, han orientado los cambios en las cubiertas del suelo y han estimulado los estilos productivos para adaptarse y permanecer, aumentando las áreas agrícolas heterogéneas.

Keywords: Multitemporal analysis, Landsat, land cover transition, rural-urban change.

Palabras claves: Análisis multitemporal, Landsat, transición de coberturas, cambio rural-urbano.

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1. Introduction

In the processes related to human occupation of the territory, there are several changes that require the understanding and research about the elements that motivate local, regional and global changes. This approach requires information integration from social, natural and geographic sciences (Rindfuss *et al.,* 2004; Turner *et al.,* 2007), to understand the factors that influence land covers, site diversity and interpret dramatic changes in the transformation of land use, mainly impacting rural areas, such as cultivated land is diminishing (Boudet *et al.,* 2020; Chen *et al.,* 2020; D'Amour *et al.,* 2017; Xia *et al.,* 2020), which lead to the loss of food security of human communities at local scales. This reduction in land for agricultural production affects the long-term economic development, food security and ecological security of regions, as well as the livelihoods of farmers and rural residents' wellbeing (Xia *et al*., 2020).

The rapid expansion of cities is showing and it is also affecting the biodiversity of ecosystems and reducing the areas providing high-value ecosystem services (Narducci *et al.,* 2019). Landscape changes over time reflect the management of natural resources, cultural practices (van der Ploeg and Ventura, 2014) and priorities in land use planning (Verburg *et al.,* 2009). Classifying the terrain allows us to assess and identify changes in the use and cover of inhabited spaces and to understand the interactions and relationships with communities in that territory. This spatial social construction enables assessment of land use planning scenarios to integrate the environmental component in the decision-making process for plans and programmes, which can have significant effects on the environment and communities (Loiseau *et al.,* 2012; Sanhouse-Garcia *et al.,* 2017; Ashiagbor *et al.,* 2020; Chen *et al.,* 2020).

Modification of the landscape is a product of agrarian activity and the physiographic transformations derived from settlement types (Rivera, 2014, Xia *et al.,* 2020) and national or regional policies. A comparative analysis study that shows the state of land management due to anthropogenic changes is necessary (Zúñiga *et al.,* 2003; Carvajal, *et al.,* 2009; Murillo-López, 2010; Sanhouse-Garcia *et al.,* 2017), accompanied by multitemporal analyses to identify the changes in land cover and uses

(Turner II *et al.,* 2007; Napieralski *et al.,* 2013), to provide primary source of data that represents the terrain and spatial analyses.

In the processes of human occupation and transformation of the landscape, territories have been configured that are the result of adaptation processes, which developed from the introduction of the great richness and conservation of coffee variety seeds, biodiversity and the provision of ecosystem services, located in landscapes in the north of the Andes mountain range, with regions of medium mountains (1000 to 1900 m.a.s.l.) and with an average climate (precipitation between 1200 and 2300 mm, temperature between 17 and 24°C). The regions with these characteristics were denominated Coffee Cultural Landscape of Colombia (CCL), where the culture and economy were developed around the coffee crop in small plots (0.5-3 ha), in which the distances between plants and the combination with other species of trees created symmetrical figures with multiple forms in the vegetation arrangements. The plots are part of small farms (average 5.3 ha) in which management practices, decision making and administration are carried out by the family, with its members educated and employed in a traditional way in daily tasks and learning about the environment, which is preserved in memory and inherited from generation to generation (Fernandez *et al.,* 2010; UNESCO, 2021; PCC, 2021).

This panorama of the Coffee Cultural Landscape of Colombia led to its declaration in 2011 as a World Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO), as it is considered as a scenario that should be prioritized for the preservation of the tangible (type of architecture in housing and crops, introduction of biodiversity-friendly systems and benefits in the generation of ecosystem services) (Ruiz-Cobo *et al.,* 2010; Botero-Arango *et al.,* 2020, Rojas-Cano *et al.,* 2021) and the intangible (culture, rootedness, sense of place, heritage and identity) and, because of the risk in the destruction of its unique characteristics, in which man with his ingenuity has managed to modify the landscapes.

In Colombia, the area occupied by rural areas is distributed among forests and semi-natural areas (56.7%), agricultural areas (38.6%), non-agricultural (2.2%) and other (includes non-agricultural infrastructure and other land uses) (2.5%) (DANE, 2016); and the management, administration and sustainable use of covers and land uses is not clearly incorporated into the issue of rural development; the territory occupied by rural areas is still unknown (cover, uses, variables, resources and distribution), and it is still unclear which uses generate greater pressure and how the dynamics of human activities have changed and fragmented the landscape. The CCL's richness is being transformed, which has been poorly studied for the change in land cover and land use caused by the introduction of agro-industrial systems of coffee, banana, avocado, pastures and the expansion of the urban frontier of the cities (Nieto *et al.,* 2016; Molina-Rico *et al.,* 2019). In the case of the department of Risaralda, the agricultural area went from 78.5% in 1970 to 50% in 2014 (DANE, 1970; DANE, 2016), with changes leading to the loss of land for agriculture and occupation of condominiums for human dwelling.

The above emphasizes the need to consider the territory as an important concept in policymaking (INCODER and Misión Rural, 2013) and the need for a multitemporal analysis that shows ground cover changes. Therefore, it is necessary to evaluate the consequences of urban expansion on farmland to determine possible areas of conflict, as well as strategies to create more sustainable forms of urban expansion and understand cultural landscapes as the results of long-term biological and social relationships (Lindholm and Ekblom, 2019). Therefore, we propose the following questions: (i) How have land covers changed between 1997 and 2014 in Pereira? and (ii) What were the main changes in the CCL of the city of Pereira? In addition, if the CCL is undergoing different changes, it is expected to find empirical evidence of how, and on what scale, these regions are responding to human-induced changes over time. To answer this question, it was necessary to approach it practically, using geospatial information at two moments in time (1997 and 2014); further, this work aimed at analysing the multitemporal changes in land cover and its transitions in the coffee cultural landscape of the municipality of Pereira.

2. Study area

The research was carried out between 2017 and 2018 in the city of Pereira, Colombia. The territory is located on the western slope of the central mountain range (three mountain ranges cross the Colombian territory from south to north). Pereira has an area of 607 km^2 and is located between 4º 43' 4.8" North and 75º 50' 38.4" West; and 4º 52' 15.6" North and 75º 36' 18" West in the central-western part of the country. The urban area has an average annual temperature of 21.6 °C, and the average annual precipitation is 2354.3 mm (IDEAM, 2014).

The study area is mountainous, so it presents a variety of climates and the elevation ranges between 900 and 5,200 m.a.s.l. (Fig. 1). The coffee cultural landscape (CCL) was classified into six zones, Pereira belongs to zone C with rural areas located in the central mountain range of the Andes and with an altitude that ranges for coffee cultivation between 1,500 and 1,900 m.a.s.l. Other crops such as corn, beans, plantain, and other subsistence products are grown in the landscape, but coffee is, of course, the dominant crop covering 57% of the total area of the coffee farms (Fernandez Retamoso *et al.,* 2010; PCC, 2021).

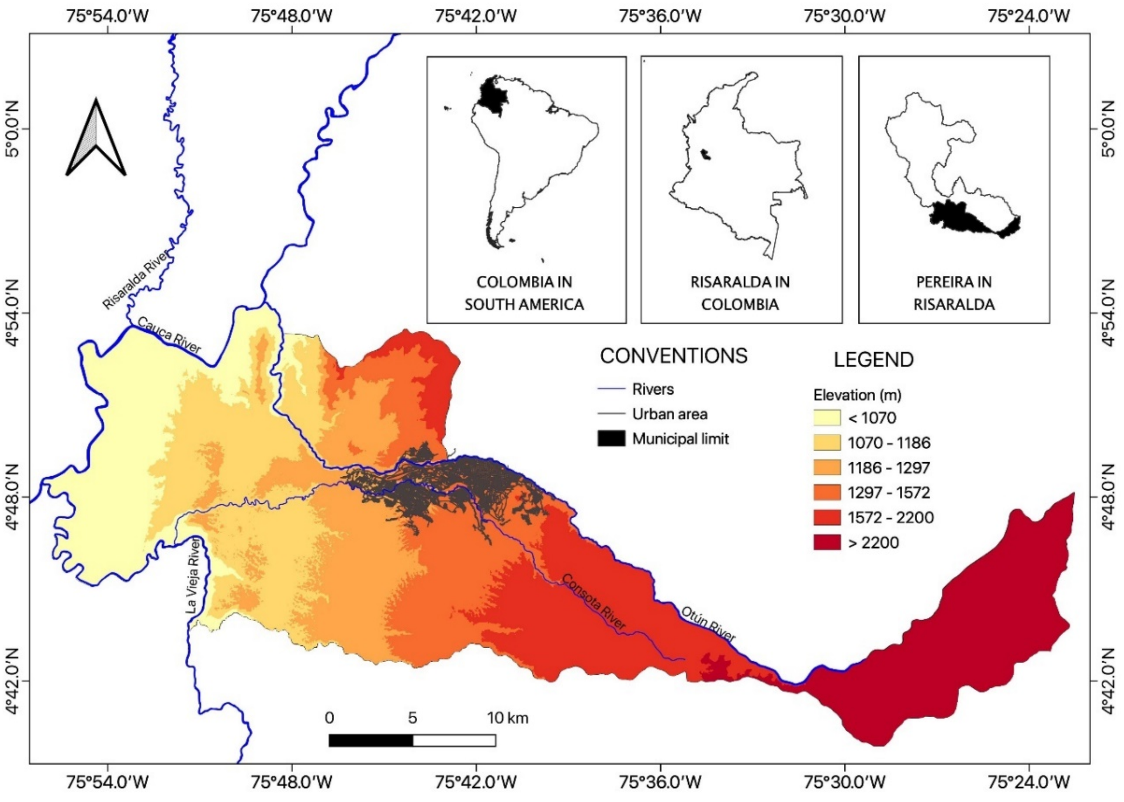

Figure 1. Municipality of Pereira showing elevational differences.

According to the 2018 census, Pereira has an approximate population of 467,269 inhabitants, of which 81,432 (17.4%) are inhabitants of the rural zone (DANE, 2019). Pereira has a history associated with agricultural production, from the pre-Columbian population of Quimbaya and the indigenous Zerrillos, who supported themselves through agriculture; by the mid-nineteenth century, the Cauca colonies built estates for the production of sugarcane and cocoa towards the flatter areas between Pereira and Cartago, while the colonies from Antioquia, Caldas and Tolima developed subsistence crops on the western slopes of the central mountain range between the Otún and Consota Rivers (Rivera, 2014).

Pereira emerged from two contradictory cultures, the grand hacienda with colonial identity and slavery towards the areas with lower slopes (between the *corregimiento* of Cerritos and Cartago) and the displaced landless peasants of Antioquia, Valle del Cauca, Tolima and Caldas, who settled with smallholdings in the steepest areas between the Consota and Otún Rivers. Currently, the type of farm in Pereira continues to have similar characteristics as those of the settlers in the early nineteenth century. According to the 2016-2019 Municipal Development Plan, the rural sector has been categorized into four zones, where the greatest presence of farms with areas between two and four hectares is highlighted. These farms are mainly located east of the city of Pereira in the territory between the Consota and Otún Rivers (smallholdings), while the western area of the municipality has fewer farms but with an average area of 25.9 ha. This territorial distribution shows permanence in the type of occupancy of the rural territory of Pereira (Table 1 and Fig. 1).

Table 1. Distribution characteristics by rural territory zone in Pereira.

Zone	*Veredas*	*Corregimientos*	Area of Zone (ha)	Farm (number)	Cover	Mean area per farm (ha)
1	38	La Florida, La Bella, Tribunas Corcega, eastern part of Arabia	4,617	2,264	Coffee crop (CC); heterogeneous agricultural areas (HAA); rotation crop (RC)	2.04
2	34	Morelia (not including Los Planes), Altagracia, la Estrella; La Palmilla and the western part of Arabia	8,642	2,187	CC; heterogeneous agricultural areas (HAA); permanent crop (PC)	3.95
3	24	Combia Alta and Combia Baja	4,967	1,368	CC; heterogeneous agricultural areas (HAA); permanent crop (PC)	3.63
4	10	Caimalito, Puerto Caldas, Cerritos and the Planes de Morelia	19,726	762	Permanent crop (PC); pasture (Ps)	25.89

Adapted from the Pereira City Council, 2016. Technical support document for the 2016-2019 Municipal Development Plan "Pereira, Capital del Eje" (*Pereira, Capital of the Axis*), Pereira. *Vereda and Corregimiento: it's political-administrative local level division*

3. Material and methods

3.1. Data (Landsat)

The Landsat satellite images were selected and downloaded from the server of the Earth Resources Observation and Science Center (EROS), United States Geological Survey (USGS); the search for available images included the study area and images that contained the least amount of interference (clouds and flaws) (https://earthexplorer.usgs.gov/). Two images were chosen: one image was for the year 1997, which was taken in August (Landsat 5), and the other image was for the year 2014, which was taken in July (Landsat 8) (Table 2). Since the years selected depended on the availability and quality of the satellite images, as well as avoiding interference by cloudiness, dry-season months were chosen for the study area.

Table 2. Characteristics of the Landsat images used in the supervised classification for the analysis period.

Date	**Time**	**Path/Row**	**Sensor**	**Spatial resolution of bands used (m)**
1997/8/21	14:50:36.921	009/057	LANDSAT 5	30
2014/7/19	15:18:48.190	009/057	LANDSAT 8	30

3.2. Methodological approach

The research aimed to analyse land cover transitions in the city of Pereira between 1997 and 2014 and answer the following questions: (i) How have land covers changed between 1997 and 2014 in Pereira? and (ii) What were the main changes in the CCL of the city of Pereira? The theorical approach was based on Rindfuss *et al.,* (2004), and we used remote sensing and addressed the CORINE land cover classification categories for Colombia. In this way, biophysical changes were evaluated at two points in time and the socio-economic analysis was framed in the statistics provided by the National Administrative Department of Statistics (DANE).

To this end, a supervised classification of the land cover in both periods was proposed; initially, Landsat satellite images were used to classify the cover based on the nomenclatures proposed by CORINE Land Cover and adapted for Colombia. Subsequently, processing of the information to calculate the net areas of each cover type for each year was carried out; then, the multitemporal analysis was performed to determine the rates of change for each cover type; and finally, change patterns analysis and accuracy assessment were performed to identify transitions by cover, which land cover have changed and to which classes (cross tabulation matrix) and where it was located (land cover transitions map). The proposed scheme homogenized the analysis categories for comparing the same territory in two different moments and thus interpret the primary cover information for Pereira.

3.3. Land cover classification

Land cover classification was performed using Landsat images, which have several spectral bands, and depending on their band combination, a colour was assigned to the image; each spectral band was associated with the specified ground cover. For the image with Landsat 8, RGB (red, green and blue) colour bands 5, 6 and 4 were used, while for the Landsat 5 image, RGB bands 4, 5 and 3 were used. For the supervised classification, training areas (ROIs, regions of interest) were selected that were the basis for classification. The ROI was selected based on information available in Google Earth images, Bing maps and from field work. A total of 15 characteristics were assigned to land cover: dense forest (DF), gallery and/or riparian forest (GRF), plantation forest (PF), bamboo forest (BF), stover (S), paramo (P), coffee crop (CC), permanent crop (PC), rotation crop (RC), heterogeneous agricultural area (HAA), pasture (Ps), glacier and perpetual snow (GS), bare rock (BR), water surface (WS) and urban fabric (UF).

The cover categories were based on CORINE Land Cover (CLC) adapted for Colombia. Four cover classes of the five CLCs were used for the first level: *i. Artificial Surfaces* are lands that comprise the areas of cities, towns and peripheral areas that are being incorporated into urban zones; *ii. Agricultural Areas* are mainly dedicated to the production of food, fibres and other industrial raw materials, including crops and pastures; *iii. Forests and semi-natural areas* comprise wooded, scrub and herbaceous vegetation cover with little or no anthropic intervention and also includes bare soils and rocky and sandy outcrops; and finally, *iv. Water surfaces,* which includes permanent, intermittent and seasonal bodies and canals (Table 3) (IDEAM *et al.,* 2008).

Table 3. Nomenclature of land cover units according to the CORINE Land Cover methodology adapted for Colombia.

CORINE Land Cover Colombia	
1. ARTIFICIAL SURFACES	**3. FOREST SAND SEMI-NATURAL AREAS**
1.1. Urban fabric	*3.1. Forest*
1.1.1. Continuous urban fabric	3.1.1. Dense natural forest
1.1.2. Discontinuous urban fabric	3.1.2. Fragmented natural forest
2. AGRICULTURAL AREAS	3.1.3. Gallery and/or riparian forest
2.1 Annual or rotation crops	3.1.4 Mangrove forest
2.1.1 Other annual or rotation crops	3.1.5 Plantation forest
2.2 Permanent crops	*3.2. Shrub and/or herbaceous vegetation associations*
2.2.1 Other permanent crops	3.2.1 Natural grasslands and savannas
2.2.2 Sugar cane	3.2.2 Shrubs and bushes
2.2.3 Panela cane sugar	3.2.3 Sclerophyllous and/or thorny vegetation
2.2.4 Banana and plantain	3.2.4 Paramo and subparamo vegetation
2.2.5 Coffee	3.2.5 Rupicolous vegetation
2.2.6 Cacao	*3.3. Open spaces with little or no vegetation*
2.2.7 Oil palm	3.3.1 Beaches, dunes, sands
2.2.8 Fruit trees and berry plantations	3.3.2 Bare rock
2.2.9 Greenhouse crops	3.3.3 Sparsely vegetated or degraded areas
2.3 Pasture	3.3.4 Burned areas
2.3.1 Clean pasture	3.3.5 Glaciers and perpetual snow
2.3.2 Wooded pasture	**5. WATER SURFACES**
2.3.3 Weedy or shrubby pasture	*5.1. Inland waters*
2.4 Heterogeneous agricultural areas	5.1.1 Rivers (50 m)
2.4.1 Crop mosaic	5.1.2 Natural lagoons, lakes and marshes
2.4.2 Pasture and crop mosaic	5.1.3 Canals
2.4.3 Crop, pasture and natural spaces mosaic	5.1.4 Reservoirs and water bodies
2.4.4 Pasture and natural spaces mosaic	

Source: IDEAM *et al.,* 2008. Magdalena-Cauca Basin Land Cover Map: CORINE Land Cover Methodology adapted for Colombia at a scale of 1:100,000. Institute of Hydrology, Meteorology and Environmental Studies, Agustín Codazzi Geographical Institute and Regional Autonomous Corporation of the Magdalena River. Bogotá, DC, 200p.

3.4. Information processing

Landsat satellite images were used as the basis for processing information, in which each spectral band was combined to define and calculate image attributes. After adjusting the image, the ENVI 4.8 programme was used to extract the features, which consisted of a supervised or rule-based classification of the covers assigned by the CORINE nomenclature (ENVI, 2008; IDEAM *et al.,* 2008). Next, each image was clipped with the Pereira shapefile, and the area information was extracted by cover type. Georeferencing the images (1997 and 2014) and map was carried out using the WGS84 reference system (World Geodetic System, 1984) and the UTM projection (Universal Transverse Mercator) zone 18 N for Colombia.

Subsequently, for manipulating, extracting and analysing the image information as shapefiles, the programme QGIS version 2.1.6 was used, which is an Open Source Geographic Information System (GIS), which enables working with various formats and functionalities of vector and raster data, also supporting different types of databases (Sanhouse-Garcia *et al.,* 2017; Santiago, 2014). In this study, this tool was used for the treatment of vectors, georeferencing, improving information and the geographical presentation of land cover.

3.5. Multitemporal analysis

A comparison of previously classified images was performed independently; then, the areas for each type of land use were calculated with the ENVI programme. The requirement was to create the same thematic legend for the two moments so that they were comparable. The analysis had two parts: determining the total change by use with the net exchange (gain or loss) and the annual rate of change, which was estimated according to the equation proposed by (Puyravaud, 2003). This rate (r) was calculated as follows:

$$r = (1/(t_2 - t_1)) \times \ln(A_2/A_1)$$

where $(t_2 - t_1)$: study period; A_1: land area at the beginning of the period; A_2: land area at the end of the period

Subsequently, a table was generated with the annual rate of change for the 1997-2014 study period, showing the transitions that occurred, which allowed for determination of the uses with the greatest gain or loss (net change) for the municipality of Pereira and the proportion by use of the annual change.

3.6. Change patterns analysis and accuracy assessment

Change patterns analysis and accuracy assessment were performed to identify transitions by cover, which land cover have changed and to which classes. A cross-tabulation matrix was constructed that allowed observing the transitions of the different classes evaluated, detecting changes and making an analysis of the real patterns that these changes entail (Rojas-Briceño *et al,* 2019). The matrix contains a vertical and horizontal axis with the classes for each moment in time (1997-2014). The data on the main diagonal represent the area of each cover without change during the time evaluated; those areas outside the diagonal show the changes between the two dates for each of the covers. The matrix was read by interpreting the columns as the increase in areas in hectares and the rows as the decrease in areas in hectares.

To identify where the principal transitions were located we made a map showing land cover transition. We used the cross-tabulation matrix and identified the changes of each cover and towards which class; for the map we selected the changes that were greater than 200 ha, allowing the spatial location of the changes.

The accuracy of the classification output was assessed by generating a confusion matrix with the ENVI programme. To generate the confusion matrix, the 34,666-validation pixel (observed class) were overlayed on the final classified image and the observed class points compared to the coinciding classified pixel (Ashiagbor *et al.,* 2020). Kappa coefficient of agreement and overall accuracies were calculated from the confusion matrix.

4. Results

4.1. Net change in land covers for 1997 and 2014 in Pereira, CORINE Levels 1, 2 and 3

The level 1 cover analysis showed an overview that the agricultural areas for 1997 and 2014 were the dominant cover, with 60.7% and 59.4%, respectively, followed by forests and semi-natural areas (34.3% and 31.9%); artificial surfaces had corresponding areas of 3.7% for 1997 and 7.6% for

2014 of the total area of Pereira; finally, water surfaces were evident in 1.2% of the total area for both years (Table 4 and Fig. 2).

Table 4. Classification of cover area for CORINE Level 1.

COVER	Year 1997		Year 2014	
	Area (ha)	Area (%)	Area (ha)	Area (%)
Agricultural areas	36,876.33	60.7 %	36,045.72	59.4 %
Forests and semi-natural areas	20,847.87	34.3 %	19,356.03	31.9 %
Artificial surfaces	2,276.73	3.7 %	4,599.45	7.6 %
Water surfaces	715.32	1.2 %	715.05	1.2 %
Total surface	60,716.25	100 %	60,716.25	100 %

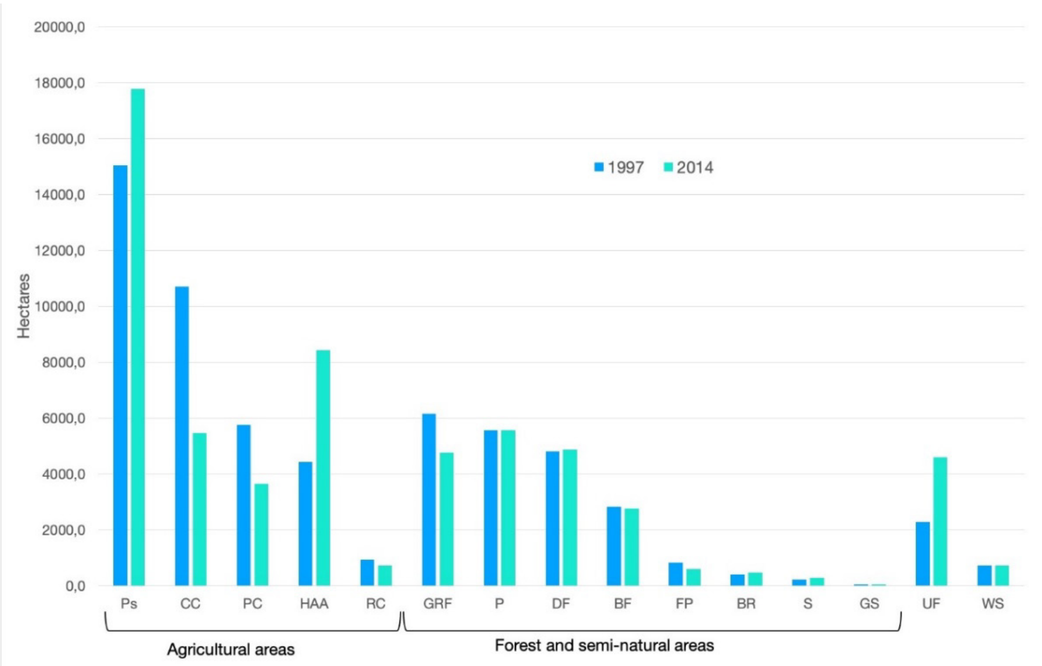

Figure 2. Net cover in hectares for the years 1997 and 2014 in the municipality of Pereira.

The natural and semi-natural surfaces for Pereira in 1997 were mainly distributed as follows: Gallery and riparian forest (GRF) encompassed 6,145.7 ha (10.12%) with patches distributed throughout the municipality; paramo (P) encompassed 5,573.6 ha (9.2%) belonging to the Los Nevados National Natural Park (NNP) (high elevation zone and east of the municipality); dense forest (DF) encompassed 4,804.6 ha (7.9%) of the territory and was mainly located in the upper area of the Otún River basin and east of the city of Pereira; and bamboo forest (BF) encompassed 2,824.9 ha (4.6%). To a lesser extent the following land covers were also present: water surfaces (WS), associated with natural lagoons, lakes and surface water courses; bare rock (BR), mainly in the high elevation area of the Los Nevados NNP east of the municipality; stover (S), near the urban area; and finally, glaciers and perpetual snow (GS) (Fig. 2 and 3).

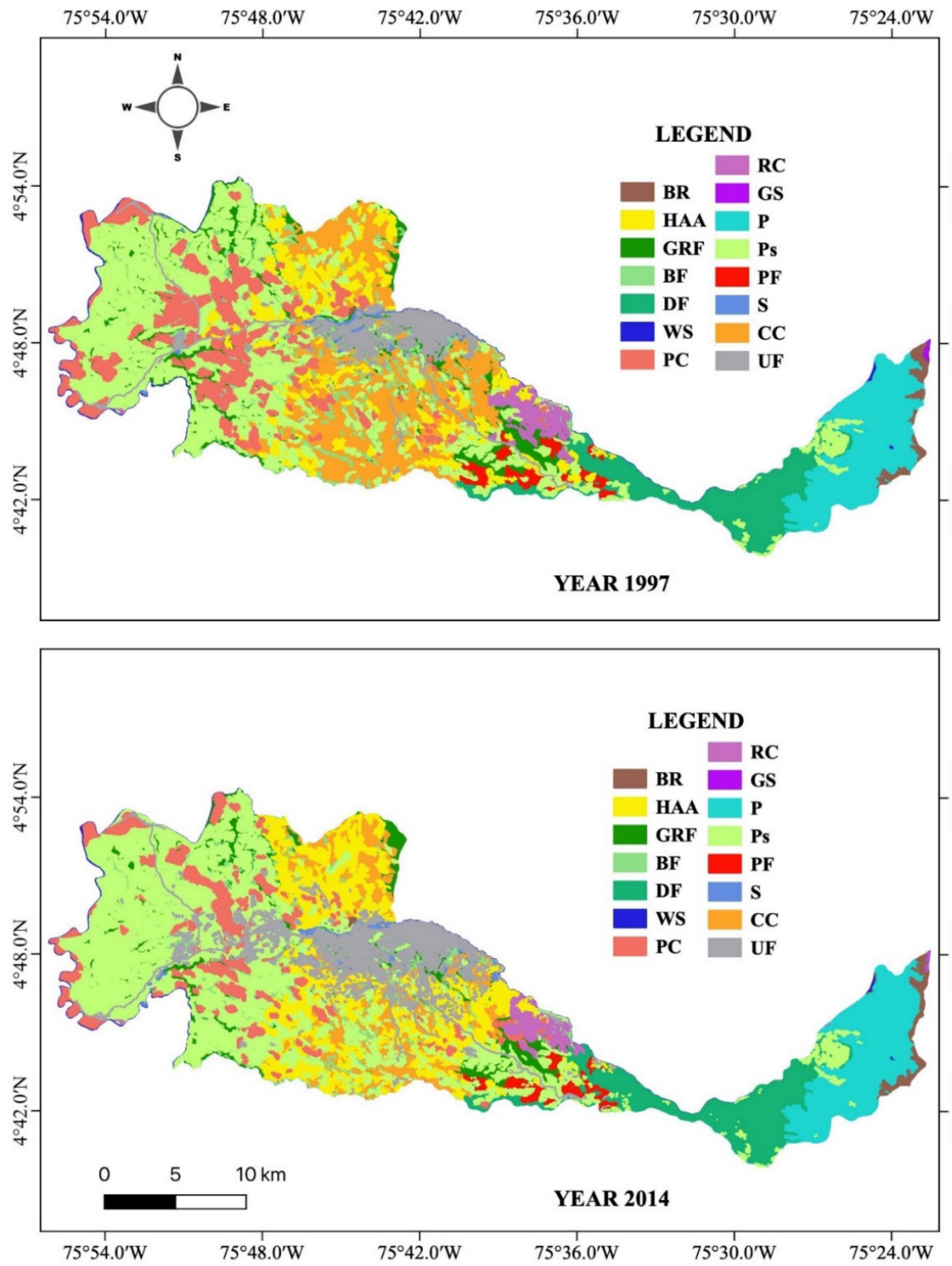

Figure 3. Land cover of the municipality of Pereira for the years 1997 and 2014.

The area dedicated to agricultural land in 1997 in Pereira is described as follows from largest to smallest cover area: (9) Pasture (Ps) comprised the largest use in the municipality, with 15,047 ha (24.8% of the total area) and was mainly found west of the municipality and in the lowest altitude areas; (*10*) heterogeneous agricultural areas (HAA) comprised 4,438.9 ha (7.3%); (*11*) CC comprised 10,706 ha (17.6%), and both cover classes (10 and 11) were observed mainly in the centre of the municipality from north to south; (*12*) permanent crops (PC) comprised 5,747 ha (9.5%) and were mostly concentrated in the west in the low elevation zone; (*13*) rotation crops (RC) covered 937 ha (1.5%); (*14*) FP covered 821.1 ha (1.3%) and were located mainly east of the urban fabric; and finally, (*15*) continuous and discontinuous urban fabric (UF) comprised 2,276 ha (3.7%) of the total surface of Pereira (Fig. 2 and 3).

For 2014, the natural and semi-natural territory for Pereira was distributed as follows: paramo (P) comprised 5,558.7 ha (9.2%) of land cover and belonged to the Los Nevados NNP (high elevation and east of the municipality); dense forest (DF) comprised 4,877.6 ha (8%) of the territory and was found mainly towards the east of the municipality; the cover for gallery and riparian forest (GRF) was 4,757.7 ha (7.8%) with patches distributed throughout the territory of the municipality; bamboo forest (BF) comprised 2,765 ha (4.5%); and finally, water surfaces (WS), bare rock (BR), stover (S) and glaciers and perpetual snow (GS) comprised the smallest areas in terms of cover (Fig. 2 and 3).

The net areas of the agricultural lands in Pereira for the year 2014 were identified and the following characteristics were determined: (*9*) pasture (Ps) continued to be the largest land cover in the municipality with 17,788 ha (29.3% of the total area) and was mainly concentrated in the western zone of the municipality; (*10*) heterogeneous agricultural area (HAA) increased to 8,433 ha (13.9%); (*11*) CC comprised 5,454 ha (9%), occurring in the central zone between the north and south of the municipality; (*12*) permanent crop (PC) covered 3,647 ha (6%) with patches distributed towards the lower elevation zone west of Pereira; (*13*) rotation crop (RC) comprised 722.8 ha (1.2%); (*14*) FP covered 603.6 ha (1%) and was concentrated in the middle basin of the Otún River towards the area east of the municipality; and finally, (*15*) continuous and discontinuous urban fabric (UF) comprised 4,599 ha (7.6%) of the total surface of Pereira (Fig. 2 and 3).

4.2. Changes in land cover for the 1997-2014 period (annual rate of change)

The covers in CORINE Level 1 showed the following changes: three of the four covers presented annual decreases in area, with forest and semi-natural areas having the greatest change (-0.38%), followed by agricultural areas (-0.16%) and to a lesser extent water surfaces (-0.002); artificial surfaces showed an annual growth of 4.14% (Table 5).

Table 5. Annual rate of change in cover classes between 1997-2014 in Pereira.

COVER	Period		Net change	Year	Rate of change (r)	Rate (%)
	1997 Area (ha)	2014 Area (ha)				
Agricultural areas	36,876.33	36,045.72	-830.61	17	-0.00134	-0.1340
Forests and semi-natural areas	20,847.87	19,356.03	-1,491.84	17	-0.00437	-0.4367
Artificial surfaces	2,276.73	4,599.45	2,322.72	17	0.04136	4.1365
Water surfaces	715.32	715.05	-0.27	17	-0.00002	-0.0022

The annual rates of change between 1997 and 2014 showed losses and gains among the land covers analysed. The cover that lost the most territory was CC, with a negative rate per year of -3.97%, followed by permanent crop (PC) (-2.67%), PF (-1.81%), rotation crop (RC) (-1.53%), gallery and riparian forest (GRF) (-1.51%), glacier and perpetual snow (GS) (-1.34%) and to a lesser extent, bamboo forest (BF), paramo (P) and water surface (WS) also decreased (Table 6).

The covers that gained surface area included the continuous and discontinuous urban fabric (UF), with the highest annual change rate of 4.14%, which was followed by heterogeneous agricultural areas (HAA) (3.77%), stover (S) (1.61%), pasture (Ps) (0.98%), bare rock (BR) (0.77%) and dense forest (DF) (0.09%) (Table 6).

Table 6. Annual rate of change in land cover classes between 1997 and 2014 in Pereira.

Use	Period				Net change	Year	Rate of change (r)	Rate (%)
	1997 Area (ha)	1997 (%)	2014 Area (ha)	2014 (%)				
WS	715.32	1.18	715.05	1.18	-0.27	17	-0.0000	-0.002
DF	4,804.56	7.91	4,877.64	8.03	73.08	17	0.0009	0.089
GRF	6,145.74	10.12	4,757.67	7.84	-1,388.07	17	-0.0151	-1.506
PF	821.07	1.35	603.63	0.99	-217.44	17	-0.0181	-1.810
CC	10,706.04	17.63	5,454.63	8.98	-5,251.41	17	-0.0397	-3.967
BF	2,824.92	4.65	2,765.34	4.55	-59.58	17	-0.0013	-0.125
HAA	4,438.89	7.31	8,433.27	13.89	3,994.38	17	0.0378	3.775
GS	51.93	0.09	41.31	0.07	-10.62	17	-0.0135	-1.346
P	5,573.61	9.18	5,558.67	9.16	-14.94	17	-0.0002	-0.016
Ps	15,047.28	24.78	17,788.05	29.30	2,740.77	17	0.0098	0.984
PC	5,747.13	9.47	3,646.98	6.01	-2,100.15	17	-0.0268	-2.675
S	220.05	0.36	289.17	0.48	69.12	17	0.0161	1.607
BR	405.99	0.67	462.60	0.76	56.61	17	0.0077	0.768
RC	936.99	1.54	722.79	1.19	-214.20	17	-0.0153	-1.527
UF	2,276.73	3.75	4,599.45	7.58	2,322.72	17	0.0414	4.136

4.3. *Change patterns analysis and accuracy assessment*

The net changes and annual rates of change for each cover generally show growth or decrease in their surface areas and the trends of change for the period studied; by going deeper into the patterns of change it is possible to show which covers are gaining areas and at whose expense. It was found that the greatest changes were observed in the western zone of Pereira and between the north and the south, close to the urban area (Fig. 4). For the 1997 classification it was estimated that an overall accuracy of 96.1% and a Kappa coefficient of 0.96; while for 2014, the following were evaluated an overall accuracy of 84.1% and Kappa coefficient equal to 0.81 (Table 7).

In land cover change matrix was found that the pasture (Ps) was the cover that more surface obtained, the acquired territory was transferred mainly from permanent crops (PC) (2,405.5 ha), coffee crops (CC) (1,173.3 ha) and gallery and riparian forest (GRF) (850.1 ha). The urban fabric (UF) was the cover with the highest rate of positive change and acquired this area mainly from CC (836.5 ha), Ps (509.9 ha), heterogeneous agricultural areas (HAA) (365.9 ha), PC (282.9 ha) and, to a lesser extent, GRF (189.1 ha) and bamboo forest (BF) (106.1 ha). The HAA obtained territory essentially from coffee crops (3,641.3 ha) and pasture (1,039.9 ha) (Table 7 and Fig. 4).

Drastic changes were evident in the covers that decreased the most in their surface areas, such as coffee crops and permanent crops (Fig. 4); both gave way to HAA (3,641.3 ha and 315.5 ha respectively) and pasture (1,173.3 and 2,405.5 ha). In order to, the forest and semi-natural areas were moved where the movement of the agricultural frontier was evident; the areas with dense forest (DF), galery and riparian forest (GRF) and bamboo forest (BF) were affected by the increase in covers such as coffee crops, HAA, permanent crops, transitory crops and pastures (Table 7).

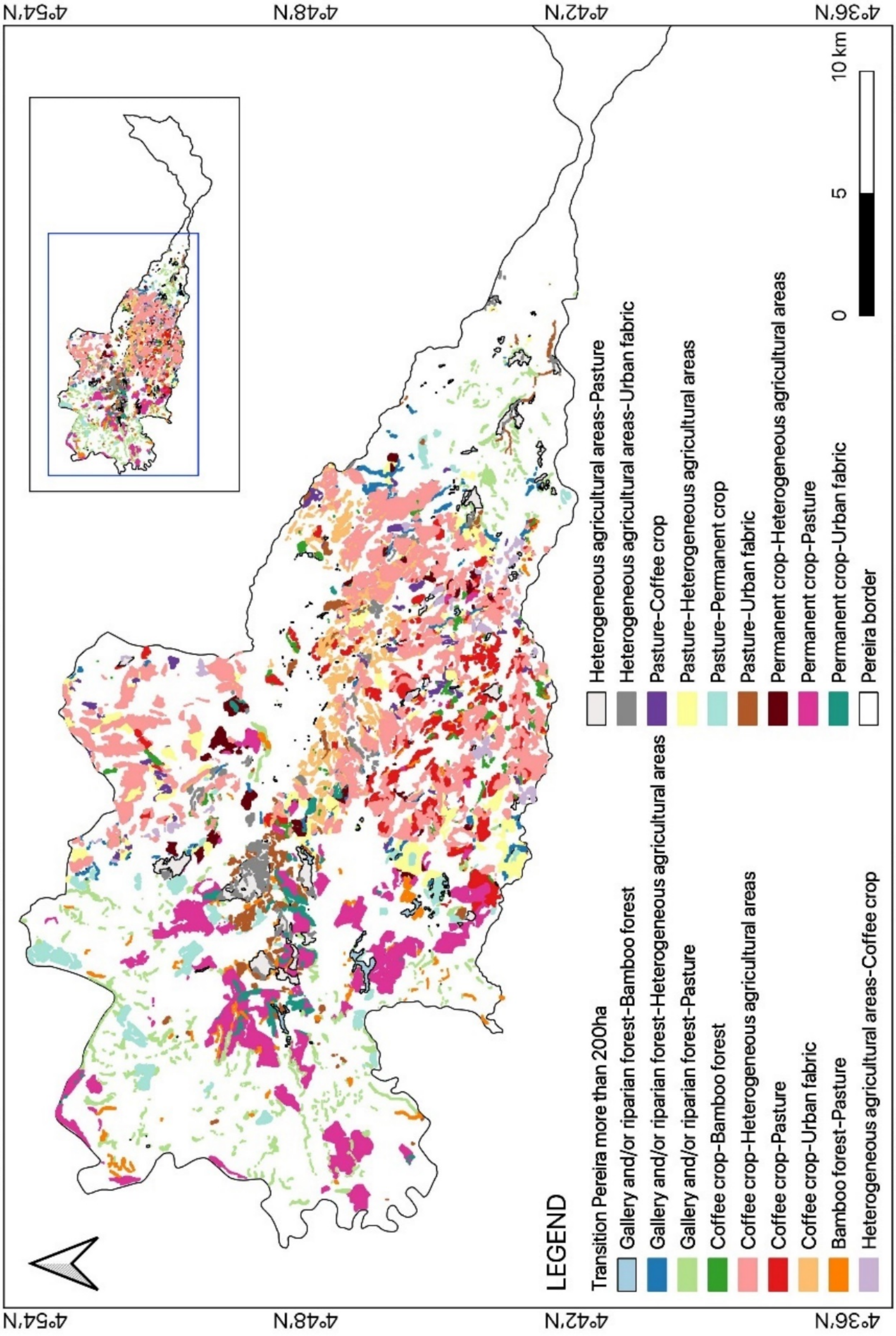

Figure 4. Land cover transitions in Pereira between 1997-2014.

		Year 2014 (Overall Accuracy: 84.1%; Kappa coefficient: 0.81)															
Year 1997 (Overall Accuracy: 96.1%; Kappa Coefficient: 0.96)		WS	DF	GRF	PF	CC	BF	HAA	GS	P	Ps	PC	S	BR	RC	UF	T97	%
	WS	**690.9**	0.9	1.3			0.8			10.1	2.7	6.3		2.3		0.1	715.3	1.2
	DF		**4,560.4**	4.3	69.4	5.0	0.9	32.6		19.5	102.0	1.4			4.0	5.1	4,804.6	7.9
	GRF	1.1	6.0	**4,122.2**	92.3	178.4	208.4	263.4			850.1	148.5	44.9	0.5	40.1	189.8	6,145.7	10.1
	PF		106.6	150.7	**349.8**	22.6	1.9	14.9			167.1	3.7			0.5	3.3	821.1	1.4
	CC	0.1		82.4	0.1	**4,483.9**	238.3	3,641.3			1,173.3	162.3	83.4	4.2	0.1	836.6	10,706.0	17.6
	BF		2.1	29.3	1.4	101.0	**2,134.4**	126.8			283.1	24.5	8.1		8.2	106.1	2,824.9	4.7
	HAA	0.1	26.7	136.4	59.7	219.0	15.4	**2,876.9**			687.3	51.4		0.2		365.9	4,438.9	7.3
	GS								**41.3**					10.6			51.9	0.1
	P	3.9	14.4							**5,434.9**	9.3			111.2			5,573.6	9.2
	Ps	12.9	159.1	133.7	29.0	278.7	47.6	1,039.9		20.0	**12,000.5**	728.5	19.7		67.9	509.9	15,047.3	24.8
	PC	6.1		43.5		111.4	95.5	315.5			2,405.5	**2,483.2**	0.8	2.2	0.6	282.9	5,747.1	9.5
	S			5.1			2.1				10.4		**131.8**			70.7	220.1	0.4
	BR									74.2			0.4	**331.5**			406.0	0.7
	RC		0.1	40.4	0.7	52.2	16.1	99.7			64.2	34.6			**600.7**	28.4	937.0	1.5
	UF		1.4	8.5	1.3	2.4	4.0	22.4			32.6	2.8	0.1		0.8	**2,200.6**	2,276.7	3.7
	T14	715.1	4,877.6	4,757.7	603.6	5,454.6	2,765.3	8,433.3	41.3	5,558.7	17,788.1	3,647.0	289.2	462.6	722.8	4,599.5	**60,716.3**	
	%	1.2	8.0	7.8	1.0	9.0	4.6	13.9	0.1	9.2	29.3	6.0	0.5	0.8	1.2	7.6		

Table 7. Land cover change matrix in Pereira between 1997-2014 (area in hectares).

5. Discussion

The study and analysis of land cover change and spatial patterns requires an interdisciplinary science that involves i.) biophysical aspects through remote sensing and ii.) the human aspect as the decision makers who can determine the change in the territory (Rindfuss *et al.,* 2004; Turner II *et al.,* 2007). Some international, national and regional politics was crucial in land cover changes in Pereira for the analysis period, in addition, the practices and cultural heritage have preserved some covers, demonstrating the change dynamics in the territory.

5.1. Analysis of land cover change in Pereira for the 1997-2014 period

The struggles for territory in present-day Pereira during the colonial period refer to conflicts over territorial power between groups of Spaniards, creole heirs and indigenous American peasantry (Quimbaya peasantry). Between 1850 and 1950, Pereira began to grow due to the high levels of poverty and exclusion of the landless peasant population of Caldas, Antioquia and northern Valle (Palacios, 1979; Rivera, 2014). The violence and displacement of the population in the allocation of land tenure to new landowners triggered the growth of new smallholder populations in the central-western area of the country.

The highest slopes are in the eastern area of Pereira (Fig. 1), and in this territory, there is the National Natural Parks of Colombia with the Los Nevados NNP, which contributes to the conservation of important ecosystems worldwide, such as three of the remaining glaciers in the country (Nevado del Ruíz, Nevado de Santa Isabel and Nevado del Tolima), Super-Paramo and Paramo ecosystems, High Andean Wetlands and High Andean Forests and Andean Forests (PNN, 2020). The covers identified in this area of the municipality show the specialized management of this territory by the system of protected areas (SINAP: Sistema Nacional de Áreas Protegidas -SIDAP: Sistema Departamental de Áreas Protegidas). These covers maintain their net areas, and the changes seen could be related to the climate changes in which the changes in snow (GS) surface lead to decreases and increases in bare rock (BR).

The forests in Latin America have been reduced by more than 50% of the original cover in 2000; countries such as Brazil, Mexico and Costa Rica showed the most significant changes (Sanhouse-Garcia *et al.,* 2017). In Colombia, loss of forest between 1990 and 2014 was 6,095,312 ha with a rate of change of -0.41 ha for that period (Galindo *et al.,* 2014); in contrast, for the municipality of Pereira, the dense forest (DF) occurring in the upper middle zone of the Otún River basin and the paramo (P) were maintained for the study period (1997-2014). These measures taken by national institutions and regional companies have allowed for conservation and management in the protection of these forest covers and semi-natural areas.

Contrary to what occurred with the dense forest (DF), gallery and riparian forests (GRF) showed decreased surface areas during the course of the study (81.65 ha/year), since this type of cover is scattered over the territory of Pereira. It is believed that these forests have mainly been converted to pasture (Ps), expanding the agricultural frontier and maintaining animal access to the protected water in these areas. Something similar occurred in the mountainous area of Spain between 1990 and 2006, where the area occupied by forest became pasture and bush due to deforestation and fires (Martínez-Vega *et al.,* 2017).

The agricultural territory comprises the largest surface area for 1997 and 2014 (62.1% and 60.4%, respectively), but there is evidence of a change in the land cover type. For 1997, CC encompassed 10,706 ha, corresponding to 17.6% of the agricultural area of Pereira, while for 2014, this cover was 5,454 ha (9%); meanwhile, the heterogeneous agricultural area (HAA) increased in the analysis period from 4,438.9 ha (7.3%) to 8,433 ha (13.9%) (Fig. 2 and 3). This change could be explained by the coffee crisis experienced in Colombia in the 1990s; however, the beginning of this cultivation in the region dates back to the beginning of the 20th century, in which coffee began to emerge as a prosperous business in Antioquia and the landless peasants who arrived in Pereira arrived with the idea of colonizing land for this crop (Rivera, 2014). From 1930 to 1980, an economic boom occurred in Colombia due to the cultivation of coffee, which became the most significant product for the economic and social development of the country in the 20th century and it was supported by the National Federation of Coffee Growers (Toro Zuluaga, 2005; Rettberg, 2010). This period of prosperity was cut short in 1989, when the International Coffee Agreement for the members of the International Coffee Organization (ICO) ended. The suspension of export quotas and the decrease in the international price of coffee led coffee growers to generate new strategies to boost agricultural production on farms, diminishing the size of coffee growing areas, which were replaced with other types of crops.

Prior to 1997, coffee production intensification occurred, guided by the demand of the international market and institutions, such as the National Federation of Coffee Growers of Colombia. Coffee growing in Colombia was and continues to be mainly a smallholder farmer activity, and peasant families have influenced the reproduction and geographical spread of coffee (Palacios, 1979; Guhl, 2004; Toro Zuluaga, 2005; Barón, 2010). Agricultural families in the region converted subsistence crops into coffee production (Guhl, 2008). Coffee cultivation had an impact on the societies and landscape of Pereira and coffee plantations (Toro Zuluaga, 2005). However, with the collapse of the agreement in 1989, there was a slowdown in the demand for this product, thus, in 1997, the Federation generated policies aimed at reducing the areas intended for coffee cultivation, which initially resulted in changes in land cover. Smallholder farmers consolidated local power structures, which allowed for a faster response in adjusting the demands for agricultural products, and quick landscape changes.

The continuous and discontinuous urban fabric (UF) showed the highest growth in the area and study period from 2,276 ha (3.7%) in 1997 to 4,599 ha (7.6%) in 2014, doubling the occupied surface with an annual growth rate of 4.1%. This information is close to that found by (Carvajal, 2017) in the La Vieja River basin for the analysis period of 1989-2000, where he identified an annual growth of 4.7%. This growth is linked to the pressure exerted on other land uses, generating change in the ecosystems. These changes are associated with growth of the urban population (urbanization), expansion of the built area (urban growth) and low-density dispersed urban development in the urban-rural perimeter (urban sprawl) (Nelson, 2005). These processes are observed in the maps of cover transitions in the city of Pereira, mainly the discontinuous growth in the 2014 map compared with the 1997map, showing the pressure on CC and gallery and riparian forest (GRF).

The urban-rural relationship in China has experienced a process from binary opposition and segmentation to overall planning and integration (Chen *et al.,* 2020). Therefore, promoting sustainable development in the territory requires consideration of the relationships among urban-rural areas to augment agricultural cover and forests and semi-natural areas, promote stewardship of nature and improve social aspects, such as employment and food security. The growth of urbanized territory should be integrated with other land covers through planning, government incentives and academic knowledge.

5.2. Annual rate of change

The lost area that corresponded to agricultural territory and forest and semi-natural areas represented 136 ha per year, which was translated to artificial areas. Forest cover (dense forest, gallery forest, bamboo, stover and paramo) of Pereira for 1997 (32.2%) and for 2014 (30.1%) was lower with respect to the departmental average (37%) and the national average (51.6%) (IDEAM, 2017). This finding indicated the strong pressure exerted by the population, urban growth and agricultural uses over time. According to (Chen *et al.,* 2020), it is necessary to consider the potential, capacity and requirements of rural development, which will improve the social function of rural territories, such as employment, food and agricultural goods supply, and the promotion of biodiversity.

In this study, pasture (clean, weedy, and wooded pasture) was the largest cover area for both 1997 and 2014 (with 24.8% and 29.3% of the total area for both years) and gained 0.98% per year

(161.22 ha per year); however, when comparing the area reached in 2014 (17,788 ha) with the area estimated by the Secretariat of Agricultural Development of Risaralda (2015), which states 22,490 ha for the same year, there are 4,702 ha unaccounted for. Therefore, it is likely that in the heterogeneous agricultural area (HAA), some pasture areas are hidden; these pastures are mixed with other uses that make their detection difficult from satellite images. Likewise, the fragmentation of some surfaces is evident, where mixed covers occur. Similar results were found by Ellis *et al.* (2010) in a marginal coffee growing region of Mexico, where annual rate of change for pasture was positive and the vast majority of land reported previous land cover for coffee production.

Heterogeneous agricultural areas (HAA) with an annual growth rate of 3.77% are the result of fragmentation and different management practices; the spatial and temporal configuration of this mosaic is the consequence of diverse coexisting agricultural uses and of activities, such as industry and tourism (Guhl, 2008). This finding shows that the area of CC for the year 1997 was converted into farms by 2014 with various types of crops and subsequently urbanized.

5.3. Dynamics of coffee production and export and changes in land cover

CC lost the most surface area in the municipality of Pereira in the study period, with an annual loss rate of -3.97%. The coffee axis was one of leading coffee exporters in the twentieth century and with the crisis of 1989, there was a change in land cover in the region. However, the metric tons of coffee produced for export between 1992 and 2018 show no major changes, producing an average of 605 thousand tons per year. However, the country's share of coffee in global exports declined; 19.6% in total exports in 1997, and 4.5% in 2014 (Fig. 5). A different behaviour was found by Ambinakudige and Choi (2009) in India, where conversion of rice paddies (the land for subsistence farming) to coffee was a result of increased coffee prices in the early 1990s, immediately after the Indian Coffee Board's control of the coffee market was removed. By the end of the 1990s, most of the land allotted by the government for coffee cultivation had already been converted to that crop.

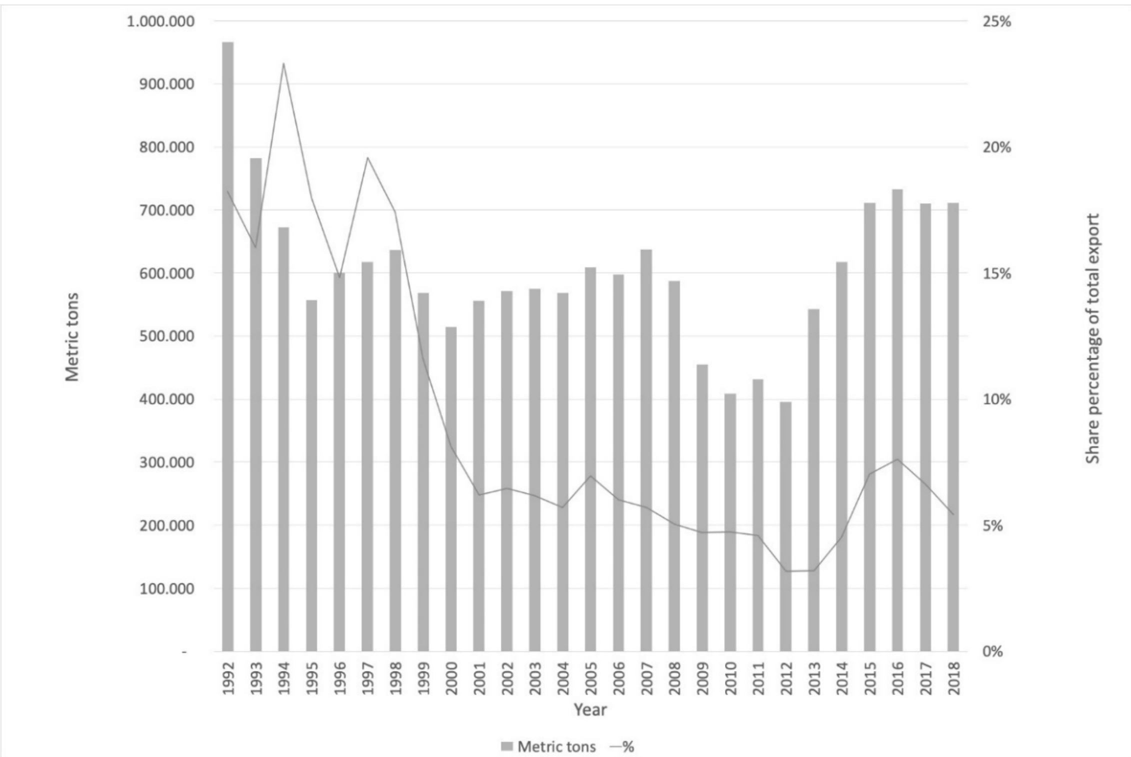

Figure 5. Coffee exports by share percentages and metric tons between 1992 and 2018.

With the collapse of the International Coffee Agreement in 1989, there was an international decrease in the price of this product, which generated a progressive decrease in cultivated area. CC between 1997 and 2014 showed an annual decrease rate of -3.97% in Pereira, while this decrease generated a change in the landscape and although the region is still culturally known as the coffee axis and remains on the UNESCO's World Heritage list as a Coffee Cultural Landscape - CCL, there has been a profound loss of that type of land cover (Table 7 and Fig. 4). Although some farmers abandoned this type of cultivation and sold farms, others reduced the area used for CCs but remained through time and through constant price crises. According to Guhl (2008), those persistent producers revitalize the surface of their farms, changing from pasture to coffee and from coffee to pasture or mixing with other types of agricultural products, which has allowed them to maintain themselves. Farmers have styles or forms of agriculture that are firmly rooted in a stock of cultural knowledge (Van der Ploeg and Ventura, 2014). Those styles comprise ways of organizing and reorganizing the internal and external requirements of the farms, which allow farmers to remain in the territory, as well as contributing to the heterogeneity of the agricultural systems in the cultural coffee landscape of Colombia.

The land cover has changed in the last 17 years for the study area, due mainly to the coffee crisis, that was particularly hard on the small Colombian coffee producers, who were less able to adapt to the new circumstances because of financial constraints: Prices paid to producers decreased by a third (32.6 percent) between January 1985 and December 2004 (Rettberg, 2010). Traditional and modernized CCs were eradicated to plant plantains, avocado, citrus and grass, mainly African grasses, to produce meat and milk (Carvajal *et al.,* 2013). These changes, in addition to mismanagement of the territory by government entities, have introduced problems, such as the displacement of the rural population, decreased food supply for both urban and rural populations, and problems of pollution and erosion of natural resources. Likewise, when the costs of production or the cost of being there are very high, the production of marketable goods that are generated in that territory to cover the costs is not enough, leading to possible changes in both the use of the territory and the type of owners who can acquire the land and use it under other conditions.

Although the decrease in the area dedicated to coffee cultivation in the municipality of Pereira is evident, there are regions in Colombia where this crop has become important and other zones of the coffee axis still maintain coffee productivity. The dynamics of the territory, the changes in the landscape and the production of agricultural goods are dynamized by geographic conditions, the quality of production and disease control, the price of products in the market, the type of productive systems, the land market and other variables not considered in this study.

These multitemporal analyses of land cover change demonstrate spatial arrangements and aid in understanding the dynamism of socioecological systems such as the CCL and how human processes guide such changes in the land. The importance of this type of work is to understand the transitions in land cover because they are a mirror reflecting the stage of socio-economic development (Chen *et al.,* 2020). In consequence it is going to help make better decisions for resources management and access to these resources, in addition to supporting and preserving rural communities and cultural practices that promote the security of society (food supply, job generation in rural areas and promotion of natural environments).

The interesting and dynamic nature of the dual human-environment system that creates changes in the landscape is one of the challenges presented by this type of multi-temporal analysis. Nevertheless, observation and monitoring with emphasis on the local and regional generates a detailed classification of the land for the evaluation of changes directed at specific problems. These studies detail biophysical changes and are an important source of primary information for planning. This research highlights the territories and covers that have undergone the greatest change, suggesting that local authorities should take up this work in their planning to recognize the zones that need to be intervened; that is, if the CCL is to be preserved, the zones that have changed towards coffee cultivation should be highlighted and promoted, and those zones that have lost area to other types of land covers should be intervened in.

6. Conclusions

Agricultural areas were dominant in Coffee Cultural Landscapes of Pereira and they were the land covers that changed the most in the 1997-2014 period. The land cover that lost the most territory was coffee crop, with a negative rate per year of -3.97%, mainly due to political-economic factors, such as the dissolution of the International Coffee Agreement and the National Federation of Coffee Growers that discouraged coffee cultivation and permanent crops. Likewise, sociocultural factors, such as smallholder farmers have guided the changes in land cover and have stimulated productive styles to adapt and remain, increasing heterogeneous agricultural areas.

Forest and semi-natural areas were replaced where the movement of the agricultural frontier was evident and they were affected by increase in land covers such as coffee crops, heterogeneous agricultural areas, permanent crops, transitory crops and pastures. The last transformed 850 ha of galery and riparian forest, 283 ha of bamboo forest and 102 ha of dense forest.

Livestock activities changed representative areas of Coffee Cultural Landscapes of Pereira between 1997 and 2014, consequently, pasture was the land cover that more area obtained, and the acquired territory was transferred mainly from permanent crops (2,405.5 ha), coffee crops (1,173.3 ha) and gallery and riparian forest (850.1 ha).

Related to rural-urban changes it was found that continuous and discontinuous urban fabric was the land cover with the highest positive annual change rate (4.14%), showing a growth from 2,276 ha in 1997 to 4,599 ha in 2014. These changes are associated with growth of the urban population (urbanization), expansion of the built area (urban growth) and low-density dispersed urban development in the urban-rural perimeter (urban sprawl), due to city-level planning policies that promoted rural parcelling for the expansion of artificial surfaces.

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