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ANALYSIS OF DISTURBANCE DYNAMICS IN TINIGUA NATIONAL NATURAL PARK USING TIME SERIES OF LANDSAT SATELLITE IMAGES

Pablo E. CABRERA[1], Gloria Yaneth FLOREZ-YEPEZ[1],
Jhon Fredy BETANCUR-PEREZ[2], Yeison Alberto GARCES-GOMEZ[1,*]

[1] Universidad Católica de Manizales – Cra 23 # 60-63, Manizales – Colombia
[2] Universidad de Manizales – Centro de Investigación en Medio Ambiente y Desarrollo CIMAD – Cra 9A # 19-03, Manizales – Colombia

Abstract

By applying data processing techniques of earth observation which makes easier to study human-induced changes in forest cover along with the availability of highly refined and standardized data, such as image collections LandSat 5 ETM (Enhanced Thematic Mapper), Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) y Landsat 8 OLI (Operational Land Imager)/TIRS (Thermal Infrared Sensor) different types of variables are considered; together with tools of Google Earth Engine, an approach is developed that makes the spatial analysis more efficient and allows to know the evolution of a geographical space of interest. For this case, it was searched through remote sensing, to provide elements of study that allowed to know the spatial evolution of the processes of transformation of the natural coverages of the Tinigua National Natural Park, finding that the first processes of change, between 1989 and 1996 were presented taking from the rivers named "Guayabero", "Guaduas" and "Río Perdido" as ways of mobility; subsequently, between 1996 and 1998, years after the first peak of change in coverage, Colombia suffered from the harshness of the armed conflict, in that period it went from 117 hectares of forest transformed in 1996, to 2423 hectares of loss of that natural coverage in 1998, later, for 1999 this figure was drastically reduced.

Keywords: *Land cover; Remote sensing; Landsat; Google Earth Engine; Long-term data record*

Introduction

Protected areas of Colombia come to 14.268.224 hectares (142.682km^2) of the national surface represented in 62 protected areas [1], of these ones, only 11 of them have an area of less than 10.000 hectares, indicating that most national parks have extensions that justify the use of remote sensing to carry out monitoring tasks , surveillance, control and follow-up.

Through the interpretation of satellite images, visual information and statistical figures are generated that, complemented by field data, account for the state of health of the attributes of the land cover and allows monitoring of large areas of territory, thus expanding the understanding of changes in the earth's surface at the landscape level [2–4].

The use of this information was limited by the need for large computing capabilities; in turn, these ones require a wide faculty of data storage locally [5]. However, advances in Internet and data infrastructure with an extensive connectivity have revolutionized workflows, allowing

* Corresponding author: ygarces@ucm.edu.co

unlimited access to Internet network resources from any location. In this way, data management models are arrived at, which free the user from the need of storage [5–7].

Experimental part

Area of study

The Tinigua National Natural Park (NNP) is located in the province of "Meta", between the municipalities of "Uribe" and "La Macarena"; it has an approximate area of 214,000 hectares (Fig. 1). It preserves sites of cultural importance that evidence the ancestral presence of indigenous cultures and that, at present, represent sacred sites of cultural practices. From the point of view of connectivity among the "Andean", "Amazonian" and "Orinoquense" biomes, it preserves areas of humid forest that allow species to mobilize in an altitudinal range favoring their genetic diversification, and mitigating the loss of biodiversity [8].

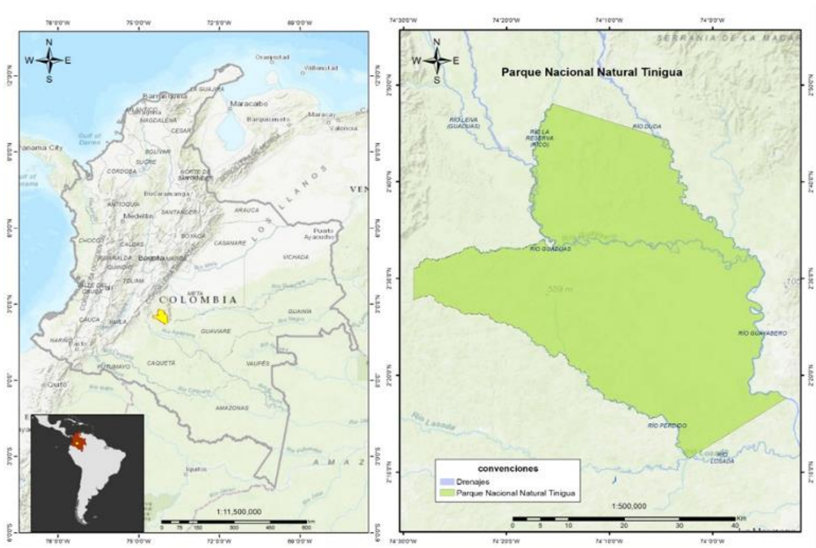

Fig. 1. Tinigua National Natural Park

Despite this, social and public order conditions make increasingly difficult the aim to keep ecosystems in resilient conditions so that they can withstand society's demands for goods and services which gradually increases [9]. On the other hand, technological advances for the capture of data from the Earth's surface from space platforms have made it possible to develop methodologies to monitor changes that occur in the coverage of the Earth's surface at different scales, from the global scale – through the atmosphere monitoring , the flows of sea currents or the movement of tectonic plates– , to monitoring of small changes in the elevation or sinking of the surface, thanks to techniques such as synthetic opening radar interferometry [10].

In addition, the recent trend to release data produced in large quantities by remote sensors is revolutionizing the use of these inputs and developing innovative methods that allow to take full advantage of it with the help of techniques to improve computing capacity and algorithms that enable to perform different types of spatial analysis through web platforms.

Data

There are different ways to analyze change using remote sensing; most of them focus on the comparison of two images from different periods, resulting in a new image with groups of pixels, whose digital levels are determined by a change in the surface [11–13]. Considering a two-dimensional spectral space (two spectral bands), it could be represented in a scatter plot formed by the two bands [14].

The first data set is available between the 1st of January 1984 and the 5th of May 2012, from the Landsat sensor 5 ETM (Enhanced Thematic Mapper). They have a resolution of 30 m/pixel; while the TIR band has been re-sampled with a cubic convolution at 30 m. These data have been atmospherically corrected by LEDAPS (Landsat Ecosystem Disturbance Adaptive Processing System) and include a mask of cloud, shadow, water and snow produced with the CFMask (C Function of Mask), as well as a saturation mask by pixel [15].

The second data set of the Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) sensor, is available between the 1st of January 1999 and the 21st of October 2020, and the third data set features surface reflectance, atmospherically corrected of the sensors Landsat 8 OLI (Operational Land Imager)/TIRS (Thermal Infrared Sensor and Land Surface Reflectance Code) [16].

Methodology

A transversal methodological process is identified in a wide range of research in remote sensing, which is aimed at standardizing and homogenizing the available information; this process can be generically divided into five phases:

i) Data Collection and processing

LandSat sensor imagery Time Series (LTS) were used, to which, algorithms were applied, to identify changes in time and generate graphical outputs that account for areas that have lost forest cover.

ii) Geometric and radiometric corrections

Geometric corrections refer to the image's adjustments to its actual position on the Earth's surface through its geo-referencing and orthorecification. Data used for the analysis is high-level processing data, available to users on the USGS platform as ARD data (Analysis Ready Data).

iii) Change Detection Analysis

At this stage, we review the algorithms available for change detection and choose the one that fits the needs of the research. For the present case, it was taken as a process route, the LandTrendr spectral-temporal segmentation algorithm (LTdr).

iv) Reliability Assessment

In this case, the result is expected to account for the moment of change, which can be corroborated by reviewing the image that produced that data, and by reviewing the trajectory of the change vector in the spectral trajectories.

v) Generation of results

At this stage, the analyses are carried out and the results are described using documents, images and maps.

For the generation of thematic data, it is used an algorithm, based on analysis of LandSat image series called LTdr [17], which allows to know the evolution of a pixel in time, to represent it as a spectral trajectory through satellite images. The implementation of LTdr's spectral-temporal segmentation algorithm is based on the comparison of the pixels of images segmented in defined periods of time, which by interpolation, were subsequently parameterized, with surface reflectance correction for the elaboration of image compounds per periods, applying correlation parameters to homogenize the digital levels of the image and facilitate the identification of outliers. The image data is reduced to a single band or spectral index and then divided into a series of straight-line segments by breaking point identification (vertex).

The temporal spectral segmentation model only requires one scene per year, but it is very difficult for the study area to have a single satellite image without clouds, especially for the first decade. For this reason, it was considered to have several images per year and make an annual composition without clouds that serves as an input for this model and allows to validate the trajectory calculations of the pixels of the selected plots.

Then, with LTdr, segmentation is performed for the first band or index selected in the image collection and generates annual vertex-adjusted data for each subsequent band. It is important that the index that serves as a parameter for segmentation is adequate in terms of its sensitivity to change, and for this, two indexes were taken into account: Normalized Difference Vegetation Index (NDVI) and Normalized Burned Ratio (NBR) [18]. Both indices show sensitivity in coverage changes, since they show changes in the sampling area for 1998, however, the Normalized Burn Index (NBR) shows a slight recovery, although without reaching pre-disruption levels. Therefore, the NBR index is taken as input within the LTdr algorithm.

Spectral trajectories allow to know the moments of change of the tree cover of the earth's surface in a timeline, which helps to understand the relationships between the territory of the area of interest and the activities of the people who occupy it. From 30 trajectories identified to validate the algorithm, we selected those ones in which, historically through coverage analysis have been identified as a transformation without recovery within the area of interest.

To determine the sites where to generate the spectral trajectories, the areas currently transformed in the park were identified according to the Map of Terrestrial, Marine and Coastal Ecosystems of the IDEAM (Institute of Hydrology, Meteorology and Environmental Studies), classified by the field "Degree of transformation", which have the attributes of "Natural" and "Transformed"

The "change" area of the park was divided into grids of 1000x1000 meters and centroids for each cell were calculated to take a representative sample and generate the spectral trajectories. To specify the areas to be sampled, a density analysis was carried out that allowed to focus these areas in order to determine the sampling plots. 30 cells were selected for the analysis of spectral trajectories in areas with higher transformation. We also defined the appropriate parameters for the composition of the image collections to be used; so that they have continuous data in the analysis period and that the detected changes are the product of physical changes in the visible characteristics of the earth's surface.

Results and discussion

Results

To understand the evolution of the processes that have led to the transformation of natural coverages, it is also important to have a visual context of the study area. For this reason, the evolution of the territory is shown below through the 1:300,000 scale change maps.

The results of the identification of changes show that, between 1992 and 2003, transformations presented in the park occurred on the course of the Guayabero River (1990), the Guaduas River (1991) and the southern part (1992), in the straight line of the Protected Area (PA), in “La Macarena”. For 1993, 1994 and 1995, no changes were detected, possibly because they did not happen or because the limited availability of cloudless images for that time made it difficult to detect the change; however, in 1996, new disturbances were identified in the central area of the park; which, by 1997, took place to a greater extent, presenting spatial patterns that relate to water flows and the establishment of paths; Processes of change were also evident from the municipality of Uribe (Fig. 2).

In this sense, three fronts of change are recognized, processes that "move" from La Macarena to the south; processes of change that "move" from the municipality of Uribe to the north and processes of change that "move" from San Vicente del Caguán, in Caquetá. by 1998, the processes of change intensified and the transformed areas were consolidated as centers of occupation; patterns of fragmentation are recognized that divide the PA into three islands that did not suffer major alterations, while in the transformed areas, some villages were consolidated that energized the processes of change of natural coverage. By 2000, processes of change were identified that evidence the emergence of a road infrastructure and the construction of the road that enters from the north to the Guayabero River was identified. Historically, armed participants have been present in these areas. In 1998, this area was the subject of a clearing process by the military forces that aimed to negotiate peace with the Revolutionary Armed

Forces of Colombia group (FARC). Subsequently, by 2002, the large coverage changes processes stabilized and the transformation dynamics decreased, however, the change did not stop (Fig. 3).

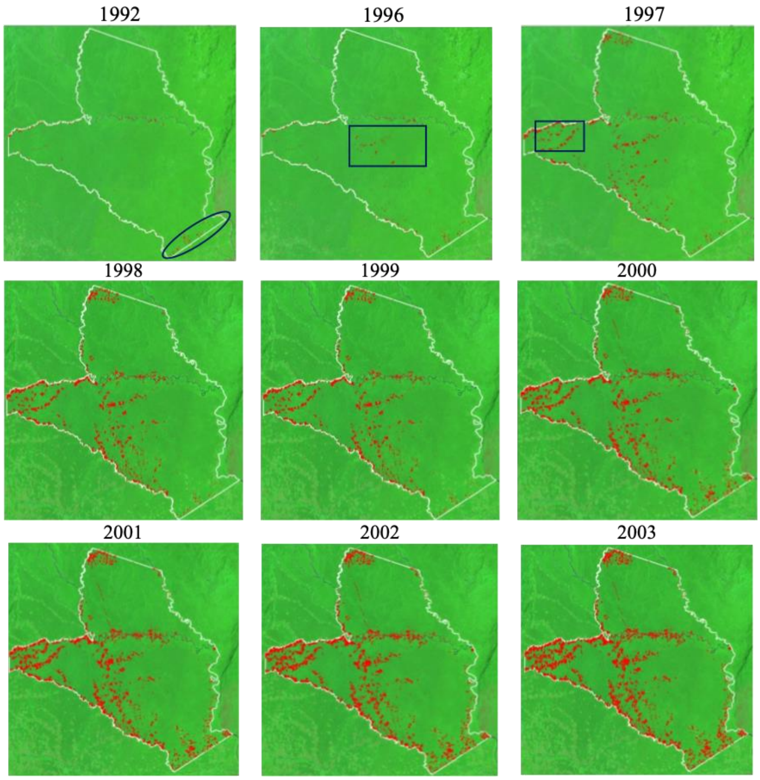

Fig. 2. Transformation 1992-2003 (green: natural, red: transformed)

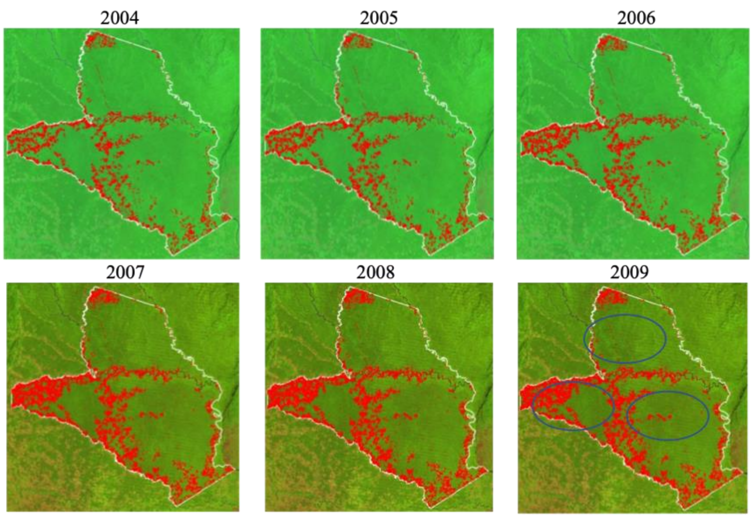

Fig. 3. Transformation 2004-2009 (green: natural, red: transformed)

In later years, three spots of natural coverage were preserved in the PA (2009), separated from each other by consolidated transformation processes in which road infrastructure works and human settlements have been built (Fig. 4).

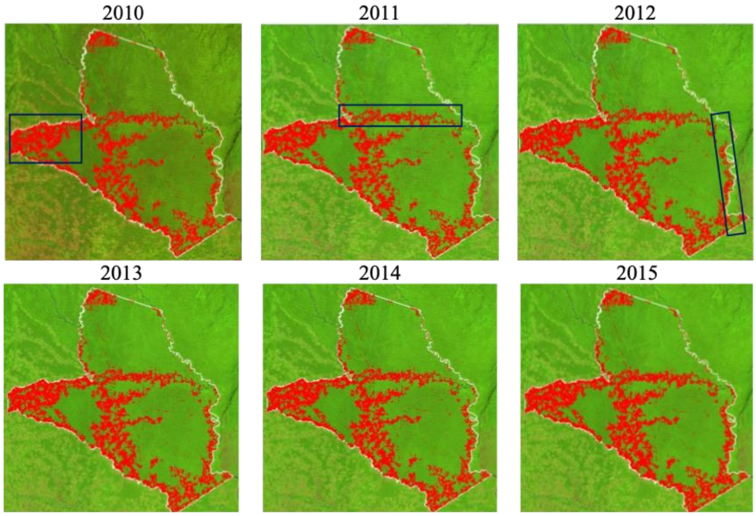

Fig. 4. Transformation 2010-2015 (green: natural, red: transformed)

In later years, it can be seen the consolidation of processes of change in the western area of the PA (2010) and the transformations on the course of the Guayabero River, in the central area of the park. It was also stabilized (2011) in the eastern sector of the PA, on the course of the Guayabero River, where it changed direction from west-east to north-south direction; when it meets La Sierra de la Macarena, there are great transformations that become stable changes.

For 2016 and 2017, some transformations can be identified, but not as quickly as the previous changes; while, for 2018, alterations in the natural coverages are evident through a rapid transformation of the territory (Fig. 5). It can also be seen how the natural areas that previously stability had, in 2018 showed strong processes of change within the polygon.

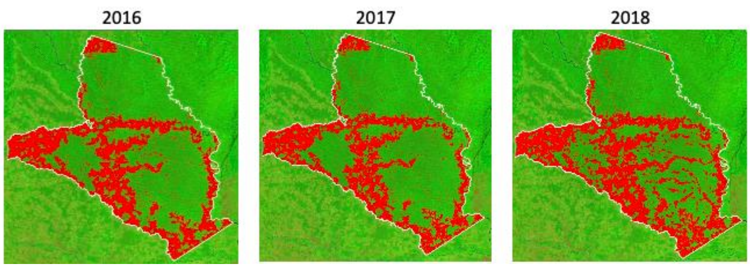

Fig. 5. Transformation 2016-2018 (green: natural, red: transformed)

For 2019 it can be seen that much of the natural coverage of the PA presents important changes and those areas that did not suffer from deforestation dynamics presented strong fragmentation processes.

In the graph of figure 6 you can see three peaks with losses higher than 2.400 hectares per year and how these ones are doubled almost every two years, and it can be the objective of future research, the relationships that these changes may have with climate change phenomena or other variables of anthropic character.

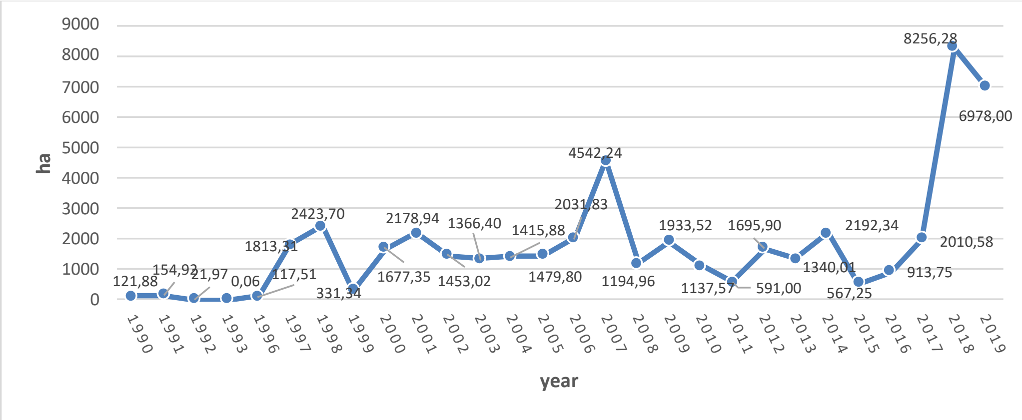

Fig. 6. Change of anthropic natural coverages in the Tinigua NNP

Discussion

The application of remote sensing techniques is generally oriented to know the changes of a geographical space when comparing two images in time, of the before-and- after [19]. However, having historical images of regular periodic sensorization, with the quality and preprocessing level of landsat data [20], allow to establish patterns of change, so that it can be determined more accurately in time when it happened; the shorter the time range taken as a unit of analysis, the better those patterns of territory transformation can be identified.

The use of the LTdr segmentation algorithm for the identification of pixel changes in time and the representation by means of segments for an area of interest allows to know the disturbances that took place there and their behavior in time [20], but the ability to identify these change events depends on the calibration of parameters , on which it is necessary to develop a level of understanding that allows to take the most advantage of the tool through trial and error exercises.

The visual interpretation of the optical images makes it possible to identify and chart the disturbances of the earth's coverages [21]; however, when the work is done over large areas and with many images, carrying out the visual interpretation can be time-demanding, especially if all stages of processing are considered. Based on the above, the LTdr offers a series of parameterization tools that allow the maximum use of landsat time series, devoting more weight in terms of time to the analysis of the results than to the process of standardization and preprocessing of the inputs [22].

Conclusions

The periodic discrimination of changes in the area of interest makes it possible to differentiate the years in which they happened and to establish a relationship with the possible causes of these processes.

The results allow to establish the relationship between the drainages as access ways and their deforestation processes, because, when identifying the patches of change that occurred in the area of interest, more than 90% were found less than 500 meters from a water resource.

The patterns of change indicate that the processes of occupation of the PA began by the water flows as penetration ways to develop later, communication ways that consolidated the occupation of the territory, this caused a fragmentation of the ecosystems and a rapid dynamic of change that identifies the years 1998, 2001, 2007 and 2018 as the years of greatest transformation of the protected area.

The analysis of the spectral temporal segmentation offered by LTdr allows to identify the changes in forest coverage, providing important information about the year of occurrence of the event and its behavior in a timeline, which allowed to go beyond the analyses limited by the availability of official inputs for interpretation of coverage between 2000 and 2012. The inputs of the LandSat 1 to 5 sensors must be processed to make them comparable with recent inputs of better resolution attributes (LandSat 7 and OLI) this is developed internally with algorithms associated with the resolution of the images, which does not allow to know the way in which the processes are carried out and therefore does not allow their adjustment , for this reason, proposing methodologies such as batch subdivision that is nothing more than dividing the data into containers so that its size is a fraction of the total data, or processing the data by types of sensors to integrate the information at the end, this can improve the processing results for future researches.

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