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ANÁLISIS DEL CAMBIO DE USO DEL SUELO MEDIANTE TÉCNICAS DE TELEDETECCIÓN Y SIG EN EL BOSQUE DE CAZADEROS, PROVINCIA DE LOJA, SUR DE ECUADOR.

ANALYSIS OF LAND USE CHANGE USING REMOTE SENSING AND GIS TECHNIQUES IN THE CAZADEROS FOREST, LOJA PROVINCE, SOUTHERN ECUADOR.

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ABSTRACT

The predominant aim of the current study has been to determine land use change over a period of eight years in the Cazaderos dry forest in the province of Loja in Ecuador using remote sensing and GIS techniques. The methodology employed included the application of supervised classification of multispectral satellite images applied to freely available Landsat 8 images using Catalyst image processing software and the application of the Object Analysis technique, which is presented as the methodological protocol in remote sensing that offers the highest level of accuracy. This process was accompanied by complementary Geographical Information System (GIS) techniques that allowed spatialization and quantification of the resulting information. The Cazaderos dry forest in the period of analysis has suffered a significant spatial fragmentation dominated by the current presence of bare soils that were previously covered by dense shrubs and have undergone a process of deforestation. During the period 2013 - 2021 the deforestation process extended to an area of 1273.95 ha corresponding to 15.21% of the total surface of the study area while reforestation reached 1426.86 ha corresponding to 17.04% of the total surface.

Keywords: Land use, Deforestation, Remote sensing, GIS, Cazaderos, Loja.

RESUMEN

El objetivo predominante del presente estudio ha sido determinar el cambio de uso del suelo durante un período de ocho años en el bosque seco de Cazaderos en la provincia de Loja en Ecuador utilizando técnicas de teledetección y SIG. La metodología empleada incluyó la aplicación de clasificación supervisada de imágenes satelitales multiespectrales aplicadas a imágenes Landsat 8 de libre acceso utilizando el software de procesamiento de imágenes Catalyst y la aplicación de la técnica de Análisis de Objetos, que se presenta como el protocolo metodológico en teledetección que ofrece el mayor nivel de precisión. Este proceso se acompañó de técnicas complementarias del Sistema de Información Geográfica (SIG) que permitieron espacializar y cuantificar la información resultante. El bosque seco de Cazaderos en el periodo de análisis ha sufrido una importante fragmentación espacial dominada por la presencia actual de suelos desnudos que anteriormente estaban cubiertos por arbustos densos y que han sufrido un proceso de deforestación. Durante el periodo 2013 - 2021 el proceso de deforestación se extendió a una superficie de 1273,95 ha correspondientes al 15,21% de la superficie total del área de estudio mientras que la reforestación alcanzó las 1426,86 ha correspondientes al 17,04% de la superficie total.

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Palabras clave: Uso del suelo, Deforestación, Teledetección, SIG, Cazaderos, Loja.

INTRODUCTION

Studies on the change in land cover and land use provide the foundations for de-termining trends in deforestation, degradation, and desertification processes in a given region (Lambin et al., 2001). Deforestation is a process that became more acute during the last two centuries as population density quadrupled and more forest area disappeared than during the entire history of humanity on Earth (Cincotta, R. P., J. Winsnewski, y R. Engelman 2000). Hereby, the soils have lost their functionality and structure in the last decades due to the intensification of agricultural production, deforestation and the increase in pollution levels of industrial origin (Azqueta, D., Alviar, M., Domínguez, L. & O´Ryan, R., 2007).

Los Cazaderos dry forest has been less studied than its next fields, the humid forests, which results to a ratio of approximately one study in dry forests for every six in humid forests (Sánchez, 2015). In addition, the knowledge of these forests is very biased towards certain areas, while others are very little known. Dry forests are ecosystems that are characterized by a well-marked seasonality, where much of the year the vegetation loses its foliage due to the lack of rainfall. The first rains, generally at the end of the year, cause the appearance of leaves and the massive flowering of some plant species, which radically transform dry landscapes (Barreto-Álvarez, D.E., Heredia-Rengifo, M.G., Padilla-Almeida, O. and Toulkeridis, T., 2020). In the dry forest of southwestern Ecuador, 313 woody species (shrubs and trees) have been recorded, of which 136 have been reported only for Ecuador, where 67 species (21 % of the total) were endemic (Aguirre, Z. y L.P. Kvist, 2006).

The biodiversity of this ecosystem, despite its biological importance, is endangered by anthropic actions that take place in those sites. This is why it is considered one of the most threatened and degraded habitats in the tropics, which is adds to high levels of poverty, with a population that depends on the natural resources of these forests. Over the years the change in land use and deforestation are the main causes of the loss of native vegetation and primary forests, the conversion of use to-wards livestock farming, or agriculture are activities that since ancient times have served as a means of livelihood for families in rural areas. Likewise, the demo-graphic expansion due to the increase in population in urban areas increase the pressure on forests.

Extensive deforestation is the main threat and hazard to biodiversity. It is closely linked to the use of the ecosystem, in relation to the technology available to cut down the forest and take advantage of the soil depending on the degree of trans-formation and the time of use. The change in land use and vegetation cover associated with habitat fragmentation is one of the most severe effects of human activities on the face of the earth (Soulé, M. y Orians., G., 2001). This research seeks to contribute to knowledge about the change in land use and defor-estation over the years in order to implement actions that help curb deforestation by quantifying the deforested area, as well as identifying focal sites for interven-tion and thus contribute to preserving our dry forests as the invaluable resource that it is.

In June 2014, the UNESCO declared 501,040 hectares as a Biosphere Reserve called “Bosque Seco”, located in the provinces of Loja and El Oro. The Bosque Seco Biosphere Reserve is composed of the cantons of Zapotillo, Macará, Puyan-go, Loja. Pindal and Celica (grouped in the Bosque Seco Mancomunidad, which coordinated the inter-institutional efforts to achieve this recognition), plus Paltas and Sozoranga, to which canton Las Lajas, in the province of El Oro, is added. The goal is to create a large binational reserve that includes the Bosque Seco and Northwest Peru biosphere reserves.

The core area of the Biosphere Reserve has 83,000 hectares of municipal areas and 9,000 that belong to the Socio Bosque Program of the Ministry of Agriculture and Livestock (MAE), an initiative to combat deforestation and promote forest conservation, which have reached a conservation status thanks to municipal ordi-nances. On the other hand, through the management of the Decentralized Auton-omous Governments, conservation measures are also promoted. This includes the initiative developed in the Zapotillo canton, province of Loja, which in 2013 de-clared the Municipal Ecological Reserve Los Guayacanes in order to protect 17,265 hectares of forest, which since then offers the local population an alternative to promote ecotourism.

It is worth to mention that currently the Cazaderos reserve is a private reserve managed by the International Nature and Culture organization. Between the community and the organization, four private reserves have already been established, of which the first two baptized as La Ceiba and Cazaderos Natural Reserve, enclosing close to 18,000 hectares and where around 170 families live. The Cazaderos Reserve is considered the most pristine dry forest in Ecuador and tourism around the flowering of the Guayacanes is being promoted in it. The basic concept is to guarantee the rights of use over the resources of these forests. These were people who never had secure rights to the land. As for the La Ceiba Natural Re-serve, 80 titles of possession were processed and there are another 90 waiting to be recognized. Nature and Culture International defined management agreements and arrangements with the communities that live in this area, with which access to the resources of the place is guaranteed. Among the most relevant commitments are, for example, that the populations are prohibited from dedicating themselves to monocultures such as corn, the timber trade and hunting.

Through the generation of income from the hand of conservation, Nature and international culture promotes the conservation of the dry forest, for example, the extraction of oils from Palo Santo, Beekeeping and Ecotourism are some of the alternatives with which it is sought allowing a sustainable use of the resources of this ecosystem.

In addition to deforestation due to the expansion of the agricultural frontier, illegal logging, mining, oil exploitation and infrastructure, factors that have contributed to a strong change in land cover and land use in the country are policies of misdirected colonization accompanied by laws that promoted deforestation (granted economic advantages to other land uses over forest use), insecurity in land tenure, undervaluation of forests and timber, and weak state control.

Based on the aforementioned, the main objective of this work is to analyze the change in land use and deforestation in a period of eight years (2013 - 2021) in the dry forest of Cazaderos applying the Object-Based Classification Methodology. Furthermore, we will perform a geostatistical and spatial treatment of land use changes through the application of Geographic Information Systems (GIS).

METHODOLOGY

STUDY AREA.

This research work is situated in the buffer zone of the Cazaderos Reserve, which is located to the southwest of the Zapotillo canton, Loja Province (Figure 1). This private reserve is owned by Nature and Culture International, which is responsible for its management for the conservation of dry forest remnants. The reserve has a surface area of 8,392.80 hectares, comprising 15.12% alfisols, 48.98% aridisols, 31.34% entisols and 4.57% inceptisols with loam - clay - silty and loam - clay - sandy textures respectively. They are presenting a depth between the classes being very superficial 6.23%, superficial 19.25%, moderately deep 67.16% and shallow 7.35% with a practically neutral pH and medium natural fertility. The canton is located between 193 and 1496 meters above sea level (PDOT. (2021). The types of soil existing in the dry forest of Cazaderos by its texture and depth characteristics (Ministerio de Agricultura y Ganadería (MAG, 2022). Its slope that is dominated by the strong classes (> 40 - 70%) 41.00%, medium (> 12 - 25%), 19.71% and medium to strong (> 25 - 40%) 19.33%, which are fragile due to erosive processes when replacing the native forest cover. Hereby exists and increasing risk of accelerated erosive processes that could lead to mass removal due to precipitations. In the same way, being very superficial and developing soils, the establishment of agricultural crops would not be the most appropriate since many crops need to deepen their roots for their vegetative development and in these soils, they will not find enough nutrients.

According to the (PDOT, 2021) of the Zapotillo canton, the canton presents an average annual temperature that oscillates between 21 and 26 ° C, while the months of May to December the Cazaderos parish presents a temperature between 23 and 24 ° c. On the other hand, the precipitation is very variable, being between 300 to 1000 mm depending on the time of the year. The highest rainfall, however, occurs in the months of January, February, and March.

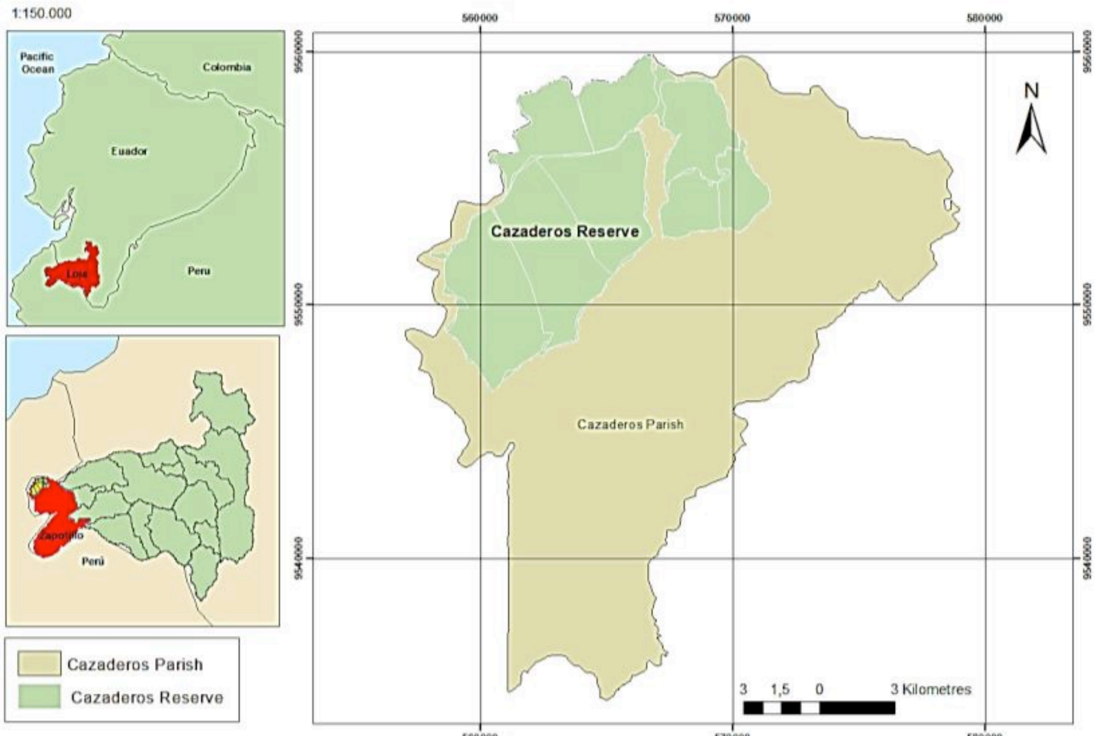
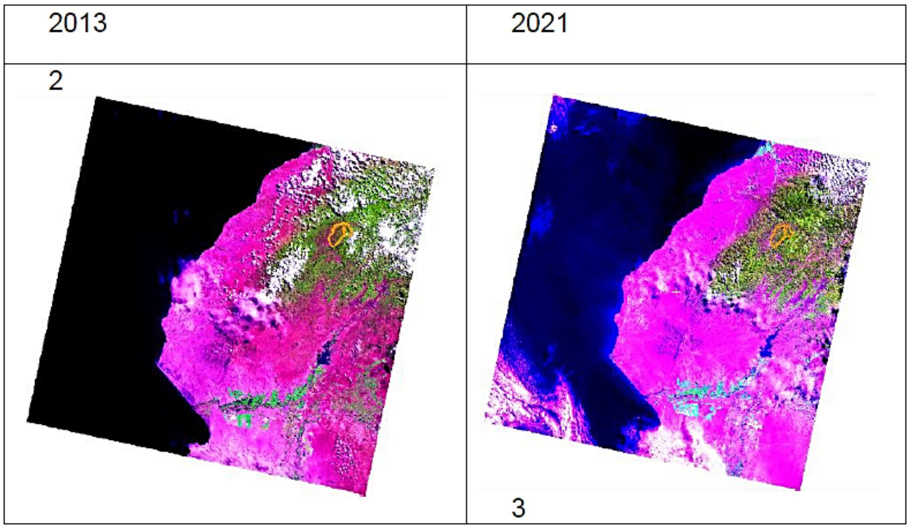


Figure 1. Geographical setting of the dry forest of Cazaderos. Source: Based on IGM 2022.

INFORMATION GATHERING AND CORRECTION OF SATELLITE IMAGES.

Cantonal and provincial cartographic information of Ecuador was selected in vector format (shape) and at a scale of 1:50,000 contained in free access repositories of Ecuador such as the Military Geographic Institute (Instituto Geográfico Militar, IGM. 2022). In the same way, images from the Landsat 8 satellite were downloaded, contained in free repositories such as the United States Geological Service (USGS, 2013) corresponding to the years within from the period 2013 - 2021 of the Cazaderos parish. It is worth mentioning that it should be considered that the images have a maximum 20% cloudiness within the study area (Chuvieco, 2008).

We preferred to work with Landsat 8 images instead of Landsat 7 (Instituto Nacional de Estadística y Geografía, 1993) because the latter present banding at the ends of the image bands as a result of a technical problem with the sensor. In the case of Landsat 9 images, it has been obvious to this study considering that in general they are quite similar to the Landsat 8 images. The Landsat 8 images used for this study correspond to the years 2013 (code LC08_L1TP_011063_20130511_20200913_02_T1_ANG) and to the year 2021 (code LC08_L1TP_011063_20210517_20210525_01_T1_ANG). Figures 2 and 3 illustrate the Landsat 8 satellite images corresponding to the years 2013 and 2021 in an RGB:654 composition with the delimitation of the Cazaderos dry forest.



Figures 2 and 3. Landsat images, RGB composition: 6, 5,4 years 2013 and 2021. Source: Own elaboration.

TECHNICAL CHARACTERISTICS OF LANDSAT 8 MULTISPECTRAL IMAGES.

Landsat has provided repetitive, global, synoptic, moderate spatial resolution coverage of the Earth's land surfaces. Landsat 8 extends Landsat's remarkable 40-year record and has enhanced capabilities. The Landsat Data Continuity Mission was successfully launched on February 11, 2013. It was officially renamed Landsat 8 on May 30, 2013. Most significantly, it can observe Earth at wavelengths that allow scientists to adjust for distortions caused especially by the atmosphere near the coast (http://earthobservatory.nasa.gov/IOTD/).

Landsat 8 carries two instruments, being the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI, a broom sensor with a four-mirror telescope, collects data in the visible, near-infrared, and shortwave-infrared wavelength regions, as well as in a panchromatic band. Two new spectral bands have been added, being a deep blue band for studies of coastal waters and aerosols (band 1), and a band for cirrus detection (band 9). A quality control band is also included to indicate the presence of terrain shadows, data artifacts, and clouds. Panchromatic and multispectral data are taken with a resolution of 15 and 30 meters respectively. TIRS collects data in two long-wavelength thermal infrared bands. The 100-meter spatial resolution of the TIRS data is recorded in the OLI data to create terrain-corrected, radiometrically, and geometrically calibrated 16-bit Level 1 data products.

kind of product	Level 1T (terrain corrected)
Type of data	16-bit unsigned integer
Output format	GeoTIFF
Pixel size	15 meters/30 meters/100 meters (panchromatic/multispectral/thermal)
Map projection	UTM (Polar Stereographic for Antarctica)
Datum	WGS 84
Orientation	North-up (map)
Resampling	Cubic convolution
Precision	OLI: 12 meters circular error, 90 % confidence
	TIRS: 41 meters circular error, 90 % confidence

Table 1. Processing parameter for Landsat 8 standard data products USGS. Source: Own elaboration with information from USGS.

Landsat 8 data products are consistent with all standard Tier 1 (orthorectified) data products created with Landsat 1 through Landsat 7 data. It consists of quantized and calibrated Digital Numbers (DN) representing multispectral imagery data acquired by the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Products are delivered in 16-bit unsigned integer format (scaled to 55,000 gray levels) and can be rescaled to TOA reflectance and/or radiance using the provided radiometric rescaling coefficients in the product metadata file (MTL file). The MTL file also contains the thermal constants needed to convert the TIRS data to the satellite brightness temperature.

Sensors Landsat 8	Banda	Name of band	Longitud de wave (µm)	Resolution (m)	Aplications
Operational Land Imager (OLI)	1	Coastal / Aerosol	0.433-0.453	30	Coastal and Aerosol studies
	2	Blue	0.450-0.515		Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
	3	Green	0.525-0.600		Emphasizes peak vegetation, which is useful for assessing plant vigour
	4	Red	0.630-0.680		Discriminates vegetation slopes
	5	Near Infrared (NIR)	0845.-0.885		Emphasizes biomass content and shorelines
	6	Short-wave Infrared (SWIR) 1	1.560-1.660		Discriminates moisture content of soil and vegetation; penetrates thin clouds
	7	Short-wave Infrared (SWIR) 2	2.100-2.300		Improved moisture content of soil and vegetation and thin cloud penetration
	8	Panchromatic	0.500-0.680	15	Sharper image definition
	9	Cirrus	1.360 - 1.390	30	Improved detection of cirrus cloud contamination
Thermal Infrared Sensor (TIRS)	10	Long-wave Infrared (LWIR) 2	10.30 – 11.30	100*	Thermal mapping and estimated soil moisture
	11	Long-wave Infrared (LWIR) 2	11.50-12.50		Improved thermal mapping and estimated soil moisture
	BQA	Quality Assessment			Quality assessments for every pixel in the scene
* TIRS bands are acquired at 100-meter resolution but are resampled to 30 meter in delivered data product.					

Table 2. Properties and applications of the Landsat 8 bands Source: USGS, 2013.

OBJECT-BASED CLASSIFICATION USING CATALYST SOFTWARE.

Subsequently, through the Catalyst program, the supervised classification of the Landsat 8 multispectral images will be carried out using the Object Analysis technique that is related to object-based image classification, which groups the pixels into a set of vector shapes representative with size and geometry, which includes the following methodological steps as shown in Figure 4.

Figure 4. Methodological steps of Object-Based Classification (PCI Geomatics). Source: CEPEIGE, (2022).

Segmentation

Allows to create a vector layer of the polygonal type on the image, delimiting the pixels or groups of pixels with different shapes and concentrations based on the calibration of the scale, shape and compactness options that will depend on the resolution of the satellite image.

Statistics calculation

It allows assigning statistics to each object such as band statistics (min, max, mean, Std Dev), geometric statistics (compactness, circularity, elongation, rectangularity and others), Vegetation Indices, among others.

Selection of training areas

The training sites include information collected in the field or analyzed in secondary sources in order to calibrate the classification model, they can also be established by selecting coverages such as crops, forests, infrastructure, water, cloud and cloud shadows that start from the superimposition of bands from multispectral satellite images in RGB composition.

Classification

Group segments into relevant classes. One can run a supervised classification (requires training areas) or unsupervised.

Post sort editing

Once the classification has been performed, there is the possibility that some units have been wrongly classified, which is why it is necessary to conduct an editing process. One can use Automatic Dissolve (Automatic Function) or Interactive Edits (Manual Function).

Accuracy Evaluation

Additionally, a confusion matrix can be generated to measure the level of precision of the used classification. Precision is the closeness in a set of repeated measurements that are considered independent. Assessment of classification accuracy is performed by comparing reference data taken from the training areas and the classification field. There are several methods of classification precision analysis, such as (Cohen, 1960) Kappa precision calculation.

Change of use analysis

The determination of the soil change in the dry forest of Cazaderos was realized with the help of the GIS and its geoprocessing tools to synthesize the classifications of the years of interest and with these results obtain the dynamic tables in a spreadsheet (Jason et al., 2010).

RESULTS AND DISCUSSION

The supervised classification of the Cazaderos dry forest applying the object-based classification technique for the year 2013 is illustrate in Figure 5.

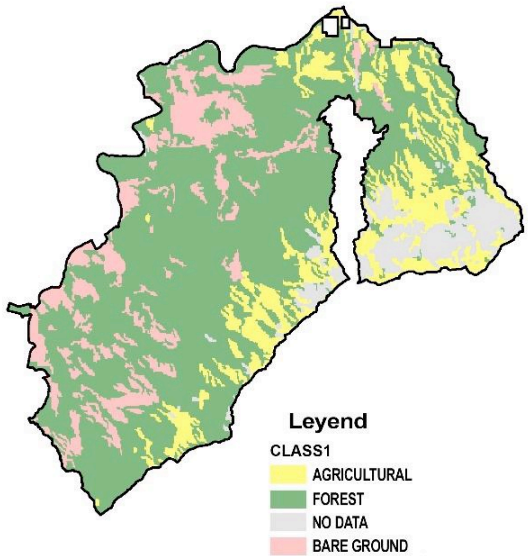


Figure 5. Land cover year 2013. Source: Own elaboration.

Table 3 lists the surfaces obtained for the land cover corresponding to the year 2013. It can be noted that for that year in the study area the forest cover with 5301.72 ha concentrates 63.30% of the total area of the dry forest of Cazadero (Podwojewski, P., Poulenard, J., Toulkeridis, T. and Gräfe, M., 2022). The agricultural cover with 1321.11 ha occupies 15.77% of the total area while the bare soil cover with 1101.96 ha extends to 13.16% of the total surface of the study area.

2013	Area (ha)	Relative area (%)
AGRICULTURAL	1321.11	15.77%
FOREST	5301.72	63.30%
NO DATA	650.16	7.77%
BARE GROUND	1101.96	13.16%
Total area	**8374.95**	**100.00%**

Table 3.Land cover areas year 2013. Source: Own elaboration.

The supervised classification of the Cazaderos dry forest applying the object-based classification technique for the year 2021 is illustrated in Figure 6.

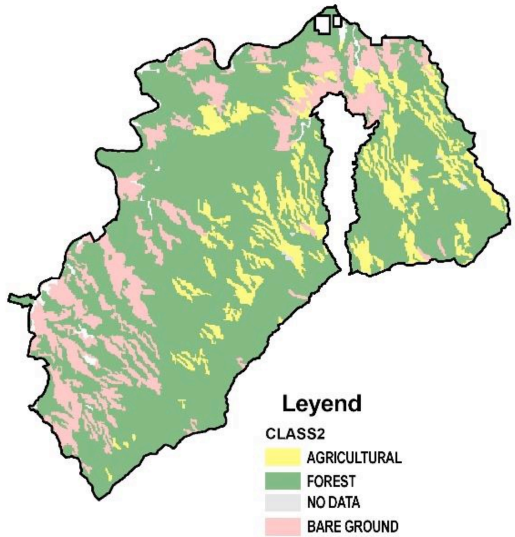


Figure 6. Land cover year 2021. Source: Own elaboration.

Table 4 lists the surfaces obtained for the land cover corresponding to the year 2021. In the study area the forest cover with 5940.09 ha concentrates 70.93% of the total surface of the dry forest of Cazaderos, while the agricultural cover with 1004.4 ha covers 11.99% of the total area. The bare soil cover with 1316.88 ha extends to 15.72% of the total surface of the study area.

The analysis of the soil change of the dry forest of Cazaderos in the eight years of study is presented in Figure 7.

The analysis of the change in land use during the period 2013 – 2021 (Table 5) allowed to appreciate the deforested and reforested surfaces. It is clear that the deforestation process in these eight years of analysis has extended in an area of 1273.95 ha corresponding to 15.21% of the total surface of the study area while the reforestation process has been expressed through the establishment of 1426.86 ha corresponding to 17.04% of the total área.

2021	Area (ha)	Relative area (%)
AGRICULTURAL	1004.4	11.99%
NO DATA	113.58	1.35%
FOREST	5940.09	70.93%
BARE GROUND	1316.88	15.72%
Total area	**8374.95**	**100.00%**

Table 4. Land cover areas year 2021. Source: Own elaboration.

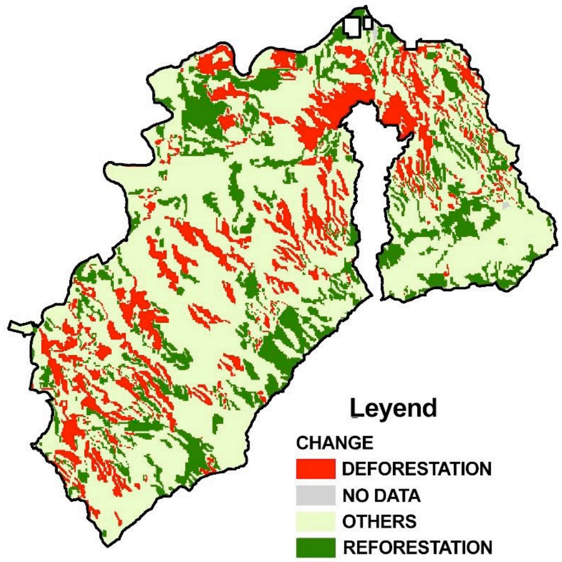


Figure 7. Land cover change in the period 2013 - 2021. Source: Own elaboration.

LAND USE CHANGE	Area (ha)	Relative area (%)
DEFORESTATION	1273.95	15.21%
NO DATA	13.59	0.16%
OTHERS	5660.55	67.59%
REFORESTATION	1426.86	17.04%
Total area	**8374.95**	**100.00%**

Table 5. Land use change surfaces in the period 2013 – 2021.

The deforestation process that the Cazaderos reserve has suffered over the last eight years has had as its main cause the selective felling of forest species such as the Guayacán and the Hualtaco, resulting in very serious consequences for the ecosystem (Suango et al., 2022). Deforestation increased due to its easy commercialization through illegal passages towards the Republic of Peru. Additionally, it should be considered that in the 1990s a considerable extension was converted into agricultural land, mainly for the activity livestock. Next, Table 6 presents the confusion matrix of the present study, which was built from the contrast of land uses and their surfaces for the years of study, 2013 and 2021, allowing to observe the transitions of the different land covers occurred and thus understand the dynamics of the afforestation and reforestation processes.

	2021				
2013	**AGRICULTURAL**	**FOREST**	**NO DATA**	**BARE GROUND**	**TOTAL**
AGRICULTURAL	396.36	826.2	6.39	92.16	1321.11
FOREST	483.66	3971.16	56.61	790.29	5301.72
NO DATA	72.54	542.07	13.59	21.96	650.16
BARE GROUND	51.84	600.66	36.99	412.47	1101.96
TOTAL	**1004.4**	**5940.09**	**113.58**	**1316.88**	**8374.95**

Table 6. Confusion matrix in land use change in the period 2013 – 2021. Source: Own elaboration.

CONCLUSIONS AND RECOMMENDATIONS

The land use classification of the Cazaderos dry forest applying the object-based classification technique using the Catalyst software proved to be very efficient in spatializing and quantifying with high precision the deforestation and reforestation processes that occurred in the study area.

GIS proved to be powerful geospatial tools for geostatistical analysis for the syn-thesis of a large amount of quantitative and qualitative data of the territory ex-pressed in the Cazaderos dry forest.

The results of the analysis of the temporal-spatial change of land use, during the eight years of analysis in the study area, yield a deforestation of 1273.95 ha that has spread in the north and center of the dry forest and that is a consequence of the exploitation of timber species of this ecosystem.

The use of RGB color combinations is recommended to more accurately discriminate forest cover and avoid overestimation of bare soil areas and underestimation of tropical dry forest cover.

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