Multi-temporal analysis of change in land use through remote perception in the Tosagua canton

Análisis multitemporal de cambio de uso de suelo mediante percepción remota en el cantón Tosagua

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Abstract

Multi-temporal analysis allows to discover changes between different reference dates, following the evolution of the natural environment and the consequences of human action on it. The purpose of the study was to carry out a multitemporal analysis of land use change in the Tosagua Canton in the period 2017-2023, through satellite images, in order to know the state of fragmentation of the vegetation cover. The changes in land use of the canton were obtained, resulting in a total change rate of 9% in 6 years. Using the supervised classification, it was possible to generate thematic maps with four classes of land use where field verification was carried out to identify land cover and it was established that for the period 2017-2019, the vegetation and agricultural land cover was 13,956.60 ha with 19,430.86 ha of vegetation cover. For 2019-2021, a vegetation cover of 10,280.03 ha and 23,980.97 ha of agricultural land was recorded and for 2021-2023 the vegetation cover area was 10,120.01 ha with 24,1134.07 ha of agricultural land. The rate of change in the use of cover was observed with a decrease of 14% during the years 2017 and 2019, while for the years 2021 and 2023 a notable recovery of the vegetation cover is observed with 6%. In addition, an overall reliability of the actual and inferred coverage of 83.8% was achieved, which indicates that the classification of land uses in the Tosagua canton is admissible.

Keywords: satellite images, remote sensing, supervised classification, validation.

Resumen

El análisis multi-temporal permite descubrir cambios entre diferentes fechas de referencia, siguiendo la evolución del medio natural y la consecuencia de la acción humana sobre el mismo. El propósito del estudio fue realizar un análisis multi-temporal de cambio de uso del suelo en el Cantón Tosagua en el periodo 2017-2023, a través de imágenes satelitales, con el fin de conocer el estado de fragmentación de la cobertura vegetal. Se obtuvo los cambios de usos del suelo del cantón teniendo como resultado una tasa de cambio total de 9% en 6 años. Utilizando la clasificación supervisada fue posible generar mapas temáticos con cuatro clases de uso del suelo en donde se efectuó la verificación en campo para la identificación de cobertura de suelo y se estableció que para el periodo 2017-2019, la cobertura vegetal y de tierras agropecuarias fue de 13.956,60 ha con 19.430,86 ha de cobertura vegetal. Para el 2019-2021, se registró una cobertura vegetal de 10.280,03 ha y 23.980,97 ha de tierras agropecuarias y para el 2021-2023 la superficie de cobertura vegetal fue de 10.120,01 ha con 24.113,407 ha de tierras agropecuarias. La tasa de cambio en el uso de cobertura se observó con una disminución del 14% durante los años 2017 y 2019, mientras que para los años 2021 y 2023 se observó una notable recuperación de la cobertura vegetal con un 6%. Además, se logró obtener una fiabilidad global de la cobertura real y deducida de 83,8% lo que indica que la clasificación de usos de suelo en el cantón Tosagua es admisible.

Palabras clave: imágenes satelitales, sensores remotos, clasificación supervisada, validación.

Introduction

Land-use change and the loss of vegetation cover are among the main problems affecting humanity, as they are major contributors to global climate change and are directly related to food production security, human health, urbanization, biodiversity, and the quality of water and soil (López, 2006).

In Ecuador, agraraian reforms and land conlozations starting in the 70's have accelerated land-use change. Ninety-nine point four percent of the deforested area between 1990 and 2000 have been transformed into agricultural land, 0.14% in infraestructure, mainly in urban areas and dense rural settlements, and 0.46% into other types of covers. The expansion of agricultural land depended on deforestation: approximately 97.5% of the increase in these area were caused by land change for farming and pasturing. The most important factor for land-use change were a series of agricultural exports booms, mainly in the coastal region: Cacao (1860-1940) and bananas (1950-1973). Other lesser cycles such as ivory palm and rubber required less tranformation of forested areas, and to a certain extent, depended on forests (Sierra, 2013).

Land use in the Manabí province comprises approximately 1,572,962 ha, 44% is destined for livestock in which the province is very succesful; land conservation and protection occupies 31%, comprising all natural vegetation such as forests and scrubland; 21% is used by the agricultural sector, including short cycles, semipermanent, permanent; and 5% dedicated for other uses (Instituto Espacial Ecuatoriano; Ministerio de Agricultura y Ganadería, 2022).

Currently, effective technologies such as remote sensing and geographic information systems (GIS) are successfully applied to identify the spatial footprint of these impacts and to support decision-making that enables managers to take corrective and forward-looking actions (Ponvert and Lau, 2013). The main objective of multi-temporal studies is to find a way to combine or integrate multiple images from different dates, reflecting different phenological stages of vegetation, in order to improve the accuracy of classifications (Romero, 2006).

According to Gónima et al. (2010) the use of satellite imagery is a powerful tool for the study and monitoring of natural and anthropogenic phenomena occurring within the earth-atmosphere surface system. The images obtained by satellites offer a unique and specific perspective of the earth, its resources, and the impact of human activity on it. Remote sensors have proven to be an important source of information for a wide range of applications, including urban planning, environmental monitoring, crop management, oil prospecting, mining exploration, land use, and real estate localization, among others (Cardozo and Da Silva, 2013).

The objective of this research was to determine land use change using geographic information systems (GIS) for the period 2017-2023, in order to calculate the percentage of land use variation in the study area, and to validate the results using a confusion matrix.

Materials and methods

The present study was conducted in Tosagua municipality, located at coordinates 0°47'20.49" S and 80°14'4.94" W, with the aim of obtaining a land use classification and identifying the changes that occurred during the period 2017-2023.

Surveying and marking the zone of study

Field surveys were conducted in Tosagua municipality, which has a total area of 37,323.44 hectares. The study area was defined through 68 control points. For the fieldwork, a GPS navigator and a field notebook were used to record the location data of the various land cover and land use types within the municipality.

Obtaining sattellite images of the zone of study

The images were obtained through the Planet Explorer platform, which offers a vast amount of spatial information, particularly the Sentinel-2 image repository from various periods. Four images with a spatial resolution of 10×10 meters were selected for the identification of land cover types.

Image selection

Satellite images were obtained from the Sentinel-2 satellite for the years 2017, 2019, 2021, and 2023, during the months of June and July. Efforts were made to select images with the lowest percentage of cloud cover within the study area—specifically, those with less than 10% cloud coverage, as this is a recurring issue in the study region.

Georeferences of spatial data

The images were georeferenced using ArcGIS software, based on coordinates in the Universal Transverse Mercator (UTM) projection, Datum: WGS 84, Zone 17 South.

Supervised classification

This classification was based on the availability of study areas with known class membership, using point selection algorithms

to generate a spectral signature for each class, in addition to having prior knowledge of the study area (table 1).

Table 1. Class and categories classification, and use of land.

Informal classes	Categories
Plant cover	Native forests
	Forestry plantations
	Grass plants
	Short-cycle farming
Agricultural lands	Semi-permanent plantations
	Permanent plantations
Water bodies	Swamps, rivers, others
Anthropic zones	Populations, roads
No data	Cloudiness issues

Confusion matrix

A confusion matrix was used to assess the accuracy of the classification compared to the field observations. This method is one of the most commonly used, as the matrix contains information on the total values or percentages of observed and estimated data for each classified feature or property. From this matrix, various parameters can be calculated to indicate the classification's precision.

According to Chuvieco (1995) the estimation of a map's accuracy can be carried out using three basic criteria: by comparing the classification inventory, by evaluating the reliability of the training area classifications to verify whether they correctly fit the intended categories, and by selecting specific verification areas.

Land use rate

To calculate the annual rate of land use change, the equation proposed by the Food and Agriculture Organization of the United Nations (FAO, 1996) was used.

$$TDA: Tasa = \left[\frac{S_2}{S_1}\right] 1/n - 1$$

Where: TDA= annual change rate, S_2= surface in date 2, S_1= surface in date 1, n= number of years between the two dates (Ruiz et al., 2013).

Results and discussion

After the analysis of the different pictures taken by the Sentinel-2 throughout the years, the following data was obtained

Land use change data bases in the municipality of Tosagua

By performing supervised classification of the Sentinel-2 images from the years 2017, 2019, 2021, and 2023, the following data were obtained regarding the land use changes that occurred during the different years (table 2).

Table 2. Land use change data bases in the municipality of Tosagua between 2017-2023.

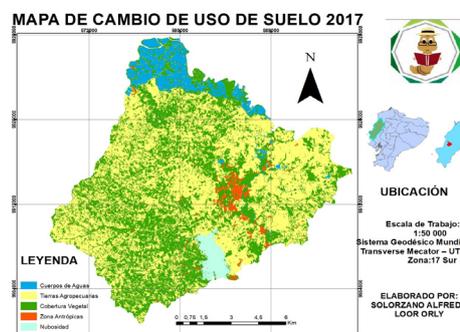| Years		Plant cover	Agricultural lands	Body of water	Anthropic zones	Cloudiness
2017	Area (ha)	13,956.59	19,430.85	2,284.3	640.11	818.18
	%	37.6	52.3	6.2	1.7	2.2
2019	Area (ha)	10,280.02	23,980.97	2,400.52	661.92	
	%	27.5	64.3	6.4	1.8	
2021	Area (ha)	10,120.01	24,613.4	2,577.27	640.7	
	%	26.7	64.9	6.8	1.6	
2023	Area (ha)	11,437.58	22,029.97	2,509.64	735.16	881.63
	%	30.4	58.6	6.7	2.0	2.3

Figure 1. Land use change in Tosagua, Ecuador, 2017.

In this regard, Bianco et al. (2021) argued that the increase in agricultural land was due to the expansion of agriculture to meet the demand for agricultural products, which coincided with the predominance of this land use in Tosagua (figure 2). Additionally, Carranza et al. (2024) emphasized that deforestation and the conversion of forests into farmland were common practices that significantly affected vegetation cover, reflecting a reduction in natural areas in favor of intensive agricultural land use.
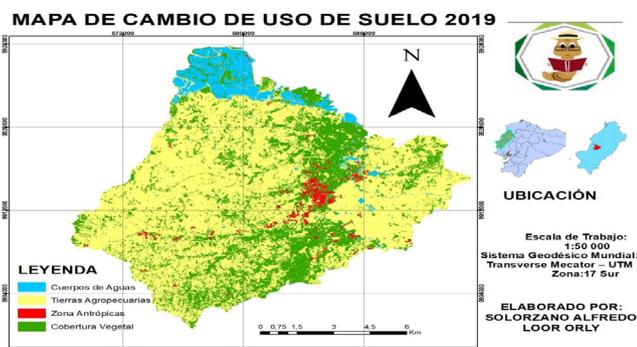
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Figure 2. Land use change in Tosagua, Ecuador, 2019.

Figure 3. Land use change Tosagua, Ecuador, 2021.

Regarding vegetation cover, Benítez (2022) argued that it is important to maintain these areas for the conservation of biodiversity and the regulation of local climate. The presence of water bodies (6.2%; 2,284.30 ha), anthropic zones (1.7%; 640.11 ha), and cloud cover (2.2%; 818.18 ha) was lower but still relevant. Hoyos et al. (2022) pointed out that, although water bodies were less extensive, they were essential for the hydrological sustainability of agricultural regions, while anthropic zones reflected urban growth and its impacts on land use.

This phenomenon was consistent with the observations of Bianco et al. (2021), who highlighted the increasing trend of intensive agriculture in rural areas of Ecuador, implemented to meet the growing demand for food. Lozano et al. (2021) also noted that the conversion of forests into agricultural land was a common practice, which explained the significant reduction in vegetation cover in favor of agricultural uses. Additionally, Alemán et al. (2021) warned of the environmental implications of this transformation, stressing the loss of biodiversity and negative effects on local climate regulation.

On the other hand, water bodies maintained a similar proportion, slightly increasing from 6.2% (2,284.30 ha) to 6.4% (2,400.52 ha), which was crucial for water sustainability, as noted by Hoyos et al. (2022). Anthropic zones also showed a slight increase, from 1.7% (640.11 ha) to 1.8% (661.92 ha), indicating moderate urban growth that could impact territorial structure and land use (figure 3).

This pattern of change aligns with the studies of Bianco et al. (2021), who noted that agricultural expansion in Ecuador has been a response to the growing demand for agricultural products.
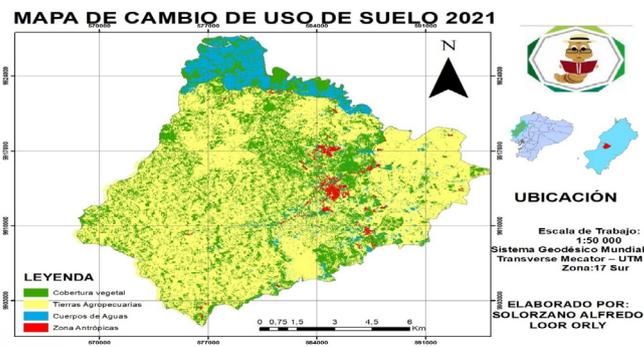
Lozano et al. (2021) explained that the conversion of natural areas into agricultural land is a common practice that has led to a significant loss of vegetation cover, as observed in Tosagua. Carranza et al. (2024) emphasized the importance of vegetation cover for biodiversity and climate regulation, and noted that its decline has had negative implications for both. Vásquez-Ramírez (2024) pointed out that although water bodies showed a slight increase from 6.2% (2,284.30 ha) in 2017 to 6.8% (2,577.27 ha) in 2021, their conservation is crucial for the region's water sustainability.

Anthropic zones have maintained moderate growth, increasing from 1.7% in 2017 and 2019 to 1.8% in 2019, and returning to 1.7% in 2021, reflecting controlled urban growth. Jemio (2024) highlighted that accuracy in identifying land use changes may have improved over time due to advancements in remote sensing technology (figure 4).
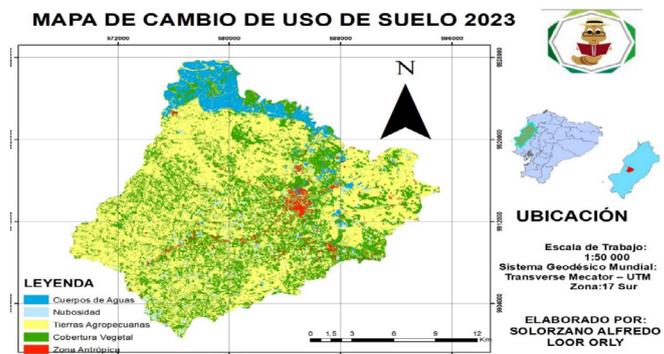

Figura 4. Lanf use change in Tosagua, Ecuador, 2023.

The evolution of land use in Tosagua presents various implications. According to Herrera (2024), reforestation and conservation policies in Ecuador have begun to show positive results, which could explain the recent increase in vegetation cover. Gutiérrez and Galvis (2024) argued that the adoption of more efficient agricultural technologies has led to a decline in agricultural expansion, as reflected in the reduction of agricultural land in 2023.

Carranza et al. (2024) stated that economic and social changes, such as rural-to-urban migration, have led to a more efficient use of agricultural land, while controlled urban development has contributed to moderate growth in anthropic zones. Vásquez-Ramírez (2024) indicated that variations in the presence of water bodies may be related to water conservation efforts and changes in water resource management practices.

Land use change annual rate in Tosagua obtained from a multi-temporal analysis of satellite images between 2017-2023

Land use change in Tosagua between 2017-2023

Following the creation of the land use change maps, table 3 was developed to reflect land use changes that occurred between 2017 and 2021. For the analysis, informal classes detailed in the classifications for 2017–2019, 2019–2021, and 2021-2023 were merged, in order to observe the number of hectares per year that are undergoing land use transitions.

Table 3: Land use change in Tosagua, Ecuador 2017-2023.

Description						
Informal classes	Plant cover	Agricultural land	Water bodies	Anthropic Zones	Cloudiness	total
2017	13,956.60	19,430.86	2,284.31	640.12	818.18	**37,130.06**
2019	10,280.03	23,980.97	2,400.52	661.92		**37,223.44**
Change/ha	**-3,676.57**	**4,550.11**	**116.22**	**21.80**	818.18	
Change/year/ha	-1,838.28	2,275.06	58.11	10.90		
2019	10,280.03	23,980.97	2,577.27	661.92		**37.200,20**
2021	10,120.01	24,113.41	2,509.64	640.70	871,63	**37.245,07**
Change·ha⁻¹	**-160.02**	**132.43**	**-67.63**	**21.22**	**-871,63**	
Change·year⁻¹·ha⁻¹	-80.01	66.22	-33.82	10.61	-435,82	
2021	10,120.01	24,113.407	2,284.31	640.70	818,18	**37.176,02**
2023	11,437.58	22,029.98	2,509.64	735.17	881,63	**37.294,01**
Change/ha	**1,317.57**	**-2,083.43**	**-225.34**	**94.35**	**63,45**	
Change/year/ha	658.78	-1,041.71	-112.67	47.17	31,72	

-: Cover decrease.
+: Increase cover.

By analyzing the changes between the time intervals (2017-2019; 2019-2021; and 2021-2023), it is possible to observe the increase and decrease in the different land use change categories in Tosagua Canton. The most significant change occurred during the 2017-2019 period, with a decrease in vegetation cover of 3,676.57 hectares, representing an annual loss of 1,838.28 ha·year⁻¹. In contrast, for the 2019-2021 period, the loss of vegetation cover was smaller, with a decrease of 160.02 hectares, corresponding to a change of 80.01 ha·year⁻¹. This trend reversed in the 2021-2023 period, which recorded an increase in vegetation cover of 1,317.57 hectares.

Identification of annual land use change rate in Tosagua 2017-2023

The annual rate of change was determined using the formula proposed by FAO (1996), as detailed in table 4. This table includes the sum of vegetation cover across the different periods.

Table 4. Annual change rate in Tosagua, Ecuador 2017-2023.

Description	2017 ha	2019 ha	Change/ha	Change rate	% Change
	13,956.60	10,280.03	**-3,676.57**	-0.14	-14,00
	2019 ha	**2021 ha**	**Change·ha⁻¹**	**Change rate**	**% Change**
Plant cover	10,280.03	10,120.01	**-160.02**	-0.01	-1.00
	2021 ha	**2023 ha**	**Cambio·ha⁻¹**	**Tasa cambio**	**% Cambio**
	10,120.01	11,437.58	**1,317.57**	0.06	6.00

The analysis of the annual rate of change (ARC) made it possible to visualize vegetation cover changes in the study area over two-year intervals, highlighting the intensity of land cover dynamics in the canton. Between 2017 and 2019, a high but negative value of -14.00% was observed, as vegetation cover declined from 13,956.60 ha in 2017 to 10,280.03 ha in 2019. A similar trend occurred between 2019 and 2021, with a -1.00% change. However, during the 2021-2023 period, a notable recovery trend in vegetation cover was observed, with a 6.00% increase.

To quantify the reliability of the minimum distance supervised classification method, a confusion matrix was created (table 5) using field-verified points. This matrix was built from a representative sample, where the diagonal represents the number of verification points with agreement between the two sources (map and ground truth). The columns correspond to the reference classes (field data), while the rows represent the categories derived from the classification.

The overall accuracy was 83.80%, which was considered acceptable for this type of imagery, in accordance with the methodology of Chuvieco (1995) and the results obtained by López (2018), who reported an overall accuracy of 96.70%, also considered acceptable for deforestation-related studies.

Table 5. Confusion matrix of land use change in Tosagua - Ecuador

Description	Plant cover	Agricultural lands	Body of water	Populated area	Cloudiness	Total	User accuracy	Comision error
Plant cover	20	3				23	87	13
Agricultural lands	7	35	1			43	81	19
Body of water			2			2	100	0,00
Populated area				0		0	0	0
Cloudiness					0	0	0	0
Total	27	38	3	0	0	68		
Producer accuracy	74	92	67					
Omision error	0,26	0,8	0,33	0,00	0,00			
Global accuracy	(20+35+2)/68*100 = 83,8%							

Conclusion

Over the six-year period covered by the study, agricultural land continued to predominate over vegetation cover in Tosagua Canton. However, this activity is compromised by the lack of an irrigation system, as it depends on the rainy season or proximity to rivers and lagoons. Through supervised classification, it was possible to determine the increase and decrease of the different land use categories. Vegetation cover experienced a decrease of 3,676.57 ha during the 2017-2019 period, with a deforestation rate of -14.00%. However, for the 2019-2021 period, the deforestation rate dropped to -1.00%, indicating a lower loss of vegetation cover. In contrast, the 2021-2023 period showed a recovery, with a 6.00% increase in vegetation cover, amounting to a gain of 1,317.57 ha.

The confusion matrix allowed for the verification of reference points between actual land cover and that derived from the classification. From this matrix, an overall accuracy of 83.8% was obtained, indicating that the classification is acceptable.

References

Barrantes Mann, G. A. L., Flores-Olivos, A. J., Liza-Zatti, S. A. y Santa-Cruz Arévalo, J. E. (2021). Políticas públicas para el sector agrario en el Perú. *Journal of Business and Entrepreneurial Studies*, http://journalbusinesses.com/index.php/revista

Benítez, A. (2022). Análisis espaciotemporal del proceso de pérdida forestal en los municipios de Charo, Hidalgo, Indaparapeo, Queréndaro y Zinapécuaro. Michoacán, México. *Revista Cartográfica*, *106*, 99-123.

Bianco, M., Díaz, I., Chiappe, M., Figueredo, S., Narbondo, I. y Russi, E. (2021). Dinámicas de la expansión agricola en territorios uruguayos. *Revista Latinoamericana de Estudios Rurales*, *6*(12), 1-35.

Carranza, M., Aragundi, L., Macias, K., Paredes, E. y Villegas, A. (2024). Conservación y manejo sostenible del suelo en la agricultura: Una revisión sistemática de prácticas tradicionales y modernas. *Código Científico Revista de Investigación*, *5*(E3), 1-28. doi:https://doi.org/10.55813/gaea/ccri/v5/nE3/303.

Cardozo, O. y Da Silva, C. (2013). Aplicaciones urbanas de los sensores remotos. *Revista Geográfica Digital*, *20*, 1-6.

Chuvieco, E. (1995). *Fundamentos de teledetección espacial*. Madrid, España, Editorial Rialp, S.A, 430 p.

Gónima, L., González, M. y Ruiz, L. (2010). Desarrollo de una metodología sencilla para la georreferenciación y medición de distancias a partir de imágenes de satélite sistemáticamente georreferenciadas. *Bol. Invest. Mar. Cost.*, *39*(1), 7-23.

Gutiérrez Cervera, A. A. y Galvis Ramírez, A. J. (2024). Asimilación de tecnologías en el sector agrícola del Cesar - Colombia, herramienta de desarrollo económico. *Revista AGLALA*, *15*(1), 22-39.

Herrera, R. (2024). Principales amenazas e iniciativas de conservación de la biodiversidad en Ecuador. *Journal of Economic and Social Science Research*, *4*(1), 33-56.

Hoyos Gonzales, A. I., Quinteros Camacho, N. L. y Crisólogo Rodríguez, M. E. (2022). Evaluación multitemporal de la superficie del humedal HuachoHualmay-Carquín entre

los años 1986 y 2019. *South Sustainability*, *3*(1), e053. https://doi.org/10.21142/SS-0301- 2022-e053

Instituto Espacial Ecuatoriano (IEE); Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP); Sistema de Información Nacional de Agricultura, Ganadería, Acuacultura y Pesca (SINAGAP). (2022). *Sistema productivo de la provincia de Manabí*. 120 p.

Jemio, L. C. (2024). Seguros agrícolas paramétricos: Una revisión de la literatura. *Development Research Working Paper Series*, No. 05/2024, Institute for Advanced Development Studies (INESAD), La Paz.

López, E. (2006). *Patrones de cambio de uso del terreno en la Cuenca del Lago de Cuitzeo*. Tesis de Doctorado, Universidad Autónoma de México. México.

Lopez, A. (2018). Análisis multitemporal de cambio de uso de suelo mediante percepción remota en el cantón Bolívar-Ecuador. Tesis de Maestría, Universidad Técnica de Manabí. Ecuador.

Lozano, A., Alvarez, C. y Moggiano, N. (2021). El cambio climático en los andes y su impacto en la agricultura: Una revisión sistemática. *Scientia Agropecuaria*, *12*(1), 101-108. DOI: https://dx.doi.org/10.17268/sci.agropecu.2021.012

Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). (1996). Forest resources assessment 1990. Survey of tropical Forest cover and study of change processes. FAO. Roma.

Ponvert Delisles, D. y Lau Quan, A. (2013). Uso de las imágenes de satélites y los SIG en el campo de la Ingeniería Agrícola. *Revista Ciencias Técnicas Agropecuarias*, *22*(4), 75-80.

Ruiz, V., Savé, R. y Herrera, A. (2013). Análisis multitemporal del cambio de uso del suelo, en el Paisaje Terrestre Protegido Miraflor Moropotente Nicaragua, 1993-2011. *Revista Científica Ecosistemas*, *22*(3), 117-123.

Romero, F. S. (2006). La teledetección satelital y los sistemas de protección ambiental. *Revista AquaTIC*, *24*, 13-41.

Sierra, R. (2013). Patrones y factores de deforestación en el Ecuador continental, 1990-2010. Y un acercamiento a los próximos 10 años. Conservación Internacional Ecuador y Forest Trends. Quito, Ecuador. pp. 1-47.

Vásquez-Ramírez, G. L. (2024). El desarrollo potencial de proyectos en infraestructura natural para la seguridad hídrica. *South Sustainability*, *5*(1), e097. DOI: 10.21142/SS-0501-2024-e097

Declaration of authorship based on the CRediT taxonomy

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