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SOCIETY FOR SCIENCE AND EDUCATION

Detailed Land Cover and Land Use Mapping, A New Approach: Case Study, Usumacinta Watershed, Mexico

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ABSTRACT

Land use system is the interface between society and the biophysical environment; it is concern how humans use ecosystems services provide by natural resources. Land-use and land-cover changes have great effects for the environmental and socioeconomic sustainability of rural communities. A capacity for detecting and reporting land use change is critical to evaluating and monitoring trends in natural resource conditions and the effectiveness of public investment in their management. In Mexico, despite ongoing mapping land use - land cover efforts; there remains a need for development of basic datasets providing quantitative and spatial land use/land cover information, mainly a detailed scale. Recent availability of high-resolution satellite remote-sensing images coupling with advances digital image processing techniques offers an improved opportunity to map in a more detailed scale the land use and land cover, which will be an important tool to monitor the environment at local scales. It is the objective of this study, conduct a detailed mapping of land use-land cover in Usumacinta watershed, using high-resolution satellite images and analyze changes occurred when is compared with National Institute of Statistic and geography map - Series VII,2016. The basis for the land use and vegetation cover presented in this study is the digital land cover and land use classification elaborated with SPOT imagery, spatial resolution 1.5 meters, using an object-based classification method in combination with an image classification based on expert knowledge. The resulting map was updated using Sentinel images 2021 and 2022, by means of onscreen digital interpretation. The result is a detail map of land use land cover, where new classes were generated as association and consociation units. As a conclusion is established that the resulting map is more stable in time, and it can be used as indicative to implement restoration measures on natural vegetation and as input to calculate a more precise estimations of agriculture statistics. All of these aspects can guide the design and implementation of public policies about land use.

Keywords: land use; land cover; mapping; Satellite images; object-based classification

INTRODUCTION

Land use system is the interface between society and the biophysical environment; it is concern how humans use ecosystems services provide by natural resources. Land-use and land-cover changes have great effects for the environmental and socioeconomic sustainability of rural communities [1]. It is also considered a central part of the functioning of the Earth system as well as reflecting human interactions with the environment at scales from local to global [2].

Land use–related research, notably for agriculture and forestry, has a long history of direct and strong application to land management. A capacity for detecting and reporting land use change is critical to evaluating and monitoring trends in natural resource conditions and the effectiveness of public investment in natural resource management. The information needs for such a synthesis are diverse; remote sensing has an important contribution to making and documenting the actual change in land use/land cover in regional and global scales [3] and in the last decades because of availability of high-resolution satellite, at local scales. Understanding the dynamics of agricultural change (or agricultural trajectories) is an important dimension of sustainability and a necessary first step to evaluating land management strategies in relation to local livelihoods [4]. A capacity for detecting and reporting land use change is critical to evaluating and monitoring trends in natural resource conditions and the effectiveness of public investment in their management. Land cover change occurs at different spatial scales, range from local to global geographical scales; moreover, there appears to be a gap in the available information for local decision-making process and rational planning.

In Mexico, despite ongoing mapping land use - land cover efforts; there remains a need for development of basic datasets providing quantitative and spatial land use/land cover information, mainly a detailed scale. Rates of forest loss are accelerating due to extensive grassing, subsistence agriculture and shifting cultivation. National Institute of Statistic and Geography provides spatial information about land cover and land use, at the national level, scale of 1:250,000. This information is not suitable for local planning purposes; this is particularly evident in highlands, where farming systems are set up in small plots (between one and five hectares); therefore, by scale limitations of products used (LANDSAT images, 30 meters spatial resolution), mapping of land use and land cover on that small plots, it is no thinkable. In cartography products of Landsat images, agriculture on small plots are not mapped as a separate units, and is mainly associated with grassland and secondary vegetation, and in a lesser proportion with primary vegetation.

Recent availability of high-resolution satellite remote-sensing images coupling with advances digital image processing techniques offers an improved opportunity to map in a more detailed scale the land use and land cover, which will be an important tool to monitor the environment at local scales. In these sense it is the objective of this study, conduct a detailed mapping of land use-land cover in Usumacinta watershed, using high-resolution satellite images and analyze changes occurred when is compared with INEGI map

METHODS

The Study Area

The Usumacinta watershed, an important trans-boundary basin encompasses 77.265 km2, from which the 43.6% is located in Mexico (area considered in this study), 56.3% in Guatemala and 0.04% in Belize (figure 1) In Mexico is one of the most important watersheds and includes 5 municipalities of Tabasco State, 15 of Chiapas, and one of Campeche. The area has an average annual precipitation ranging from 1200 to 4000 mm; supports a population of about 1.000.000 inhabitants distributed in 5000 localities. The area includes 12 natural protected areas (8.500 km2).

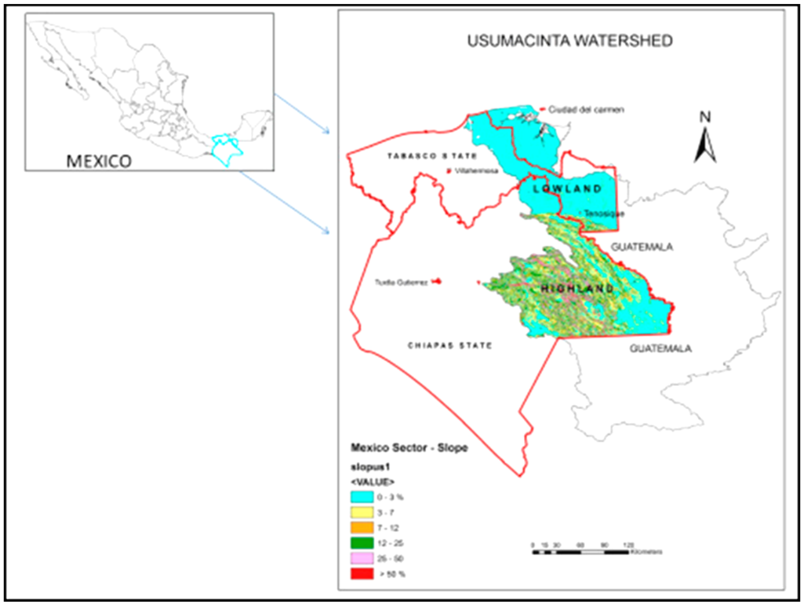

Figure 1. Study area, Usumacinta watershed, Mexico

In the Usumacinta watershed in Mexico the native vegetation is grouped into three main ecosystems, namely: hydric vegetation (mangroves, "popal" and "tular"), coniferous and oaks forest (includes the mountain Mesophyll Forest) and the Tropical Forest Evergreen [5]. The impact of human activities, mainly those related to agriculture and livestock, which in some areas date from the time of the colony has affected in a moderate to severe such ecosystems.

The watershed is constituted by two well defined sectors: Low land (low Usumacinta) and highland (Lacantun-Chijoy); in the low land the livestock is the principal activity (65%) and the crops 35%. The highland area the land cover consist of coniferous and oaks forest, mountain Mesophyll Forest and the Tropical Evergreen forest, on different stages of degradation. The land use consists of extensive livestock and annual (mainly maize and beans) and perennial crops (coffee, oil palm). Shifting cultivation which consists of various slash-and-burn methods, is one of the most widespread farming systems. It is stablished in small plots (< 5 hectares) in areas of moderate to steep land, it is dedicated to self-sufficiency with weak technology and little capital.

Methodology

Figure 2 shows the general methodological scheme of the procedure used in this research is shows in figure 2. The data used in this study include:

- High resolution multispectral images (30 SPOT images of spatial resolution 1.5 meters, 2013, 2014, 2016).
- Sentinel images (2021, 2022) spatial resolution 10 meters.
- LANDSAT images (2021), spatial resolution 30 meters
- Land cover and land use, series VII, INEGI, 2016 [6]
- Digital Elevation Model (spatial resolution 15 meters) [7]

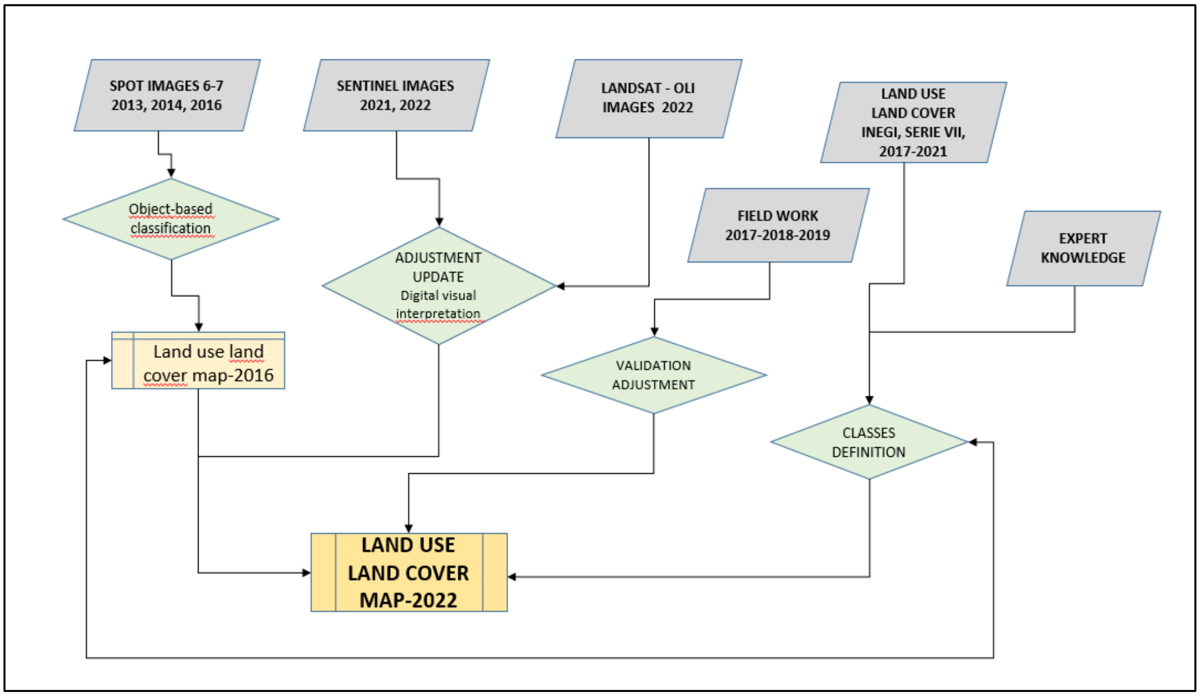

Figure 2. General scheme of the land cover and land use mapping process

The basis for the land use and vegetation cover presented in this study is the digital land cover and land use classification elaborated with SPOT imagery, spatial resolution 1.5 meters [8]. In this case, an object-based classification method was used in combination with an image classification based on expert knowledge; the general procedure implemented with E-Cognition software, V-8.7.2 is illustrated in Figure 3.

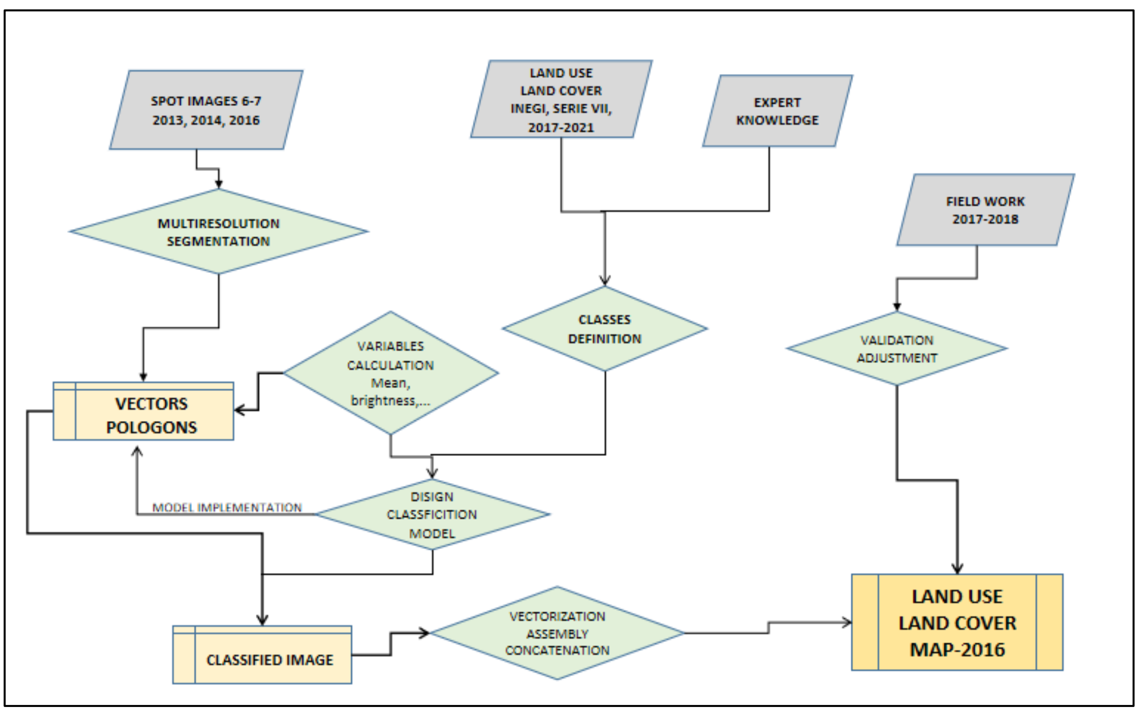

Figure 3. Methodological approximation of land use land cover classification, using object base classification method.

For each of the objects resulting from the segmentation process the following variables were calculated: mean, brightness, standard deviation and maximum difference for each of the four bands. In addition, the following spatial characteristics were calculated: area, length/amplitude, distance in "x" to the left edge of the scene and distance in "y" to the right edge of the scene. With these variables, a classification model was designed that includes decision models, also considering auxiliary information from the digital elevation model and the land use and vegetation map, series VII (INEGI, 2016 [7].

The classification results are exported as vectors (shape.file). Then a process of assembly, concatenation, adjustment and definition of new use classes is performed. In this process, on-screen digitizing was used, with the support of seamless images from google earth (high resolution images). Through field trips (years 2017-2018 - 2019) GPS points were taken of the different uses and vegetation cover, which served to validate the classification results.

A novel aspect in the elaboration of the land use and vegetation mapping presented in this study is the definition and proposal of new use classes, where the cartographic concepts of association and consociation are used. Here the authors replicate, adapt and improve the definition of new land use classes (associations) defined in previous projects [9,10]. The interpretation and definition of these classes is based on the recognition, through digital visual interpretation, of complex patterns of use.

Finally, based on the resulting map, an update of land cover and land use was made, using Sentinel images of the year 2021 and 2022 (10 meters of spatial resolution), the process was carried out by means of on-screen digital interpretation. Due to the fact that in the vectorization process the minimum cartographic surface unit considered was 0.1 hectare, a generalization was made, taking into account 0.5 hectares as the minimum cartographic unit area.

RESULTS AND ANALYSIS

The results of land cover and land use mapping are presented in Figure 4. Table 1 shows description of land use and land cover classes and their respective areas.

In relation to the resulting map, when compared with INEGI cartography (series VII, 2016), the following considerations can be made:

a) The high spatial resolution of the SPOT images (1.6 meters) together with the information collected in the field, allowed identifying in detail areas with permanent agriculture, which were not reported in the INEGI information, among these it is worth mentioning the oil palm, for which it was possible to identify not only the adult plantations (more than 20 years old), but the new plantations that fluctuate between 1, 5 and 10 years old. In this case, their identification was possible thanks to the fact that this type of use presents a very characteristic spatial pattern, in addition to the SPOT images, google earth images were very useful in their identification. In the case of planted forests, based on visual interpretation and field information it was possible to determine the type of forest, which in most cases corresponds to plantations mainly of rubber, teak, melina, cedar and others to a lesser extent such as mahogany and eucalyptus forest. Both oil palm and planted forests are mapped in the INEGI cartography as a single class.

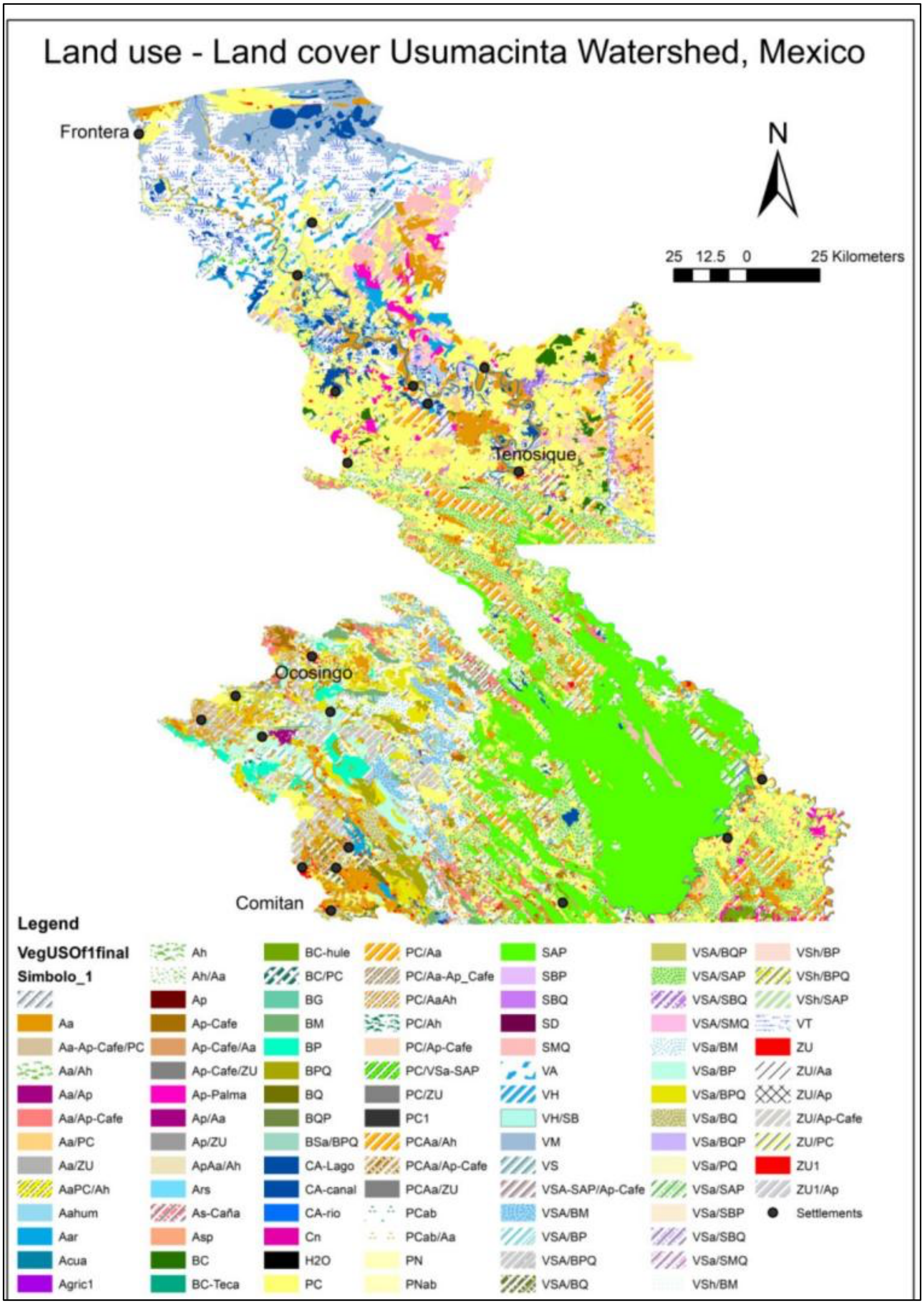

Figure 4. Land use land cover map, Usumacinta Watershed, Mexico

Table1. Land use land cover, description and area (hectares)

Landuse - Landcover - Description	Code	Area - Has
Annual crops	Aa	24,2769.70
Annual crops - coffee plantations/pasture	Aa-Ap-Cafe/PC	248.536
Annual crops /acahuales	Aa/Ah	82,678.31
Annual crops/perennial crops	Aa/Ap	2,912.01
Annual crops - coffee plantations	Aa/Ap-Cafe	26,796.55
Annual crops/pastures	Aa/PC	74,909.08
Annual crops/settlements	Aa/ZU	4,618.25
Annual crops – pastures within flooding areas	Aahum	7,167.47
Annual crops-pastures/ acahuales	AaPC/Ah	4,042.66
Irrigated Annual crops	Aar	18,854.55
Aquaculture	Acua	24.59
Acahuales (secondary vegetation)	Ah	1,418.53
Acahuales/ Annual crops	Ah/Aa	2,266.08
Perennial crops	Ap	82.75
Oil Palm	Ap-Palma	38,793.23
Coffee plantations	Ap-Cafe	14,678.70
Coffee plantations/ Annual crops	Ap-Cafe/Aa	9,094.84
Coffee plantations /settlements	Ap-Cafe/ZU	739.44
Perennial crops/ Annual crops	Ap/Aa	19.00
Perennial crops/ settlements	Ap/ZU	22.04
Perennial crops- Annual crops/acahuales	ApAa/Ah	450.57
Irrigated semi-permanent crops	Ars	183.62
semi-permanent crops	As	965.71
semi - permanent crops (sugar cane)	As-sugar cane	6,769.43
semi permanent crops/permanents	Asp	6,769.43
Planted forest	BC	19474.23
Planted forest (rubber)	BC-hule	6224.32
Planted forest (teak)	BC -teca	6224.32
Planted forest - pasture	BC-PC	0.71
Pasture	PC	650,282.95
Pasture / Annual crops	PC/Aa	14,8833.20
Pasture/annual crops-Coffee plantations	PC/Aa-Ap-Cafe	6778.21
Pasture / Annual crops-acahuales	PC/AaAh	5.17
Pasture / acahuales	PC/Ah	6,536.85
Pasture/Coffee plantations	PC/Ap-Cafe	828.39
Pasture/Secondary vegetation (SAP)	PC/VSa-SAP	2,196.40
Pasture- Annual crops/acahuales	PCAa/Ah	3,030.49
Pasture-annual crops/Coffee plantations	PCAa/Ap-Cafe	337.43
Arboreal Pasture	PCab	19,269.34
Arboreal Pasture/ Annual crops	PCab/Aa	207.72
Pasture/ settlements	PC/ZU	36.65
Human Settlements/ Annual crops	ZU/Aa	1,578.23
Settlements/ perennial crops	ZU/Ap	59.99
Settlements/ Coffee plantations	ZU/Ap-Cafe	159.73
Settlements/pasture	ZU/PC	51.46
Human Settlements > 20 inhabitants	ZU	6,198.42
Scattered human Settlements	ZU1	21,911.70

Quarries - bare soils	Cn -SD	1,078.33
Secondary vegetation of cloud forest	VSa/BM	5,0578.03
Secondary vegetation of pine forest	VSa/BP	5,1753.23
Secondary vegetation of pine-oak forest	VSa/BPQ	6,3546.23
Secondary vegetation of oak	VSa/BQ	14,221.97
Secondary vegetation of oak-pine	VSa/BQP	198.68
Secondary vegetation of evergreen forest	VSa/SAP	10,6517.05
Secondary vegetation of oak	VSa/BQ	10.64
Secondary vegetation of low evergreen forest	VSa/SBP	2595.08
Secondary vegetation of Low sub evergreen forest	VSa/SBQ	20,702.37
Secondary vegetation of medium sub evergreen forest	VSa/SMQ	34,297.24
Herbaceous vegetation of cloud forest	VSh/BM	6,272.23
Herbaceous vegetation of pine forest	VSh/BP	560.61
Herbaceous vegetation pine-oak forest	VSh/BPQ	1,762.24
Herbaceous vegetation evergreen forest	VSh/SAP	3,923.41
Riparian vegetation	BG	5,963.71
Cloud (mesophyll) forest	BM	20,298.99
Pine forest	BP	27,078.03
Pine-oak Forest	BPQ	23,727.65
Oak forest	BQ	2,636.29
Low evergreen forest	SBP	3,091.40
Natural pasture	PN	12,489.74
Low sub evergreen forest	SBQ	8,496.73
Medium sub evergreen forest	SMQ	36,649.51
Evergreen forest	SAP	51,5991.61
Mangrove forest	VM	98,180.58
Savannah vegetation	VS	11,113.87
Arboreal vegetation cloud forest	VSA/BM	50,120.58
Arboreal vegetation of pine forest	VSA/BP	21,520.24
Arboreal vegetation of pine-oak forest	VSA/BPQ	67,239.34
Arboreal vegetation of oak forest	VSA/BQ	10,022.43
Arboreal vegetation of oak-pine forest	VSA/BQP	83.31
Arboreal vegetation of evergreen forest	VSA/SAP	21,5993.69
Arboreal vegetation of low sub evergreen forest	VSA/SBQ	1699.30
Arboreal vegetation of medium sub evergreen forest	VSA/SMQ	35,848.58
Arboreal vegetation of low evergreen forest	VSA/SBP	27.52
Tular	VT	23,4041.46
Popal	VA	10,0283.69
Hydrophilic vegetation	VH	13752.80
Hydrophilic vegetation/low evergreen forest	VH/SBP	266.40
Arboreal vegetation of evergreen forest/Coffee plantation	VSA-SAP/Ap-Cafe	413.43
river	CA-rio	2,9625.29
Lake	CA-Lago	8,2071.45
Water channel	CA-canal	12.17

b) Based on field information and through analysis of spectral response in the images and the different spatial patterns, it was possible to define new land cover and land use classes, most of them mapped as associations, as follows:

i. Agriculture annual in association with grasslands and acahuales (Aa/PC, Aa/Ah, AaPCAh). In the INEGI map these areas were mapped mainly as cultivated grasslands or as secondary arboreal and shrub vegetation of high evergreen forest and mountain mesophyll forest. From field observations and the analysis of spatial and spectral patterns, it can be said that these units are dominated by annual rainfed agriculture (mainly corn and beans), followed by acahuales of different ages (between 2 and 6 years old) and, to a lesser extent, pastures (some of these clean and others weeded).

ii. Grasslands in association with annual agriculture and acahuales (PC/AaAh, PC/Ah, PCAa/Ah, PCab/Aa). In the INEGI information these areas were mapped mainly as cultivated grasslands. In this unit, cultivated pastures predominate (some of them clean and others weeded), followed by annual rainfed agriculture (mainly corn, beans), and to a lesser extent, acahuales of different ages (between 2 and 6 years old). It was considered important to define this unit in order to differentiate it from cultivated pastures, which predominate in the northern part of the study area, with slopes of less than 7%, and which are better managed.

iii. A class association of great importance in the area is constituted by areas that include coffee plantations, in association with annual agriculture, and pastures and in smaller proportion with dispersed urban areas (Aa-Ap-Cafe/PC, Aa/Ap-Cafe, Ap-Cafe/Aa, Ap-Cafe/Aa, PC/Aa-Ap-Cafe, PC/Ap-Cafe, PCAa/Ap-Cafe) and (Ap-Cafe/Aa, Ap-Cafe/ZU) in the first case, coffee plantations predominate, and in the second case, agriculture and pastures predominate over coffee plantations. The coffee plantations are complemented by some units where coffee-only areas were identified, and a few areas where coffee is found in association with primary vegetation, mainly mesophyll and evergreen forest.

iv. Other class associations mapped include areas with widely dispersed human settlements in association mainly with annual and permanent agriculture and to a lesser extent with grasslands (Aa/ZU, PC/ZU) and (ZU/Aa, ZU/PC, ZU/Ap) in the first case with predominance of agriculture and grasslands over settlements, and in the second case with predominance of human settlements.

v. In relation to the class associations, particularly those that include annual agriculture, pastures and/or acahuales, it is important to point out that these units are more stable over time, although in some cases these classes could be mapped separately (annual crops, pastures, acahuales), due to the great dynamics of land use, the map would soon become obsolete, since the predominant cropping system, mainly in the upper part of the area, would be more stable over time, Although in some cases these classes could be mapped separately (annual crops, pastures, acahuales), due to the great dynamics of land use, the map would soon become obsolete, since the predominant cultivation system, mainly in the upper part of the basin, is shifting cultivation by slash and burn agriculture. Another reason is that in most cases their spatial pattern is so complex that it is not practical from a cartographic point of view to map these classes individually. Annual agriculture consists mainly of corn and bean crops, and permanent agriculture mainly of coffee, and to a lesser extent fruit trees (pear and apple).

Finally, with respect to human settlements, two units were mapped, one corresponding to the more consolidated human settlements, with a population greater than 20,000 inhabitants (ZU) and a second unit that includes smaller and very dispersed settlements (ZU1), the latter occupying a larger area in the study zone (21,911.7 ha vs. 6,198.4 ha for the former).

Changes in Land Use

The following is a general analysis of changes in land cover and land use in relation to the INEGI map (series VII, 2016). To facilitate changes analysis in use that have occurred, the classes mapped by INEGI and by the authors have been grouped into four major categories, primary vegetation, secondary vegetation, anthropic cover (including crop areas, pastures and human settlements) and water bodies. The graph in Figure 5 shows the above-mentioned grouped classes for the two dates indicated.

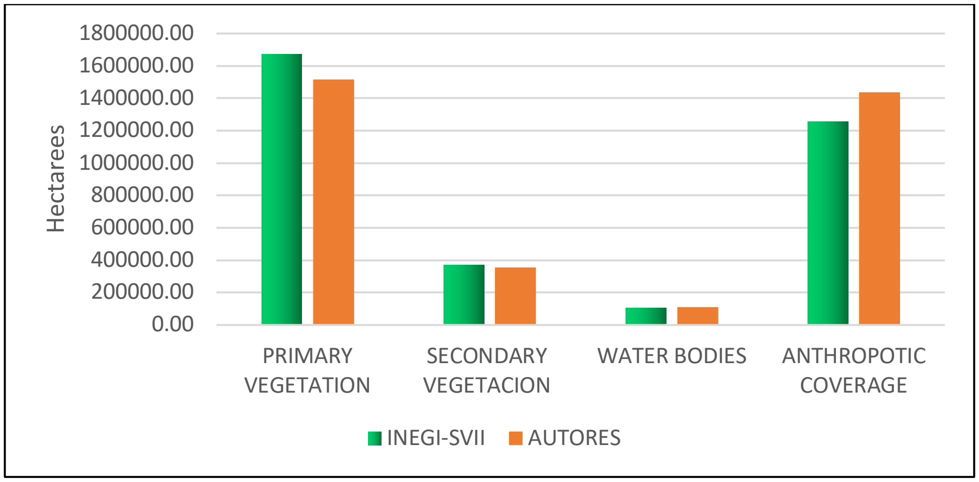

Figure 5. Changes in land use Land cover between 2016 (INEGI, series VII) and 2022 (authors).

As can be seen in Figure 5 there is a decrease in the area of primary vegetation (1,672700 ha vs. 1,467,359.4 ha), this area has been transformed into anthropic cover (mainly crops and pastures and to a lesser extent in urban areas); as shown in the graph the anthropic cover shows an increase of 178,606.3 ha (1,257,009.9 vs. 1,435,616.3 ha). In water bodies there is an increase of 54,363.3 ha (104,163.4 Vs 158,528.7), this change is mainly due to the fact that in the 2022 cartography, some rivers have been mapped that do not appear in the INEGI cartography; another reason that explains this change is a greater precision in the mapping, by using high resolution images. The changes in the area of secondary vegetation are apparently few (12,868.9 ha), although the changes in its spatial distribution are important, so in some areas part of the primary vegetation is now secondary vegetation, and in other cases, the secondary vegetation becomes crops or pasture.

CONCLUSIONS

- The use of high resolution of images to mapping land use allows to identify and discriminate more precisely the types of land cover and land use; it also allows calculate a more precise estimations on area change (loss or gain in the areal extent for different types of land use). It will permit a more precise estimation of natural vegetation which lead to more precise environmental statistics.

- With regard to the class associations, particularly those that include annual agriculture, pastures and/or acahuales, it is important to point out that these units are more stable over time, due to the great dynamics of land use and its complex spatial pattern.
- From the comparison of the two dates analyzed (2016-2022), where a reduction in the area of primary vegetation and an increase in anthropic cover can be seen, it can be concluded that the agricultural frontier continues to advance, mainly at the expense of the reduction of primary vegetation.
- The results can be used as an indicative to implement restoration measures on natural vegetation and as an input to calculate a more precise estimations of agriculture statistic's, and finally the results can provide information about the ecological footprint of the study area. All of this aspects can guide the design and implementation of public policies about land use.

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