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Land use changes and estimates of anthropogenic CO_2 emissions in a watershed

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Abstract
Anthropogenic interference has always impacted the Earth's surface, with greater intensity in recent times due to land use changes, which contribute to the emission of greenhouse gases, especially carbon dioxide. In this sense, this study analyzes land use transitions and CO_2 emissions resulting from these actions in a watershed. For this, land use mappings were made in 2007, 2010, 2013, and 2016, along with estimates of the emissions from transitions. The calculation of net CO_2 emissions included data from the transitions that occurred, from past vegetation, and pedological information. All procedures were performed with the aid of geoprocessing and remote sensing techniques, resulting in matrices of transitions and CO_2 emissions, in addition to spatialized information. The forest category showed the highest conversion to other types of land use, with a loss of 208.86 ha between 2010 and 2013. In the observed period of nine years, carbon emissions were higher than its sequestration from the atmosphere, which shows the need for management and planning to mitigate the impacts caused by intense land use changes in the studied watershed.

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INTRODUCTION

Anthropogenic interference with nature has always caused environmental damage, but it was in the middle of the 18th century, after the Industrial Revolution, that these environmental impacts reached a global scale. Anthropogenic actions result in changes both in the terrestrial surface and in the atmospheric composition, contributing significantly to environmental and socioeconomic imbalances (CARVALHO et al., 2010; HOUGHTON et al., 2001).

Land use aimed at producing goods to supply human needs has proved to be a challenge, demanding a balance between the rational use of natural resources and productivity, both essential for human survival. How man interferes with nature reflects changes in the Earth's surface and as these changes intensify, environmental concern increases (SILVA; ROSA, 2016).

Among the most significant anthropogenic actions are land use changes, which contribute to greenhouse gas (GHG) emissions and influence the atmospheric energy balance. Land use changes are considered to be one of the largest sources of carbon dioxide (CO_2) emission in the world, second only to fossil fuels (IPCC, 2014; MATA et al., 2015).

Carbon dioxide (CO_2) is a greenhouse gas originated both naturally and anthropogenically. Studies have shown that intensification of the greenhouse effect contributes to raising the temperature and to the occurrence of extreme events, highlighting increased sea level, floods, drought, cyclones, storms, and extinction of fauna and flora species (BAUMERT et al., 2005; HOSHINO et al., 2016; MOREIRA; GIOMETTI, 2008; REIS; SILVA, 2016).

It is worth mentioning that the estimation of CO_2 emissions resulting from land use changes is of great relevance for research on GHG reduction policies. Together with the growing demand to estimate such emissions arises the need to use geotechnology that improves the collection of these data, highlighting Geographic Information Systems (GIS) and Remote Sensing (RS).

Geotechnologies allow updating data periodicity, greater processing in the amount of data, and lower cost. Besides, they contribute to the acquisition of spatial information, multitemporal analysis, and assist in the diagnosis and monitoring of the Earth's surface. Therefore, they can be used in studies that seek to estimate GHG (LEITE; FREITAS, 2013; VAEZA et al., 2010).

In this context, this study assesses land use changes and estimates GHG emissions and reductions over nine years in a watershed in southeastern Brazil.

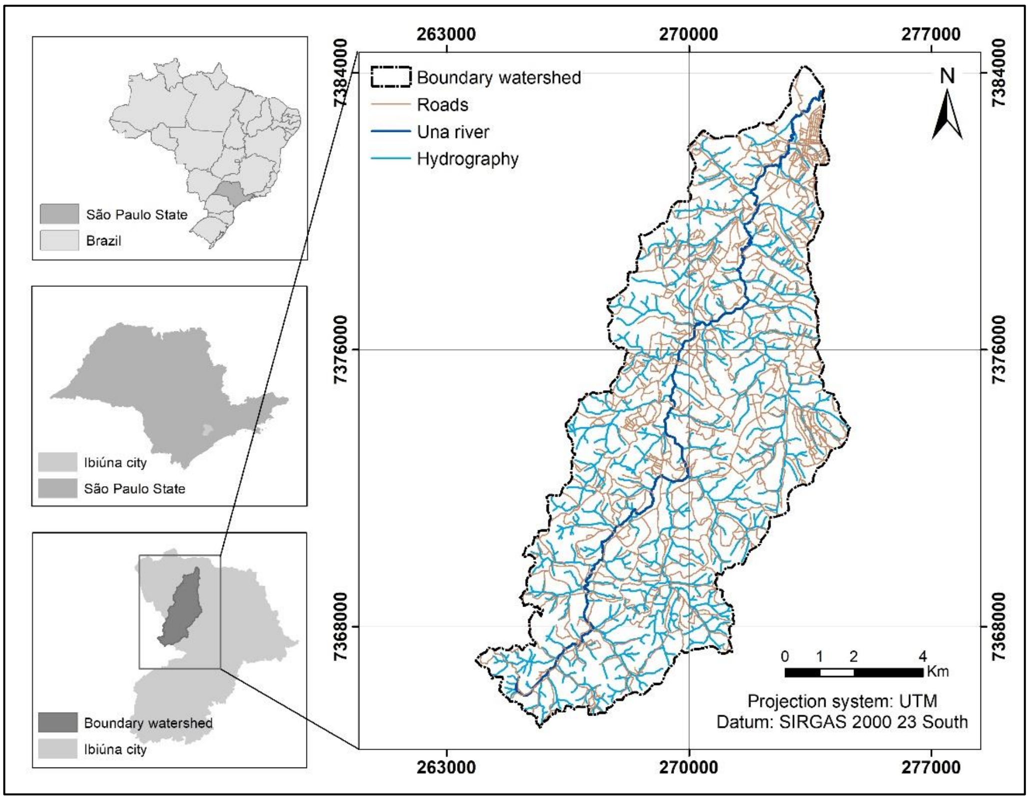
MATERIALS AND METHODS

The study was carried out in the Una river watershed, located in Ibiúna city, southeastern Brazil (Figure 1).

The watershed has an area of approximately 96 km² and stands out for being inserted in a territory of high economic development, with strong agricultural production, urban occupation, and landscape fragmentation, having different degrees of disturbance due to anthropogenic activities (LOPES et al.; 2018; ROSA et al., 2014).

The area contributes significantly to the formation of important reservoirs, including Itupararanga, considered the major regional source of water supply (LOPES et al.; 2018), highlighting Ibiúna, Sorocaba, Mairinque, and Votorantim.

Figure 1. Location of the Una river watershed, Ibiúna, São Paulo, Brazil.



Org.: by the authors, 2018.

To obtain land use transitions and estimates of net CO_2 emissions, we used a sequence of methodological steps, as described below.

Land use mapping

Land use maps were made using satellite images from Landsat 5 for the year 2007, Spot 5 for 2010, RapidEye for 2013, and Sentinel 2A for 2016. The images used correspond to November, except for the image from Landsat 5, acquired for September.

The images were classified using visual interpretation and multitemporal retroanalysis. The method of visual interpretation consists of the vectorization of the categories or classes identified in the study area through the identification of features by their shape, tone, and texture (PANIZZA; FONSECA; 2011).

The land use categories adopted for the

legends of the maps were adapted from the guidelines of the Guide of Good Practices for Land Use, Changes in Land Use, and Forest ("Guia de Boas Práticas para Uso da Terra, Mudanças no Uso da Terra e Floresta") (IPCC, 2003) and the Technical Manual of Land Use ("Manual Técnico de Uso da Terra") (IBGE, 2013). These categories are: Forest (Fo), Reforestation (R), Field (F), Agriculture (A), Urban area (Ua), Flooded area (Fa), and Pasture (P).

Past vegetation map

The past vegetation map was obtained by clipping the vector file of the past vegetation map of Brazil (IBGE, 2004) to the study area and by the construction of a Digital Elevation Model (DEM), both used to determine the forest formation that existed in the watershed.

The DEM was generated by interpolating the contour lines and the rated points using the Triangulated Irregular Network (TIN) method. The TIN consists of a vector structure with a node-arc topology, where for each of the three vertices of each element of the triangle there are coordinates and altitude information (SOUSA JUNIOR; DEMATTÊ, 2008).

Subsequently, past forest physiognomies were classified in the vegetation categories established by Bernuox et al. (2002).

Soil map and soil carbon map under soil-vegetation association

A vector file of the pedological map of São Paulo State (ROSSI, 2017) was clipped to the study area, seeking to obtain the pedological classes in the area. Due to low cartographic quality, the soil texture was analyzed to detail the pedological characteristics and to identify more specifically the soil carbon stock.

Soil particle size was analyzed after the collection of soil samples in 35 points irregularly distributed in the different land use types. The collection was carried out using a soil auger at a depth of 0-20 cm, removing 500 grams of soil. All samples were packaged and taken to the Water and Soil Laboratory of Universidade Estadual Paulista (UNESP), Institute of Science and Technology, Sorocaba city.

The samples were analyzed in the laboratory using the pipette method in thin air-dried soil (TADS), according to the methodology of the Agronomic Institute of Campinas (IAC, 2009). After obtaining the percentages of silt, sand, and clay, the texture was classified according to the Brazilian Soil Classification System (EMBRAPA, 2006).

Soil and soil texture information tables were combined using ArcGIS 10.3 (ESRI, 2014) to define the soil groups in the watershed, according to Bernuox et al. (2002). The mapping of the soil carbon stock under soil-vegetation association was carried out based on the past vegetation map and the soil groups identified.

The carbon values adopted were the same used by CETESB (2012), which refer to carbon median data resulting from the soil-vegetation association, as mentioned in the

Reference Report - Carbon Dioxide Emissions and Removals by Soils due to Land Use Changes and Liming (BRASIL, 2006).

For carbon determination, Brazil (2006) used data from soils 0-30 cm deep. Then, carbon estimates were made for each profile, obtained by multiplying the apparent soil density with the concentration and thickness of the horizon. Finally, carbon data were added to obtain carbon estimates in each location.

Land use transition

Based on the land use maps obtained, analyses of transitions between three periods (2007 to 2010, 2010 to 2013, and 2013 to 2016) were performed using the Tabulate Area tool in ArcGIS 10.3. Transition matrices consist of comparing the previous year with the following year to detect changes in each category.

Estimation of CO_2 emissions and removals

The estimates of CO_2 emissions and removals refer to changes regarding land use and soil carbon stock in a given period.

CETESB (2012) equations were used to estimate CO_2 emissions and removals from land use changes, considering the transitions that occurred from one year to another. In this sense, a forest area converted to agriculture, for instance, presents a specific equation. Therefore, each transition that occurred in an area demanded the knowledge of which equation would be used.

Estimates of CO_2 emissions and removals from soil carbon stock changes were performed using Equation 1, as proposed by IPCC (2003).

$$ESi = Ai * Csoil * \left(fc(to) - fc(tf)\right) * \left(\frac{\frac{T}{2}}{20}\right) \qquad [1]$$

Where:

ESi: net CO_2 emission in the area in a given period (tc);

Ai: land use category area (ha);

Csoil: soil carbon content resulting from the soil-vegetation association [$tc.ha^{-1}$];

fc(to): factor of soil carbon change in the previous year (dimensionless), referring to the previous land use category;

fc(tf): factor of soil carbon change in the following year (dimensionless), referring to the following land use category;

T: time interval (year).

Equation 2 was used to define the fc factor.

$$fc(to)\ or\ fc(tf) = fLu * fMg * fI \qquad [2]$$

Where:

fc(to): factor of soil carbon change in the previous year (dimensionless);

fc(tf): factor of soil carbon change in the following year (dimensionless);

fLu: factor of carbon change due to land use (dimensionless);

fMg: factor of carbon change due to management practices (dimensionless);

fI: factor of carbon change due to use of fertilizers (dimensionless).

The values of the fc factor variables are shown in Table 1.

Table 1. Factor of soil carbon change due to land use changes.

Land use	f_{Lu}	f_{MG}	f_I	f_c
Field	1	-	-	1
Forest	1	-	-	1
Urban area	0	-	-	0
Agriculture	0.58	1.16	0.91	0.612
Flooded area	0	-	-	0
Pasture	1	0.97	1	0.97
Reforestation	0.58	1.16	1	0.673

Source: Adapted from CETESB, 2012. Org.: by the authors, 2018.

Net emission matrix

Equation 3 was used to calculate net emissions.

$$NE = \sum ERLUC + \sum ERSC \qquad [3]$$

Where:

ERLUC: Emission or removal from land use change (tc);

ERSC: Emission or removal of soil carbon stock (tc).

A positive result means that CO_2 was emitted into the atmosphere, while a negative result indicates CO_2 removal from the atmosphere. The values of tons of carbon were converted to Gigagram (Gg) of carbon. Later, using Equation 4, these values were transformed into CO_2 Gigagram. The results were presented in a matrix and specialized through ArcGIS 10.3.

$$ECO2 = Ec * \left(\frac{44}{12}\right) \qquad [4]$$

Where:

ECO_2: CO_2 emission ($GgCO_2$);

Ec: Carbon emission (Gg_C);

44/12: Ratio between the molecular weights of CO_2 and carbon.

RESULTS AND DISCUSSION

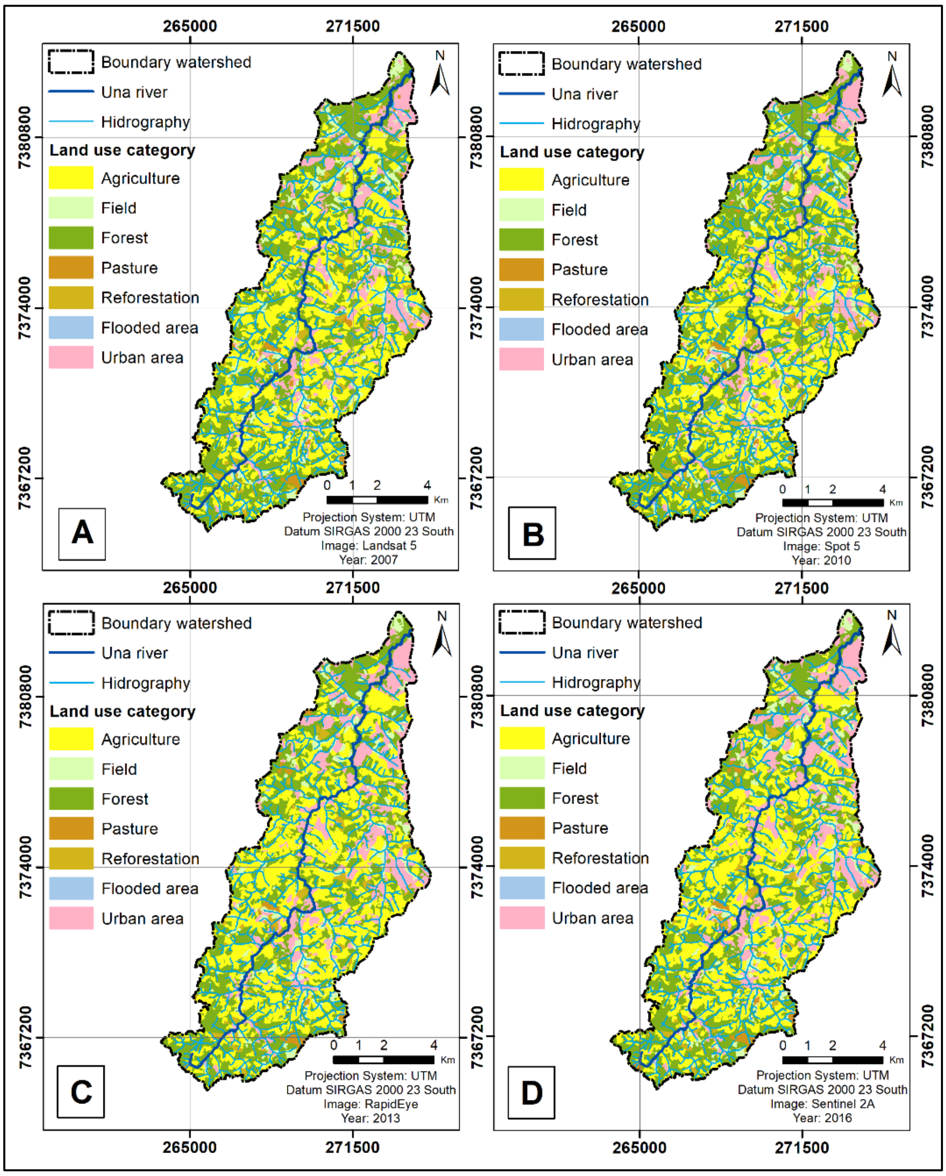
Table 2 shows the quantification of the categories for the years 2007, 2010, 2013, and 2016. Figure 2 shows land use maps in the Una river watershed.

Table 2. Quantification of land use categories for each year analyzed.

Categories	2007		2010		2013		2016	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Field	741.28	7.69	673.27	6.98	592.11	6.14	598.67	6.21
Forest	4,242.5	44.00	4,122.5	42.75	3,938.08	40.84	3,828.19	39.70
Urban area	1,107.87	11.49	1,160.03	12.03	1,356.45	14.07	1,400.14	14.52
Agriculture	3,186.71	33.05	3,315.74	34.38	3,389.67	35.15	3,433.44	35.61
Flooded area	82.28	0.85	81.77	0.85	81.36	0.84	80.84	0.84
Pasture	91.70	0.95	92.20	0.96	93.35	0.97	97.75	1.01
Reforestation	190.43	1.97	197.26	2.05	191.75	1.99	203.74	2.11
Total	9,642.77	100.00	9,642.77	100.00	9,642.77	100.00	9,642.77	100.00

Org.: by the authors, 2018.

Figure 2. Land use map for the year 2007 (A), 2010 (B), 2013 (C) and 2016 (D) for the Una river watershed.



Org.: by the authors, 2018.

There was an increase in the categories of agriculture, urban area, and pasture over nine years (Table 2). The forest category was the one with the greatest loss of area. In a study in the Atlantic forest area, Weckmuller et al. (2012) also found an increase in the urban area, agriculture, and pasture, due to the reduction of forest areas.

In turn, Eckhardt et al. (2013) identified opposite results, with the increase of natural vegetation and reduction of agricultural areas due to rural exodus. In this regard, the difficulty of using mechanized tools in areas with high declivity contributes to the abandonment of these areas and consequent recovery of the Atlantic forest.

The decrease in natural vegetation shows the level of anthropogenic exposure to which the watershed is subject, and the percentage of vegetation loss over nine years

(4.30%) reinforces the need to preserve natural areas. This preservation allows gene flow, the formation of ecological corridors, natural regeneration, and the conservation of water resources.

The Una river watershed comprises the following plant physiognomies: dense ombrophilous montane forest, seasonal deciduous forest, and seasonal semideciduous forest (Figure 3A), which correspond to three vegetation groups proposed by Bernuox et al. (2002) for the Atlantic Forest biome, as shown in Table 3.

The textures found vary between clayey, clayey-sandy loam, clayey-sandy, and clayey loam. Together with the soil types, this information made it possible to classify soils into five groups proposed by Bernuox et al. (2002), as shown in Table 4.

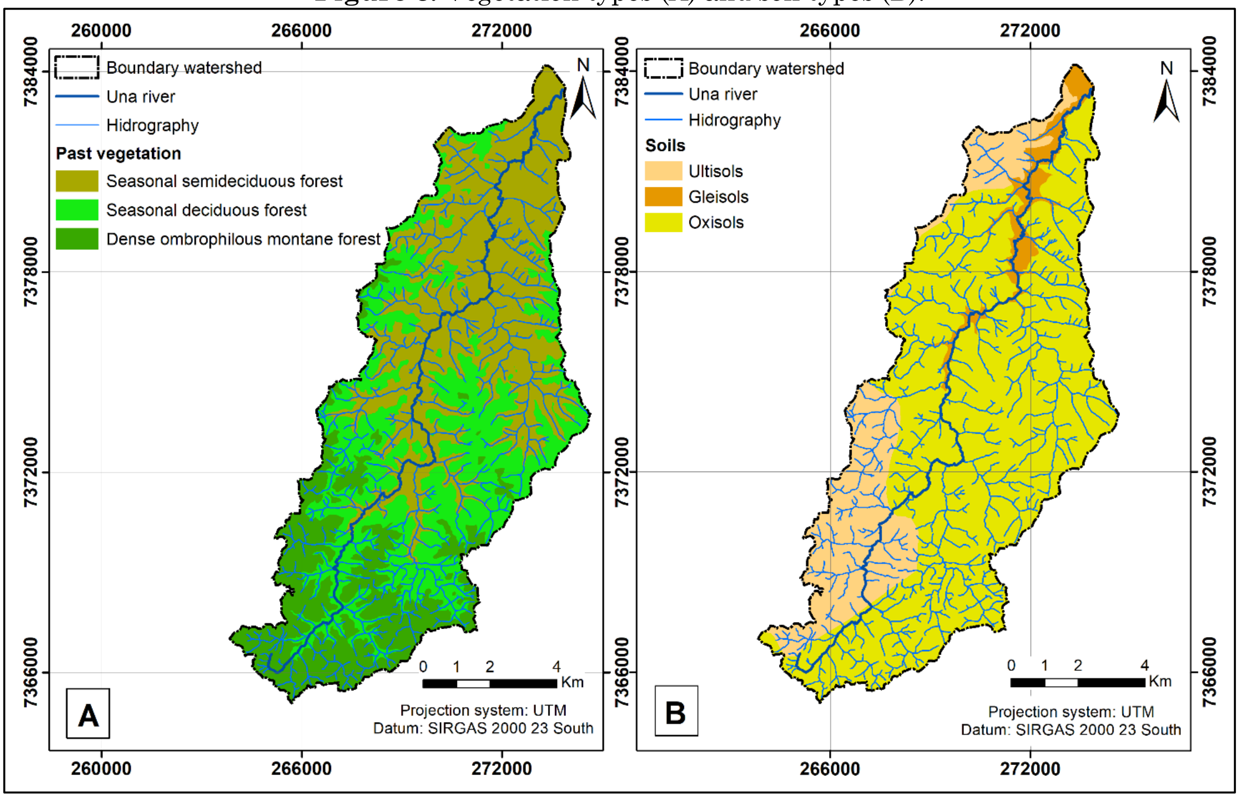
As for the soil types, the watershed presents Oxisols, Ultisol, and Gleisols (Figure 3B) and the results of the carbon stock mapping for the soil-vegetation association are shown in Table 5.

Table 3. Vegetation types found for the Una river watershed.

Vegetation Group	Plant Physiognomy
V3	Dense ombrophilous montane forest
V4	Seasonal deciduous forest
V5	Seasonal semideciduous forest

Source: Adapted from Bernuox et al. (2002). Org.: by the authors, 2018.

Figure 3. Vegetation types (A) and soil types (B).



Org.: by the authors, 2018.

Table 4. Soil groups found in the Una river watershed.

Group	Soil Category
S1	High activity clay soils
S2	Oxisols with low activity clay
S3	Soils other than Oxisols with low activity clay
S4	Sandy soils
S5	Hydromorphic soils

Source: Adapted from Bernuox et al. (2002). Org.: by the authors, 2018.

Table 5. Soil carbon stock under the soil-vegetation association of the Una river watershed.

	Soil (Kg$_c$/m^2)					
Vegetação		S1	S2	S3	S4	S5
	V3	5.83	5.23	4.29	6.33	3.58
	V4	4.67	3.08	4.00	2.59	3.27
	V5	4.09	4.43	3.74	2.7	5.36

Legend: V3) Dense ombrophilous montane forest, V4) Seasonal deciduous forest, V5) Seasonal semideciduous forest, S1) High activity clay soils, S2) Oxisols with low activity clay, S3) Soils other than Oxisols with low activity clay, S4) Sandy soils, S5) Hydromorphic soils. Source: Adapted from CETESB, 2012. Org.: by the authors, 2018.

Tables 6, 7, and 8 show the transitions from 2007 to 2010, 2010 to 2013, and 2013 to 2016, respectively. In these tables, gray cells correspond to the transitions that occurred from one period to the next; green cells correspond to permanent land use; noncolored cells refer to lack of transition; and the Transition column refers to how much area was lost in each category. The lines represent the previous year and the columns the following year (CETESB, 2011; 2012).

Table 6. Transition matrix for land use categories from 2007 to 2010 (ha).

Area (ha)	Land use in 2010									
Land use in 2007		F	Fo	Ua	A	Fa	P	R	Total 2007	Transition 2007-2010
	F	628.86	0.24	12.15	82.49	0.06	0.60	16.88	741.28	112.42
	Fo	38.93	4,112.50	26.99	62.57		1.51		4,242.50	130.00
	Ua	0.56	3.66	1,102.60	1.05				1,107.87	5.27
	A	3.37	0.66	12.98	3,167.81		1.89		3,186.71	18.90
	Fa		0.06	0.45	0.06	81.71			82.28	0.57
	P	0.34		3.16			88.20		91.70	3.50
	R	1.21	5.38	1.70	1.76			180.38	190.43	10.05
Total 2010		673.27	4,122.50	1,160.03	3,315.74	81.77	92.20	197.26	9,642.77	Total transition 280.71 ha

Legend: (Fo) Forest, (R) Reforestation, (F) Field, (A) Agriculture, (Ua) Urban area, (Fa) Flooded area, (P) Pasture. Org.: by the authors, 2018.

Table 6 shows that the category with the greatest loss of area was the forest (130.00 ha), and that the largest conversion of natural areas for human use was from forest to agriculture (62.57 ha). From 2010 to 2013 (Table 7), the forest category also accounted for the greatest loss of area, being converted mainly to urban areas, which corresponded to 89 ha.

When comparing the transitions in Table 8 with previous periods, it is noted that the least amount of transitions occurred in this period. However, the forest category still accounted for the main changes.

Table 7. Transition matrix for land use categories from 2010 to 2013 (ha).

Area (ha)	Land use in 2013								
Land use in 2010	F	Fo	Ua	A	Fa	P	R	Total 2007	Transition 2010-2013
F	513.89	6.45	75.76	61.47	0.15	3.63	11.92	673.27	159.38
Fo	48.24	3,913.64	89.00	63.01	0.49	6.52	1.60	4,122.50	208.86
Ua	1.21	0.91	1,155.03	2.82	0.06			1,160.03	5.00
A	24.39	8.57	19.47	3,256.12	0.24	3.62	3.33	3,315.74	59.62
Fa		0.40	0.43	0.52	80.42			81.77	1.35
P	0.96	0.45	10.97	0.24		79.58		92.20	12.62
R	3.42	7.66	5.79	5.49			174.9	197.26	22.36
Total 2013	592.11	3,938.08	1,356.45	3,389.67	81.36	93.35	191.75	9,642.77	Total transition 469.19 ha

Legend: (Fo) Forest, (R) Reforestation, (F) Field, (A) Agriculture, (Ua) Urban area, (Fa) Flooded area, (P) Pasture. Org.: by the authors, 2018.

Table 8. Transition matrix for land use categories from 2013 to 2016 (ha).

Area (ha)	Land use in 2016								
Land use in 2013	F	Fo	Ua	A	Fa	P	R	Total 2013	Transition 2013-2016
F	531.91	0.06	5.54	52.46	0.18		1.96	592.11	60.20
Fo	41.24	3,824.55	25.66	40.41	0.39	0.66	5.17	3,938.08	113.53
Ua		2.91	1.352.04	1.00	0.46		0.04	1,356.45	4.41
A	25.52	0.67	14.02	3,338.73	0.37	4.28	6.08	3,389.67	50.94
Fa			1.98		79.38			81.36	1.98
P			0.66		0.06	92.63		93.35	0.72
R			0.24	0.84		0.18	190.49	191.75	1.26
Total 2016	598.67	3,828.19	1,400.14	3,433.44	80.84	97.75	203.74	9,642.77	Total transition 233.04 ha

Legend: (Fo) Forest, (R) Reforestation, (F) Field, (A) Agriculture, (Ua) Urban area, (Fa) Flooded area, (P) Pasture. Org.: by the authors, 2018.

The comparison between transition matrices indicated that the forest showed prominence in the conversion to anthropogenic areas. The highest numbers occurred from 2010 to 2013, with 208.86 ha. Transitions have also shown that urbanization has increased, although agricultural areas are more prominent.

The greater conversion of the forest category in the studied periods is a worrying factor, especially when considering the amount of forests that have been suppressed and its consequences for the environment. This compromises one of the main ecosystem services, which is CO_2 sequestration or storage. When in excess in the atmosphere, CO_2 contributes to the intensification of the greenhouse effect (RIBEIRO et al., 2009).

According to Baird and Cann (2011), a large amount of CO_2 is emitted into the atmosphere when forests are cut down, with deforestation accounting for about a quarter of CO_2 emissions. Regarding urbanization, watersheds become vulnerable to rapid changes in natural conditions, influencing landscape quality and encouraging environmental degradation and irregular occupation (GUIMARÃES; PENHA, 2009).

Tables 9, 10, and 11 show the estimates of net CO_2 emissions from 2007 to 2010, 2010 to 2013, and 2013 to 2016, respectively. Gray cells represent CO_2 emissions (positive values) or removals (negative values) from one period to the next. Green and noncolored cells do not have values, the first because it corresponds to the category in which there were no transitions from one period to the next, and the other because there was no transition. In the Emission/Removal column, we have the total net issue for each category. Lines represent the previous year and columns the following year (CETESB, 2011; 2012).

Table 9 shows that CO_2 emission was greater than its removal, and the change from forest to field was the one that most contributed to emissions.

Table 9. Matrix of Estimates of net CO_2 emissions ($GgCO_2$) from 2007 to 2010.

$GgCO_2$		Land use in 2010							Emission/ Removal
		F	Fo	Ua	A	Fa	P	R	
Land use in 2007	F		-0.0021	0.0025	0.0190	0.0001	-0.0002	-0.0194	0.0001
	Fo	0.8383		0.4632	0.8100		0.0471		2.1586
	Ua	-0.0004	-0.0516		-0.0015				-0.0535
	A	0.0012	-0.0004	0.0104			-0.0001		0.0111
	Fa		-0.0006		-0.0001				-0.0007
	P	0.0020		0.0017					0.0037
	R	0.0039	-0.1030	0.0073	0.0060				-0.0858
									Total = 2.0335

Legend: (Fo) Forest, (R) Reforestation, (F) Field, (A) Agriculture, (Ua) Urban area, (Fa) Flooded area, (P) Pasture. Org.: by the authors, 2018.

Total net emissions were higher from 2010 to 2013 (Table 10) compared to the period from 2007 to 2010, which was consistent with the number of transitions that occurred, mainly of forests. From 2013 to 2016 (Table 11), in turn, there was a decrease in emissions, but these were still higher than removals.

When comparing Tables 9, 10, and 11, it can be seen that the highest estimate of CO2 emissions (4.1422 GgCO2) occurred from 2010 to 2013. During this period, the estimated emissions were approximately twice those of the 2007-2010 period and those of the 2013-2016 period. Although all categories present some type of transition that would emit this gas, forest conversions accounted for the largest emissions: 2.15, 4.26, and 2.11 for the periods of 2007-2010, 2010-2013, and 2013-2016, respectively.

Table 10. Matrix of Estimates of net CO_2 emissions ($GgCO_2$) from 2010 to 2013.

$GgCO_2$		Land use in 2013							Emission/ Removal
		F	Fo	Ua	A	Fa	P	R	
Land use in 2010	F		-0.0562	0.0535	0.0143	0.0011	-0.0044	-0.0115	-0.0032
	Fo	1.2452		2.0147	0.8223	0.0086	0.1698	0.0022	4.2628
	Ua	-0.0015	-0.0186		-0.0048				-0.0249
	A	0.0191	-0.0034	0.0184		0.0010	-0.0005	-0.0034	0.0312
	Fa		-0.0038		-0.0013				-0.0051
	P	0.0009	-0.0007	0.0087	0.0001				0.0090
	R	0.0058	-0.1670	0.0126	0.0210				-0.1276
									Total = 4.1422

Legend: (Fo) Forest, (R) Reforestation, (F) Field, (A) Agriculture, (Ua) Urban area, (Fa) Flooded area, (P) Pasture. Org.: by the authors, 2018.

Table 11. Matrix of Estimates of net CO_2 emissions ($GgCO_2$) from 2013 to 2016.

$GgCO_2$		Land use in 2016							Emission/ Removal
		F	Fo	Ua	A	Fa	P	R	
Land use in 2013	F		-0.0003	0.0120	0.0110	0.0180		-0.0004	0.0403
	Fo	1.1130		0.4066	0.5470	0.0046	0.0296	0.0145	2.1153
	Ua		-0.0316		-0.0011			-0.0003	-0.0330
	A	0.0202	-0.0005	0.0139		0.0016	-0.0005	-0.0098	0.0249
	Fa								0.0000
	P			0.0008		0.0007			0.0015
	R			0.0060	0.0030		0.0189		0.0279
									Total = 2.1769

Legend: (Fo) Forest, (R) Reforestation, (F) Field, (A) Agriculture, (Ua) Urban area, (Fa) Flooded area, (P) Pasture. Org.: by the authors, 2018.

This greater conversion of forest to other categories can be justified by the fact that these areas have a high amount of carbon in their biomass. Thus, when vegetation is suppressed to meet the demand of other land use categories, the amount of CO_2 emitted will be greater than the capacity to sequester carbon in new uses. According to Don et al. (2011) and Kim and Kirschbaum (2015), forest suppression causes a rapid loss of carbon, especially if the biomass is burned, increasing atmospheric CO_2.

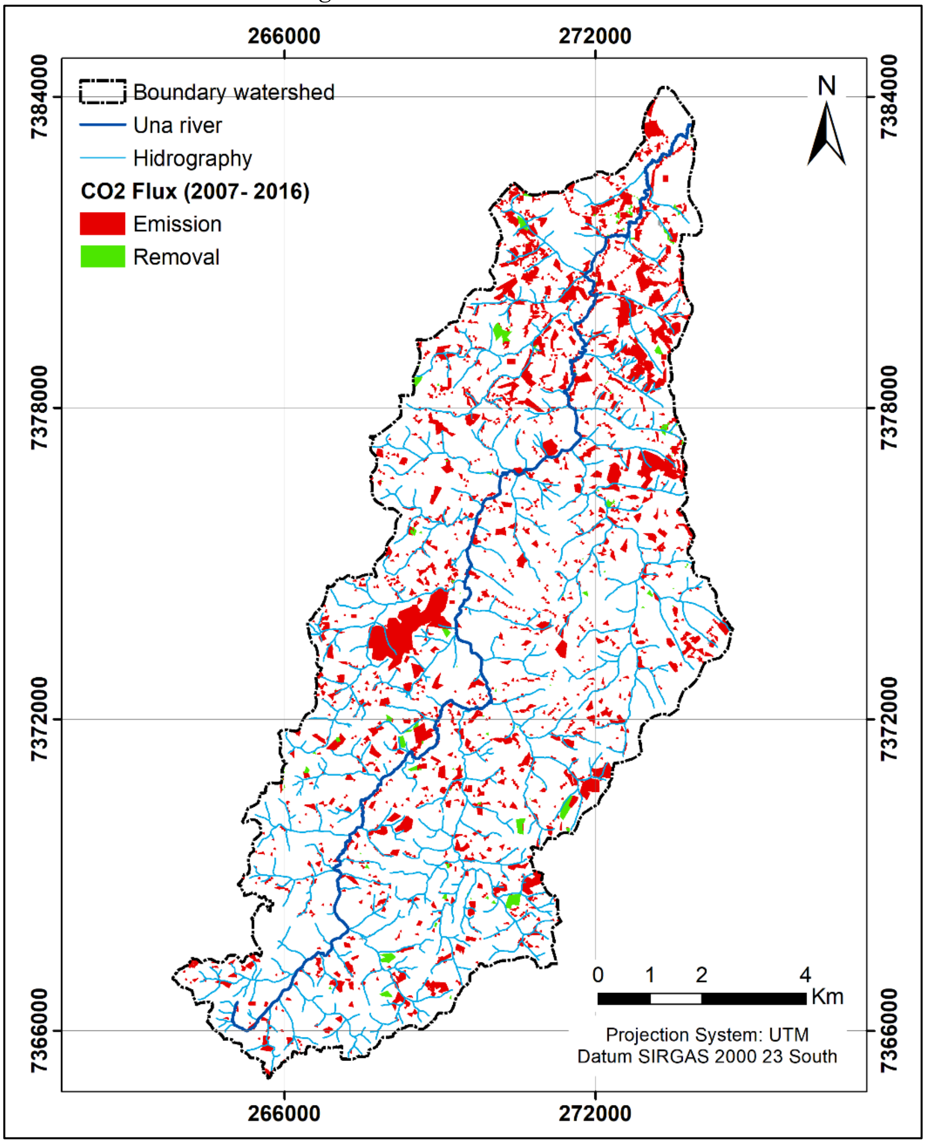
Carbon dioxide (CO_2) emissions in the three periods indicate consistency with the data reported in the study by Kim and Kirschbaum (2015), who identified emissions in the conversions from forest to agriculture and from forest to pasture, as well as from pasture to agriculture.

The estimated values of net emissions are generally consistent with the dynamics of land use in the watershed. Due to the size of the watershed, these emissions could not be compared to the state or country level, since the dynamics would be much greater in these locations. Notwithstanding, these results reinforce the importance of studying watersheds, since they are conceived as basic units of environmental planning and have multiple uses.

Looking for a comparison, the CETESB's inventory (2012) for São Paulo State identified that conversion from agriculture to urban areas between 1994 and 2008 accounted for an emission equivalent to 444.26 $GgCO_2$. This value is much higher than that obtained in the watershed (0.0142 $GgCO_2$), since they have different scales.

The Una river was shown to have anthropogenic interferences mainly in the central and northern portion, where most of the emissions were found, indicating environmental degradation in this location (Figure 4).

Figure 4. CO_2 flux due to land use change from 2007 to 2016 in the Una river watershed.



Org.: by the authors, 2018.

There is a trend of increased emissions if forest areas in this location are replaced by new occupations, that is, the watershed is susceptible to loss of environmental quality, which compromises its water resources, biodiversity, and the well-being of the local population.

Among the measures to be taken to

reduce CO_2 emissions is environmental management and planning, which includes preparing the Plans for the Recovery of Degraded Areas (PRAD), the Rural Environmental Registry (CAR), and the Environmental Control Plan (PCA) for activities with high environmental impact. Aided by proposals for the maintenance and restoation of natural areas with the use of geotechnologies, these actions can minimize the impacts of land use change.

Another effective measure would be to encourage small farmers to adopt the agrosilvopastoral system, since it associates agriculture and livestock with forest maintenance, providing an environment suitable for agricultural practices that also benefits the environment.

Land use is considered an important factor when it comes to policies related to climate change. For this reason, Rose et al. (2012) report that changes in the adopted practices and technologies can reduce GHGs and, in the long run, turn into a low cost mitigation strategy.

FINAL CONSIDERATIONS

There was an increase in land use changes over natural vegetation over nine years, equivalent to the loss of 4.30% of forests to increase agriculture and urban areas. Fields and flooded areas were reduced by 1.48% and 0.01%, respectively, while pasture areas increased by 0.06% and reforestation areas by 0.14%.

The forest category had the largest transitions for anthropogenic activities in all periods studied, mainly in 2010-2013, in which the converted area was 208.86 ha. Net CO_2 emissions into the atmosphere were recorded in all periods analyzed. The period with the highest emission was 2010-2013, totaling 4.1422 $GgCO_2$.

The main contribution to CO_2 emissions in the Una river watershed consists of vegetation suppression to meet the demand for agriculture and urbanization. Moreover, it was shown that CO_2 emissions were higher than its removals.

The study was effective in identifying anthropogenic interventions and the number of forest areas suppressed in the watershed. The methodology adopted could serve as a technical-methodological design in similar areas, seeking to diagnose the situation of CO_2 emissions and removals from land use changes in areas of relevant water and environmental interest.

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