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ESTIMATING THE USE OF PESTICIDES: AN ANALYSIS ASSOCIATED WITH THE EXPANSION OF SUGARCANE IN THE AGUAPEÍ RIVER HYDROGRAPHIC BASIN, OESTE PAULISTA-BRAZIL

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Abstract: The present work aims to estimate the use of pesticides by sugarcane in the watershed of the Aguapeí River. To this end, the research relied on data provided by Mapbiomas (2021) on sugarcane expansion in the study area - having the years 2002 and 2020 as a time scale - in addition to the limit of the subbasin area, provided by SIMA (2020) and the estimate of the use of pesticides per hectare in sugarcane cultivation, according to Pignati, Oliveira and Silva (2014). Thus, with the aid of a Geographic Information System (GIS) the use of pesticides was quantified among the subbasins of the study area. In addition to office activities, field work was carried out in order to analyze the dynamics of the landscape and corroborate the mapped elements. The results showed that between the analyzed period there was a significant change in terms of land use, with the substitution of pasture for sugarcane expansion, resulting in an exponential increase in the use of pesticides. Therefore, this work contributes to research that aims to estimate the use of agrochemicals in watersheds, in addition to assisting in studies on the environmental impacts resulting from the use of pesticides.
Keywords: Appropriation, Pesticides, Environmental analysis.

INTRODUCTION

The relationship between society and nature has been marked by increasingly intense degenerative processes since the threshold of industrial revolutions (MATOS and SANTOS, 2018; FREITAS and MARQUES, 2019), culminating in an unsustainable process of economic development. This deleterious relationship can be observed from the perspective of the appropriation of the relief, which according to Casseti (1991), is the support for the environmental changes that occur in the occupation process, carried out by society.

In the rural environment, since the spread of the so-called Green Revolution, during the 20th century, there has been a massive modernization of agriculture (LOPES and ALBUQUERQUE, 2018), which has been incorporated into the capitalist mode of production, with the main consequence being the appropriation of space by extensive monocultures.

However, many criticisms have been raised against this agrarian-export model, such as the fallacious discourse of guaranteeing world food security, however, according to Porto-Gonçalves (2006), the main objective of monocultures is the commodification of their products. For example, according to the report Status of Food and Nutritional Security in the World (2022), released by the Food and Agriculture Organization of the United Nations (FAO), in 2021 approximately 828 million people suffered from hunger, with an increase of 46 million people for the year 2020.

Inserted in this context, Brazil has consolidated itself as a major agricultural producer, standing out among the world's largest exporters (GABOARDI, CANDIOTTO and RAMOS, 2019), with soybean, corn and sugarcane as the main crops. This last product has been spreading mainly in the state of São Paulo. Such expansion is the result of government incentives led by programs such as PROÁLCOOL and PROOESTE, especially between the 1970s and 1980s (PRATES et al, 2021). In the 2000s, marked by the development of cars with flex fuel technology, there was a new impulse in the sugar and alcohol sector, promoting the advance of sugarcane fields, mainly in the west of the state (PRATES et al, 2021).

In this context, on September 18, 2008, the Secretariats for Infrastructure and Environment (SIMA) and State Agriculture and Supply (SAA) prepared the Agro-environmental Zoning for the sugar and alcohol sector of the state of São Paulo -ZAA, aiming to " disciplining and organizing the expansion and occupation of land by the sugar-energy sector, in addition to subsidizing the elaboration of public policies focused on issues related to the sector" (SÃO PAULO, 2008).

Although the ZAA is a tool for territorial planning and takes environmental variables into account, Jordão and Moretto (2015, p. 92-93) clarify that:

> [...] many of these mappings do not satisfactorily address environmental vulnerability factors, not adequately considering information related to soil quality, water quality, watercourse flow, natural vegetation cover, species diversity, conservation units and legal reserves; or still not considering any information on permanent preservation areas and other agricultural uses.

Therefore, it is denoted that the criteria for the ZAA are, above all, of agricultural aptitude, considering mainly the potential for the expansion of sugarcane than the environmental vulnerabilities (JORDÃO and MORETTO, 2015).

Among the negative consequences of policies that encourage the current agrarian-export model, those associated with environmental and health issues stand out. With regard to the environment, the establishment of monocultures results in a drastic decrease in ecological diversity, that is, in the simplification of ecosystems (DREW, 2002). Consequently, there is a greater need for the use of inputs, such as agricultural correctives and pesticides (DREW, 2002; CARMO et al, 2021).

Once exposed to the harmful effects of the aforementioned agricultural model, especially due to the excessive use of pesticides, the environment is strongly impacted (ROCHA, 2020). In this sense, Rocha, Araújo and Rizk (2020) when analyzing the exposure of the drainage network to pesticides in Pontal do Paranapanema-SP, especially those used by the sugarcane culture, reiterate that the monoculture of sugarcane interferes in the natural ecological chain.

Pesticides, when in contact with the soil surface, can be transported to the drainage network through surface runoff, or even leached into the water table, contaminating the surface and underground waters that supply the population.

Therefore, environmental contamination by pesticides contributes to adverse effects on human health, as shown by studies carried out by Oliveira et al (2018), Ismael and Rocha (2019), Neves et al (2020) and Lima, Pignati and Pignatti (2020). According to data released by Repórter Brasil (2019), based on information made available by the Water Quality Surveillance Information System (Sisagua), between 2014 and 2017 cocktails of 27 pesticides were identified in water for human consumption in about 1,396 Brazilian municipalities, many of these chemicals being associated with chronic diseases such as cancer, hormonal and reproductive disorders, and even fetal malformation.

The watershed of the Aguapeí river, located in the west of the state of São Paulo, has stood out for the significant expansion of the sugar and alcohol sector in recent decades. Thus, the present research assumes that the watershed of the Aguapeí river is susceptible to the adverse effects of the advance of this culture, such as, for example, the excessive use of pesticides.

In the process of environmental analysis, the use of geotechnologies aimed at mapping areas under the influence of human activities - resulting in the generation of environmental impacts - has proven to be an important tool, as pointed out by the works of França et al (2016), Souza e Cunha (2020), Ramos and Nóbrega (2020) and Dias, Martins and Barros (2020).

Given the degenerative effects on the environment and human health associated with pesticides, the use of Geographic Information Systems (GIS) that assist in the analysis of the spatial distribution of the use of such chemical inputs, as well as their quantification, are increasingly essential.

Therefore, this research is justified by the growing need to measure the use of these agrochemicals in order to contribute to research that seeks to analyze the susceptibility of contamination of the physical environment as well as to help in socio-environmental planning. In this sense, this work aims to estimate the use of pesticides used by the sugarcane monoculture in the hydrographic subbasins of the Aguapeí River.

CHARACTERIZATION OF THE STUDY AREA

Located in the west of the state of São Paulo - Brazil - the hydrographic basin of the Aguapeí River comprises an area of approximately 13,000 Km2, with its sources in the region of Marília and its mouth in the Paraná River. (Figure 1).

The study area is contained in the Paraná Sedimentary Basin, defined by Zalán et al (1990) as intracratonic and composed of sedimentary and volcanic rocks. The geological formations that comprise the hydrographic basin in question correspond, geochronologically, to the São Bento and Bauru groups, in addition to Cenozoic Deposits (INSTITUTO DE PESQUISAS TECNOLOGICAS - IPT, 1981).

According to IPT (1981), in the study area, the São Bento group is constituted by the Serra Geral Formation (JKsg), while the Bauru group presents outcrops of the following sedimentary formations: Santo Anastácio (Ksa), Adamantina (Ka), Marília (Km) in addition to Quaternary Deposits (Qa).

As for the geomorphology of the watershed of the Aguapeí river, it is located in the Western Plateau of São Paulo, which is subdivided into several units, among which the Central Western Plateau and the Residual Plateau of Marília are found in the study area (ROSS and MOROZ, 1997). As regards the first geomorphological unit, it comprises most of the area of the hydrographic basin (BH) in question, on the other hand, the Marília Residual Plateau occurs only in the eastern portion of the study area.

The altitude in BH ranges from 246 to 721 m, with the highest indices concentrated in the watersheds, on the other hand, the lowest hypsometric elevations occur mainly in valley bottoms associated, for example, with flood plains. As for slope, its classes range from up to 6% to over 30%, with the lowest slope indices predominating (6% to 12%), which cover the entire medium-low course of the basin (PRATES et al, 2021).

Influenced by the regional geological structure, the drainage network of the rivers contained in the Western Plateau of São Paulo are, essentially, of the consequent type, with parallelism in the NW direction, as can be seen in the Tietê, Aguapeí, Peixe and Santo Anastácio rivers (IPT, 1981).

With regard to the predominant climate, it is of the tropical (Aw) and subtropical (Cwa) type, influenced by the action of the Tropical Atlantic, Tropical Continental, Polar Atlantic and Continental Equatorial air masses, the participation of the latter being less frequent (BOIN, 2000). The average annual temperature is above 22° C and the average annual precipitation ranges from 1,200 to 1,500 mm. (CBH-AP, 1997; BOIN, 2000).

According to the pedological mapping of the state of São Paulo, carried out by Rossi (2017), in the study area there are five groups of soils, namely: Argisols, Latosols, Neosols, Haplic Gleissolos and Haplic Planosols. Argisols are the class of soils that most stand

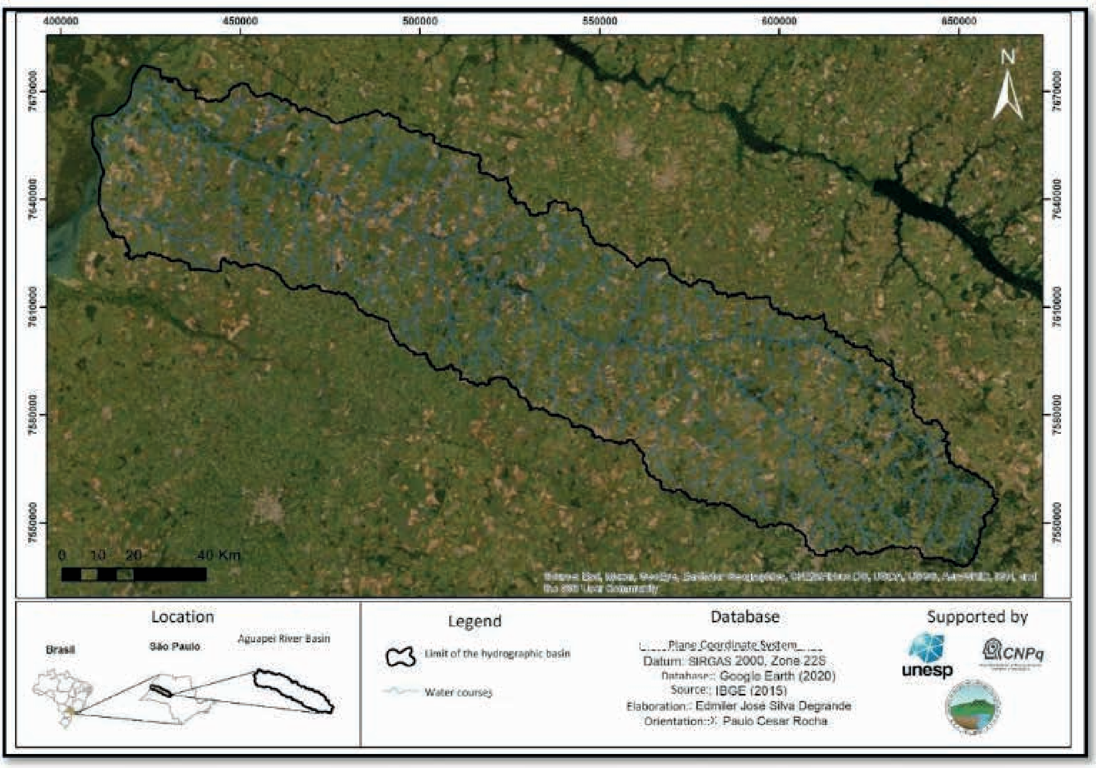

Figure 1- Chart - image of the location of the watershed of the Aguapeí river, São Paulo- Brazil

Source: IBGE, 2015

Elaboration: Edmiler José Silva Degrande out in the BH area, covering from the upper to the lower course. These types of soils have low or very low resistance to erosion processes, given their textural characteristics (LOMBARDI NETO, et al, 1992).

With regard to the original forest cover of Oeste Paulista, Sampaio (1890) highlights the domain of the Semideciduous Seasonal Forest, also occurring, to the south of the Peixe River, vegetation characteristic of the Cerrado. However, in the first decades of the 20th century, this region experienced its occupation process, driven by the expansion of the railroad as well as the advance of coffee production (LEITE, 1998). This process, in turn, was responsible for the emergence of towns and villages, giving rise to the first cities (LEITE, 1998).

Throughout the 20th century, according to the CBH-AP (1997), there was diversification in land use in the region, such as the cultivation of peanuts, cotton, in addition to raising cattle on large farms. Between the end of the 20th century and the beginning of the 21st century, the West of São Paulo has experienced sugarcane expansion, occupying areas until then intended for pasture (PRATES et al, 2021).

METHODOLOGICAL PROCEDURES

The execution of this research went through the stages of cabinet and field work. In an office, we carried out a bibliographical survey covering concepts such as land appropriation, sugarcane expansion and the socio-environmental impacts resulting from the use of pesticides. Also in the office, cartographic material was prepared, such as the expansion of sugarcane in the study area and the estimate of the use of pesticides. These products had as the temporal analysis the years 2002 and 2020, being generated in Arc Gis 10.3 software.

The spatial area used in this work was the hydrographic subbasins of the Aguapeí River, since the subdivision of the study area into subbasins facilitates the analysis of the territorial dynamics of sugarcane, as well as the helps to identify areas that have been suffering from the use of pesticides.

SUGARCANE EXPANSION MAP

The elaboration of this cartographic product was based on information acquired from Mapbiomas (2021), which has mapped the land use of the Brazilian territory with the aid of Landsat 7 and 8 images, with a resolution of 30 m.

Other data used in this procedure were the sub-basins of the Aguapeí River, provided by the Department of Infrastructure and Environment of the State of São Paulo (SIMA, 2020), which delimited them based on the drainage network on a scale of 1:50,000, in addition to the compartmentalization of the upper, medium and lower course basins, made available by the CBH-AP (2020).

ESTIMATED MAP OF PESTICIDE USE BY SUGARCANE

The mapping of the estimated use of pesticides by sugarcane was carried out using data obtained from Pignati, Oliveira and Silva (2014). For the authors, in Brazil, information about the consumption of pesticides is insufficient, making research in the environmental and health fields difficult.

In order to contribute to studies that aim to estimate the use of pesticides as well as the analysis of the socio-environmental impacts that these agrochemicals can cause, the referred authors proposed the spatialization of the use of pesticides in Brazilian municipalities, indicating the amount of this product in different cultures, among them, sugar cane. For this purpose, data such as "agronomic recipes containing the use of pesticides by municipality, volume (liters) used, size of the treated area and type of "pest" to be combated" (PIGNATI et al, 2017, p. 3,282) were considered.

Therefore, for sugarcane, 4.8 liters of pesticides per hectare were considered (PIGNATI, OLIVEIRA and SILVA, 2014). Based on this value, we estimate the use of pesticides in the hydrographic subbasins of the Aguapeí River. Therefore, this procedure started from the correlation between the sugarcane area in the subbasins (in ha) and the amount of pesticides applied, as shown by Equation 1:

$$UABH = ACa * 4,8 \quad \text{Equation 1}$$

Where:

UABH= Use of Pesticides in the Hydrographic Basin.

ACa= Area with sugarcane in hydrographic subbasins.

4.8= Amount (in liters) of pesticides used in each hectare of sugarcane.

For the elaboration of this map, we used as vector data the hydrographic subbasins of the study area (SIMA, 2021) and the shapefile of sugarcane in the BH of the Aguapeí river, referring to the years 2002 and 2020 (Mapbiomas, 2021).

This procedure had four steps, namely: 1) calculation of the area of the hydrographic subbasins (in hectare); 2) calculation of sugarcane area (in hectare); 3) quantification of the sugarcane area in each hydrographic subbasin, and, 4) application of Equation 1 to estimate the use of pesticides in the subbasins (Figure 2).

Both the calculation of the watershed and sugarcane subbasin areas occurred in the attribute tables of these respective shapefiles using the Open Attribute Table> Add field> Calculate Geometry> Hectares tools.

In order to quantify the sugarcane area in each hydrographic subbasin, it was necessary to use the tools Analisys Tools > Statistic> Tabulate Intersection, which used as input data the information from the following columns of the attribute table: Area_subbasins (referring to the shapefile of the subbasins) and Area_da_cane (referring to the sugarcane shapefile).

The result of this procedure was the generation of a new file in dbf format, which contains a column with information on the sugarcane area in the hydrographic subbasins. These data were taken to the attribute table of the shape of subbasins, through the Join and related item> Join procedure, in the sequence, a new column was added in this table of attributes (named UABH) for the application to Equation 1, through the item field calculator.

Five classes of UABH expressed in liters were generated, so that class 1 has the lowest values, while class 5 shows a high amount of UABH, reaching 123,644 liters (Table 01).

FIELD ACTIVITIES

As for the field activities, they took place on 11/12/2021 at two points in the study area, namely: Point 1 (lat. 21º 27' 18.62" S and long. 50º 55' 6.21" W), located in the middle course of the Aguapeí river basin and Point 2 (lat. 21º 7' 25.14" S and long. 51º 36' 24.53"), located in its lower course. These empirical activities aimed to corroborate the mapping carried out on sugarcane expansion, especially in the middle-lower course, in addition to verifying the areas most susceptible to the use of pesticides.

RESULTS AND DISCUSSIONS

Over the last few years, the watershed of the Aguapeí River has undergone several transformations in terms of land use. Until the beginning of the 21st century, a large part of this area was occupied by pasture,

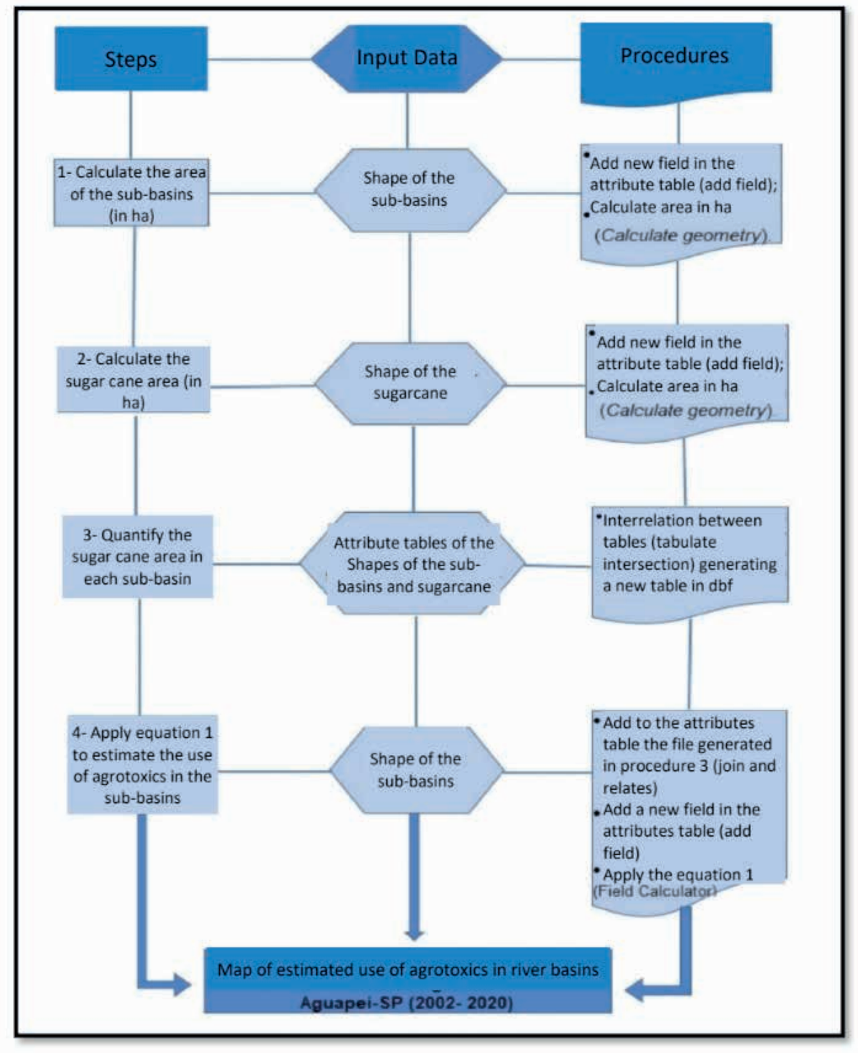

Figure 2- Flowchart of the steps taken to generate the map for estimating the use of pesticides in the hydrographic subbasins of the Aguapeí River

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Classes	UABH (in liters)
1	0,01- 3.398
2	3.399- 11.959
3	11960- 27.620
4	27.621- 56.138
5	56.139- 123.644

Table 1- BH classes of the Aguapeí river hydrographic sub-basins

Source: Pignati, Oliveira and Silva (2014)

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however, this form of use has been replaced by other cultures, with emphasis on sugarcane (PRATES et al, 2022).

In this sense, Prates et al (2021) state that since the 1980s, government incentives have contributed to the promotion of the sugar and alcohol sector in the region, such as the creation of the Development Plan for the West of the State of São Paulo (PRÓOESTE). However, even if this period was important for the implementation of new sugar and alcohol plants, it was only at the beginning of the 2000s, with the development of flex fuel technology, that in the hydrographic basin in question there was a boost in sugarcane production.

Given the above, the aim was to analyze the expansion of sugarcane in the study area from the 2000s. has dominated the landscape of Belo Horizonte (Figure 3).

In 2002, sugar expansion patches were basically concentrated between the middle and lower reaches of Belo Horizonte. During this period, the area destined to sugarcane cultivation was 85,959 ha. Already in 2020, the exponential increase of this crop is noted, when its area was 417,160 ha (Graph 1). In this last year, the presence of sugarcane occurred in all compartments of BH in addition to its density between the medium and lower course.

When comparing the areas with sugarcane between the upper, medium and lower course of the basin, it was noted that the medium course has stood out for having the largest area with sugarcane in 2002 (48,708 ha), on the other hand, this scenario changed in the next year analyzed when the sugarcane concentration occurred in the lower course, reaching 181,320 ha in 2020, as can be seen in Table 2. It must be noted that although the lower course of the watershed concentrates sugarcane production in 2020, the medium course has also contributed substantially, presenting values close to those of the low course.

The choice of areas for the advancement of sugarcane has a strong relationship with the mechanization process of the sugar and alcohol sector in recent years, thus, the characteristics of the physical environment such as low slopes and hypsometry are some of the attributes for the selection of mechanized areas since regions with a high gradient and altitude make it difficult for vehicles used in the planting and harvesting process to travel.

In this context, the medium-low course of the basin is more susceptible to appropriation by sugarcane, since low slopes (up to 12%) predominate in their areas, in addition to topography ranging from 242 m to 477 m.

In Figure 4, the expansion of sugarcane fields over the middle (A) and lower course (B) compartments can be seen. In both areas, the indiscriminate advance of sugarcane can be seen, many times putting pressure on water courses with its planting a few meters from the bottom of valleys, as can be seen in figure 4-B.

Among the adverse consequences of sugarcane expansion, the increasingly intense use of pesticides stands out, thus, based on the proposition by Pignati, Oliveira and Silva (2014), we analyze the estimated use of these chemicals in the hydrographic subbasins of the river Aguapeí.

During 2002, the amount of pesticides used by sugarcane among the hydrographic subbasins was 412,603 liters. When assessing the spatial distribution of pesticide use, we sought to group the subbasins into classes (from 1 to 5), with class 1 being the one with the lowest values of pesticide use and, therefore, class 5 representing high UABH (Figure 5).

Thus, in that year, class 1 represented 70% of the area of the subbasins, being, therefore, the most representative, which indicates that in this period, in most of the subbasins, the

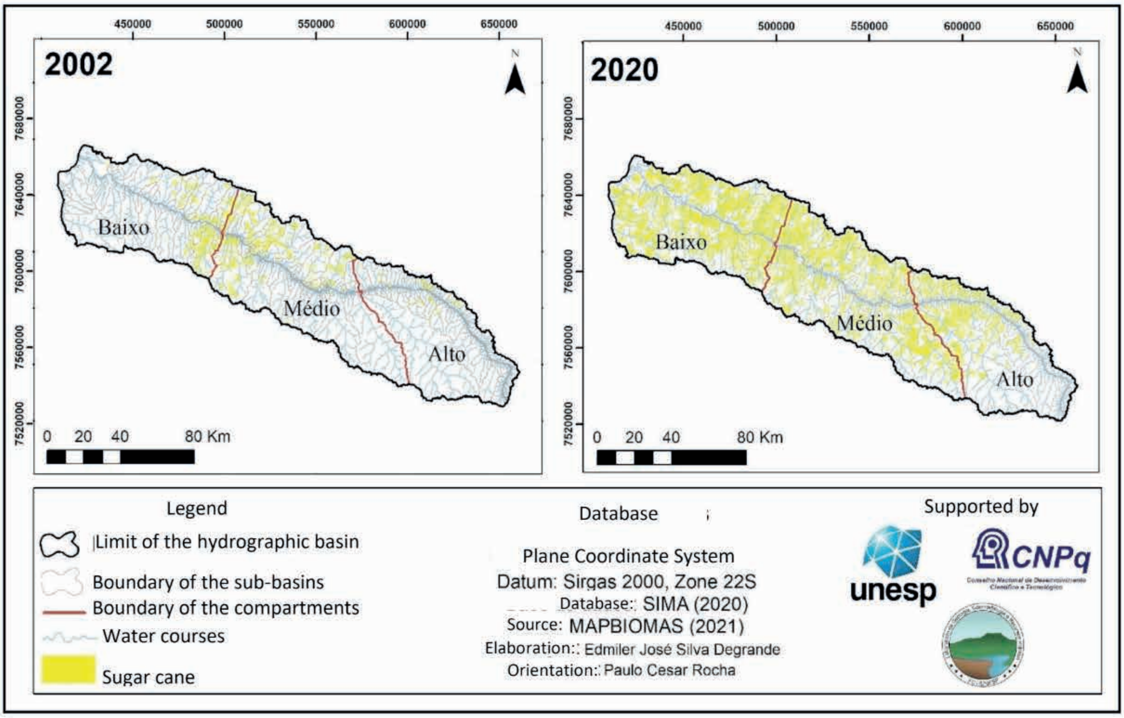
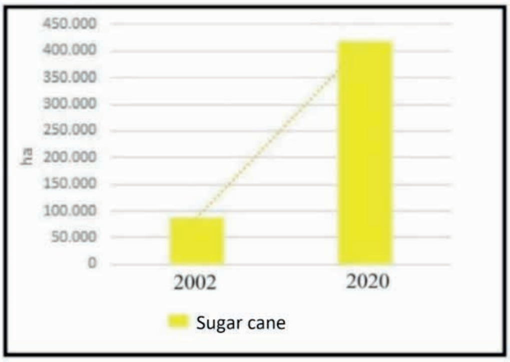


Figure 3- Expansion of sugarcane in the Aguapeí river basin (2002- 2020)

Source: MAPBIOMAS (2021)

Elaboration: Edmiler José Silva Degrande



Graph 1- Expansion of sugarcane in the river basin Aguapeí (2002- 2020)

Source: MAPBIOMAS (2021)

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Basin Compartment	2002	2020
Upper	8.506	69.640
Medium	48.708	166.200
Low	28.745	181.320
Total	**85.959**	**417.160**

Table 2- Area of sugarcane between the compartments of the watershed of the Aguapeí river (in ha)

Source: MAPBIOMAS (2021)

Elaboration: Edmiler José Silva Degrande

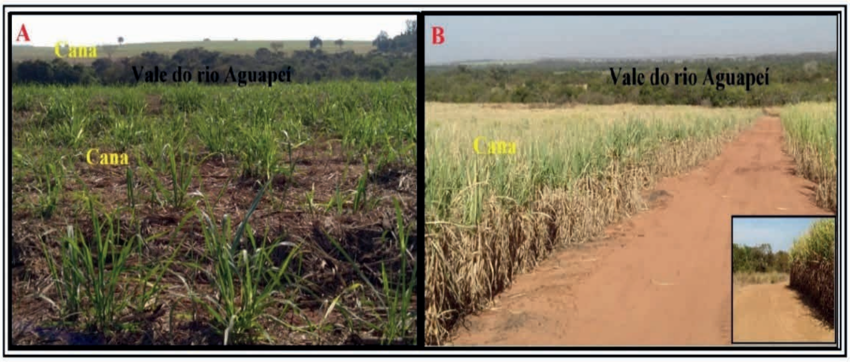


Figure 4- Sugarcane in the middle-low course of the Aguapeí river basin

Picture: Edmiler José Silva Degrande

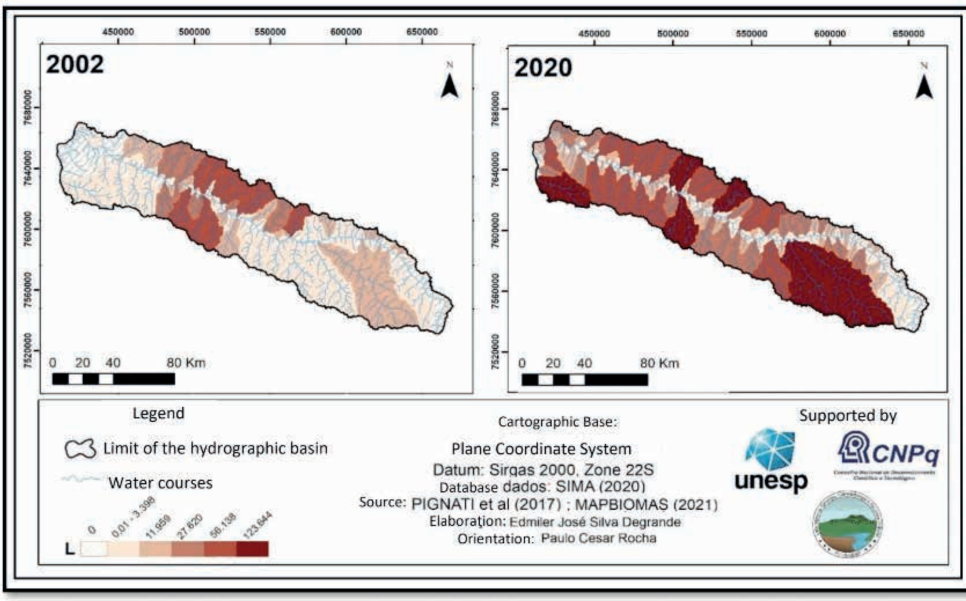
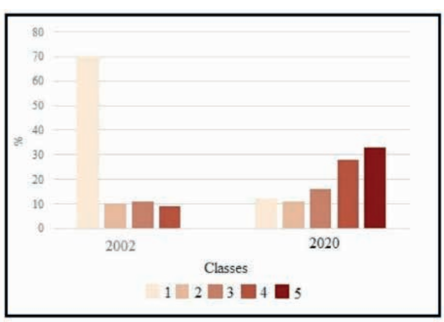


Figure 5- Estimation of the use of pesticides by sugarcane in the hydrographic subbasins of the Aguapeí River-SP (2002- 2020)

Source: Pignati, Oliveira and Silva (2014)

Elaboration: Edmiler José Silva Degrande



Graph 2- Classes of estimated use of pesticides by sugarcane among the subbasins of the river Aguapeí (2002- 2020)

Source: Pignati, Oliveira and Silva (2014)

Elaboration: Edmiler José Silva Degrande

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UABH could reach up to 3,398 liters. Class 2 represented 10% of the area while classes 3 and 4 have percentages of 11% and 9%. It must be noted that this year, there were no values in the use of pesticides corresponding to class 5 (Graph 2).

In 2020, the estimated amount of pesticides consumed by the sugarcane crop was 2,002,368 liters, that is, an increase of almost five times compared to the previous period. Thus, as the sugar and alcohol expansion gained greater proportions, there was an exponential growth in the use of pesticides.

Consequently, it appears that in 2020 class 1 corresponded to only 12% of the area of the hydrographic subbasins, showing a significant decrease, on the other hand, all other classes suffered a substantial increase, with emphasis on class 5, which did not exist in the period and became the main one, with a percentage of 33%. Therefore, in 2020, most of the subbasins of the Aguapeí River already had a quantity of pesticide use between 56,139 and 123,644 liters.

Concomitant with the increase in the area destined for the planting of sugarcane, there was an increase in the use of pesticides, thus, the estimates indicated that, if in 2002 class 1 was the one that represented the majority of the area of the subbasins, in 2020 it was class 5 started to correspond to its largest extensions.

This data makes the question of the use of pesticides in the study area worrying, as it demonstrates that the physical environment (soil and drainage network) is increasingly susceptible to the use of these chemical products, which may compromise its environmental quality since the expansion of sugarcane in the region has been occurring in an unsustainable way, many times, a few meters from areas intended for environmental preservation such as Permanent Preservation Areas - APP and water courses.

Finally, this work sought to estimate the use of agrochemicals in watersheds, and may contribute to providing information for studies that seek to analyze the impacts of the use of pesticides on the environment.

FINAL CONSIDERATIONS

The advance of sugarcane monoculture in the hydrographic subbasins of the Aguapeí River between 2002 and 2020 has been influenced by policies to encourage the expansion of the sugar and alcohol sector, especially in view of the growing demand for fuel alcohol, in the context of the development of flex fuel cars.

When mapping the sugarcane expansion, a greater concentration of this culture can be seen in the sub-basins of the lower course, although the medium course also shows high rates of use. This fact is associated with the geomorphometric characteristics of these compartments, which comprise low hypsometric and slope classes, facilitating the mechanization process by the sugar and alcohol sector.

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