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Mapping areas at risk of contamination by pesticides: a case study in the state of Rio de Janeiro, Brazil

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SUMMARY
Pesticides are substances known to be necessary for the maintenance of contemporary agricultural practices, aimed to ensuring food security for the growing world population. However, there are several negative impacts linked to the disordered use of such substances. Thus, technologies capable of assisting the planning and the risk management related to pesticides are necessary, facilitating decision making and resource allocation. In this sense, the objective of the present study was to indicate the main agricultural crops and map the municipalities at risk of environmental contamination by pesticides in the state of Rio de Janeiro. Data from the IBGE Automatic Recovery System and the 2017 Agricultural Census of the Brazilian Institute of Geography and Statistics were used. The applied methodology involved the definition of indicators and the overlapping of information plans in the Geographic Information System. Sugarcane, bananas, and cassava stood out as the most significant crops in the state's agricultural scenario. Municipalities with the risk of contamination were found in the mountain, south, metropolitan, north, and northwest regions of the state. The banana is the crop with the most risk municipalities. The method employed proved to be effective in identifying the most representative cultures and in mapping the risky municipalities in the state. The results can be used as a subsidy for more efficient risk management associated with the use of pesticides in the territory.
KEYWORDS: Environmental management. Indicators. Geographic Information Systems.

1. INTRODUCTION

After World War II, chemical pesticides became the most important form of pest management and agricultural diseases control. As Parween & Jan (2019) report, it is not clear when the search for methods of plantation protection began. However, it is known that the first methods arose from nature itself. From the observation of the negative effects of natural compounds against insects, its use was reached to everyday life. Today, such substances have become a key tool for sustaining agricultural practices and ensuring large productions (Ying, 2018).

The production of pesticides is increasing and their consumption has become inevitable due to urbanization and the accelerated growth of the world population (Dar et al., 2019). This reality is no different in Brazil. Data from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) show that the consumption of pesticides in the country has increased, reaching more than 549,000 tons sold in its territory in 2018 (IBAMA, 2020). Similarly, data from the Ministry of Agriculture livestock and supply (MAPA) show that the number of new substances registered in the country grew, increasing from 90 new granted registrations in 2005 to 139 in 2015, the year from which the number of registrations grew on an unprecedented scale, reaching 474 new registrations in 2019 in Brazil (MAPA, 2020).

Despite the social benefits of pesticide use, acute and chronic adverse effects can be observed when substances enter ecosystems (Ying, 2018). Those mentioned ecological effects can be the death of non-target animals; contamination of natural resources, in particular, water; and the decline of forests, compromising environmental services in the short and long term. Such impacts can cause social, economic, and landscape losses (Parween & Jan, 2019). The adverse effects on human health should also be considered. Studies highlight relationships between the disorderly use of pesticides and the emergence of problems in the respiratory system; skin and mucous irritations; neurological problems; hormonal and reproductive disorders; immunological problems; chronic diseases; DNA damage and cancer (Bolognesi & Merlo, 2019; Dhananjayan & Ravichandran, 2018; García-García et al., 2016; Ji et al., 2020; Kim, Kabir, & Jahan, 2016; Lee & Choi 2020; Lopes & Albuquerque 2018; Moshou et al., 2020; Sugeng et al., 2013; Taiwo, 2019).

The development of new techniques and tools to predict the potential risks of pesticides is necessary to reduce its adverse effects on human health and the environment

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(Parween & Jan, 2019). Models based on simple tools, even quantitative numerical codes and complex statistical analyses have been applied in this sense for different purposes, such as product screening, regulation, assessment, and management of contamination and exposure risks. This type of analysis can be considered complex since it involves the definition of a specific question to be answered and the obtaining of information from different sources that allow the elucidation of the phenomenon to be evaluated (Hutson & Correll, 2018). Nevertheless, according to Solomon (2010), risk assessments for pesticides play a crucial role in strategic planning, assisting society in setting priorities.

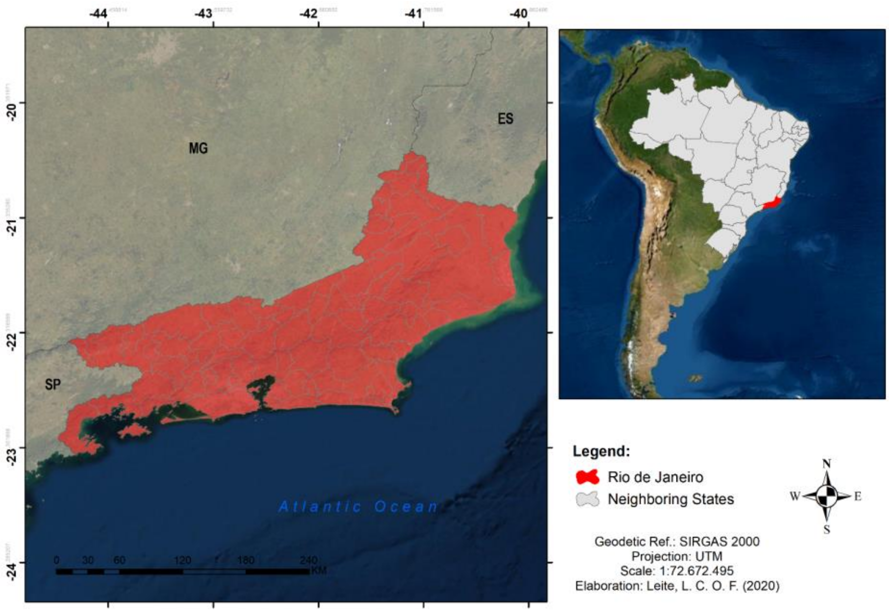
Continuous monitoring of the environmental and sanitary risks of pesticides is highly desirable, but it is impractical to show all possible situations (Hutson & Correll, 2018). Thus, the study aims to indicate the main agricultural crops and to map the municipalities at higher risk of environmental contamination by pesticides in the state of Rio de Janeiro, contributing to the effective management of the risks and resources available in the identification and mitigation of pesticide contamination.

2. MATERIAL AND METHODS

2.1. STUDY AREA

The state of Rio de Janeiro (Figure 1) is one of the federative units of Brazil, located in the southeast region of the country. Its territory has approximately 43,750,427 km², bordering the states of São Paulo, Minas Gerais, Espirito Santo, and the Atlantic Ocean. In the latter sense, held in 2010, its population was 15,989,929 inhabitants, which is estimated at 17,366,189 in 2020. With a population density of 365.23 inhabitants/km², it is the third most populous state in Brazil. Its climate is classified as Atlantic tropical, with hot and humid summer and cold and dry winter (IBGE, 2020).

Figure 1: Letter of the location of the state of Espírito Santo in Brazil, in the continent of South America.



Source: Authors, 2020.

Agriculture has little participation in the state's economic performance. In 2015 and 2016, the agricultural sector accounted for only 0.6 % of its gross domestic producer

(GDP) (CEPERJ, 2018). As Egger (2010) reports, the state's agriculture is mostly represented by small agricultural establishments with an area of less than 10 ha, focused on family and subsistence production.

Data from the National Health Surveillance Report of Populations Exposed to Pesticides (Ministry of Health, 2018) show that Rio de Janeiro was the state with the highest rate of commercialization of pesticides and related products per area planted in Brazil in 2014 (66 kg/ha). In view of its family-based agriculture, this fact can be worrisome. According to Abreu & Alonzo (2016), family producers tend to be more exposed to the adverse effects of the use of pesticides due to the absence, in many cases, of adequate structure for their management, training, and the use of personal protective equipment (PPE). In this way, measures are needed to facilitate the management of these risks.

2.2. DEFINITION OF INDICATORS

The method used in the study was developed by Leite et al. (2020). In essence, it consists in defining indicators capable of assisting in the definition of environmental contamination risk by pesticides in the municipalities of a state. The following sections describe the procedures used for the application of the method.

2.3. SURVEY OF AGRICULTURAL PRODUCTION

The Brazilian Institute of Geography and Statistics (IBGE) system of automatic recovery (SIDRA) database of the IBGE was consulted to obtain information on agricultural production in the state of Rio de Janeiro (IBGE, 2020b). Data from the extensions of planted area (ha) with agricultural crops between 2009 and 2019 and the production in tons (ton) of them were used. The total planted area (ha) of each crop was calculated by summing up its annual totals and the 90% percentile was established as the value above in which the most representative crops are found in the state's agricultural scenario. Crops with a total planted area greater than the 90% percentile were selected as priority crops for analysis.

2.4. SPATIAL ANALYSIS OF AGRICULTURAL PRODUCTION

The total planted area values of the most significant agricultural crops in the state were spatialized through the Software ArcGis version 10.2.1, for the construction of the indicator "Planted Area". A digital mesh, in shapefile format, with the political and administrative limits of the state, made available by the IBGE (2015), was used as a basis. This procedure allowed a spatial distribution analysis of the extensions of planted land with the selected crops among the municipalities of the state, making visible the concentration of larger plantations in certain regions.

2.5. OTHERS INDICATORS

Through the vector archive of the Agricultural Census of IBGE (2019), the information needed for the construction of other indicators of pesticide contamination risk was obtained. The selected census indicators were: "V- 34. Use of pesticides"; "V-35. Expenditure on pesticides"; "V-16. Land use by crops" and "V-1. Number of rural properties." In Chart 1 there is a description of the indicators used, with their respective sources and meanings.

Chart 1: Indicators used in the study with their respective meanings and sources.

Indicator	Meaning	Source
Planted area	Sum of the planted area (ha) annually with each crop between 2009 and 2019 in each municipality.	SIDRA System - Municipal Agricultural Production - IBGE (2020B)
Pesticide use	Percentage of agricultural establishments with declaration of pesticide use in relation to the total number of agricultural establishments in the municipality in 2017.	Brazilian Agricultural Census - IBGE (2019).
Expenditure in pesticides	Participation of the expenditure on pesticides in the total expenditure of the agricultural establishment, per municipality in 2017.	Brazilian Agricultural Census - IBGE (2019).
Land use for farming	Percentage of the area of the municipality covered by crops in 2017.	Brazilian Agricultural Census - IBGE (2019).
Agricultural stabilishments	Total agricultural establishments per municipality in 2017.	Brazilian Agricultural Census - IBGE (2019).

Source: Autors, based in IBGE (2019, 2020).

2.6. DATABASE BUILDING

In possession of the vector data generated in the spatial analysis of agricultural production and indicators extracted from the Rural census, the database used for the final analysis was constructed. Each indicator selected in the Agricultural census was individualized in a shapefile, with the exception of the "Planted area" indicator that was already specialized in a separate shapefile. The vector files were later converted to the raster format. The raster files went through classification at equal intervals, dividing the values of each indicator into 5 classes, from the smallest to the highest values, which received values from 1 to 5 according to the risk they represent. The classes of the lowest values of each indicator received value 1, as being of very low risk, gradually increasing to the classes of the higher values, which received value 5, as being very high risk. Once classified, the raster files began to represent the information plans used in the weighted overlap process.

2.7. OVERLAP OF INFORMATION PANS

In this step, the weighted overlay tool of ArcGis was used, which performs a weighted average between the pixel values of overlapping information planes. For the use of this tool, it was necessary to define the appropriate weight for each of the variables involved in the process. For this, the analytic hierarchy process (AHP) method was used, which makes a paired comparison between the variables that determine the phenomenon studied and, through the assignment of degrees of equality or preference between variables, the most appropriate weights are generated for each information plan (Estoque, 2012). This procedure was performed with the AHP extension of ArcGis. Table 2 is the weights obtained for each information plan.

Chart 2: Weights assigned to indicator information plans using the AHP method.

Information Plan	Weight Obtained by the AHP Method
Planted area	43,026
Pesticide use	29,640
Expenditure in pesticides	17,247
Land Use for farming	5,484
Agricultural stabilishments	4,603

Source: Authors.

The "Planted area" information plans of each of the priority crops were overlapped individually with the plans of the other indicators. The results of the overlap process were classified maps indicating the municipalities with a higher and lower risk of pesticide contamination, based on each of the specific crops.

2.8. SUMMARY MAP

The results obtained individually for each of the cultures were synthesized in a single map. The objective of this map is to indicate those municipalities where there is a greater or lesser risk of environmental contamination by pesticides considering the main agricultural crops of the state jointly. In this procedure, the “weighted sum tool” was used, which performs a sum of the values assigned to the pixels of the overlapping information plans. Weight 1 was set for all results of all cultures so that none interferes more than the others in the final result.

3. RESULTS

3.1. IDENTIFICATION OF RISK CROPS

Between 2009 and 2019, a total of 29 agricultural crops were cultivated in the state of Rio de Janeiro, according to data from the SIDRA system. Of these crops, 19 are considered permanent crops and 10 temporary crops. Considering the percentile of 90% of the totals of planted area with each crop in the state, sugarcane, banana, and cassava stand out, being selected as priorities. Sugarcane is the crop with the most planted area during the studied period, a total of 989,857 ha (57% of the total area planted with agricultural crops in the analyzed period), more than 4 times higher than bananas, second with 205,961 ha planted (11% of the state total). Cassava, in turn, ranks 3rd, with 143,969 ha (8% of the state total).

3.2. MAPPING RISK AREAS

According to the mapping of the areas of environmental contamination risk by pesticides, the occurrence of only two risk classes was verified in the individual maps of the priority crops, with values 1 and 2, with no areas with value 3, 4 or 5. In order to keep clear the importance of good practices in the management of pesticides, the results were classified between areas of lower risk (municipalities of value 1) and areas of higher risk (municipalities of value 2).

In an analysis where the same method was applied to the state of Espírito Santo (Leite *et al.*, 2020), the authors verified the occurrence of municipalities with values 1, 2, and 3, with no municipalities of value 4 and 5. This fact may be related to the fact of the state of Espírito

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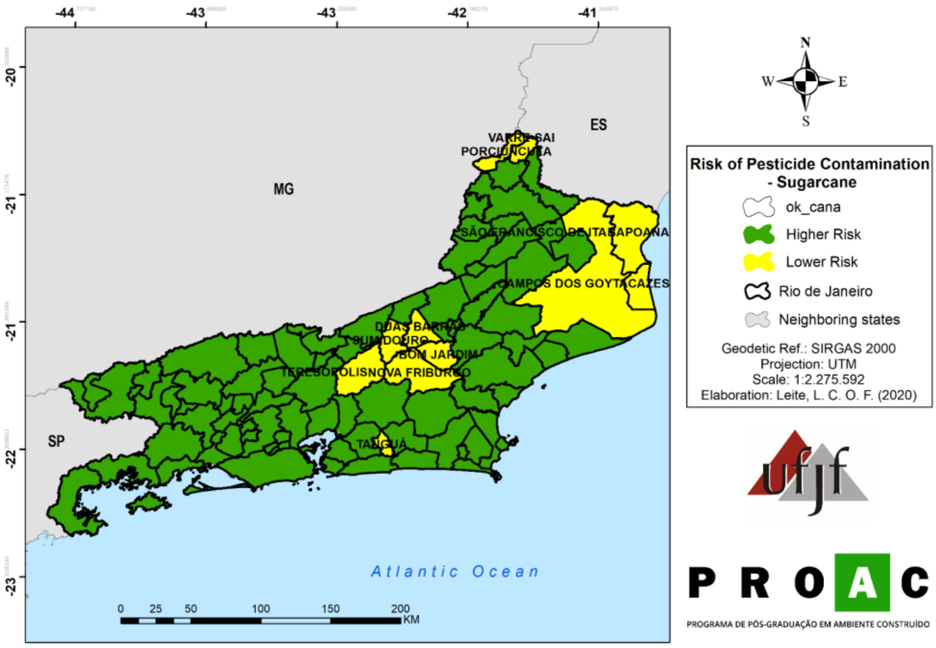
Santo has a greater agricultural vocation than Rio de Janeiro. Data on Brazilian agricultural production (IBGE, 2020b)~~,~~ corroborate this statement. Between 2010 and 2019, the state of Rio de Janeiro produced 49,367,079 tons of agricultural products with a total of 1,591,058 ha planted, being the 18th largest Brazilian state in terms of production and the 21st in planted area. In its turn, the state of Espírito Santo, in the same period, occupied the 15th largest agricultural production in Brazil and the 17th largest extension of the planted area, with 63,573,643 tons produced and 6,384,861 ha planted, a value more than 4 times higher than that of Rio de Janeiro.

3.2.1. SUGARCANE

For sugarcane culture, 11 municipalities have a higher risk of pesticide contamination, they are: Bom Jardim, Campos dos Goytacazes, Duas Barras, Nova Friburgo, Porciúncula, São Francisco de Itabapoana, São João da Barra, Sumidouro, Tanguá, Teresópolis and Varre Sai (Figure 2). Together, the municipalities mentioned represent approximately 21% of the state's territory. All other municipalities present lower risk.

Figure 1: **Map of risk of environmental contamination by pesticides associated with sugarcane crop in the state of Rio de Janeiro, Brazil.**



Source: Authors, 2020.

Considering the Planted area indicator for sugarcane, in descending order, the municipalities of greatest risk can be classified as follows: 1st - Campos dos Goytacazes (538,149 ha), 2nd - São Francisco de Itabapoana (199,855 ha), 3rd - São João da Barra (1 44.704 ha), 4th - Duas Barras (945 ha), 5th - Sumidouro (365 ha), 6th - Varre Sai (300 ha), 7th - Tanguá (145 ha), 8th - Bom Jardim (130 ha) and , Nova Friburgo, Porciúncula and Teresópolis, which do not have areas planted with the crop.

When analyzing the municipalities at higher risk among the others, through the Pesticide use indicator, we verified the following ordering as to the percentage of establishments that declare to use pesticides: 1st - Sumidouro (83 %), 2nd - Nova Friburgo (73 %), 3rd - Teresópolis (69 %), 4th- Bom Jardim (59 %), 5th - Porciúncula (58 %), 6th - Tanguá (53

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%), 7th - Varre Sai (52 %), 8th - São João da Barra (50 %), 9th - San Francisco de Itabapoana (41 %), 10th- Duas Barras (32 %) and 11th - Campos dos Goytacazes (10 %).

Regarding the percentage of pesticide expenses in the total expenses of agricultural establishments according to the Pesticide expenses indicator, we have the following order: 1st - Sumidouro (14%), 2nd - Bom Jardim (13%), 3rd - Nova Friborg (12%), 4th - São João da Barra (7%), 5th - São Francisco de Itabapoana (7%), 6th - Tanguá (5%), 7th - Porciúncula (5%), 8th - Teresópolis (4%), 9th - Varre Sai (4%), 10th - Duas Barras (4%) and 11th - Campos dos Goytacazes (2%).

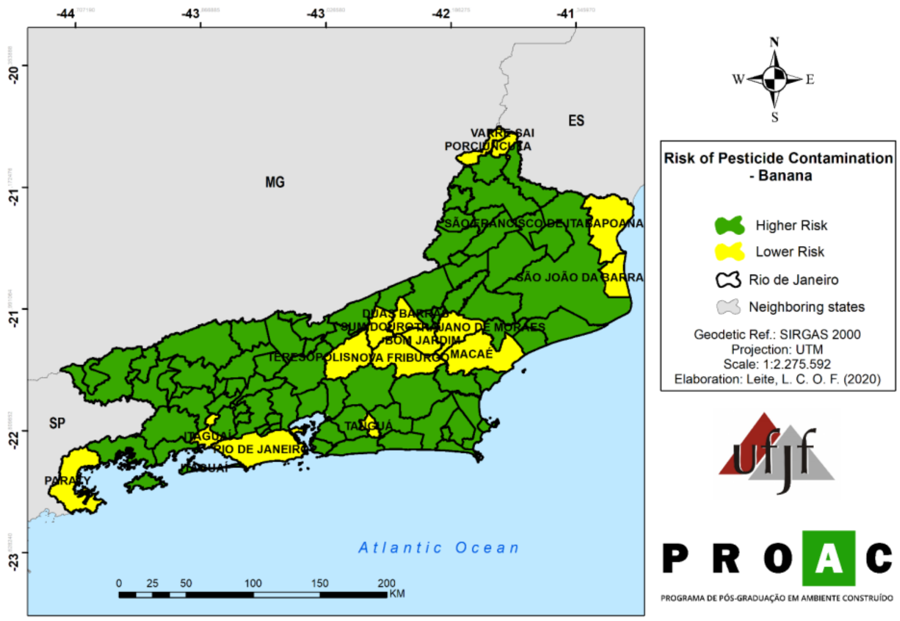
For the Land use for crops indicator, we have the following order: 1st - São Francisco de Itabapoana (34%), 2nd - São João da Barra (28%), 3rd - Nova Friburgo (27%), 4th - Sumidouro (27%), 5th - Varre Sai (26%), 6th - Teresópolis (26%), 7th - Bom Jardim (20%), 8th - Tanguá (17%), 9th - Porciúncula (17 %), 10 ° - Campos dos Goytacazes (14%) and 11 ° - Duas Barras (11%).

For the Number of agricultural establishments indicator, the order of the municipalities with the highest risk among the other municipalities in the state is: 1st - Campos dos Goytacazes, 2nd - São Francisco de Itabapoana (3,683); 3rd -Teresópolis (3,492), 4th - Sumidouro (2,674), 5th - Nova Friburgo (2,057), 6th - Porciúncula (1,091), 7th - Bom Jardim (1,006), 8th - São João da Barra (692), 9th - Varre Sai (676), 10th - Duas Barras (570) and 11th - Tanguá (441).

3.2.2. BANANA

The banana crop is the one with more municipalities considered to be at higher risk of contamination by pesticides, a total of 15. They are: Bom Jardim, Duas Barras, Itaguaí, Macaé, Nova Friburgo, Paraty, Porciúncula, Rio de Janeiro, São Francisco de Itabapoana, São João da Barra, Sumidouro, Tanguá, Teresópolis, Trajano de Moraes and Varre Sai (Figure 3). Together, these municipalities represent 21% of the state's area. The remaining 74 municipalities have a lower risk of contamination.

Figure 3: Map of risk of environmental contamination by pesticides associated with banana culture in the state of Rio de Janeiro, Brazil.



Source: Authors, 2020.

Considering the Area planted indicator for bananas, in descending order, the municipalities of greatest risk can be classified as follows: 1st - Itaguaí (24,660 ha), 2nd- Paraty (17,260 ha), 3rd - Macaé (15,673 ha), 4th - Trajano de Moraes (9.58 5 ha), 5th - Rio de Janeiro (5,542 ha), 6th - Sumidouro (2,453 ha), 7th - Duas Barras (1,789 ha), 8th - Nova Friburgo (1,484 ha), 9th - Bom Jardim (1,389 ha) , 10th - Tanguá (351 ha), 11th - São Francisco de Itabapoana (335 ha), 12th - Varre Sai (62 ha), 13th - São João da Barra (56 ha), 14th - Teresópolis (54 ha) and 15th - Porciúncula (0 ha).

When analyzing the municipalities at higher risk among the others, through the Pesticide use indicator, we verified the following ordering as to the percentage of establishments that declare to use pesticides: 1st - Sumidouro (83 %), 2nd - Nova Friburgo (73 %), 3rd - Teresópolis (69 %), 4th - Bom Jardim (59 %), 5th - Porciúncula (58 %), 6th - Tanguá (53 %), 7th- Varre Sai (52 %), 8th - São João da Barra (50 %), 9th - São Francisco de Itabapoana (41 %), 10th - Duas Barras (32 %), 11th - Trajano de Moraes (28 %), 12th - Rio de Janeiro (19 %), 13th - Itaguaí (14 %), 14th- Macaé (9 %) and 15th - Paraty (5 %).

As for the percentage of expenses with pesticides in the total expenses of agricultural establishments according to the Expenses with pesticides indicator, we have the following order: 1st - Sumidouro (14 %), 2nd - Bom Jardim (13 %), 3rd - Nova Friburgo (12 %), 4th - São João da Barra (7 %), 5th- São Francisco de Itabapoana (7 %), 6th- Trajano de Moraes (6 %), 7th- Tanguá (5 %), 8th - Porciúncula (5 %), 9 %) , 10th- Varre Sai (4 %), 11th - Duas Barras (4 %), 12th - Macaé (1 %), 13th - Itaguaí (1 %), 14th - Rio de Janeiro (1 %) and 15th - Paraty (0%).

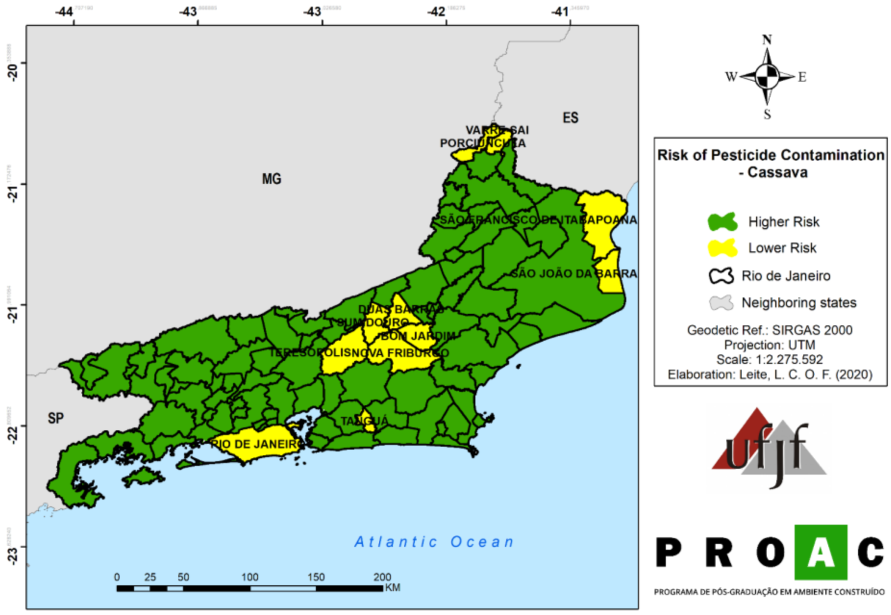
For the Land use indicator for crops, we have the following order: 1st - Rio de Janeiro (42%), 2nd - São Francisco de Itabapoana (32 %), 3rd - São João da Barra (28 %), 4th - Itaguaí (28 %), 5th - Nova Friburgo (27 %), 6th - Sumidouro (27 %), 7th - Varre Sai (26 %), 8th - Teresópolis (26 %), 9th - Bom Jardim (20 %), 10th - Tanguá (17 %), 11th - Porciúncula (17 %), 12th - Duas Barras (11 %), 13th - Trajano de Moraes (10 %) , 14th - Paraty (5 %) and 15th - Macaé (5%).

As for the Number of agricultural establishments indicator, the order of the municipalities most at risk was: 1st - São Francisco de Itabapoana (3,693), 2nd - Teresópolis (3,492), 3rd - Sumidouro (2,674), 4th - Nova Friburgo (2,057), 5th - Trajan de Moraes (1.1.674), 6th - Rio de Janeiro (1,101), 7th - Porciúncula (1,091), 8th - Bom Jardim (1,006), 9th - Macaé (886), 10th - São João da Barra (692), 11th - Varre Sai (676) , 12th - Paraty (601), 13th - Duas Barras (570), 14th - Tanguá (441) and 15th - Itaguaí (434).

3.2.3. CASSAVA

For cassava culture, 11 municipalities have a higher risk of contamination: Bom Jardim, Duas Barras, Nova Friburgo, Porciúncula, Rio de Janeiro, São Francisco de Itabapoana, São João da Barra, Sumidouro, Tanguá, Teresópolis and Varre Sai (Figure 4). Together, these municipalities represent 14% of the total area of the state. All 78 remaining municipalities present lower risk.

Figure 4: Map of risk of environmental contamination by pesticides associated with cassava crop in the state of Rio de Janeiro, Brazil.



Source: Authors, 2020.

Considering the Planted area indicator for cassava, in descending order, the municipalities most at risk can be classified as follows: 1st - São Francisco de Itabapoana (53,920 ha), 2nd - Rio de Janeiro (14,425 ha), 3rd - Tanguá (2,555 ha), 4th - Sumidouro (1,397 ha), 5th - Duas Barras (1,355 ha), 6th - São João da Barra (564 ha), 7th - Nova Friburgo (527 ha), 8th - Bom Jardim (513 ha), 9th - Teresópolis (145 ha), 10th - Varre Sai (1 ha) and 11th - Porciúncula (0 ha).

When analyzing the municipalities at greatest risk through the Pesticide use indicator, we verified the following ordering as to the percentage of establishments that declare to use pesticides: 1st - Sumidouro (83 %), 2nd - Nova Friburgo (73 %), 3rd - Teresópolis (69 %), 4th - Bom Jardim (59 %), 5th - Porciúncula (58 %), 6th - Tanguá (53 %), 7th - Varre Sai (52 %), 8th - São João da Barra (50 %), 9th - São Francisco de Itabapoana (41 %), 10th - Duas Barras (32 %) and 11th - Rio de Janeiro (19%).

As for the percentage of the participation of expenses with pesticides in the total expenses of agricultural establishments according to the Expenses with pesticides indicator, we have the following order: 1st - Sumidouro (14 %), 2nd - Bom Jardim (13 %), 3rd - Nova Friburgo (12 %), 4th - São João da Barra (7 %), 5th - São Francisco de Itabapoana (7 %), 6th - Tanguá (5 %), 7th - Porciúncula (5 %), 8th - Teresópolis (4 %), 9 %) , 10th - Duas Barras (4 %) and 11th - Rio de Janeiro (1%).

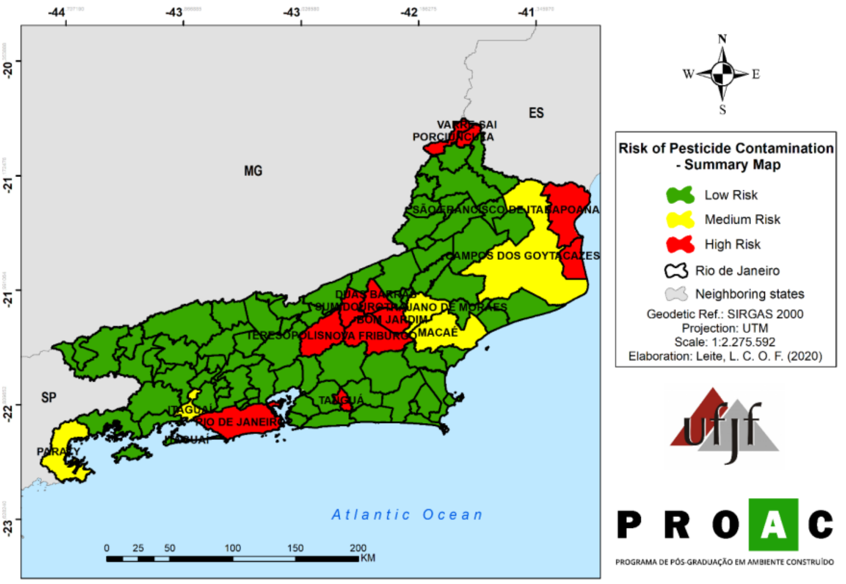
For the Land use indicator for crops, we have the following order: 1st - Rio de Janeiro (42 %), 2nd - São Francisco de Itabapoana (34 %), 3rd - São João da Barra (28 %), 4th - Nova Friburgo (27 %), 5th - Sumidouro (27 %), 6th - Varre Sai (26 %), 7th - Teresópolis (26 %), 8th - Bom Jardim (20 %), 9th - Tanguá (17 %), 10th - Porciúncula (17 %) and 11th - Duas Barras (11%).

As for the Number of agricultural establishments indicator, the order of the municipalities most at risk among the other municipalities of the state is: 1st - São Francisco de Itabapoana (3,693), 2nd - Teresópolis (3,492), 3rd - Sumidouro (2,674), 4th - Nova Friburgo (2,057), 5th - Rio de Janeiro (1.101), 6th - Porciúncula (1,091), 7th - Bom Jardim (1,006), 8th - São João da Barra (692), 9th - Varre Sai (676), 10th - Duas Barras (570) and 11th - Tanguá (441).

3.2.4. SUMMARY MAP

Analyzing all cultures together, three categories of contamination risk were verified, classified as low, medium, and high risk (Figure 5). The high-risk class covers 11 municipalities, they are: Bom Jardim, Duas Barras, Nova Friburgo, Porciúncula, Rio de Janeiro, São Francisco de Itabapoana, São João da Barra, Sumidouro, Tanguá, Teresópolis, and Varre Sai. The medium-risk class covers 5 municipalities: Campos dos Goytacazes, Itaguaí, Macaé, Paraty, and Trajano de Moraes. The remaining 76 municipalities have a low risk of contamination. Although there are more municipalities inserted in the high-risk class than in the middle class, if added, these municipalities represent 14% of the state territory. In turn, medium-risk municipalities account for approximately 16%.

Figure 5: Map of risk of environmental contamination by pesticides associated with sugarcane, banana, and cassava crops jointly in the state of Rio de Janeiro, Brazil.



Source: Authors, 2020.

As for the municipalities inserted in the high-risk class, it is possible to observe a concentration in the mountainous region of the state, despite the existence of municipalities in other regions such as north, northwest, and metropolitan. The southern region of Rio de Janeiro, however, does not present any high-risk municipality. For medium-risk municipalities, a more uniform distribution occurs. The northern region covers 2 municipalities while the metropolitan region, the center, and the south of Rio de Janeiro cover only 1 each.

Considering the high-risk areas, the Planted area indicator contributed to the result only in some municipalities. This is the case of São Francisco de Itabapoana and São João da Barra, 2nd and 7th largest municipalities in terms of area planted with sugarcane. Banana culture did not directly interfere in the results, with all municipalities below the top 10. For cassava culture, São Francisco de Itabapoana stands out as the largest municipality in terms of the planted area, followed by the capital Rio de Janeiro.

In the medium-risk class, the Planted area indicator also contributed to the outcome of some municipalities. The banana crop has, among the 6 state leaders in the planted area, 4 of the 5 municipalities inserted in the class. For sugarcane, only the municipality of Campo dos Goytacazes stands out, being the state leader in the planted area with the crop, all the other being below the 24th municipality. In cassava culture, Campos dos Goytacazes occupies the 4th place, with the other municipalities below 15th place

The pesticide use indicator was directly related to the result observed in high-risk municipalities. Sumidouro, Nova Friburgo, Teresópolis, Bom Jardim, Porciúncula, Tanguá, Varre Sai, and São João da Barra are the 8 municipalities in the state with the most properties that declared to have used pesticides. For medium-risk municipalities, this indicator was less important. All 5 municipalities in the class are below 17th place in the state scenario.

Similarly, the Pesticide expenses indicator was of great importance for the outcome of high-risk municipalities. Of the 11 municipalities included in this class, 11 are among the 14 municipalities with the most use of pesticides. This is the case of Sumidouro, Bom Jardim, Nova Friburgo, São João da Barra, São Francisco de Itabapoana, Tanguá, Porciúncula, Teresópolis, Varre Sai, and Duas Barras. Only the capital Rio de Janeiro seems not to have been affected by the indicator, occupying 48th place. For the municipalities of the medium-risk class, this indicator had less influence. Only Trajano de Moraes stands out, being the 8th main in the state. All other municipalities in the class are below the 23rd position.

The Indicator Land use for crops was also important for the results obtained. Of the 11 municipalities in the high-risk class, 10 are among the 17 main in the state. Only the municipality of Duas Barras is excepted, occupying 26th place. Among the municipalities classified as medium risk, Itaguaí stands out, occupying the 6th position in the state scenario. All other municipalities are below 20th place.

For the indicator Number of agricultural establishments, there is a lower influence on the outcome of high-risk municipalities. Only 4 of the 11 municipalities included in this class are among the 6 municipalities of the state with the most rural properties, they are: São Francisco de Itabapoana, Teresópolis, Sumidouro, and Nova Friburgo. All other municipalities are below 13th place. For medium-risk municipalities, this influence is even lower. Only the municipality of Campos dos Goytacazes stands out in the 1st place as a municipality of the state with the most agricultural establishments. The other municipalities are below 12th place.

4. CONCLUSIONS

The used method proved to be effective for the identification of the most significant crops and for mapping the areas of pesticide contamination risk in the state of Rio de Janeiro. Sugarcane, banana, and cassava are the most representative crops in the state agricultural scenario.

The concentration of high-risk municipalities was verified, mainly in the mountainous, metropolitan, northern, and northwestern regions of the state. This result is tied to the high number of rural properties that claim to have used pesticides, the high participation of these substances in the expenses of the properties, the high rate of land use for tillage in these municipalities, and, in some cases, the highlight in the production of crops identified as a priority.

The results of this study can be incorporated into the decision-making process for the creation of legislation at the state level that seeks to avoid environmental and human contamination with pesticides. It is recommended to conduct future studies that indicate the priority pesticides used in the municipalities, considering their environmental dynamics and toxicity to help adequate understanding and forecasting of the risks associated with such compounds.

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