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IDENTIFICATION OF SCENARIOS FOR ASSESSING THE ENVIRONMENTAL RISK OF PESTICIDES IN SURFACE WATER IN THE BRAZILIAN CERRADO: GOIÁS AND BAHIA

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Abstract: The objective of this study was to identify scenarios for environmental risk assessment (ERA) of pesticides in surface water in Brazil. An exploratory analysis was conducted using data on croplands and lentic water bodies in the Cerrado biome in the states of Goiás and Bahia. The ratios between the drainage areas of watersheds with soybean crops and the surface areas of lakes and reservoirs were calculated to identify typical and critical scenarios for ERA of pesticides. The methodology applied proved effective for generating the information necessary to establish scenarios for ERA of pesticides in surface water bodies in Brazil. The results obtained for soybean cultivation in the Cerrado biome in the states of Goiás and Bahia indicated that there is a difference between the typical and critical scenarios identified and the first-level ERA scenario for pesticides in surface waters adopted by IBAMA. However, further studies are needed so that, with a larger dataset, it will be possible to conclude on the need to modify the scenario adopted in the ERA for different crops and regions of Brazil.

Keywords: water resources, contamination, pesticide registration, ecological exposure, GIS.

Introduction

The environmental risk assessment (ERA) of pesticides in Brazil, conducted by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) for product registration purposes, follows the methodology of the United States Environmental Protection Agency (EPA) (IBAMA, 2012). The methodology is presented in detail in USEPA (1998) and features the use of four levels (tiers) of assessment, with the first being the most conservative and the last the closest to reality. If the pesticide under evaluation shows no risks, or presents acceptable risks, at the first tier, it may proceed to registration; otherwise, it is evaluated at the second tier and so on. One of the basic elements of the ERA process is the agricultural use scenario in which the pesticide is evaluated at each level (Spadotto, 2006; Spadotto et al., 2010).

Given that the national pesticide registration system follows the methodology used by the regulatory agency in the United States, distortions may arise in the analysis of environmental exposure, since the edaphoclimatic conditions in Brazil are significantly different from those in the United States (Amorim et al., 2010).

In the European Union (EU), the generation of scenarios for pesticide risk assessment during the registration process has been extensively studied and reported in FOCUS (2001). In this report, the expert group describes the pesticide ERA methodology in the EU regarding the risk of contamination in surface water bodies, stating that this methodology is very similar to that adopted by the EPA, differing only in the scenarios adopted at each level.

For the first (more conservative) level of pesticide ERA in surface water in the U.S. and Brazil, a scenario with a cultivated area of 10 hectares, located around a "standard pond" with a surface area of 1 hectare ($10.000m^2$) and a depth of 2m, as proposed by Parker et al. (1995), is adopted. In the EU, however, a scenario with a cultivated area surrounding a lake, with the lake covering 10% of the cultivated area and a water column depth of 30cm over a 5cm sediment layer, with organic carbon content of 5% and bulk density of $0.8g.cm^{-3}$, is adopted (FOCUS, 2001).

Brazil does not have a database with official land use and land cover maps for the entire country, at the necessary scale and with sufficient details to be applied in defining scenarios for ERA, and information on mapping of lentic (static or slow moving) water bodies (lakes and reservoirs) in agricultural areas is not available. Thus, both the development of new methodologies and the collection of such information are necessary.

To identify scenarios for pesticide ERA in surface water bodies in Brazil, an exploratory analysis was conducted using data on croplands and lentic water bodies in the Cerrado biome in the states of Goiás and Bahia. The ratios between the drainage area of watersheds with crops and the surface area of existing lakes and reservoirs were calculated to identify typical and critical scenarios for pesticide ERA.

Materials and Methods

The identification of scenarios for pesticide ERA in surface water bodies applied in this study is based on the methodology proposed and previously used for the Cerrado biome in the states of Mato Grosso (Mingoti et al., 2017) and Mato Grosso do Sul (Mingoti et al., 2019). In the present study, in addition to applying the method to new study areas, modifications were made to the data analysis and interpretation of results.

The methodology for identifying scenarios for ERA of pesticides in surface water bodies consists of six steps: (1) definition of the crop of interest (or representative crop); (2) selection of municipalities with the crop of interest; (3) division of the selected municipalities into watersheds; (4) identification of the crop of interest in the watersheds of each selected municipality; (5) mapping of lakes and reservoirs in the watersheds with the crop of interest or downstream of the watersheds with that crop; and (6) determination of the drainage area of the watersheds and the surface area of the mapped lakes and reservoirs, as well as the ratio between them.

The definition of the crop of interest for pesticide ERA occurs as the first step, as the applicant company must indicate the crops for which product registration is required (Brazil, 2002; IBAMA, 2012). Thus, a case study was conducted on soybean cultivation in areas of the Brazilian Cerrado biome in the states of Goiás and Bahia. The choice of this crop is justified by: (i) its importance as a major commodity (Figueiredo et al., 2001); (ii) its distribution across much of Brazilian territory (Garagorry et al., 2010); (iii) the availability of secondary data on cultivated area from various sources (MMA, 2015; IBGE, 2016); and (iv) the existence of established pest management techniques involving the use of pesticides (Gazzoni et al., 1988; Sosa-Gómez et al., 2010).

Data on soybean planted area from the Municipal Agricultural Survey (PAM) (IBGE, 2016) for the years 2012, 2013, and 2014, the IBGE (2013) cartographic database with municipal boundaries, and the geomorphology map of Brazil (IBGE, 2006; IBGE, 2009), available in vector format at INDE (2016).

The study was limited to areas of the Cerrado biome due to the availability of updated land use mapping (MMA, 2015), which was necessary for this study. Municipalities were selected based on the area planted with soybeans and the predominant geomorphology (relief type) within their boundaries. Geomorphology was conside-

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red because it is a characteristic related to the ratio between the drainage area of river basins watersheds and the surface area of water bodies (Hiruma and Ponçano, 1994) and also because this ratio is used in the scenario for pesticide ERA at the first level of the EPA methodology (Parker et al., 1995), which is adopted in Brazil (IBAMA, 2012).

Using the ArcGIS 10.3 GIS, all input geospatial data were converted to the equidistant conic projection in the SIRGAS 2000 reference system. Next, the tabular data on soybean planted areas were merged with the cartographic database of municipal boundaries, and Brazilian municipalities were classified according to their predominant relief type based on IBGE mapping.

Subsequently, municipalities in the states of Goiás and Bahia were selected (three municipalities in each state), based on the following criteria: (i) identification of the municipality with the largest average area of planted soybeans in each relief type within the Cerrado biome; and (ii) utilization of three relief types classified based on the average area of planted soybeans in the municipality identified under the previous criterion.

For the selected municipalities, a division into watersheds was performed using the Digital Elevation Model (DEM) from the Shuttle Radar Topographic Mission (SRTM) project, made available by the United States Geological Survey (USGS) on its website in raster format with a spatial resolution of 90m, and the SWAT (*Soil and Water Assessment Tool*) 2012 (Arnald et al., 1998; Arnald et al., 2012) in plug-in format for the ArcGIS.

Watersheds were generated using the SWAT 2012 model for the entire area of the selected municipalities, using 100 ha as the ideal size criterion. The MDE was converted to the equidistant conic projection in the SIRGAS 2000 reference system, and cumulative flow values were calculated for each component pixel of the image.

The identification of soybean areas within the generated watersheds was performed using visual identification techniques on satellite images within the ArcGIS. Satellite images were obtained from the following sources: ArcGIS Online Base Maps; Google Earth; and Open Street Map (OSM). The selection of images followed the order of preference of the years 2014, 2013, and 2012, or more recent years when available. The interpretation of soybean croplands considered the following aspects: (i) regular shapes; (ii) absence of shadows; (iii) smooth texture (Machetti and Garcia, 1986); and (iv) dark green hue and parallel structure.

The mapping of lakes and reservoirs was performed through visual interpretation of satellite images for the watersheds identified with soybean croplands and in the watersheds downstream of these. For each mapped lake or reservoir, a polygon was generated using the ArcGIS, and its area was calculated. For each of the mapped lakes and reservoirs, the corresponding drainage area was determined by identifying the accumulated flow in the pixel corresponding to the lake or reservoir's slope and multiplying that value by the area of each pixel.

Results and Discussion

The municipalities in the Cerrado biome selected in the state of Goiás (GO) were: Cristalina, Jataí, and Rio Verde. These three municipalities are in the same relief type (Plateau), as soybean planted areas in Cerrado biome municipalities with other relief types are comparatively very small. The location of watersheds with soybean crops and of lakes or reservoirs can be seen in **Figure 1**. In the three selected municipalities, the watersheds with soybean crops are distributed along the municipal boundary.

Table 1 shows the relief type, the number of mapped lentic water bodies, and statistical measures of the ratio between the drainage area of watersheds and the surface area of lakes and reservoirs in the selected municipalities in the state of Goiás.

In the selected municipalities, only 2% of the mapped lentic water bodies had values for the ratio of the watershed drainage area to the surface area of the lake or reservoir that were less than or equal to the reference value, which is $10 m^2.m^{-2}$ (Parker et al., 1995; FOCUS, 2001).

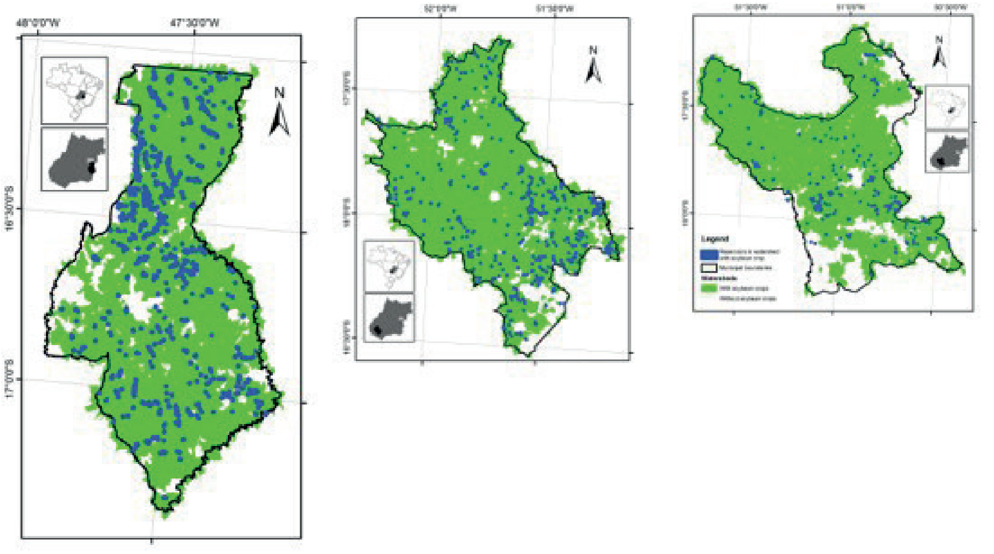
The mean values of ratios in Cristalina, Rio Verde, and Jataí are, respectively, 500, 321, and $755 m^2.m^{-2}$, and for the three municipalities combined, the mean value of ratios is $568 m^2.m^{-2}$. Measures of data dispersion (standard deviation, coefficient of variation, range, and interquartile range) indicate high variability. It is important to note that the median and interquartile range values are not affected by outliers and are, respectively, better measures of central tendency and dispersion for highly skewed data than the mean and standard deviation.

Typical values (50% of the values) occur around the median, within the interquartile range, between Q1 and Q3 (Zimmermann, 2014; Spiegel et al., 2016; Quinsler, 2022). Thus, the typical values of the ratio of the watershed drainage area to the surface area of the lentic water body in Cristalina, Rio Verde, and Jataí are, respectively, between 79−525, 87−362, and 165−791$m^2.m^{-2}$. For the dataset of the three municipalities, the typical values range from 105 to 599$m^2.m^{-2}$. It should be emphasized that the three selected municipalities in Goiás are in the same relief type (Plateau).

The highest ratios between the drainage area of watersheds and the surface area of lentic water bodies represent the most critical situations for pesticide ERA. However, values between 1.5 and 3.0 times the interquartile range, below Q1 or above Q3, are considered outliers.

Values deviating by more than 3.0 times the interquartile range, below Q1 or above Q3, are considered extreme. Thus, the values of the ratio between the drainage area of watersheds and the surface area of lentic water bodies greater than 1,865, 1,190, 2,671, and 2,081$m^2.m^{-2}$, respectively for Cristalina, Rio Verde, Jataí, and for the combined dataset of the three municipalities, are considered extreme.

Based on the results obtained, the skewness is high (skewness coefficients > 1). The means are greater than the medians for the three municipalities and for the overall dataset, which corresponds to a positive skewed distribution, that is, there is a concentration of data at low values, to the left of the median, and a "tail" to the right where, at the extreme, the highest values of the ratio between drainage area and surface area of lentic water bodies are found, characterizing critical yet atypical scenarios.



(A) (B) (C)

Figure 1. Distribution of watersheds with soybean crops (in green) and mapped lakes and reservoirs (in blue) in the Cerrado biome in the state of Goiás, in the municipalities: (A) Cristalina, (B) Jataí, and Rio Verde (C).

Measures	Cristalina	Rio Verde	Jataí	Total[1]
Relief Type	Plateau	Plateau	Plateau	
Number of Lentic Water Bodies	502	226	443	1,171
		Area Ratio ($m^2.m^{-2}$)		
Mean	500	321	755	568
Standard Deviation	887	462	1,207	997
Coefficient of Variation	178%	144%	160%	176%
Minimum Value	2	5	9	2
1st Quartile (Q1)	79	87	165	105
Median	206	190	376	256
3rd Quartile (Q3)	525	362	791	599
Maximum Value	6,863	3,787	11,707	11,707
Range	6,862	3,782	11,699	11,705
Interquartile Range	447	276	627	494
Skewness Coefficient	4	5	4	4

[1] Considering the overall dataset from the three selected municipalities.

Table 1. Relief type, number of mapped lentic water bodies, and statistical measures of the ratio between the drainage area of watersheds and the surface area of lakes and reservoirs in the selected municipalities in the state of Goiás.

The municipalities in the Cerrado biome selected in the state of Bahia (BA) were: Formosa do Rio Preto, in the Plain relief type; Luís Eduardo Magalhães and São Desidério in the Plateau relief type. The location of the watersheds with soybean crops and lentic water bodies is shown in **Figure 2**.

The **Figure 2** shows that, in all mapped municipalities, the watersheds with soybean crops and their respective lentic water bodies are distributed unevenly along the municipal boundary.

The relief type, the number of mapped lentic water bodies, and the statistical measures of the ratio between the drainage area of watersheds and the surface area of lakes and reservoirs in the selected municipalities are shown in **Table 2**.

In the selected municipalities of Bahia, none of the mapped lentic water bodies had a ratio of watershed drainage area to lake or reservoir surface area less than or equal to the reference value, which is $10m^2.m^{-2}$. The lowest value found was $12m^2.m^{-2}$, in the municipality of Formosa do Rio Preto. This lower minimum ratio value, for a municipality where relief is predominantly of the plain type, may indicate that the mapped lakes and reservoirs are located on watercourses of lower order than those in the other municipalities studied.

In Luís Eduardo Magalhães and São Desidério, the minimum ratios were higher than the reference value. The magnitude of the observed difference may stem from geomorphological differences between Brazil and the United States of America, where the reference value was defined.

The mean ratio value in each municipality (especially in Formosa do Rio Preto) and, consequently, in the overall dataset for the three municipalities, are high. As observed for Goiás, the measures of data dispersion point to high variability, which may indicate that there is no pattern in the order of watercourses in which lakes or reservoirs are located within watersheds with soybean cultivation. The measures of dispersion also indicate the complexity involved in studying typical and critical scenarios for the ERA of pesticides in surface waters in Brazil.

The typical values for the ratio of drainage area to the surface area of the lentic water body in the municipalities of Formosa do Rio Preto, Luís Eduardo Magalhães, and São Desidério, and in the overall dataset (for the three municipalities), are, respectively, between 1,560−151,390, 934–8,846, 526–3,514, and $786–65,568m^2.m^{-2}$ Thus, the ratios between the drainage area of watersheds and the surface area of lentic water bodies exceeding 600,882, 32,582, 12,479, and $259,915m^2.m^{-2}$, respectively for Formosa do Rio Preto, Luís Eduardo Magalhães, and São Desidério, and for the combined dataset of the three municipalities, are considered extreme.

The skewness in the data for Formosa do Rio Preto and São Desidério is high (skewness coefficients > 1). For Luís Eduardo Magalhães, it is approximately symmetric, but it is noteworthy that the number of mapped lentic water bodies in this municipality is small, which may have influenced the results.

The means are higher than the medians for the three municipalities and for the dataset as a whole, indicating a positive skewed distribution, more pronounced in Formosa do Rio Preto and São Desidério, with data concentrated in the lower values of the ratio between drainage area and surface area of lentic water bodies to the left of the median, while the highest values are at the right end, characterizing the most critical and atypical scenarios.

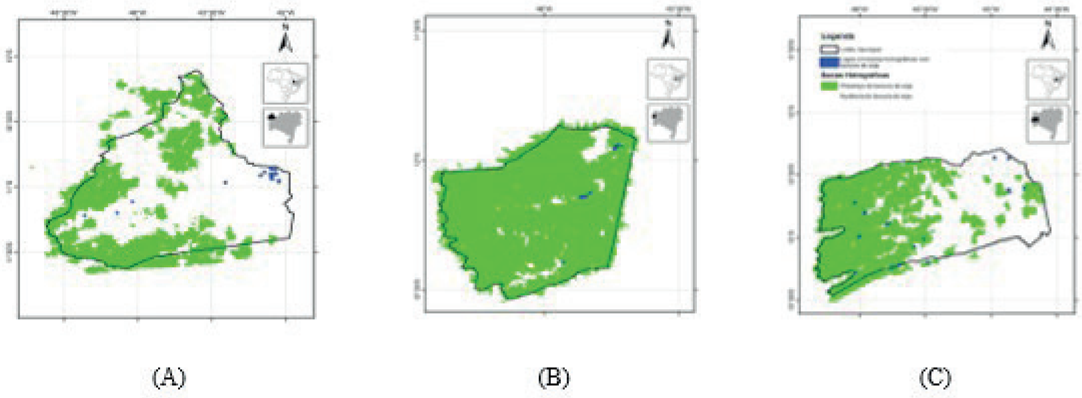


Figure 2. Distribution of watersheds with soybean crops (in green) and mapped lakes and reservoirs (in blue) in the Cerrado biome in the state of Bahia (BA), in the municipalities: (A) Formosa do Rio Preto; (B) Luís Eduardo Magalhães; and (C) São Desidério.

Measures	Formosa do Rio Preto	Luís Eduardo Magalhães	São Desidério	Total[1]
Relief Type	Plain	Plateau	Plateau	
Number of Lentic Water Bodies	39	6	16	61
		Area Ratio ($m^2.m^{-2}$)		
Mean	116.145	5,484	10,152	77,459
Standard Deviation	191,037	6,341	22,722	161,074
Coefficient of Variation	165%	116%	224%	208%
Minimum Value	12	398	183	12
1st Quartile (Q1)	1,560	934	526	786
Median	21,541	2,755	1,353	4,450
3rd Quartile (Q3)	151,390	8,846	3,514	65,568
Maximum Value	816,018	15,785	73,401	816,018
Range	816,006	15,387	73,217	816,006
Interquartile Range	149,750	7,912	2,988	64.782
Skewness Coefficient	2	1	3	3

[1] Considering the overall dataset from the three selected municipalities.

Table 2. Relief type, number of mapped lentic water bodies, and statistical measures of the ratio between the drainage area of watersheds and the surface area of lakes and reservoirs in the selected municipalities in the state of Bahia.

Noting that the choice of the case study area limits the results to only a sample of Brazilian rural conditions, the results presented suggest that the characteristics of the first-level scenario, adopted by IBAMA for pesticide ERA in surface water bodies, may not correspond to typical scenarios, nor to critical scenarios in soybean planted areas in Brazil. Further studies should be conducted to verify the proportion of surface runoff or water infiltration into the soil throughout the watershed, which may, in turn, require a correction of the values obtained in this study. Furthermore, terracing, a common practice in agricultural areas, involves dividing the slope (the continuous area where rainwater runoff occurs) into sections and may reduce the effective drainage area for the respective lake or reservoir. The order of the watercourse within the watershed may also affect the ratio between the drainage area and the surface area of the lake or reservoir.

Conclusions

The methodology applied proved effective for generating the information necessary to establish scenarios for the Environmental Risk Assessment (ERA) of pesticides in surface water bodies in Brazil. The results obtained for soybean cultivation in the Cerrado biome in the states of Goiás and Bahia indicated that there is a difference between the typical and critical scenarios identified and the first-level ERA scenario for pesticides in surface waters adopted by IBAMA. However, further research is needed so that, with a larger dataset, it will be possible to determine whether the scenario adopted in the ERA needs to be modified for different crops and regions of Brazil.

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