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Inventory of pesticides and their potential risk of contamination in the Cariús River watershed (Cariri–CE, Brazil)

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A B S T R A C T

The present study deals with pesticides, and their potential risk of contamination in the municipalities of the Cariús river basin (Cariri - CE). In general terms, it aimed to analyze the environmental fragility of the use of pesticides and to identify the active principles used, their respective environmental risks and their process of accumulation, transport and contamination of soil and water, in the area that covers the municipalities of Santana do Cariri, Nova Olinda, Farias Brito and Cariús, located in the south of the state of Ceará. For its accomplishment, the GUS Index - Groundwater Ubiquity Score was applied to the active principles of the pesticides commercialized and applied in the region in a model suggested by Neves, Gomes and Spadotto (1998), which takes into account the variables of leaching and runoff surface, resulting and natural characteristics (pedology, hydraulic conductivity, altitude and slope), in the delimitation of areas with natural susceptibility to environmental impacts resulting from the application of pesticides. The results indicated that the entire region is susceptible to contamination caused by the indiscriminate use of pesticides, with great potential for contamination of groundwater and surface water. Due to their properties with high leaching capacity, the following products should be abolished: Connect, Atrazine Nortox 500 SC, Calaris, Nicosulfuron Nortox 750 WG, DMA® 806 BR, Tucson, Quallis, U46, Artys, Aminol, Tordon and Disparo®. Glyphosate, Karate Zeon 50 CS, Klorpan, Pyrinex 480 EC and Decis 25EC should be avoided or replaced by alternative techniques. It is recommended to diversify production and promote organic agriculture through sustainable agricultural techniques/practices and lower environmental impacts.

Keywords: pesticides, environment, water, natural susceptibility.

Inventário de agrotóxicos e seu potencial risco de contaminação da bacia hidrográfica do Rio Cariús (Cariri – CE, Brasil)

R E S U M O

O presente estudo versa sobre os agrotóxicos, e o seu potencial risco de contaminação nos municípios da bacia hidrográfica do Rio Cariús (Cariri – CE). Em termo geral objetivou analisar a fragilidade ambiental ao uso de agrotóxico e identificar os princípios ativos utilizados, seus respectivos riscos ambientais e seu processo de acumulação, transporte e contaminação de solo e da água, na área que abrange os municípios de Santana do Cariri, Nova Olinda, Farias Brito e Cariús, localizados no sul do estado do Ceará. Para sua realização seguiu-se a aplicação do Índice de GUS - Groundwater Ubiquity Score nos princípios ativos dos agrotóxicos comercializados e aplicados na região em uma modelagem sugerida por Neves, Gomes e Spadotto (1998), que leva em conta as variáveis de lixiviação e escoamento superficial, resultantes e as características naturas (Pedologia, condutividade hidráulica, altitude e declividade), na delimitação de áreas com susceptibilidade natural aos impactos ambientais resultante da aplicação de agrotóxicos. Os resultados indicaram que toda região é suscetível de contaminação provocada pelo uso indiscriminado de agrotóxicos, com grande potencial de contaminação de águas subterrâneas e superficiais. Por terem propriedade com alta capacidade de lixiviação os seguintes produtos devem ser abolidos: Connect, Atrazina Nortox 500 SC, Calaris, Nicosulfuron Nortox 750 WG, DMA® 806 BR,

Tucson, Quallis, U46, Artys, Aminol, Tordon e Disparo®. Já o Glifosato, Karate Zeon 50 CS, Klorpan, Pyrinex 480 EC e Decis 25EC, devem ser evitados ou substituídos por técnicas alternativas. Recomenda-se diversificar a produção e a promoção da agricultura orgânica por meio de técnicas/práticas agrícolas sustentáveis e de menores impactos ambientais.
Palavras-chave: agrotóxicos, meio ambiente, água, susceptibilidade natural.

Introduction

Since prehistory (Neolithic from 8000 BC to 5000 BC) humans were been able to develop techniques necessary to produce his own food, in the so-called Agricultural Revolution. From then on, it made its history by selecting and crossing different seeds and species of plants and animals to obtain the characteristics that would be the most advantageous, mainly for increasing production and resisting attacks from the most varied species of insects, animals, algae, nematodes, molluscs, mites, fungi, bacteria and any other biotic or abiotic elements that could harm the development of a plant.

In this perspective, pesticides are defined as any product used to modify the composition of flora and fauna, in order to control or eliminate the negative action of living beings considered harmful. At first, pest control was done using organic compounds extracted from plants, such as ash, calcium oxide (lime) and other materials found in nature. Art. 2 of LAW No. 7,802, of July 11, 1989, includes a list of substances and products used as defoliants, desiccants, stimulators and growth inhibitors (Brasil, 1989).

The considerable increase in the volume of pesticides used in Brazil has brought about a series of disturbances and environmental changes, both by the contamination of the communities of living beings that compose it, and by its accumulation in the biotic and abiotic segments of the ecosystem. According to Otenio et al. (2022) in the last decade, the use of these substances in Brazil has grown worryingly, while the world average consumption has grown by 93%; in Brazil, this increase was 190%.

There are currently more than 17,725 pesticides registered in the country (AENDA, 2021). Only three types of crops – soybean, corn and sugarcane – account for about three quarters of the total (IPEA, 2019) number of crops. According to Dulce (2018), 30% of the 504 pesticides recently released by Brazilian legislation are banned in the European Union, because the risks they pose are known. However, they are the sales leaders in Brazil. According to the first inventory of pesticides in a Brazilian agribusiness region, more than 150 active principles are used in the Jaguaribe River basin (state of Ceará), and these substances reach the mouth of the rivers (Cavalcante et al., 2012; Gama et al., 2013, 2017; Oliveira et al., 2016; Santana et al., 2020; Santos et al., 2019; Sousa et al., 2016).

The lack of technique in the application, added to the flexibility in the use of these products in the country, has been causing a decrease in soil fertility. According to Monquero and Silva (2021), the soil is the final destination of all chemicals used in agriculture, both those used directly in the soil and those used on plants. Springs are also contaminated, with loss of biodiversity, water degradation and air quality problems.

In addition to contributing to climate change and compromising human health as a result of the consumption of contaminated food and problems related to its application. In this context, there is a recurrent concern of understanding the agricultural profile and environmental characteristics (climate, topography, soil types, etc.) of the application area, so that later applications of models capable of measuring environmental vulnerability and natural susceptibility to environmental impacts can be made, through the elaboration of the Risk Index for contamination of soil and groundwater and surface water.

This research seeks to delimit the areas most susceptible to the risk of environmental contamination caused by the use of pesticides in the region of the Cariús river valley. To predict the behavior and environmental impacts caused by pesticides in the Cariús river valley, two investigative aspects were carried out: 1st - Identification of the active principles in the products used. 2nd – analysis of environmental risks using forecast models, which provide immeasurable information regarding the processes of accumulation, transport and environmental contamination.

The results reported here can be useful for studies on regions with highly populated agricultural areas and can help sensitize public managers to invest in a sustainable rural growth agenda. Its importance is due to the need to identify the areas most vulnerable to chemical contamination caused by agricultural activity.

Thus, the objective of this work was to analyze the environmental fragility and the delimitation of areas with natural susceptibility to environmental impacts resulting from active principles of pesticides sold and applied in the region, serving as a planning tool for the execution of ecologically sustainable rural enterprises, as well as guiding the choice of products with lower risk potential.

Study área

The study area corresponds to the microwatershed of the Cariús River, a tributary of the Jaguaribe River, the largest river in the state of Ceará, which covers four municipalities located in the extreme south of the state. Three of these belong to the southern geographic mesoregion of Ceará (Santana do Cariri – CE, Nova Olinda - CE, Farias Brito - CE) and another one is located in the Center-South mesoregion of Ceará (Cariús – CE).

Together, they share an area of 2,704.706 km², home to 71,554 inhabitants (IBGE, 2021). The climate of the region varies from Tropical Hot Humid to Tropical Hot Semi-arid, with an average annual rainfall of 854.4 mm, with a very irregular distribution of rainfall (temporally and spatially), being the heaviest between the months of January and May (IPECE, 2017).

Material and methods

Table 1. Basic profile of the municipalities in the study area. Source: (Ipece, 2017)

County	Territorial area (km²)	Estimated population (2021)	GDP per capita (2019)	Climate	Rainfall (mm)
Santana do Cariri	855.165km²	17,726	R$7,588.62	Tropical Hot Semi-arid	972.8
Nova Olinda	282.584 km²	15,798	R$9,353.48	Tropical Warm Sub-humid	682.7
Farias Brito	530.540 km²	19,330	R$9,689.49	Semi-arid Hot Tropical	896.5
Cariús	1,036.417 km²	18,700	R$7,731.54	Semi-arid Hot Tropical	865.6
Total / Average	2,704.706 km²	71,554	R$ 8,590.78	-	854.4

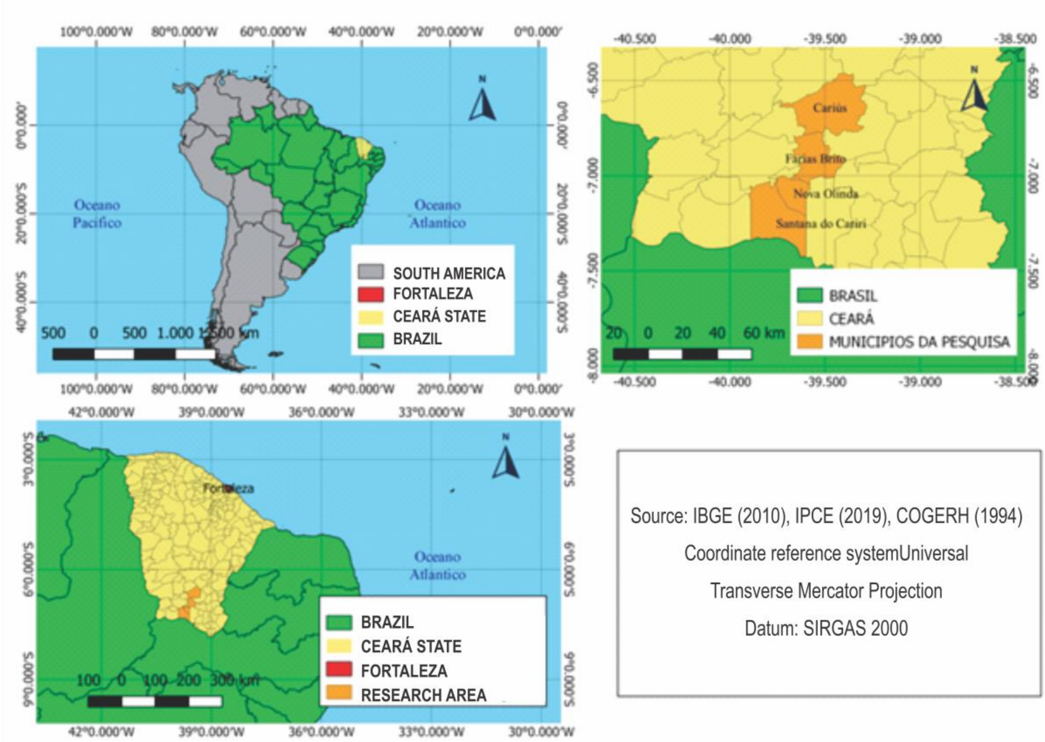

Figure 1. Study area: Cariús river basin

Two municipalities in the study area stand out in limestone mining (Santana do Cariri and Nova Olinda). However, the economic base is the traditional and subsistence agricultural sector. Both agriculture and livestock production techniques are conventional and use little mechanization.

Attempts to increase the production of rural activities and modernize the countryside have been taking place due to the increase in cultivated area and the indiscriminate use of chemical inputs. It is the producers themselves (lay people) who choose the products, without adequate technical monitoring, and they apply the ones they find most convenient for their crops (Table 2). According to the 2017 Agricultural Census, only 17.82% of establishments are assisted by agronomists or agricultural technicians (IBGE, 2017).

Table 2. Agricultural technical data. Source: (IBGE, 2017).

Follow-Up Technician	**Technical Assistance / Establishment**				
	Santana Do Cariri	**New Olinda**	**Farias Brito**	**Cariús**	**Total**
Receive	227	122	754	231	1334
Do not receive	1110	891	1646	2508	6154
Temporary	1659	979	2600	3695	8933
Permanent	284	298	69	457	1108
Fertilized	274	84	328	379	1065
Did not fertilize	1045	929	2068	2358	6400
Used pesticide	655	549	1560	1979	4743
Use pesticides (preventively)	44	63	69	114	290
Did not use pesticides	664	464	836	758	2722

In these enterprises, permanent (11.03%) and temporary (88.07%) crops are cultivated, in addition to animal husbandry. All production is destined to supply the local market and for subsistence, with a predominance of family farming work regime. In 2017, 64.9% of establishments used pesticides in their production (IBGE, 2017). This practice only increases every year.

Agricultural production is quite diversified, with emphasis on short-term crops, especially those that are part of the region's diet: corn was grown in 6,363 establishments, followed by jackfruit, beans, and rice, which are respectively planted in: 5,964, 4,036, 562 and 487 establishments. (IBGE, 2017). This type of planting is extremely vulnerable to climatic instabilities and most pesticides that are used (Table 3).

Table 3. Agricultural production data. Source: (IBGE, 2017).

Temporary crop	**Establishment / City**				
	Santana do Cariri	**New Olinda**	**Farias Brito**	**Cariús**	**Total**
Pineapple	32	-	-	-	32
Pumpkin, strawberry, pumpkin	52	07	468	35	562
Cotton (herbaceous)	-	-	-	02	02
Peanut	10	06	217	89	322
Rice	11	21	194	261	487
Sugar cane	02	03	09	07	21
Foraged sugar cane	-	-	06	04	10
Onion	01	-	-	-	01
Broad bean	290	526	2025	1195	4036
Bean	892	825	1979	2268	5964
Smoke	11	-	-	-	11
Sesame	03	04	46	18	71
Sunflower	-	-	01	-	01
Cassava	245	27		26	298
Watermelon	40	05	164	10	219
Melon	02	-	39	02	43
Corn	866	887	2255	2355	6363
Foraged corn	19	11	07	03	40
Foraged sorghum	-	01	03	13	16
Tomato	01	01	-	-	01
Foraged palm	04	-	06	-	10

With regard to permanent crops, banana, cashew and guava are the most significant (Figure 2).

Livestock farming is exclusively extensive, as there are few investments in the sector. The herds are raised on family properties and occupy a large territorial area, causing several environmental impacts: soil compaction, replacement of native forest with pasture, use of herbicide, etc. The most expressive creations are: chickens, cattle, swine, sheep and goats (Figure 3).

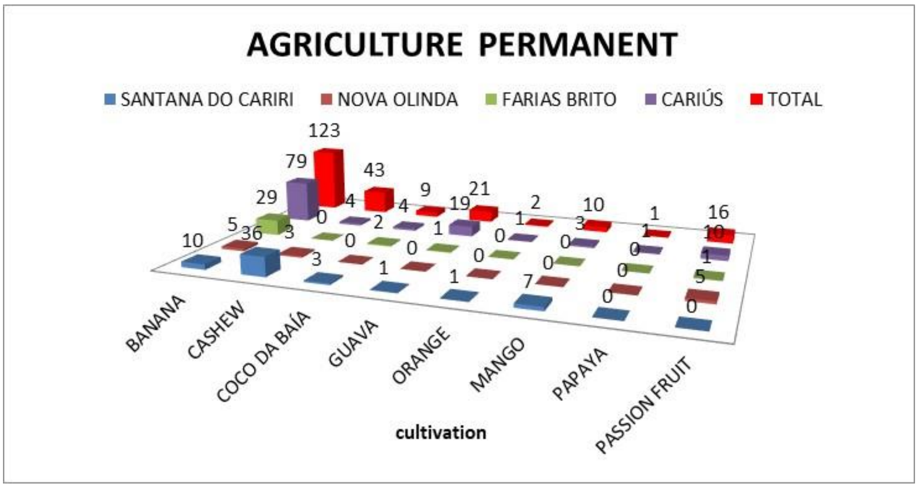

Figure 2. Establishment with permanent crops. Source: (IBGE, 2017).

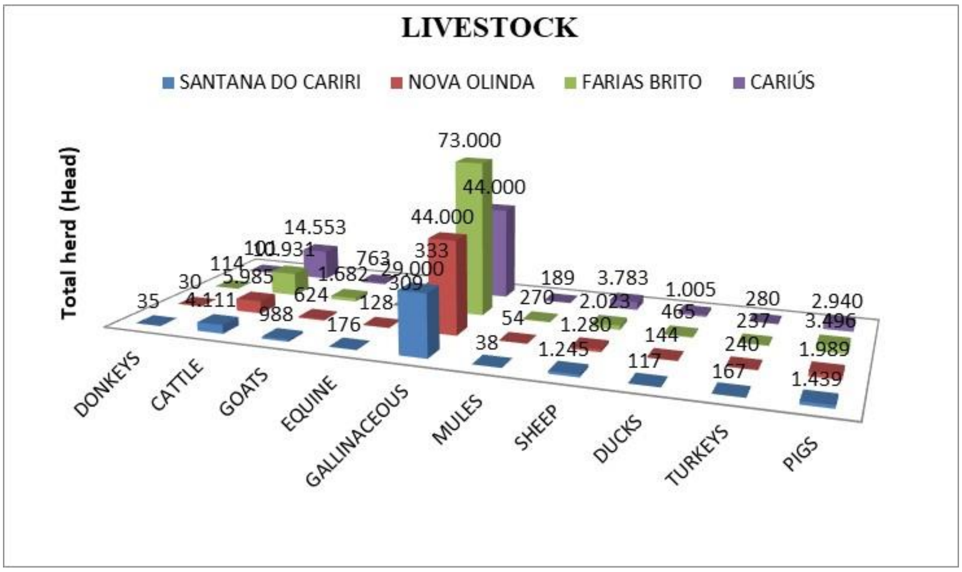

Figure 3. Herd size. Source: (IBGE, 2017).

Methodology

The methodological approach used in this research was the EX-POST-FACTO. This choice reflects our aim to investigate the cause and effect relationships between the use of pesticides and their respective interactions with geological and pedological characteristics of the event site and, with that, create an inventory of environmental risk. This type of approach is preferred when it is impossible to apply experimental procedures. In this case, the researcher does not have direct control over the independent variables, because their manifestations have already occurred, reaching the researcher when their effects have already been exerted.

Survey of pesticides applied in the Cariús river basin

The active principles present in pesticides were identified from on-site technical visits, consultation of the product leaflet through visits to points of sale, cultivation sites, Municipal Departments of Agriculture and interviews with farmers and ranchers in the area under study. Subsequently, a detailed inventory of all pesticides sold and used in the region before and during the 2022 harvest was prepared.

Thus, such components were submitted to the modeling described in the literature, with the aim of evaluating the behavior of the active ingredients, as well as the potential for contamination in surface and underground waters. It is important to bear in mind that the identification, edapho-climatic characterization and physicochemical properties of the active principles are essential to assess the susceptibility of environmental contamination.

Assessment of the potential for contamination of groundwater and surface water.

The method adopted for the qualification of environmental risk was elaborated by the application of models capable of dimensioning the susceptibility of contamination by pesticides in aquatic bodies, through the variables of leaching and surface runoff. Both are types of transport that can lead to contamination of water resources by pesticide residues (Marques et al., 2009).

In order to determine the potential of certain compounds to be leached until reaching groundwater and to evaluate which products are the most appropriate, the Groundwater Ubiquity Score (GUS) Index of the main active ingredients was calculated, correlating with the estimate of hydraulic conductivity, which in turn was determined by the physical properties of the soil, infiltration capacity and surface runoff of water, through cartographic information provided by soil mapping and slope of the studied area.

The GUS Index is calculated using the half-life values of the compost in the soil (DT50 soil) and the coefficient of adsorption to soil organic matter (Koc), without taking into account other properties, such as water solubility (Ismael and Rock, 2019). It is an efficient method that evaluates the leachability of molecules and the possibility of contamination of groundwater (Marques et al., 2012). The GUS index - Groundwater Ubiquity Score, is obtained by applying Equation 01:

$$\boxed{\mathbf{GUS = \log (t_{1/2}\ solo) \times (4 - Log\ K_{oc})} \qquad \textbf{(01) Equation}}$$

Where $t_{1/2}$ is the half-life in soil (days) e K_{oc} is the coefficient of adsorption to organic matter.

In this model, the active ingredients investigated are classified into ranges according to their tendency to leaching, where: GUS < 1.8: does not undergo leaching (NL - Null leaching of groundwater); 1.8 < GUS < 2.8: transition range (FT); GUS > 2.8: probable leaching (PL).

The potential for infiltration and surface runoff of water in the soil was due to the relation between hydraulic conductivity and terrain slope. Suggested by Gomes et al. (2020), the hydraulic conductivity levels prepared for each type of soil are classified into three categories: high, medium and low.

The results of hydraulic conductivity and surface runoff were systematized through geographic data. Where georeferenced information was conducted in QGIS Software 3.16. Enabling the interpretation of vector data and the creation and analysis of cartographic products through exploratory soil recognition map, hydraulic conductivity map, hypsometer map (altitude) and slope map, and drainage network map.

For the cartographic base of the hypsometer (altitude), slope and drainage network maps, the Digital Elevation Model (DEM) was used, based on the Shuttle Radar Topography Mission (SRTM) data from the mosaic of the fusion of the Letters: Iguatu (06_405) / Crato (07_405), both available for download on the TOPODATA platform.

Its features were delimited (cut out) by the mask layer of SHAPE municipal limits of the State of Ceará, taken from the cartographic database of the Companhia de Gestão dos Recursos Hídricos (COGERH).

The pedological map was extracted from the soil SHAPE of the IBGE database, scale 1:5,000.000 and overlaid on the search area boundary layer. Then, a change was made in the attribute table to categorize the degree of risk of the interaction of the soil type with the active substances present in the pesticides used.

Results and discussions

Inventory of pesticides in the region

Soil is the main receptor and accumulator of chemical compounds used in agriculture. Once applied, several chemical, physical, physical, and biological processes are initiated, and they are the ones that determine the probabilities of environmental risk. The durability, amplitude and dimension of its impacts are determined by the retention, chemical degradation, leaching, drift, and surface runoff processes, and by the interaction of all these factors (Miranda, 2021).

By infiltrating the soil, pesticides can contaminate groundwater, given that their residues are often found at points of water collection for domestic use and for animal husbandry (Ismael and Rocha, 2019). It is worth remembering that this risk potential depends on the chemical and physical composition of the soils in the region, climate, relief (slope), amount of water from surface runoff, etc.

It is almost impossible to accurately predict the environmental behavior of pesticides and their interaction with the environment, as there are several factors to be evaluated and quantified, such as: quantity and frequency of use, meteorological factors, type of application, etc. However, there is already a description of products in the literature and the way in which they are retained, processed and transported.

Several are the pesticides that have been sold and applied in the municipalities that make up the Cariús river basin. The data obtained from the sales inventory reveal that, in addition to being varied, they are used in large quantities. Regarding the agronomic class, 60.8% of the products analyzed are herbicides, and 39.2% are insecticides (Table 4). On the other hand, in the Jaguaribe River basin region, the highest use of fungicides was observed, followed by herbicides and insecticides (Gama et al., 2017).

Table 4. Product sales inventory from January to March 2022. Source: (Adapar, 2022).

Product	Place of sale and quantitatives (L)						Total
	Agronomic Class	**Active principle**	**Santana do Cariri**	**Nova Olinda**	**Farias Brito**	**Cariús**	
Glyphosate	Herbicide	Glyphosate	800	600	1920	659	3979
Dma® 806 BR	Herbicide	2,4- D	180	-	1340	-	1520
Nicosulfuron nortox 750 WG	Herbicide	Nicosulfurom	60	-	280	1009	1349
Lannate® BR	Insecticide	Methomyl	20	-	12	200	232
Decision 25EC	Insecticide	Deltamethrin	06	04			10
Brilliantbr	Insecticide	Methomyl	-	-	220	01	221
Bazuka 216 SL	Insecticide	Methomyl	-	-	350	01	351
Karate zeon 50 CS	Insecticide	Lambda-cyalothrine		-	24	70	94
Connect	Insecticide	Beta-cyflutrin and imidacloprid	240	-	50	72	362
Atrazina Nortox 500 SC	Herbicide	Atrazine	125	-	880	1340	2.345
Klorpan	Insecticide	Chlorpyriphos	-	-	21	22	43
Tucson	Herbicide	2.4- D	-	-	120	15	135
Nufoate	Herbicide	Glyphosate	-	-	40		40
Quallis	Herbicide	2,4- D		-	120	600	720
U46	Herbicide	2,4- D	-	-		402	402
Calaris	Herbicide	Atrazine	-	-	24	264	288
Artys	Herbicide	2,4-D	-	-	-	100	100
Roundup	Herbicide	Glyphosate	-	-	-	109	109
Upmyl	Insecticide	Methomyl	-	-	-	18	18
Pyrinex 480 EC	Insecticide	Chlorpyriphos	-	-	-	100	100
Aminol	Herbicide	2,4-D	-	-	-	200	200
Tordon	Herbicide	2,4-D	-	-	-	70	70
Trigger®	Herbicide	2,4-D	-	-	-	200	200
Total estimated sales (L)			365	604	5401	5452	11822

As for the Toxicological classification, six of the 23 products used in the region have active ingredients belonging to class I, considered Extremely Toxic Products; (red band). Among these are: 2,4-D and Methomyl, as shown in Figure 4. The profile verified here is similar to that reported in the Jaguaribe River basin, most are in classes 3 and 4, for ecological risks, while those belonging to classes 1 and 2 of greater environmental risks are the most used (Gama et al., 2013).

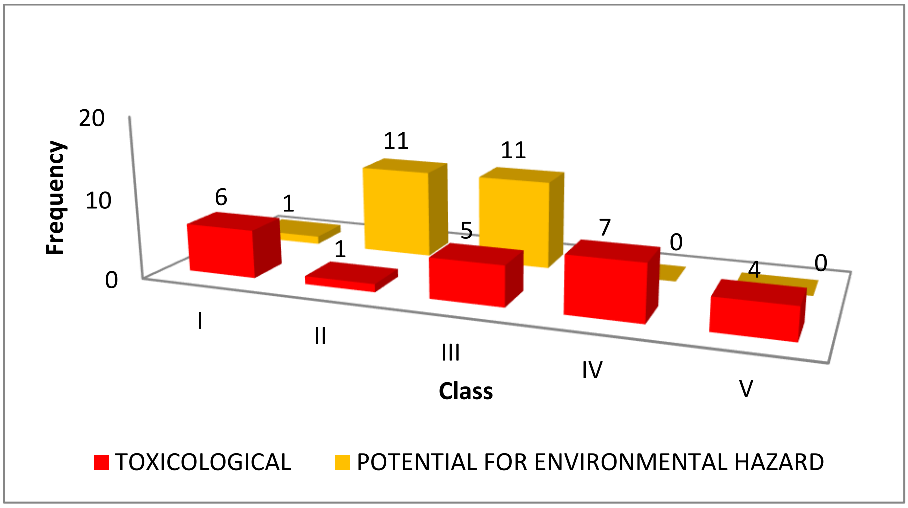

Figure 4. Risk classification of pesticides used in the research area in 2022. Source: (Adapar, 2022).

In Table 5, we can see the risk of groundwater contamination using the GUS Index, which evaluates the interaction of physical-chemical properties and the leaching potential of the active principles of pesticides used in the researched area.

Table 5. Physical-chemical properties of the main pesticides used in the research area. Source: (Milhome et al., 2009; Gama et al., 2013).

Active Principle	$DT50_{Soil}$ (d)	DT50 $_{Hid}$ (d)	K_{oc} ($mL.g^{-1}$)	GUS	GUS Index Result
Glyphosate	12	E	21699	-0.36	LN
2,4-D	10	E	56	2.25	FT
Methomyl	07	83	25	2.20	FT
Lambda-cyalothrine	25	07	157000	-1.67	LN
Beta-cyfluthrin and imidaclopride	191	E	225	3.76	PL
Atrazine	100	86	75	3.75	PL
Chlorpyriphos	50	25.5	8151	0.15	LN
Nicosulfurom	26	16	21	3.79	PL
Deltamethrin	<23	92	460000	-2.26	NL

* Note: DT50: half-life; Koc; coefficient of adsorption to organic matter; GUS: groundwater vulnerability index; E: stable (very persistent). GUS classification: LN: Null Leach, FT: Transition Band, PL: Leach Potential.

Pesticides with the active ingrediente Beta-Cyfluthrin and Imidacloprid, Atrazine and Nicosulfuron have a high potential of contamination. While 2,4-D and Methomyl present a risk of intermediate leaching, the other pesticides showed groundwater degradation rates close to zero. On the other hand, according to Gama et al. (2013), 13.2% are classified as potential contaminants, 17.9% are in the transition range, 56.3% are classified as non-contaminants and 11.3% are inconclusive in the Rio Jaguaribe basin.

Risks of pesticide contamination in water bodies

A great tool for assessing the risk of contamination of soil and water resources in a watershed is the simulation of the movement of pesticides, based on mathematical models and environmental monitoring tools using data provided by the Geographic Information System (SIGs) and an empirical model (Lima et al., 2007).

The basic principle of this method is to use environmental information in cartographic databases to accurately deduce the behavior of water throughout the research area. In this logic, the infiltration and surface runoff potential were elaborated from matrix information involving soil information, hydraulic conductivity, slope and terrain hypsometry (Neves et al., 1998).

Soil map and hydraulic conductivity

Hydraulic conductivity is a property that expresses in values the ease of movement and its ability to transport chemical substances. Its quantification is extremely important for the agricultural sector, as it indicates soil preservation and groundwater contamination, being one of the factors that condition the movement of contaminating compounds on the surface (Ribeiro, 2020).

To determine soil conductivity, Gomes, Spadotto and Pessoa (2020) considers the variables of texture, aggregate stability and soil depth. In this logic, and with the combination of these four variables.

Neves et al. (1998) proposed the classification of the hydraulic conductivity of the main Brazilian soil classes into high, medium and low. Taking into account the pedological characteristics of the research region and the results obtained in the soil classification presented in the literature, we concluded the hydraulic conductivity information, shown in Figure 5.

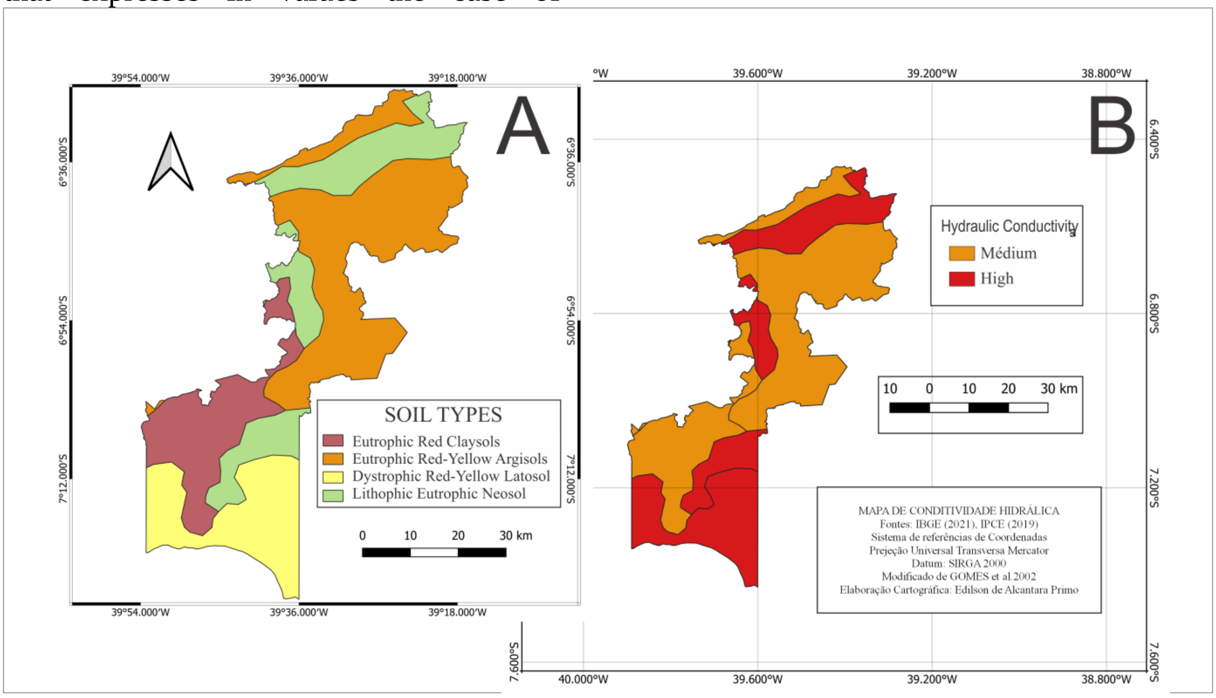

Figure 5. (A) Soil map; (B) classification regarding the hydraulic conductivity of soils.

The soil map of the region indicates that 64% of the terrain is sandy soil, approximately 1115.38 Km^2. In this soil type, the following soil classes were found: Neosol litholic Eutrophic (611.75 Km^2), and Dystrophic red-yellow Latosol (503.63

Km^2), According to Gomes, Spadotto and Pessoa (2020), both have high potential for hydraulic conductivity and increase the risk of contamination of groundwater by pesticides.

About 36% of the land, approximately 1944.05 Km^2, is formed by clayey, classified as Eutrophic red-yellow clayey. This type of soil has a moderate permeability; therefore, the hydraulic conductivity is medium. Thus, the surface runoff is much higher in this perimeter, with greater occurrence of erosion, superficial transport of chemical products and greater probability of contamination of surface water bodies.

The slope of the land is one of the geomorphological properties of the soil that has a direct influence on surface runoff, infiltration potential, transport of chemical compounds and sediments (erosion). Through the Digital Elevation Model (DEM) and a resource of the Geographic Information System (GIS), a hypsometer map (altitude) was prepared and the slope was extracted from it.

Through the slope information plan, the terrain was grouped into three classes: less than 3% (low), between 3% and 8% (smooth) and between 8% and 20% (high). According to Neves et al. (1998), areas with values greater than 20% are discarded as they are unviable for agricultural activity, as shown in Figure 6.

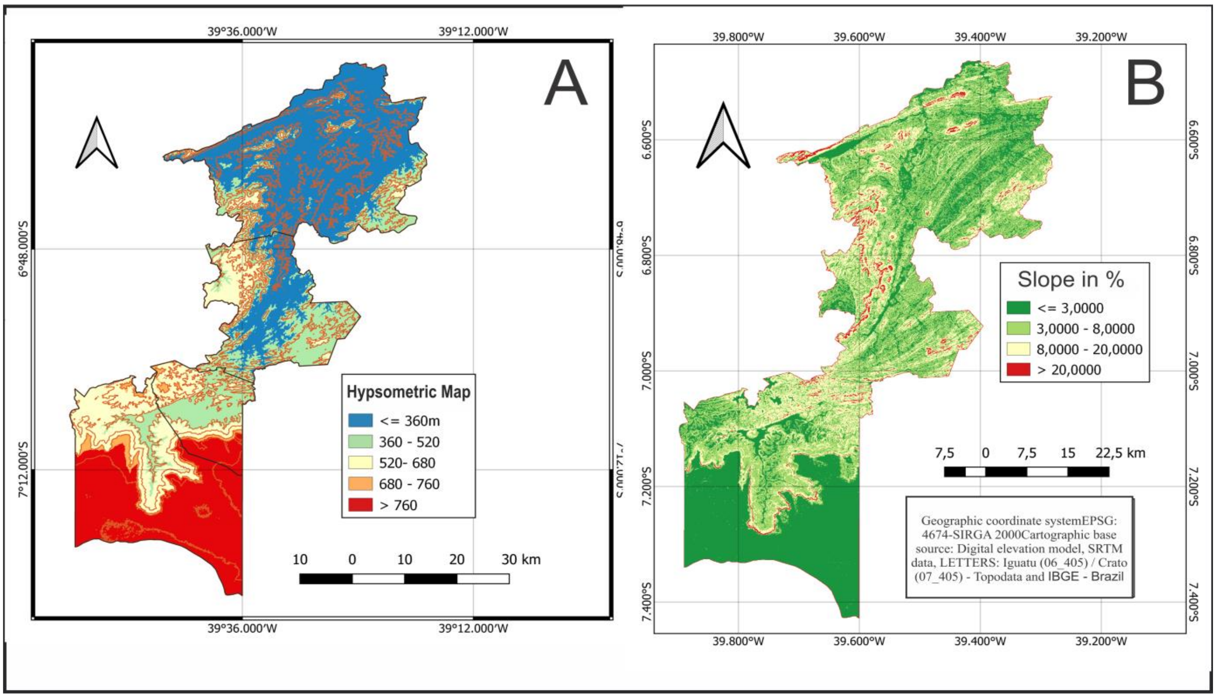

Figure 6. (A) Hypsometer map (altitude) and (B) classification map regarding the slope of the research area.

The steeper the area, the greater the surface runoff, the dispersion of contaminants and the risk of contamination of surface waters. However, the lower the slope, the greater the infiltration potential and the risk of groundwater degradation.

Table 5 shows that the infiltration potential is inversely proportional to surface runoff. It is possible to demonstrate the risk of contamination by pesticides in groundwater by crossing information on hydraulic conductivity and terrain slope.

Table 5. Pesticides infiltration potential based on hydraulic conductivity and slope. Source: (Neves et al., 1998)

Hydraulic Conductivity	Declividade		
	Low (<3%)	Smooth (3 a 8%)	High (8 a 20%)
Low	Medium	Short	Short
Average	High	Medium	Short
High	High	High	Medium

The combination of soils with high hydraulic conductivity and low slopes is capable of determining the natural susceptibility to environmental risk caused by the use of pesticides. As a result of this interaction, zoning was possible by delimiting the risk profile: Low, Medium, High, and Very High (Figure 7).

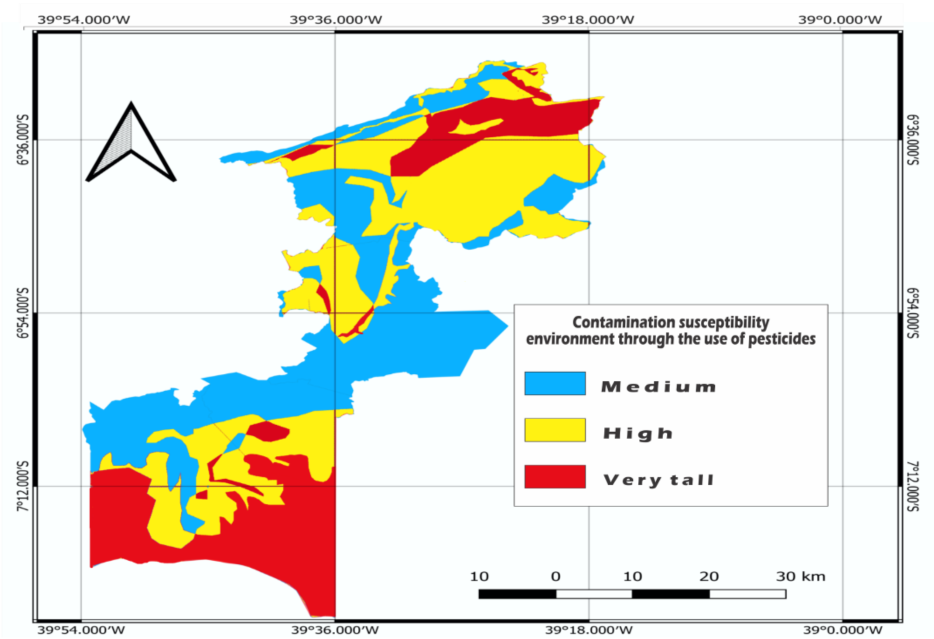

Figure 7. Map of natural susceptibility to environmental contamination by the use of pesticides

After evaluating the physical, and environmental conditions and the chemical characteristics of the pesticides applied, it is possible to affirm that this is an area extremely sensitive to adverse reactions caused by the active compounds found in pesticides. It is possible to identify several points with a very high potential for contamination of soil, surface water, and groundwater.

Final considerations

Approximately 66% of the territory of the Ceará municipalities of Santana do Cariri, Nova Olinda, Farias Brito, and Cariús have high and very high susceptibility to environmental impacts caused by the application of pesticides. 1030.97 Km^2 (38%) is a high risk zone, 753.00 Km^2 (28%) is a very high risk zone and 920.73 km^2 (34%) is equivalent to a medium risk zone. Soils with a high degree of impermeability were not found within an intersection with slope > 3% rate.

Four of the 23 different sprayed products have the following substances in their active principle: Beta-Cyfluthrin and Imidacloprid, Atrazine and Nicosulfuron. GUS Index 3.76, 3.75, and 3.79, respectively. They are extremely dangerous, as they have a high potential to be leached into the water table, as they have a GUS index greater than 2.8.

Twelve pesticides with moderate leaching potential were identified, as they contain ingredients based on 2,4-D (GUS = 2.25) and Methomyl (GUS = 2.20), classified in the transition range to leaching potential. = 1.8 < GUS < 2.8.

The following products must be abolished: Connect, Atrazine Nortox 500 SC, Calaris, Nicosulfuron Nortox 750 WG, DMA® 806 BR, Tucson, Quallis, U46, Artys, Aminol, Tordon and Disparo®, since their chemical properties indicatehigh leaching potential.

Based on the results, it is evident that Glyphosate, Karate should be avoided and/or replaced by alternative techniques, such as Zeon 50 CS, Klorpan, Pyrinex 480 EC, and Decis 25EC. Even with low infiltration potential, it is possible to cause some environmental imbalance.

Due to the lack of adequate technical support for any application of agrochemicals, it is recommended to replace the use of pesticides with more effective and chemical-free pest control techniques, or at least maintain them at tolerable and safe levels for the environment and human health.

Thus, it is necessary to diversify the production and promotion of organic agriculture, with the adoption of public policies for investment in technical advice, training of farmers in sustainable practices and access to rural credit conditioned to investments in agricultural techniques/practices with lower environmental impacts.

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