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Agri-environmental assessment of the agrochemical containers and solid waste in Calimaya, central Mexico

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Resumo: O manejo de embalagens de agroquímicos e resíduos sólidos é um potencial indicador da sustentabilidade ambiental do uso de solo agrícola, pois está associado ao nível tecnológico do cultivo, às práticas de manejo dos agricultores e às iniciativas públicas e privadas da sociedade. O objetivo desta pesquisa foi identificar, caracterizar e analisar a diversidade de embalagens de agroquímicos, e a disposição final de resíduos sólidos em áreas de cultivo agrícola e florestal no Município de Calimaya, Estado do México. Foram analisadas 119 áreas de cultivo na zona rural no período de agosto a novembro de 2019. Encontraram-se evidencias do manejo incorreto dos resíduos sólidos e do descarte de embalagens de agroquímicos, principalmente pesticidas e fertilizantes, destacando-se as práticas de descarte desses resíduos sólidos nas áreas de cultivo, predominantemente nos cultivos de milho (*Zea mays* L.) e batata (*Solanum tuberosum* L.), bem como a queima desses resíduos ou seu abandono em corpos de água.

Palavras-chave: Resíduos perigosos, gestão de resíduos, impacto ambiental, práticas de manejo de agroquímicos.

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Abstract: The management of agrochemical containers and solid waste is a potential indicator of environmental sustainability of the cropland use, due to it is associated with the crop technological level, the management practices of farmers and the public and private initiatives of society. The objective of this research was to identify, characterize and analyse the diversity of agrochemical containers and the final disposal of solid waste in the agricultural and forest cropping areas in the Municipality of Calimaya, State of Mexico. It was analysed 119 cropping areas out in the rural zone in the period between August to November 2019. Evidence of incorrect handling of solid residues and the disposal of agrochemical packaging, mainly pesticides and fertilizers, was found, highlighting the practices of discarding solid residues in cropping areas, predominantly maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) crops, as well as the burning of these wastes or their abandonment in water bodies.

Key-words: Hazardous waste, waste management, environmental impact, agrochemical management practices.

1. INTRODUCTION

The Metropolitan Zone of Toluca Valley (MZTV), State of Mexico, is an important region of central Mexico with a high population density and a predominance of intensive and semi-intensive conventional agriculture (GONZÁLEZ HUERTA et al., 2008; PÉREZ LÓPEZ et al., 2010; CONANP, 2013; SEMARNAT, 2016; SCIGA-INEGI, 2018). Calimaya is one of the four municipalities of the MZTV with the highest number of cropping areas of grain maize (*Zea mays* L.), forage oat (*Avena sativa* L.), faba bean (*Vicia faba* L.), and potato (*Solanum tuberosum* L.)

(SCIGA-INEGI, 2018; SIAP, 2019). In this Municipality, the overexploitation of soil and water resources is characterized by negative impacts caused by real estate activity, sand and gravel mining, and conventional agriculture (LOUREIRO et al., 2023). In addition to the predominance of cropland use in the Calimaya territory (LOUREIRO et al., 2023), the consumption of pesticides in crops has also been described through the diversity of types and active substances (DELGADO MENDOZA, 2016; LOUREIRO et al., 2021). Likewise, solid domestic waste, mainly inorganic, has been identified as an environmental problem in this Municipality (VALENCIA GARCÍA et al., 2016). Therefore, field monitoring is a fundamental strategy to determine the environmental impact of empty agrochemical containers (EAC) and solid waste on the geographic context of this territory and region.

Agrochemicals use in conventional agriculture is a technical-scientific paradox that challenges agronomy and environmental sciences; on the first hand, pesticides and fertilizers from phytotechnical management are directly associated with increased crop productivity (FLORES-SÁNCHEZ et al., 2019; KOCH et al., 2019), and the other hand, organic and inorganic residues of these substances are widely related to negative impacts on human health (ERAS et al., 2017; BERNARDINO HERNÁNDEZ et al., 2019) and terrestrial and aquatic ecosystems (LARA F. et al., 2000; DUFFNER et al., 2012; ARELLANO-AGUILAR et al., 2017; BONDORI et al., 2019; LOUREIRO et al., 2021).

The residues generated by agriculture (BRIASSOULIS et al., 2013; LEYVA MORALES et al., 2014; ERAS et al., 2017; LAGARDA-LEYVA et al., 2019) are part of a complex context of anthropogenic solid waste that can pollute and contaminate different environmental systems through processes such as percolation, infiltration, leaching, flooding, and air dispersion (LOPEZ STEINMETZ et al., 2020). The following highlights some strategies or information used as sources for data collection that integrate research on the agrochemical management practices and their final disposal: 1) The inventory of empty containers (LEYVA MORALES et al., 2014; DELGADO MENDOZA, 2016; LOUREIRO et al., 2021); 2) Classification of agrochemical types (LEYVA MORALES et al., 2014; DELGADO MENDOZA, 2016; BERNARDINO HERNÁNDEZ et al., 2019; LAGARDA-LEYVA et al., 2019; LOUREIRO et al., 2021); 3) Formulations types (KNOWLES, 1998); 4) Containers types (BRIASSOULIS et al., 2013; ERAS et al., 2017; LAGARDA-LEYVA et al., 2019); and 5) Inactivation and final disposal of containers (LARA F. et al., 2000; BRIASSOULIS et al., 2013).

The EAC have been collected in the potato crop in Calimaya for the identification of pesticides active substances, however, the issue of these solid residues in these crops was not deepened (DELGADO MENDOZA, 2016). The high exposure of farmers to the mixture of pesticides in Calimaya has been reported by Sánchez Mendoza (2019). According to Loureiro et al. (2021) the presence of highly hazardous pesticides restricted or prohibited in other countries, their excessive use, and the incorrect handling of these substances in the agricultural and forest cropping areas of this Municipality, are factors that increase the risk of soil and water contamination and may exceed the safe limits predicted by environmental chemistry. Given the importance of this environmental problem in Calimaya, this research provides a method to analyse and monitoring the final disposal of EAC in agricultural and forest cropping areas.

2. MATERIAL AND METHODS

2.1. Study zone and environmental system

This study was carried out in the Municipality of Calimaya, State of Mexico (Figure 1), which belongs to the MZTV (SCIGA-INEGI, 2018), is located between 19° 06'57.56 and 19° 13'15.92" North and 99° 44'04.97 and 99° 31'49.26" West (IGECEM, 2013). The Municipality has an area of 103 km² equivalent to the 0.45% of the area of the State of Mexico (INEGI, 2018; INEGI, 2020). Calimaya has two climate types according to the Köppen classification (INEGI, 2008): C (w2) (w), temperate sub humid with 55.86% of the territorial surface, and C (E) (w2) (w), semi-cold sub humid with 44.14%.

The predominant soil types in Calimaya are, respectively, Haplic Phaeozem (54.67%) Andosol (Humic, 22.94%; Molic, 3.58%; Ochric 1.47%), Eutric Regosol (11.04 %), Eutric Cambisol (7.72%), Eutric Fluvisol (1.25%), Pellic Vertisol (0.24%), and Lithosol (0.09%) (INEGI, 1976a, b, c, d). The croplands in 2019 corresponds to a total area of 66.1799 km² (LOUREIRO et al., 2023). Calimaya is in the “Río Lerma 1” hydrographic watershed, which has a territorial extension of 2058.31 km² with an average annual volume of natural runoff of 224348 hm³, annual volume of surface water extraction of 72880 hm³, average annual availability deficit of 0.193 hm³ (CONAGUA, 2018b). Calimaya is located on the Toluca Valley Aquifer that covers a total area of approximately 2811.16 km², recharge of 336.80 hm³ and extraction 422.40 hm³, and overexploited (CONAGUA, 2018a).

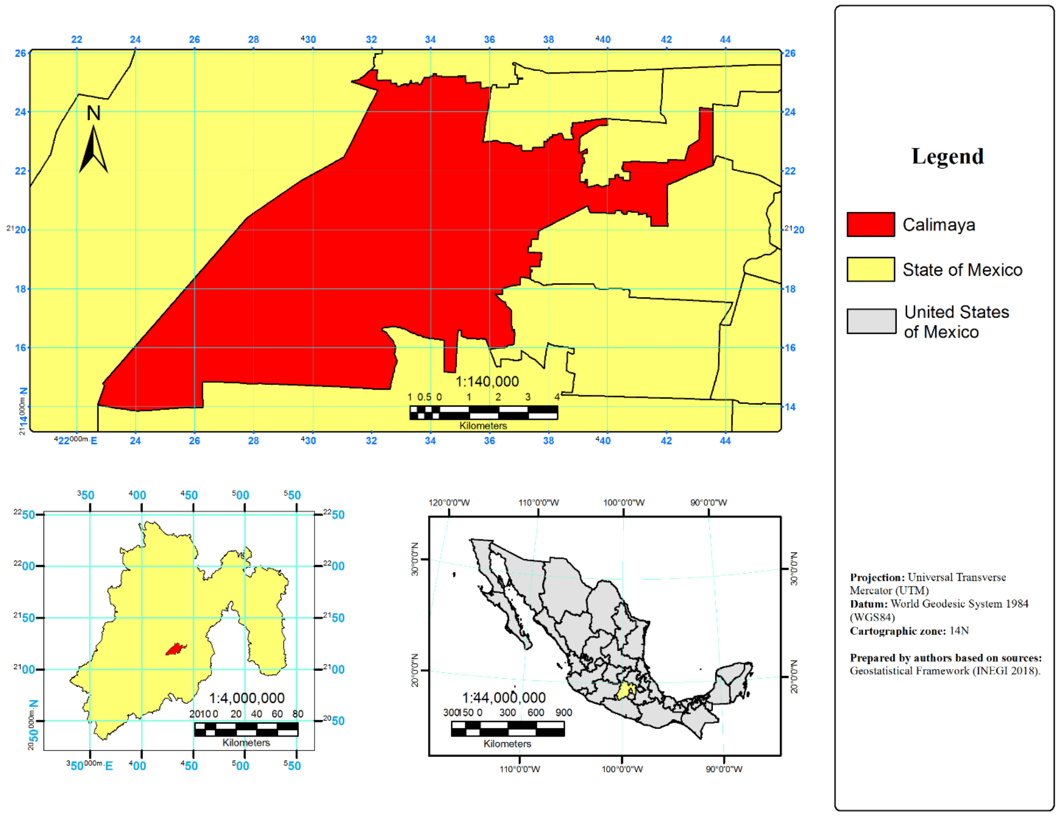

Figure 1 – Municipality of Calimaya, State of Mexico.

2.2. Field work

A total of seven field trips were made from August to November 2019 to the agricultural and forestry areas of Calimaya. Prior to this field work, satellite images from Google Earth Pro (2019) of the Google Maps application (version 10.23.5) on Android system, were analysed to identify and georeferenced relevant agricultural and environmental areas, and access points in the territory.

During field work firstly the collection of data was carried out by accessing, identifying, and characterizing the crops nearby to the available highways or roads. Secondly, inside each cropping area, GPS extreme points and the track were taken designing polygonal shapes. Thirdly, within the polygons of the crops, the EAC were searched and collected in polypropylene bags and the presence of solid waste was reported. The following personal protective equipment (PPE) were used: neoprene chemical handling gloves, nuisance disposable dust mask (100% polyester, 100% metallic nose piece and 100% elastane elastic tape) for short-term applications, transparent polypropylene bags without closure (60 x 90 cm) for the collection of EAC. A garden hoe (handle 137 cm) for pulling containers from difficult access places were acquired and support material for data collection in the field. In this investigation, the term "solid waste" was used as a general definition of different materials: recyclable material like paper, glass, bottles, cans, metals, certain plastics and biodegradable waste like food-cum-kitchen waste, green waste, and paper. The construction of the inventory of variables related to EAC and solid waste is based on different background studies (KNOWLES, 1998; LARA F. et al., 2000; BRIASSOULIS et al., 2013; LEYVA MORALES et al., 2014; DELGADO MENDOZA, 2016; ERAS et al., 2017; BERNARDINO HERNÁNDEZ et al., 2019; LAGARDA-LEYVA et al., 2019; LOUREIRO et al., 2021).

Photographs were taken to characterize the crops, solid waste and EAC as evidence of field work with a Sony Alpha SLT-A55 digital camera. A stonemason's square rule (41 x 61 cm) was used to describe and show the EAC dimensions. Lastly, the completion of the sweep of each of the cropping areas was performed as follows: first the names of the agrochemicals (registered trademarks) and their quantity alongside the number of photographs taken and GPS points marked were reported; second, the polypropylene bags were labelled by their respective collection polygons.

2.3. Georeferencing

The 119 GPS fieldwork observations from GPS points were processed in ArcMap v.10.4 by digitizing a centroid per polygon to represent agricultural and forest cropping areas along with other relevant environmental observations. The centroids were determined by using the Sentinel 2 Multispectral Instrument (MSI) satellite imagery with a resolution of 10 m (13 spectral bands covering the spectral range 0.44–2.19 μm) and processed with a real colour combination of bands. The observations were reviewed based on their environmental importance, cropping diversity, EAC found within agricultural and forest cropping areas or streams and the disposal of solid waste in the croplands and in riverbeds. In order to verify and review the observations in ArcMap, vector files regarding digitized rivers from topographic maps scale 1: 50 000 (INEGI, 2013a, b, c; 2014), edaphic maps scale 1: 50 000 (INEGI, 1976a, b, c, d), and vector files from the geostatistical framework were used from the National Institute of Geography and Statistics (INEGI for its acronym in Spanish) (2018); as the official free access information available. The limits of the Nevado de Toluca Flora and Fauna Protection Area (APFFNT for its acronym in Spanish) were obtained from vector files from the National Commission of Protected Natural Areas (CONANP for its acronym in Spanish) (2020).

2.4. Internet data collection

The internet data collection was carried out in the Google search engine (August-November 2019) where it was sought to confirm the information available of the registered trademarks of the agrochemicals reported in the fieldwork logbook. In addition to the websites and company names of the manufacturers or traders of agrochemicals, the digital documents related to the registered trademarks that were searched were: safety data sheet, technical fact sheet and agrochemical label.

2.5. Data analysis and statistics

The variables analysed in this study were obtained by direct observation in the field and confirmation of information on the internet (safety data sheet, technical fact sheet and agrochemical label): types of agricultural or forest crops, agrochemical types, container type, commercial formulation, manufacturing, and trade companies. In addition, the final disposal of solid waste and the presence of burning solid waste in cropping areas have also been analysed. A simple meta-analysis was used to analyse the absolute and relative frequency of the data identified in the fieldwork or the internet. The analysis of all data was processed and calculated on Excel (Microsoft Office, 2019).

3. RESULTS AND DISCUSSION

Twelve crops have been identified in the sampled cropping areas in Calimaya (Tables 1 and 2; Figure 2). The most frequent agricultural crops in this study were: maize, potato, oats and faba bean. Only one intercrop with maize and barley (*Hordeum vulgare* L.) was identified (Tables 1 and 2, Figure 2). Three cropping areas were identified with lettuce (*Lactuca sativa* L.), two areas with onion (*Allium cepa* L.), and other crops with a single area, cempasuchil (*Tagetes erecta* L.), coriander (*Coriandrum sativum* L.) and peas (*Pisum sativum* L.). There were two areas of forest crops, one with oyamel (*Abies religiosa* (Kunth) Schltdl. & Cham.), and another with white cedar (*Cupressus lusitanica* Mill.). In addition to the predominant species, bean (*Phaseolus vulgaris* L.) and gladiolus (*Gladiolus grandiflorus* Hort.) were observed near the sampled areas but were not sampled due to access issues. The available agricultural statistical information confirms such diversity and importance of these crops in Calimaya and the region (SCIGA-INEGI, 2018; GACETA MUNICIPAL DE CALIMAYA, 2019; SIAP, 2019). According to the statistical yearbook of Agri-Food and Fisheries Information Service (SIAP for its acronym in Spanish) (2019) in the agricultural year of 2019 (spring-summer, autumn-winter), the crops of grain maize, forage oat, faba beans and potato in the Municipality, corresponded to a total of 4936.98 ha of planted and harvested area. Therefore, the field work for the collection and identification of EAC was carried out between August and November (2019), a representative period of the end of the cycle of the predominant crops. It is important to highlight that in 2019 the cropland use covered more than 60% of the territory of Calimaya (LOUREIRO et al., 2023). The adjoining boundaries of the cropland with other land uses (LOUREIRO et al., 2023) indicates that the negative impacts of anthropic activities in the cropping areas is affecting the entire territory. In this field work a total of 534 EAC were collected from which 352 were from pesticides, 127 from other agrochemicals and 52 were not identified. From these EAC, 126 registered trademarks of pesticides and 60 of the other agrochemicals were identified (Tables 1-6).

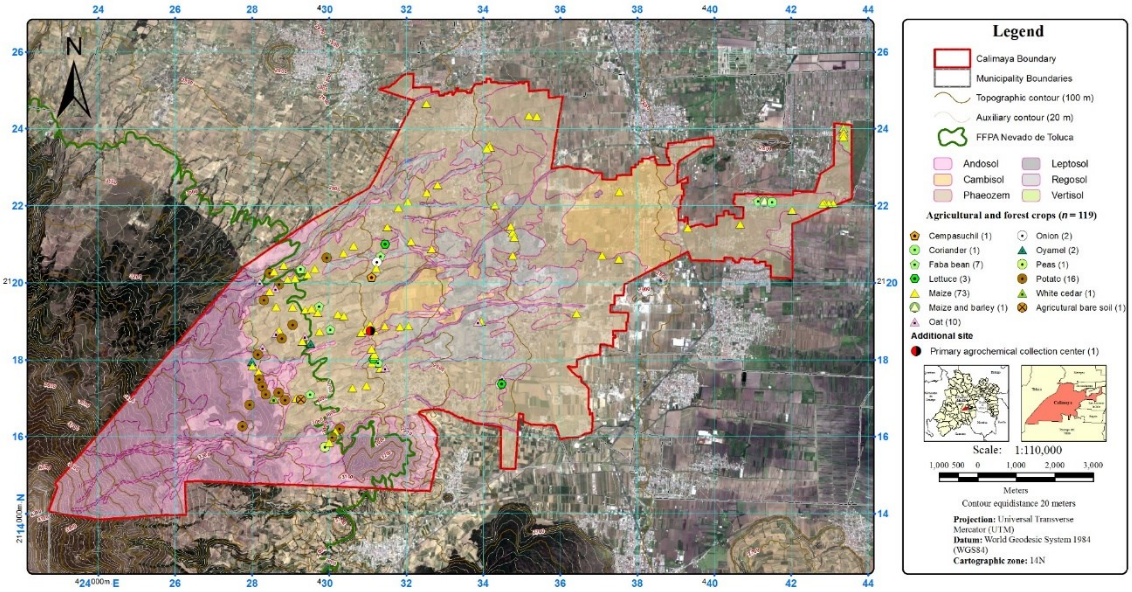

Figure 2 – Agriculture and forest cropping areas in the Municipality of Calimaya, State of Mexico. Prepared by authors based on sources: Topographic maps E14A47, E14A38, E14A47, E14A48, series III, scale 1:50,000 vector files (INEGI, 2013a, b, c; INEGI, 2014); Soil maps E14A47, E14A38, E14A47, E14A48, scale 1:50,000 vector files (INEGI, 1976 a, b, c, d); Geostatistical framework vector files (INEGI, 2018); Natural Protected Areas vector files (CONANP, 2020); Sentinel 2 Multispectral Instrument (MSI) satellite imagery with a resolution of 10 m (13 spectral bands covering the spectral range 0.44–2.19 μm) and processed with a real colour combination of bands; Fieldwork sampling in the agricultural period of August to November, 2019.

The predominant crops in the MZTV pre-existed the boundary delimitation of the APFFNT (REGIL-GARCÍA & FRANCO-MAASS, 2009; CONANP, 2013; SEMARNAT, 2016). For this reason, it is possible to verify cropping areas, mainly potato, within the limits of the APFNNT in Calimaya (Figure 2). Approximately 26.52% of cropland use in Calimaya are within the boundaries of the APFFNT (LOUREIRO, 2023). According to Regil-García & Franco-Maass (2009), the territorial aptitude of agricultural species such as potatoes, oats, maize and faba beans cultivated in the APFFNT is low and never higher than forest aptitude.

The soils in Calimaya (Figure 2) are of volcanic origin and are physically unstable, largely developed on pumice, which are poorly consolidated materials, and when the subsoil layers are exposed, they are easy to be carried away by torrential currents (ESPINOSA RODRÍGUEZ, 2003, 2021; SEMARNAT, 2016). Haplic Phaeozem, also suitable for forestry, is currently occupied by rainfed agriculture (Figure 2). Andosols naturally covered by coniferous forests are occupied by potato crops (Figure 2). Crop production accentuates the development of extensive gully systems, as well as subterranean processes of soil subsidence, which affects agriculture and populations settled in flat areas (ESPINOSA RODRÍGUEZ, 2003, 2021; SEMARNAT, 2016).

The West and Southwest regions (Figure 3) were the ones with the highest number of sites with solid waste and EAC within the agricultural and forestry areas, mainly due to the higher density of sample observations. Furthermore, in this specific region it was quite common to find evidence of burned solid waste together with EAC, mainly in cropping areas close Zaragoza de Guadalupe. However, even with a lower number of sample observations, the presence of solid waste, EAC and burned solid waste in the Eastern and Northern regions of Calimaya was also evidenced.

Table 1 – Solid waste and empty agrochemical containers identified in agricultural and forest cropping areas of the Municipality of Calimaya, State of Mexico (August-November 2019).

Status	**Solid waste**[1]						**Burning solid waste**				Agrochemical containers (general)[2]			
	AF			RF (%)			AF	RF (%)			AF	RF (%)		
Absence	12			10.08			99	83.19			27	22.69		
Presence	107			89.92			20	16.81			92	77.31		
Sample size (*n*)	119			100.00			119	100.00			119	100.00		
Agricultural or forest crop	AF	RF (%)	Absence	RF (%)	Presence	RF (%)	Absence	RF (%)	Presence	RF (%)	Absence	RF (%)	Presence	RF (%)
Cempasuchil	1	0.84	NA	NA	1	100.00	1	100.00	NA	NA	1	100.00	NA	NA
Coriander	1	0.84	NA	NA	1	100.00	1	100.00	NA	NA	NA	NA	1	50.00
Faba bean	7	5.88	3	42.86	4	57.14	6	85.71	1	14.29	4	57.14	3	42.86
Lettuce	3	2.52	1	33.33	2	66.67	2	66.67	1	33.33	2	66.67	1	33.33
Maize	73	61.34	1	1.37	72	98.63	59	80.82	14	19.18	8	10.96	65	89.04
Maize and barley	1	0.84	NA	NA	1	100.00	NA	NA	1	100.00	1	100	NA	NA
Oat	10	8.40	2	20.00	8	80.00	9	90.00	1	10.00	4	40.00	6	60.00
Onion	2	1.68	1	50.00	1	50.00	2	100.00	NA	NA	1	50.00	1	50.00
Oyamel	2	1.68	1	50.00	1	50.00	2	100.00	NA	NA	1	50.00	1	50.00
Peas	1	0.84	NA	NA	1	100.00	1	100.00	NA	NA	NA	NA	1	50.00
Potato	16	13.45	3	18.75	13	81.25	14	87.50	2	12.50	4	25.00	12	75.00
White cedar	1	0.84	NA	NA	1	100.00	1	100.00	NA	NA	1	100.00	NA	NA
Unidentified pre-existing crop	1	0.84	NA	NA	1	100.00	1	100.00	NA	NA	NA	NA	1	100.00
n	119	100.00	12	10.08	107	89.92	99	83.19	20	16.81	27	22.69	92	77.31
Crop (AF ≤ 3)	13	10.92	3	23.08	10	76.92	11	84.62	2	15.38	7	53.85	6	46.15
Crop (AF > 3)	106	89.08	9	8.49	97	91.51	88	83.02	18	16.98	20	18.87	86	81.13

[1]Solid waste were observed: plastic, glass, metal, and paper. [2]Total agrochemical containers collected in the field work: 534 (355 pesticides containers; 127 containers of other agrochemicals; 52 containers of unidentified agrochemicals). Absolute frequency (AF). Relative frequency (RF). Not applicable (NA).

Table 2 – General classification of empty agrochemicals containers identified in agricultural and forest cropping areas of the Municipality of Calimaya, State of Mexico (August-November 2019).

Status	**Pesticide containers[1]**						**Containers of other agrochemicals[2]**				Containers of unidentified agrochemicals[3]			
	AF	RF (%)					AF	RF (%)			AF	RF (%)		
Absence	42	35.29					74	62.18			97	81.51		
Presence	77	64.71					45	37.82			22	18.49		
Sample size (*n*)	119	100.00					119	100.00			119	100.00		
Agricultural or forest crop	AF	RF (%)	Absence	RF (%)	Presence	RF (%)	Absence	RF (%)	Presence	RF (%)	Absence	RF (%)	Presence	RF (%)
Cempasuchil	1	0.84	1	100.00	NA	NA	1	100.00	NA	NA	1	100.00	NA	NA
Coriander	1	0.84	NA	NA	1	100.00	NA	NA	1	100.00	1	100.00	NA	NA
Faba bean	7	5.88	4	57.14	3	42.86	5	71.43	2	28.57	7	100.00	NA	NA
Lettuce	3	2.52	2	66.67	1	33.33	2	66.67	1	33.33	3	100.00	NA	NA
Maize	73	61.34	16	21.92	57	78.08	45	61.64	28	38.36	56	76.71	17	23.29
Maize and barley	1	0.84	1	100	NA	NA	1	100	NA	NA	1	100	NA	NA
Oat	10	8.40	5	50.00	5	50.00	6	60.00	4	40.00	7	70.00	3	30.00
Onion	2	1.68	1	50.00	1	50.00	2	100.00	NA	NA	2	100.00	NA	NA
Oyamel	2	1.68	1	50.00	1	50.00	1	50.00	1	50.00	2	100.00	NA	NA
Peas	1	0.84	1	100.00	NA	NA	NA	NA	1	100.00	1	100.00	NA	NA
Potato	16	13.45	9	56.25	7	43.75	9	56.25	7	43.75	14	87.50	2	12.50
White cedar	1	0.84	1	100.00	NA	NA	1	100.00	NA	NA	1	100.00	NA	NA
Unidentified pre-existing crop	1	0.84	NA	NA	1	100.00	1	100.00	NA	NA	1	100.00	NA	NA
n	119	100.00	42	35.29	77	64.71	74	62.18	45	37.82	97	81.51	22	18.49
Crop (AF ≤ 3)	13	10.92	8	61.54	5	38.46	9	69.23	4	30.77	13	100.00	NA	NA
Crop (AF > 3)	106	89.08	34	32.08	72	67.92	65	61.32	41	38.68	84	79.25	22	20.75

[1]Registered trademark of pesticide: 126; Pesticides type: bactericide, bactericide and phytoplasmicide, bactericide and fungicide, fungicide, herbicide, insecticide, insecticide and acaricide, insecticide and nematicide; Containers type: plastic bags and bottles. [2]Registered trademark of other agrochemicals: 60; Agrochemicals type: amino acids, biostimulant, pH regulating adjuvant, surfactant adjuvant, fertilizers (inorganic, inorganic foliar, organomineral foliar, organomineral, organomineral with amino acids, chelated organomineral), abiotic inducer of resistance against plant pathogens, vegetative growth regulator; Containers type: plastic bags, bottles, sachets and sacks, and cardboard and tin can. [3]Containers type: Plastic bottles. Absolute frequency (AF). Relative frequency (RF). Not applicable (NA).

Table 3 – Types of empty agrochemical containers collected in agricultural and forest cropping areas in the Municipality of Calimaya, State of Mexico (August-November 2019).

Agrochemical type	Container type	AF	RF (%)
Pesticides[1]	Plastic bag	41	32.54
	Plastic bottle	85	67.46
	Registered trademark	126	100.00
Other agrochemicals[2]	Cardboard and tin can	1	1.67
	Plastic bag	6	10.00
	Plastic bottle	41	68.33
	Plastic sachet	1	1.67
	Plastic sack	11	18.33
	Registered trademark	60	100.00

[1]Types: Bactericide, bactericide and phytoplasmicide, bactericide and fungicide, fungicide, herbicide, insecticide, insecticide and acaricide, insecticide and nematicide. [2]Types: amino acids, biostimulant, pH regulating adjuvant, surfactant adjuvant, fertilizers (inorganic, inorganic foliar, organomineral foliar, organomineral, organomineral with amino acids, chelated organomineral), abiotic inducer of resistance against plant pathogens, vegetative growth regulator. Absolute frequency (AF). Relative frequency (RF).

Table 4 – Types of agrochemicals identified through the collection of empty containers in agricultural and forest cropping areas in the Municipality of Calimaya, State of Mexico (August-November 2019).

Agrochemical type	Pesticides[1]		Other agrochemicals[2]	
	AF	RF (%)	AF	RF (%)
Amino acids	NA	NA	2	3.33
Bactericide	3	2.38	NA	NA
Bactericide and phytoplasmicide	2	1.59	NA	NA
Bactericide and fungicide	1	0.79	NA	NA
Biostimulant	NA	NA	2	3.33
pH regulating adjuvant	NA	NA	3	5.00
Surfactant adjuvant	NA	NA	4	6.67
Inorganic foliar fertilizer	NA	NA	3	5.00
Organomineral foliar fertilizer	NA	NA	4	6.67
Inorganic fertilizer	NA	NA	17	28.33
Organomineral fertilizer	NA	NA	4	6.67
Organomineral fertilizer with amino acids	NA	NA	8	13.33
Chelated organomineral fertilizer	NA	NA	4	6.67
Fungicide	41	32.54	NA	NA
Herbicide	31	24.60	NA	NA
Abiotic inducer of resistance against plant pathogens	NA	NA	1	1.67
Insecticide	27	21.43	NA	NA
Insecticide and acaricide	18	14.29	NA	NA
Insecticide and nematicide	3	2.38	NA	NA
Vegetative growth regulator	NA	NA	8	13.33
Registered trademark	126	100.00	60	100.00

[1]Containers type: plastic bag and bottle. [2]Containers type: plastic bag, bottle, sachet, and sack; cardboard and tin can. Absolute frequency (AF). Relative frequency (RF). Not applicable (NA)

Table 5 – Types of commercial formulation of agrochemicals identified through the collection of empty containers in agricultural and forest cropping areas in the Municipality of Calimaya, State of Mexico (August-November 2019).

Type of commercial formulation	Pesticides[1]		Other agrochemicals[2]	
	AF	RF (%)	AF	RF (%)
Aqueous concentrated solution	35	27.78	12	20.00
Aqueous suspension	NA	NA	2	3.33
Concentrated suspension	13	10.32	2	3.33
Concentrated suspension for seed treatment	1	0.79	NA	NA
Emulsifiable concentrate	26	20.63	NA	NA
Granulated solid	1	0.79	12	20.00
Liquid	NA	NA	22	36.67
Miscible liquid	7	5.56	1	1.67
Oil dispersion	3	2.38	NA	NA
Oil-in-water emulsion	1	0.79	NA	NA
Soluble granules	2	1.59	NA	NA
Soluble powder	4	3.17	3	5.00
Soluble solid	NA	NA	2	3.33
Water dispersible granules	8	6.35	NA	NA
Water-soluble crystals	NA	NA	3	5.00
Wettable powder	25	19.84	1	1.67
Registered trademark	126	100.00	60	100.00

[1]Types: Bactericide, bactericide and phytoplasmicide, bactericide and fungicide, fungicide, herbicide, insecticide, insecticide and acaricide, insecticide and nematicide. [2]Types: amino acids, biostimulant, pH regulating adjuvant, surfactant adjuvant, fertilizers (inorganic, inorganic foliar, organomineral foliar, organomineral, organomineral with amino acids, chelated organomineral), abiotic inducer of resistance against plant pathogens, vegetative growth regulator. Absolute frequency (AF). Relative frequency (RF). Not applicable (NA).

Table 6 – Manufacturing and trade companies of agrochemicals identified through the collection of empty containers in agricultural and forest cropping areas in the Municipality of Calimaya, State of Mexico (August-November 2019) – Part 1.

Manufacturing and trade companies	Pesticides[1]		Other agrochemicals[2]	
	AF	RF (%)	AF	RF (%)
Ag Crop, S.A. de C.V.	NA	NA	1.00	1.67
Agricam, S.A. De C.V.	2.00	1.59	NA	NA
AgriCenter, S.A. de C.V.[3]	NA	NA	2.00	3.33
Agrícola Innovación, S.A. de C.V.[3]	NA	NA	1.00	1.67
Agricultura Nacional de Jalisco, S.A de C.V.[3]	1.00	0.79	NA	NA
Agricultura Nacional, S.A. de C.V.[3]	9.00	7.14	NA	NA
Agroenzymas Retenum, S.A.P.I de C.V.	NA	NA	4.00	6.67
Agrogen, S.A. de C.V.	NA	NA	2.00	3.33
Agroquímicos Rivas, S.A. de C.V.	1.00	0.79	NA	NA
Agroquímicos Versa, S.A. de C.V.[3]	12.00	9.52	NA	NA
Agroscience Biochemical, S.A. de C.V.	NA	NA	1.00	1.67
Albion Advanced Nutrition, S. de R. L. de C.V.	NA	NA	1.00	1.67
Allister de México, S.A. de C.V.[3]	NA	NA	2.00	3.33
AMVAC México, S. de R.L. de C.V.[3]	1.00	0.79	1.00	1.67
Arvensis, S.A. de C.V.	NA	NA	1.00	1.67
Arysta Lifescience México, S.A de C.V.	14.00	11.11	6.00	10.00
BASF Mexicana, S.A. de C.V.[3]	3.00	2.38	1.00	1.67
Bayer de México, S.A. de C.V.[3]	8.00	6.35	NA	NA
Biokrone, S.A. de C.V.	NA	NA	1.00	1.67
BioStar México, S. De R.L. de C.V.	NA	NA	2.00	3.33
Registered trademark	126	100.00	60	100.00

Table 6 – Manufacturing and trade companies of agrochemicals identified through the collection of empty containers in agricultural and forest cropping areas in the Municipality of Calimaya, State of Mexico (August-November 2019) – Part 2.

Manufacturing and trade companies	Pesticides[1]		Other agrochemicals[2]	
	AF	RF (%)	AF	RF (%)
Cheminova Agro de México, S.A.	1.00	0.79	NA	NA
Compo Expert México, S.A de C.V.	NA	NA	1.00	1.67
Cosmocel, S.A.	NA	NA	2.00	3.33
Cuprosa, S.A. de C.V.[3]	1.00	0.79	NA	NA
Dow Agrosciences de México, S.A. de C.V.	4.00	3.17	NA	NA
DuPont Mexicana, S. De R.L. de C.V.	3.00	2.38	NA	NA
Eurochem Agro México, S.A. de C.V.	NA	NA	1.00	1.67
Farmacia Agroquímica de México, S.A. de C.V.	NA	NA	4.00	6.67
Fertigro Agroproducts, S.A. de C.V.	NA	NA	4.00	6.67
Fertilizantes y Productos Agroquímicos, S.A de C.V.	NA	NA	1.00	1.67
FMC Agroquímica de México, S. de R.L. de C.V.[3]	8.00	6.35	1.00	1.67
Germinare, S.A. de C.V.	NA	NA	1.00	1.67
Gowan Mexicana, S.A.P.I. de C.V.[3]	2.00	1.59	1.00	1.67
Helm de México, S. A.[3]	4.00	3.17	NA	NA
Ingeniería Industrial, S.A. de C.V.[3]	6.00	4.76	1.00	1.67
Internacional Química de Cobre, S.A. de C.V.[3]	2.00	1.59	NA	NA
ISQUISA, S.A. de C.V.	NA	NA	1.00	1.67
Koor Intercomercial, S.A.[3]	1.00	0.79	NA	NA
Mezclas y Fertilizantes, S.A. de C.V.[3]	NA	NA	3.00	5.00
Monsanto Comercial, S. de R.L. de C.V.	2.00	1.59	NA	NA
Nufarm Grupo México, S. de R.L. de C.V.[3]	1.00	0.79	NA	NA
Palau BioQuim, S.A. de C.V.	NA	NA	1.00	1.67
Promotora Técnica Industrial, S.A de C.V.	4.00	3.17	NA	NA
Química Internacional Aplicada, S.A. de C.V.	NA	NA	2.00	3.33
Química Lucava, S.A. de C.V.[3]	5.00	3.97	NA	NA
Química Sagal, S.A. de C.V.	1.00	0.79	NA	NA
Rainbow Agro Sciences, S.A. de C.V.[3]	1.00	0.79	NA	NA
Shokubutsu Agro, S.A. de C.V.	NA	NA	1.00	1.67
Síntesis y Formulaciones de Alta Tecnología, S.A de C.V.[3]	6.00	4.76	NA	NA
Stoller México, S.A. de C.V.[3]	NA	NA	1.00	1.67
Summit Agro México, S.A. de C.V.[3]	3.00	2.38	NA	NA
Syngenta Agro, S.A de C.V.[3]	10.00	7.94	NA	NA
Tecnología Tecnomet, S.A. de C.V.	NA	NA	1.00	1.67
UPL Agro, S.A. de C.V.[3]	7.00	5.56	NA	NA
Valent de México, S.A. de C.V.[3]	NA	NA	1.00	1.67
Velsimex, S.A. de C.V.CLP[3]	2.00	1.59	NA	NA
Yara México, S.A. de C.V.	NA	NA	6.00	10.00
Zoetis México, S. de R.L. de C.V.[4]	1.00	0.79	NA	NA
Registered trademark	**126**	**100.00**	**60**	**100.00**

[1]Types: bactericide, bactericide and phytoplasmicide, bactericide and fungicide, fungicide, herbicide, insecticide, insecticide and acaricide, insecticide and nematicide. [2]Types: amino acids, biostimulant, pH regulating adjuvant, surfactant adjuvant, fertilizers (inorganic, inorganic foliar, organomineral foliar, organomineral, organomineral with amino acids, chelated organomineral), abiotic inducer of resistance against plant pathogens, vegetative growth regulator. [3]Agrochemical containers production companies that do not participate in the Campo Limpio Program (AMOCALI, 2023). [4]Manufacturer Company of a veterinary product. Absolute frequency (AF). Relative frequency (RF). Not applicable (NA).

When there is no adequate agrochemical management plan, which includes their final disposal (LARA F. et al., 2000; LAGARDA-LEYVA et al., 2019), the high consumption of these products by intensive agriculture can generate negative environmental impacts, mainly on water bodies (ARELLANO-AGUILAR et al., 2017). The incorrect management of domestic solid waste in a Municipality (VALENCIA GARCÍA et al., 2016) was taken as an indicator that agricultural solid waste, such as EAC, will not be properly managed. The 87.35% of garbage dumps in Mexico are opencast and 12.65% are landfills (INEGI, 2010). This situation does not comply with the Official Mexican Standards (SEMARNAT, 2003, 2013). In this field research the presence of solid waste in the water bodies (intermittent rivers) near the 48 (36.92 %) agricultural and forest cropping areas were observed (Figure 3). All flows and channels were denominated as rivers, regardless of their length or width, based on how they are officially described (INEGI, 2013a, b, c; 2014). Different types of solid waste outside the EAC were not classified, still, it can be said that in addition to the incorrect disposal of EAC in the Calimaya croplands, solid waste of domestic origin was abundant (Figure 4a, b, and d). Domestic solid waste and EAC were commonly found in river channels close to maize cropping areas (Figures 3 and 5a). The vertical gradient of Calimaya corresponds to 2560 and 4640 masl (Figures 2 and 3). Geomorphology can favour environmental pollution when there is no efficient management of solid waste and its final disposal (LOPEZ STEINMETZ et al., 2020). Agrochemical residues from areas of intensive agriculture can be transported by surface water drains and rivers (ARELLANO-AGUILAR et al., 2017), ultimately can reach the lower parts of the relief and to groundwater (DUFFNER et al., 2012). Calimaya is in the "Río Lerma 1" hydrographic watershed (CONAGUA, 2018b) in a recharge zone of the over exploited Toluca Valley Aquifer (CONAGUA, 2018a). In addition to the collection and channelling of drinking water from runoff of the northern slope of the Nevado de Toluca, water is also extracted from the aquifer through wells, for agricultural, industrial, and public-urban sectors and services usage (GACETA MUNICIPAL DE CALIMAYA, 2016, 2019). There are deep wells located in the communities of San Marcos de la Cruz, Santa María Nativitas, San Lorenzo Cuauhtenco, San Andrés Ocotlán, La Concepción Coatipac and San Bartolito Tlaltelolco (GACETA MUNICIPAL DE CALIMAYA, 2019), showed in Figure 3. The intense rainfalls and intensive agriculture associated with the susceptibility of the soil types of Calimaya (Figure 2) to hydric erosion can favour processes of pollution and contamination, mainly in the superficial and subsurface water bodies (Figure 3), such as the existing wells in the territory (GACETA MUNICIPAL DE CALIMAYA, 2016, 2019).

Solid waste, mainly from domestic origin, were observed in 34 (69.39%) of these natural water bodies, including the only lake in the municipality known as San Antonio la Isla (Figure 3). Figure 4a shows the collection of agrochemicals in a river channel located on the edge of a maize cropping area. In addition to the problem of open-cast solid waste deposits, in this study it was possible to verify that abandoned mines are used as urban and agricultural waste deposit (Figure 4d). Burned solid waste was also observed in 16.81% of these agricultural and forest cropping areas (Table 1; Figure 3). Figure 5d shows burned EAC and burned solid waste near a potato cropping area. In Calimaya, farmers use EAC to mark farming cropping areas in which they already applied agrochemicals, mainly in maize cropping areas (Figure 5c). According to the Food and Agriculture Organization of the United Nations (FAO) (2020), "many pesticide suppliers and national authorities recommend the burying or burning of waste pesticides and empty containers". However, buried chemicals are pollutants in soil and groundwater, while burning pesticide containers release highly toxic gases that can harm farmers' health and the surrounding population (FAO, 2020).

The National Institute of Ecology (INE for its acronym in Spanish) (1993) of Mexico stated that the disposal of containers in the field or in water bodies was not adequate, however, they still recommended the burning of plastic agrochemical containers (when consumption was in small quantities). According to the General Law for the Prevention and Integral Management of Waste, Article 31, section IX (DOF, 2018), pesticides and their containers that contain remnants are subject to a management plan. Moreover, on Article 67, fraction IX (DOF, 2018) states that is prohibited the incineration of hazardous waste which are made of or contain persistent, bioaccumulable organic compounds and organochlorine pesticides. The abandonment of EAC on the maize cobs (Figure 5c) can expose consumers to intoxication by active substances residues after harvest and commercialization of such produce.

The improper disposal of solid waste and EAC (Tables 1 and 2, Figures 3-5) is a common practice in agriculture in developing countries (VARGAS TREJOS, 2015; VALENCIA GARCÍA et al., 2016; ZAPATA DIOMEDI & NAUGES, 2016; GÓMEZ GONZÁLEZ, 2017; LAGARDA-LEYVA et al., 2019). The main issue regarding this practice is that most of the EAC are attached to the maize cob (Figure 5c). The exposure risk to human health due to incorrect disposal practices of agrochemicals is imminent (ZAPATA DIOMEDI & NAUGES, 2016; FAO, 2020). The inadequate management of agrochemicals by Calimaya farmers may be closely related to the low technological level of the crops, in addition to the lack of technical training for the management of these agricultural supplies. Farmers' behaviour in pesticide waste disposal after use was reported to Bondori et al. (2019) as a critical point for reducing pesticide exposure and environmental contamination.

Overall, there was a predominance of EAC found in maize and potato cropping areas, which represent the 79.79% of the total areas studied (Tables 1 and 2). Less frequent agricultural and forest crops such as cempasuchil, coriander, lettuce, intercropping with maize and barley, onion, oyamel, peas, white cedar and unidentified pre-existing crop showed a lower relative frequency of presence of pesticide and other agrochemicals (Tables 1 and 2; Figure 2). In field work only one primary agrochemical collection centre was found, which is located close to maize cropping areas (Figures 2, 3 and 5c). Plastic is the main material of EAC collected in the cropping areas of Calimaya (Table 3). Plastic waste is an environmental problem that must be solved with the partnership between manufacturing and/or trade companies and farmers (LARA F. et al., 2000; BRIASSOULIS et al., 2013;

DOMÍNGUEZ-RODRÍGUEZ et al., 2015; ERAS et al., 2017; LAGARDA-LEYVA et al., 2019; PICUNO et al., 2020).

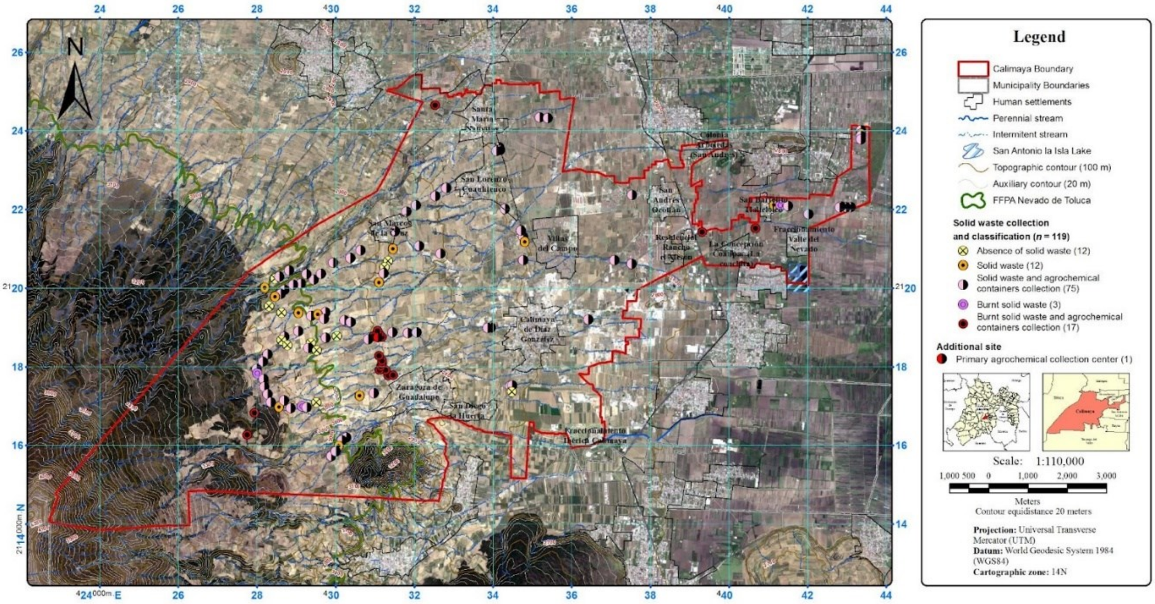

Figure 3 – Solid waste, agrochemical containers disposal and solid waste burn practices in the agriculture and forest cropping areas of Calimaya, State of Mexico. Prepared by authors based on sources: Topographic maps E14A47, E14A38, E14A47, E14A48, series III, scale 1:50,000 vector files (INEGI, 2013a, b, c; INEGI, 2014); Geostatistical framework vector files (INEGI, 2018); Natural Protected Areas vector files (CONANP, 2020); Sentinel 2 Multispectral Instrument (MSI) satellite imagery with a resolution of 10 m (13 spectral bands covering the spectral range 0.44–2.19 μm) and processed with a real colour combination of bands; Fieldwork sampling in the agricultural period of August to November, 2019.

In Mexico, according to the Federal Commission for the Protection against Sanitary Risks (COFEPRIS for its acronym in Spanish) (2020), agrochemicals are classified into two main officially registered categories: pesticides and plant nutrients. However, in the COFEPRIS database other agrochemical types, such as adjuvants are also considered as plant nutrients (COFEPRIS, 2020). For this reason, Tables 2-6 show two categories of these products: pesticides and other agrochemicals. The most frequent types of pesticides found in Calimaya, described according to their respective technical fact sheets (Table 4), were: fungicides, herbicides, insecticides, and double type “insecticide and acaricide”. Among the other agrochemicals, inorganic fertilizers (Table 4), mainly in maize and potato cropping areas (Table 2). Pesticide diversity (Table 4) is directly associated with crop phytotechnical problems (LEYVA MORALES et al. 2014; GUEVARA-HERNÁNDEZ et al. 2015; BERNARDINO HERNÁNDEZ et al. 2019; LOUREIRO et al., 2021). The conventional crop of Cacahuacintle maize (GONZÁLEZ HUERTA et al. 2008) is predominant in the territory of Calimaya (Figure 2). The use of herbicides, insecticides, and fungicides in maize crop is frequent (GUEVARA-HERNÁNDEZ et al. 2015; BERNARDINO HERNÁNDEZ et al. 2019, LOUREIRO et al., 2021), a fact observed in this territory (Figures 2-5, Tables 1-6). Fertilizers are an important class of agricultural supplies in conventional crops of maize (FLORES-SÁNCHEZ et al. 2019) and potato (KOCH et al. 2019). Different EAC classified as plant biostimulants or biofertilizers with mixed formulas were also found (Table 4). Biostimulants and biofertilizers are considered strategic inputs to increase the quality of crop production (DU JARDIN, 2015), therefore, these products were found in Calimaya (Table 4), and thus, they are also potential sources of inorganic and organic waste and residues.

The 16 types of agrochemicals formulation found in Calimaya (Table 5) is highlighted, because of the diversity of commercial agrochemical formulations that implies technical training for the proper use and handling and correct final disposal or reuse (KNOWLES, 1998; BEJARANO GONZÁLEZ, 2017). Aqueous concentrated solution, emulsifiable concentrate, wettable powder, and concentrated suspension were the most frequent pesticide formulations (Table 5). The other agrochemicals identified have the following most frequent formulations: liquid, granulated solid and aqueous concentrated solution (Table 5). Due to the existence of intensive and semi-intensive agriculture in Calimaya (Figure 2-5; Tables 1-6), the quality of water resources must be considered, due to fertilizers and pesticides are an additional source of inorganic and organic residues to the groundwater (SRIVASTAV, 2020).

The agrochemicals which are more water-soluble tend to be more persistent in the environment, specifically agrochemicals with longer half-lives, resulting on a rapid mobility within the environment, accentuated in hillslope relief, and increasing the risk of environmental pollution (DUFFNER et al., 2012). Calimaya has edaphic and hydrographic conditions (Figures 2 and 3) that can favour environmental pollution and contamination derived from the active substances of agrochemicals used and the presence of hazardous solid waste in the agricultural and forest cropping areas (Tables 1 and 2; Figure 3). Loureiro et al. (2021) have described 68 pesticide active substances (PAS) found in the cropping areas of Calimaya. The study has designated a risk index for soil and water contamination and determined that 23.53% of these PAS have a moderate risk, 47.06% low risk and 27.94% very low risk. Only imidacloprid was classified as having a high risk of soil and water contamination (LOUREIRO et al., 2021). However, these risk estimates are based solely on PAS. The incorrect final disposal of the EAC pesticides in the cropping areas and surrounding water bodies verified in the present study indicates that the risk of soil and water contamination is higher than estimated by Loureiro et al. (2021). In addition to this, it has been detected in this Municipality that farmers occupationally exposed (FOE) to PAS already have alterations of the upper respiratory tract (rhinitis, pharyngitis) and conjunctivitis associated with exposure to a mixture of pesticides, mainly Atrazine and 2, 4-D (SÁNCHEZ MENDOZA, 2019). Sánchez Mendoza (2019) have suggested that the increase in oxidative stress in FOE, as an adaptive response of the antioxidant system, are toxic effects that can be attributed to pesticide exposure. That is, both the exposure of the FOE and the monitoring data presented in the current study (Tables 1 and 2), indicate the incorrect handling of said PAS.

According to Picuno et al. (2020), in the context of final disposal, EAC are considered as hazardous waste due to the presence of chemical residues after application. Primary agrochemical collection centres (PACC) are essential to avoid accumulation of solid waste and hazardous substances in the environment (LEYVA MORALES et al., 2014; DELGADO MENDOZA, 2016; GÓMEZ GONZÁLEZ, 2017). However, only one PACC was found in the field work (Figures 2; 3; 4c). The 53.45% of manufacturing and trade companies mentioned in this study (Table 6) are not participating in the Campo Limpio Program. Public and private initiatives should stimulate good agricultural practices, implementing the management of solid agricultural waste in accordance with current national legislation and international recommendations based on scientific research (DOF, 2018; LAGARDA-LEYVA et al., 2019; SEMARNAT, 2020; SENASICA, 2019; AMOCALI, 2023). Despite the incorporation of 46.55% companies into the Campo Limpio Program (Table 6), which implies the existence of a management plan, in this work it was verified the presence of a high diversity of commercial containers from these companies in the cropping areas. Thus, the results of this study (Table 1-6; Figures 2-5) showing an inadequate operation and regulatory oversight in the current management plans (SEMARNAT, 2013; DOF, 2018; SEMARNAT, 2020; SENASICA, 2019; AMOCALI, 2023), and highlighting the importance of environmental education and technical training for farmers. Joint action between local authorities, agricultural inputs companies is essential to promote sustainable agricultural practices.

The evidence of inadequate solid waste management in Calimaya (Figures 2-5; Tables 1-6) highlights the need to implement efficient management plans that reduce or prevent negative impacts on the environment and on the health of the farmers. The environmental monitoring in 2019 (Figures 2-5, Tables 1 and 2), which has as a precedent of the collection of containers in 2014 (DELGADO MENDOZA, 2016), shows that in this time interval there was no positive change in the practice of final disposal of EAC. Furthermore, in the current research it was possible to verify that is extensive the practice of the final disposal of urban solid waste in the agricultural and forest cropping areas (Figure 3), mainly within water bodies (Figures 5a and b) and abandoned mines (Figure 4d). Moreover, studies should focus on estimating the amount of solid waste identified in Calimaya. The municipalities of the MZTV share many similarities in terms of agricultural practices, therefore this research in Calimaya regarding the collection of EAC through field work and with the geographic context, mapped samples (Figures 2 and 3) have regional relevance.

4. CONCLUSIONS

In the agricultural and forest cropping areas of the Municipality of Calimaya, State of Mexico, evidence was found regarding the incorrect solid waste management and EAC disposal, mainly of pesticides and fertilizers, highlighting the practices of abandoning this solid waste in the cropping areas, predominantly in maize and potato areas, as well as the burning of these residues or their abandonment within and near water bodies.

The 534 EAC abandoned in the Calimaya croplands is an indirect indicator of the environmental risk associated with agricultural management, which is directly related to the environmental impacts caused by solid waste and the active substances of agrochemicals on soil and water resources and the human health. Environmental education and technical assistance to farmers are fundamental strategies to reduce the risk of environmental impacts associated with the use of agrochemicals in this Municipality.

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