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eirene Suisse

CENSALUD
CENTRO DE INVESTIGACIÓN Y DESARROLLO EN SALUD
UNIVERSIDAD DE EL SALVADOR

Environmental and Health Risks of Pesticides and Fertilizers used in El Salvador:

Case Study of the Sugarcane Industry in sub-basin El Aguacate of the Paz River

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ASOCIACIÓN UNIDAD ECOLÓGICA SALVADOREÑA, UNES,
Calle Camagüey 6G, Colonia Yumuri, San Salvador,
El Salvador, Central América.

Authors and contributions:

MICHEL WILDI, MSC.	Chemical Risk Assessor and Ecotoxicologist Chapters: 1, 2 ,3 ,4 ,4 ,5 ,5 ,6 ,7 ,8, 9 ,10 ,11 Researcher Eirene Suisse/UNES
MAURICIO VASQUEZ JANDRES, BSB	Hydrobiologist Subchapters: 6.2 and 8.3 Researcher, CENSALUD/UES
NATALIA SANTAMARÍA, BG	Geophysicist Subchapter: 4.3.2 and maps School of Physics, UES
ANDREA PADILLA MORENO, BIGS	Internationalist Subchapter: 5.3.2 and Revisions Specialist in gender and ecofeminism, UNES
GUILLERMO RECINOS PAREDES, BSB	Biologist Subchapter: 4.3.3 Research associate, CENSALUD/UES
GREGORIO RAMÍREZ, BSW	Sociologist Subchapter: 4.3.1 Organization and territorial articulation, UNES
DINA LÓPEZ, PHD	Professor Emerita, Department of Geological Sciences, Ohio University. Counseling, scientific support and research review.

Contacts:

michel.wildi@gmail.com; unescomunicaciones@gmail.com

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Introduction

The latest policy initiative to regulate pesticides in El Salvador (Figure 1) was launched on September 5, 2013. In fact, on that date, Decree 473 was accepted by the Legislative Assembly, stipulating among other things, a list of substances to be banned and the creation of a technical committee to evaluate the health and environmental risk of pesticides. Unfortunately, this idea supported by the formerly President of the Republic Mauricio Funes, never became a reality.

To this date, the last contribution of Salvadoran legislation for pesticide management dates back 15 years and only 57 substances or groups of pesticide substances are regulated in the country by national decrees and international agreements. However, in El Salvador more than $55 million of these products are imported into the country each year. During the 12 months of the year more than 80,000 tons of fertilizers, 3,000 tons of herbicides, 1,200 tons of insecticides, and 138 tons of fungicides (MAG, 2019b) are applied to crops without any control over the conditions under which these products are applied or the hazards they involve to human health and the environment. These data indicate that 1.33 pounds of pesticide are applied each year per inhabitant in El Salvador assuming a population of 6.5 million people (WPR, 2021).

Although the competent authorities exercise no control and the legal framework is deficient, the effects are already being felt in public health and the environment. El Salvador is at the top of the list of Central American countries with the highest rate of chronic kidney disease (47 deaths/100,000 inhabitants per year), including chronic kidney disease (CKD) from unknown sources that affects farmers in coastal areas who grow mainly sugarcane (Hoy et al., 2017). The incidence of acute intoxications corresponds to almost one in every thousand Salvadorans (94.6 intoxications/100,000 inhabitants) (Quinteros & López, 2019). These numbers are probably only the tip of the iceberg, because they do not include all the chronic effects that these products have on the health of users, their families and the general population exposed to contaminated food and water. At the environmental level, El Salvador's main ecological sites (Ramsar sites) of global importance are threatened by the loss of biodiversity in relation of species richness and quantity. In addition, to the already extremely high climatic pressures on ecosystems, there are anthropogenic pressures from the overexploitation of freshwater resources and pesticide contamination of large-scale crops.

Figure 1 El Salvador is located in Central America, between the north and south of the American continent, bordered to the west by Guatemala, to the north by Honduras, to the east by Honduras and Nicaragua in the Gulf of Fonseca and to the south by the Pacific Ocean.

In response to the passivity of competent authorities, and the effects that the use of pesticides bring about on the different ecosystems of the country and human health; the objective of this scientific research, therefore is to re-launch the pesticide risk assessment process by providing some essential, current, and contextualized information in El Salvador on the health and environmental risks. This paper includes sugar production as a case study, because it is mainly present in the study area and is characterized by an extremely intense production that includes high water and pesticide consumption. In addition, statistical studies of the geographic correlation between areas cultivated with different crop types, environmental temperature, and the number of kidney disease patients in El Salvador indicate that sugarcane is the crop most correlated with this disease (Vandervort et al., 2014).

This research was carried out in three main phases, which included a review of the scientific literature and an analysis of existing data, social surveys and finally a preliminary sampling compaign of pesticides and fertilizers in the aquatic system. Therefore, specific questions were addressed at the national and territorial levels. The research questions addressed in this study are the following:

1. What is the National and International legal framework applied in El Salvador regarding to the regulation of the importation and use of pesticides? What deficiencies could be highlighted?

2. What chemicals are sprayed in the sugarcane fields in relation to the production cycle? What are the volumes imported into the country and the identified hazards of each substance to the human health and aquatic and terrestrial ecosystems?

3. How are the people working on these crops and the surrounding communities exposed to these products? What are the other direct and indirect effects of the forms of exposure of these monocultures on these populations?

4. What substances should be monitored in the aquatic system and is there any evidence to suggest there is a significant risk of exposure of the aquatic environment to these products?

5. What recommendations can be made at the regulatory level, at the monitoring level and at the use level of these products to reduce the risks to human health and the aquatic environment?

This research includes 9 chapters covering the legal and regulatory aspects of pesticides (Chapter 1), the total load of pesticides used in El Salvador and the sugarcane production cycle (Chapter 2), the identification of health and environmental hazards of the active ingredients used in sugarcane fields (Chapter 3), the description of the case study (Chapter 4), the characterization of exposure of the communities (Chapter 5) and the environment to pesticides (Chapter 6), and then the assessment of health (Chapter 7) and environmental risks (Chapter 8). Chapter 9 focuses on legal recommendations, risk reduction measures and some alternatives to consider.

1 Regulation of Pesticides in El Salvador

1.1 Introduction

The legal instruments available to the State to regulate the manufacture, import, use and disposal of potentially hazardous and polluting chemical substances are key elements to guarantee the health of its population and protect its environment. The purpose of this chapter is to determine what legal and technical instruments El Salvador has at its disposal and which substances with pesticide effects are currently regulated in the country.

1.2 Methodology

The analysis of the international legal framework is based on the international agreements ratified by El Salvador on chemical substances including pesticides. These include the Basel and Stockholm Conventions and the Montreal Protocol. The pesticide-acting substances regulated in these agreements and the specific conditions that apply to their importation, production and commercialization in the country have been compiled in tabular form.

The analysis of the regulatory instruments applied at the national level is based on the law on control of pesticides, fertilizers, and products for agricultural use (LCP 1973, reforms 1993), Law on Environment (LMA 1998, update 2012) and the plant and animal health law (LSVA 1995, Reforms 2005). A chronological analysis and comparison of the list of internationally and nationally regulated substances was carried out. An analysis of the latest initiatives in national pesticide regulation was also performed.

1.3 Results

1.3.1 International Regulatory Framework

El Salvador ratified the Basel Convention on the control of transboundary movements of hazardous wastes and their disposal on December 13, 1991 (SBC, 2011). This convention is implemented in El Salvador through the

Law on Environment and the Penal Code. Article 59 of the Law on Environment prohibits the introduction of hazardous waste into the national territory, as well as its transit, discharge, or storage (ERS, 2016). The Penal Code establishes penalties of deprivation of liberty for this type of crime, ranging from 6 to 10 years' imprisonment (ERS, 2016). Hazardous waste includes among others *"wastes resulting from the production, preparation and use of biocides and phytopharmaceuticals, including pesticide wastes, and herbicides that do not meet specifications, are expired[1], or are unsuitable for their original intended use"* (citation VIII, A4030, PNUMA, 1992).

El Salvador ratified the Rotterdam Convention on February 24, 2004, for the application of the prior informed procedure for certain hazardous chemicals and pesticides in international trade (SCR, 2017b). The objective of the convention is the protection of human health and the environment from potential harm caused by certain hazardous chemicals traded internationally (SCR, 2010). This convention considers the economic and use conditions of the importing country. Appendix III of the Convention identified a list of 50 chemicals, including 35 pesticides. For each of these substances, the Prior Informed Consent (PIC) procedure was carried out and import restrictions were established per country. The "Rotterdam Convention" column in Table 1 summarizes the pesticides authorized or not authorized for import into El Salvador.

El Salvador signed on July 30, 2001, and ratified on May 27, 2008, seven years later the Stockholm Convention on Persistent Organic Pollutants (POPs). The convention has been in force in El Salvador since August 25, 2008, with the reservation that the country does not recognize the compulsory jurisdiction of the International Court of Justice (UNEP, 2014). The signatory countries of the Stockholm Convention commit to take the necessary measures to restrict, reduce or eliminate the production and use of certain persistent organic pollutants (SSC, 2018).

Appendix A of the Convention specifies the substances to be banned and/or eliminated and Appendix B specifies the substances whose production and use must be restricted. Appendix C contains substances whose emissions from unintentional production must be reduced or eliminated. These appendices list 32 substances and groups of substances, 16 of which have pesticide uses. According to the latest decision in May 2019, dicofol will be added Appendix A (SSC, 2019). The column "Stockholm Convention" in Table 1 lists the pesticides regulated by Appendix A, B, C of the Convention applicable to El Salvador.

Although pesticides banned by the Stockholm Convention have not been imported into Central America since 2000 (Bravo et al., 2011), they have been used in the past and their illegal trade and dumping, as well as their persistence remain a major environmental concern (UNEP, 2002).

The Stockholm and Rotterdam Conventions regulate no less than 43 substances or groups of substances used as pesticides. Table 1 shows the substances with pesticide activity and their regulatory framework. Each substance has its own particularities in terms of regulation of its production and use, including specific exemptions and import requirements. Details are available in the original regulatory documents (SCR, 2017b; SSC, 2019).

Finally, the Montreal Protocol ratified by El Salvador on October 2, 1992, regarding substances that deplete the ozone layer, bans several chlorinated and fluorinated substances. This includes chlorofluorocarbons that can be used for agricultural purposes (ONU 2019).

[1] "Expired" means not used for the period recommended by the manufacturer and may have chemically reacted and converted to other by-products.

Table 1 Summary of pesticides regulated by the Stockholm Convention on Persistent Organic Pollutants (POPs) and the products that can be imported or not into El Salvador under the Rotterdam Convention. Appendix A of the Convention specifies the substances to be banned and / or phased out and Appendix B specifies the substances whose production and use must be restricted. Appendix C contains substances whose emissions from unintended production must be reduced or eliminated

Chemical product	CAS	Use (SCR, 2017a; SSC, 2019)	Stockholm Convention (SSC, 2018)	Rotterdam Convention (SCR, 2017a)
2,4,5-T and its salts and esters	93-76-5	Herbicide	-	It not allowed
Alachlor	15972-60-8	Herbicide	-	It allowed
Aldicarb	116-06-3	Insecticide, nematicide and acaricide	-	Subject to conditions[1]
Aldrin	309-00-2	Insecticide	Appendix A	It not allowed
Alpha hexaclorocyclohexane	319-84-6	Lindane synthesis by-product	Appendix A	-
Azinphos-methyl	86-50-0	Insecticide	-	Subject to conditions[1]
Beta hexachlorocyclohexane	319-85-7	Lindane synthesis by-products	Appendix A	-
Binapacryl	485-31-4	Fungicide and acaricide	-	Subject to conditions[1]
Captafol	2425-06-1	Fungicide	-	It not allowed
Carbofuran	1563-66-2	Acaricide, insecticide and nematicide	-	Subject to conditions[1]
Chlordane	57-74-9	Insecticide	Appendix A	It not allowed
Chlordecone	143-50-0	Insecticide	Appendix A	
Chlordimeform	6164-98-3	Insecticide, acaricide and ovicide	-	It not allowed
Chlorobenzilate	510-15-6	Pesticide (Acaricide)	-	It not allowed
Chlorofluorocarbons	Not Assigned	Pesticides and others	Included in the Montreal Protocol	
Mercury compounds[2]	-	Pesticide	-	It not allowed
Tributyltin compounds	1461-22-9[3]	Pesticide	-	Importation is allowed
DDT	50-29-3	Insecticide	Appendix B	Importation is not allowed
Ethylene dichloride	107-06-2	Non-agricultural pest control biocides	-	Subject to conditions[1]
Dicofol	115-32-2	Acaricide	Appendix A	-
Dieldrin	60-57-1	Insecticide	Appendix A	Importation is not allowed
Dinitro-ortho-cresol (DNOC) and its salts[4]	534-52-1	Exfoliant, herbicide, insecticide, larvicide, ovicide and fungicide	-	Subject to conditions[1]
Dinoseb and its salts and esters	88-85-7	Pesticide, fungicide, herbicide, desiccant, insecticide	-	Importation is not allowed
EDB (ethylene dibromide)	106-93-4	Insecticide, nematicide fumigant	-	Importation is not allowed
Endosulfan and its related isomers	33213-65-9, 115-29-7	Herbicide, insecticide, fungicide, algaecide, disinfectant applications were in agricultural seeds, leather, wood preservation, cooling tower water, ropes, and paper mill systems	Appendix A	Subject to conditions[1]

Chemical product	CAS	Use (SCR, 2017a; SSC, 2019)	Stockholm Convention (SSC, 2018)	Rotterdam Convention (SCR, 2017a)
Endrin	72-20-8	Insecticide, rodenticide	Appendix A	-
Fluoroacetamide	640-19-7	Insecticide, rodenticide	-	Importation is not allowed
Formulations benomyl, carbofuran, thiram[5]	137-26-8, 1563-66-2, 17804-35-2	Extremely hazardous pesticide formulations	-	Subject to conditions[1]
Phosphamidon[6]	13171-21-6	Extremely hazardous pesticide formulations	-	Importation is not allowed
HCH (mixed isomers)	608-73-1	Insecticide	-	Importation is not allowed
Heptachlor	76-44-8	Insecticide	Appendix A	Importation is not allowed
Hexachlorobenzene	118-74-1	Insecticide	Appendix C	Importation is not allowed
Lindane	58-89-9	Insecticide and against ectoparasites	Appendix A	Importation is not allowed
Methamidofos	10265-92-6	Insecticide	-	Subject to conditions[1]
Methylparathion[7]	298-00-0	Extremely hazardous pesticide formulations	-	Subject to conditions[1]
Mirex	2385-85-5	Insecticide and fire retardant	Appendix A	-
Monocrotophos	6923-22-4	Insecticide and acaricide	-	Importation is not allowed
Ethylene oxide	75-21-8	Pesticide	-	Subject to conditions[1]
Parathion	56-38-2	Insecticide, acaricide	-	Importation is not allowed
Pentachlorobenzene	608-93-5	Fungicide, fire retardant	Appendix C	-
Pentachlorophenol and its salts and esters	87-86-5	Herbicide, insecticide, fungicide, algaecide, disinfectant	Appendix A	Importation is not allowed
Toxaphene	8001-35-2	Insecticide, acaricide	Appendix A	Importation is not allowed
Trichlorfon	52-68-6	Insecticide, acaricide	-	Subject to conditions[1]

[1] Permit import subject to certain conditions. [2] Including inorganic mercury compounds, alkyl mercury compounds, and alkoxyalkyl and aryl mercury compounds. [3] CAS: 1983-10-4, 2155-70-6, 24124-25-2, 4342-36-3, 56-35-9, 85409-17-2. [4] Such as ammonium salt, potassium salt and sodium salt. [5] Dry powder formulations containing a combination of benomyl in an amount equal to or greater than 7%, carbofuran in an amount equal to or greater than 10% and thiram in an amount equal to or greater than 15%. [6] Soluble liquid formulations of the substance exceeding 1000 g/l of active ingredient. [7] Emulsifiable concentrates (EC) with 19.5% or more of active ingredient and powders containing 1.5% or more of active ingredient.

1.3.2 National Regulatory Framework

Pesticides are regulated in three national laws, namely Law on the Control of Pesticides, Fertilizers and Products for Agricultural Use (LCP 1973, update 1993), Law on Environment (LMA 1998, update 2012) and Law on Plant and Animal Health (LSVA 1995, update 2005).

According to paragraph (c) of Article 50 on the prevention and control of soil contamination of the LMA, the Ministerio de Medio Ambiente y Recursos Naturales (Ministry of Environment and Natural Resources (MARN) promotes "integrated pest management and the use of natural fertilizers, fungicides and pesticides in agricultural activity, which maintain the balance of ecosystems, in order to achieve the gradual replacement of agrochemicals with bioecological natural products"(Art. 50, LMA, 2012). This article has a final objective to replace all agrochemicals with agroecological products. Article 50 specifies that MARN must ensure that the chemicals used have minimal impact on the ecosystem. In addition, the LMA also specifies that a special law will specify the agrochemicals whose use is prohibited (LMA, 2012).

The LSVA specifies the measures to be taken for the protection of plant and animal health. Article 1 stipulates more specifically, that actions developed by the Ministerio de Agricultura y Ganadería (Ministry of Agriculture and Livestock) (MAG) must be in line with the protection of the environment and human health (LSVA, 2005). This law specifies that the MAG is responsible for coordinating with other actors in integrated pest management, in other words, methods in line with environmental protection (CMACCGP, 2016).

The LCP regulates the production, marketing, distribution, importation and use of various pesticides and other substances used for veterinary and livestock purposes (LCP, 2005). This law is the central axis that provides the regulatory framework for the importation, sale and use of pesticides. Article 5 defines different technical terms that are used in the context of this research. The term pesticide comes from the English word "pest", meaning harmful insects or plants, as well as from the Latin "cida", meaning to strike, knock down and kill (CNRTL, 2019).

The term "pesticides" is defined on page 3 of the present LCP Law as "any chemical or chemical-biological substance or mixtures of substances intended to prevent or combat pests or diseases in animals and plants, such as: insecticides, fungicides, germicides, nematocides, acaricides, molluscicides, rodenticides, ornithocides, bactericides, viricides, repellents, attractants and other products for use in both animals and plants (...)".

Herbicides are part of the main groups of pesticides which are defined as "substance used for the destruction or elimination of undesirable or harmful weeds to agricultural crops".

The LCP defines fertilizers as "commonly known as chemical or organic fertilizers: any substance or mixture of substances that are incorporated into the soil or plants in any form for the purpose of promoting or stimulating their growth or development or increasing soil productivity".

The requirements that must be met during their use are mentioned in Chapter VIII of the LCP, where specific measures must be taken to ensure that surface waters and water sources are not contaminated (LCP, 2005). Failure to comply with these obligations is qualified as a serious fault with pecuniary sanctions or temporary or a definitive suspension from the institution (Art. 52 LCP, 2005). Based on the LCP, two executive agreements were published including No. 151 (27/06/2000) and No. 18 (29/01/2004).

Article 1 of Agreement No. 151 (MAG, 2000) prohibits the registration, import, export, manufacture, marketing, and distribution of 34 pesticide active substances, either in technical form or in formulation. Technically speaking, it is only a list of 32 different substances because toxaphene and chlorinated camphene, as well as ethylene dibromide and 1,2-dibromoethane are the same molecules. Of these 32 substances, 12 are banned or the use will be reduced under the Stockholm Convention and 26 are banned from import into El Salvador under the Rotterdam Convention. The other six substances banned in El Salvador that are not part of the Stockholm Convention, Rotterdam or the Montreal Protocol are presented in the following table (Table 2). These substances are banned or strictly regulated in the United States or Europe

Agreement N° 18 (MAG, 2004) regulates the commercialization, distribution, storage and use of 12 pesticides (Table 3). Five of these pesticides can only be imported conditionally into El Salvador. The activities mentioned above are regulated by means of special documents.

The Legislative Assembly approved on September 5, 2013, with 45 votes in favor, Decree No. 473 on the reform of the LCP (MARN, 2013a). Article 2 of this reform contains a list of 53 active substances and commercial products prohibited in El Salvador. Article 3-A prohibits fertilizers containing heavy metals and metalloids.

Table 2 Pesticides banned in El Salvador in addition to the substances covered by the International Agreements of Stockholm, Rotterdam, and Montreal.

Chemical product	CAS	Use
Daminozide	1596-84-5	Plant growth regulator
Leptophos	21609-90-5	Plaguicide, fungicide
Fluorine Sodium Acetate	62-74-8	Rodenticide
Quintozene	82-68-8	Fungicide
Dibromo Chloro Propane	96-12-8	Nematicide
Arsenical Compounds	Not Assigned	Insecticide, fungicide, and herbicide

Table 3 Substances regulated by Agreement No. 18 (29/01/2004); special measures are detailed in the Agreement.

Chemicals Products	CAS	Overhead applications	Special measurements	Example of special measurements
Aldicarb	116-06-3		4	> 20 m from water sources.
Carbofuran	1563-66-2	Prohibited	3	Authorized for application in drip irrigation systems.
Dimethoate	60-51-5	Prohibited	2	It cannot be used in the following crops: potato, tomato, soybean, citrus, pineapple, and rice.
Endosulfan	33213-65-9 115-29-7	Prohibited	1	> 20 m from water sources.
Ethoprophos	13194-48-4		3	> 20 m from water sources.
Phorate	298-02-2	Prohibited	6	Training for the distributor and the user in its proper handling.
Aluminum phosphide	20859-73-8		4	For pest control in stored grains only.
Methamidophos	10265-92-6	Prohibited	1	It may not be used in the following crops: cotton, pasture, ornamentals, coffee, celery, etc.
Methyl parathion[7]	298-00-0	Prohibited	3	It should not be used on coffee, sugarcane, citrus, broccoli, tomato, chili, tobacco, rice, and ornamental plants.
Methomyl	16752-77-5	Prohibited	4	> 20 m from water sources.
Paraquat	4685-14-7	Prohibited	3	Applications in rivers, lakes, lagoons and other water sources or aqueducts are prohibited.
Terbufos	13071-79-9	Prohibited	5	It may only be sold with the provision of appropriate application and personal protective equipment.

Article 3-B mentions the creation of a technical committee in charge of formulating requirements for the registration, regulation and control of pesticides and fertilizers (ALRES, 2013). This technical committee is composed of people from the Ministries of Health (MINSAL), MARN and MAG. By then President of the Republic, Carlos Mauricio Funes Cartagena, received the decree on September 19, 2013, and returned it with observations to the Legislative Assembly on October 1 of the same year, noting that the list of 53 substances contained only 11 substances that were not already prohibited by national and international regulations (Funes, 2013). A second comment was made on the fact that the proposed list contained a mixture of names of active substances and commercial products (p. 3 (Funes, 2013)), suggesting mentioning only active ingredients named according to the internationally accepted IUPAC nomenclature. The list of active substances that are not prohibited in El Salvador in relation to Agreement No. 473 are shown in Table 4.

The 42 agrochemicals approved by then President of El Salvador to be legislatively banned are: 1) Methyl parathion, 2) Endosulfan, 3) Methamidophos, 4) Aldicarb, 5) DDT, 6) Leptophos, 7) Ethyl parathion, 8) Endrin, 9) Dieldrin, 10) Aldrin, 11) Heptachlor, 12) Chlordimeform, 13) Toxaphene, 14) Hexachlorobenzene, 15) Chlordecone, 16) Arsenicals, 17) Sodium Fluoroacetate, 18) Dibromo Chloropropane, 19) Chlorofluorocarbons, 20) Dodecachloro, 21) 2,4,5-T, 22) Ethylene Dibromide, 23) Captafol, 24) Pentachlorophenol, 25) HCH, 26) Phosphamidon, 27) Monocrotophos, 28) Quintozene, 29) 1,2-Dibromoethane, 30) Chlorinated Camphene, 31) Lindane, 32) Sodium Cyanide, 33) Dinoseb and Dinoseb Salts, 34) Chlordane, 35) Daminozide, 36) Mercury Compounds, 37) Chlorobenzilate, 38) Fluoroacetamide, 39) Biphenyl, 40) Dichlorinates, 41) Dioxins and 42) Furans.

The 12 agrochemicals excluded from the ban list were the following: 1) Paraquat (gramoxone); 2) Methomyl (lannate), 3) Carbofuran (furadan); 4) 2,4-Dichlorophenoxyacetic acid (whip); 5) Chlorpyrifos, 6) Glyphosate (ranger), 7) Dicamba, 8) Imidacloprid, 9) Thiodicarb (armor), 10) Terbufos (counter), 11) Dimethoate and 12) Phorate.

Additionally, in the amendment to the proposed reform the by the President retook an advisory and consultative Committee integrated by the MAG, MARN and MINSAL.

Table 4 Active substances stipulated in Agreement No. 473 that are not prohibited by National or International legislation in El Salvador.

Substance	CAS	Use
2,4-D	94-75-7	Herbicide
Carbofuran	1563-66-2	Acaricide, insecticide and nematicide
Chlorpyrifos	2921-88-2	Insecticide
Dicamba	1918-00-9	Herbicide
Dimethoate	60-51-5	Acaricide, insecticide
Phorate	298-02-2	Insecticide, acaricide
Glyphosate	1071-83-6	Herbicides
Imidacloprid	138261-41-3 105827-78-9	Insecticide
Methomyl	16752-77-5	Insecticide
Paraquat	4685-14-7	Herbicides
Terbufos	13071-79-9	Insecticide, acaricide
Thiodicarb	59669-26-0	Insecticide

This Committee would be in charge of issuing opinions at the request of the MAG, when the latter considered it pertinent. The transition from a Technical Committee to a Committee merely of consultative nature and only at the request of the MAG, weakened the possibility of having initiatives to stop the use of toxic substances and their effects on health and the environment.

It is important to note that the by then President repeatedly mentioned the need for the prohibition of active substances to be based on scientific principles, preferably on a risk assessment (p. 4, 7, 8 and 12). The scientific principles that were to be considered are those developed by the relevant international organizations (Funes, 2013). Clearly, the group that advised the by then President on this decision were unaware or made it appeared that they did not know of the amount of scientific literature justifying the prohibition of these substances, which were already banned in other more developed countries. Currently, the decree has been shelved.

The chronology available in Appendix I, shows some interesting facts about this process. It seems that two main causes could explain the failure to complete this process of revision of the law: 1. The intervention of national pressure groups (e.g., the coffee industry) and international (e.g., Crop Science) to challenge the process, 2. The failure to create the technical committee responsible for the risk assessment of the remaining 11 substances.

Protection of Protected Natural Areas against Contamination

Protected natural areas are covered by special provisions established in the Law of Protected Natural Areas (LANP, 2005). These protected areas include wetlands such as the Ramsar sites located in the study area. The objective of this law is the conservation of biological diversity, ensure the functioning of ecological processes and guarantee the perpetuation of natural systems. Chapter VII of this law defines offenses and penalties related to damage caused by a third parties to these protected areas. Article 45 stipulates the so-called "very serious" infractions, including "the use in the zone or buffer zone of agrochemical products that are not authorized by the responsible authority" (LANP, 2005).

Quality Control of Imported Agrochemicals in El Salvador

Furthermore, to the problems related to pesticide legislation in El Salvador, it is necessary to consider that there is usually no adequate quality control of the chemical content of imported products. The lack of adequate laboratories, with few exceptions such as the MAG laboratory (which does not have the legal attribution to analyze imported products) or the MINSAL laboratories, the capacity for organic analysis of these products is limited and is not routinely performed. It is known that there is evidence that many pesticides may contain heavy metals.

The heavy metal content of fertilizers is also of concern. Fertilizers often contain heavy metals such as Cd, Co, Cu, Ni, Pb, Zn, Fe and Mn (e.g., Gimeno-Garcia et al., 1996). Phosphates may contain high concentrations of these metals and arsenic, as is the case with Moroccan phosphates (e.g., Cd concentration, Mar, and Okazaki, 2012). Between 2011 and 2014, each year El Salvador imported more than 97% of calcium phosphate from Morocco (Atlas of Economic Complexity, accessed 2/15/2021). To the best of our knowledge, there are no determinations of heavy metals in fertilizers applied in El Salvador.

1.4 Conclusion

There is a regulatory framework for 57 substances or groups of substances that can be used as pesticides in El Salvador. Of these substances, only 14 do not refer to an international agreement obligation and are regulated by an agreement adopted at the national level. The only update of the Salvadoran pesticide regulation dating from 2013 has been archived, which means that it will not be applied. This means that since 2004, no scientific evidence on health and environmental risk assessment produced in the last 16 years has been considered to adapt the Salvadoran legislative framework. This regulatory gap could result in significant risks to the health of the population and the environment.

For example, Regulation (EC) No. 1107/2009 of the European Parliament on the placing of pesticides on the market (EC, 2009) has allowed a position on 1,353 active substances (34 are pending) used as pesticides, 855 of which are not approved for use on the European market (EC, 2009). Of the 12 active substances in El Salvador's Executive Agreement No. 18 (MAG, 2004), only aluminum phosphide and methomyl are approved. As shown in Table 3, El Salvador restricts the aerial use of only 9 pesticides. For example, at the European level, as a rule, pesticides have not been allowed to be applied by air since 2009 (Zwetsloot et al., 2018).

2 Agrochemical Load in El Salvador and its Use in Sugarcane Fields

2.1 Introduction

In the framework of the evaluation of chemical risks associated to the use of pesticides in El Salvador and more specifically in sugarcane crops, it is necessary to have 3 essential inputs. First, it is required to obtain a list of the commercial formulations used and their main active ingredients. Secondly, it is essential to know the quantities used to estimate the total pesticide load to which the country is subject. Finally, as part of this research, it is necessary to know when and how their products are applied on sugar crops.

2.2 Methodology

The list of agrochemicals registered in El Salvador and the import data were provided by Registration and Inspection of the General Direction of Plant and Animal Health of the MAG.

These data were used to determine the dynamics of the import of phytosanitary products during the year, to calculate the total quantities sprayed of each active ingredient and to estimate the absolute consumption of pesticides for each type of crop.

To determine these three elements, a database has been created with the OpenOffice Base program to cross-reference information from different tables and facilitate the calculations. This database contains, the list of products registered in El Salvador (180,000 data), fertilizers and pesticides imported for each month from September 2018 to August 2019 (65,025 data) and the cultivated areas by crop type mentioned in the MAG agricultural yearbook 2018-2019 (MAG, 2018, pp. 2018-2019).

Determination of Import Dynamics

The analysis of agrochemical import dynamics in El Salvador is based on the amounts in tons of commercial products imported each month between

September 2018 and August 2019[2]. For each month, the amounts imported by the following classes: "fertilizers", "herbicides", "insecticides" and "fungicides" were summed. For the calculation of the formulations[3] of the imported amounts, the declared used by the registration for each product was considered. The herbicide use class of the registration was considered as herbicide; the insecticide, acaricide and nematicide use classes were considered as insecticides; the fungicide and bactericide classes were considered as fungicides; the fertilizer, foliar and micronutrient classes were considered as fertilizers.

Commercial products sold in liquid form were estimated with a density of 1 kg/L to report import data in tons by use class. This analysis provides an overview of the masses of pesticides and fertilizers entering the country each year. Nonetheless, it should be noted that each product contains active ingredients in different concentrations. For this reason, the total pesticide load used was subsequently calculated based on the masses of active ingredients. The same work was carried out to determine the dollar value imported per year by class of use.

Calculation of the Total load of Pesticides sprayed in El Salvador.

The sum by commercial products used was performed during the period of September 2018 and August 2019 in SQL (Structured Query Language) functions contained in OpenOffice Base. The import records contain a "Used" column so only rows containing "YES" were added.

Then, the list of total quantities of commercial products used during this period was exported to OpenOffice. Commercial products may contain a mixture of two or three different active substances in different concentrations. Commercial products containing more than one active ingredient were considered several times depending on the concentration of each active ingredient; the mass of the product in each mixture was considered. The concentrations of the 397 active ingredients contained in the 320 commercial products were determined from information obtained from distributor websites, label photos and telephone records. When the active ingredient concentrations per commercial product were known, the total amount of commercial product sprayed was multiplied by the concentration of each active ingredient. Annual amounts were calculated for each active ingredient used.

Estimated fumigation amounts by crop type.

The MAG's register of phytosanitary products was searched for each of the commercial products imported between September 2018 and August 2019 to find out on what type of crops they could be applied.

Next, the area for each type of crop was researched in the MAG 2018-2019 agricultural yearbook. A theoretical percentage of treated area per crop type was calculated for each of the commercial products. This calculation is based on two assumptions, the rate applied is the same for each type of crop and that all crops for which a product is intended have been treated.

For example, the product called "FOLIKILL 1.5 DP" is used for tomato (851 Mz, 595.7 hectares) and chili (274 Mz, 191.8 hectares) crops. Our hypothesis is that this product was sprayed equally on all tomato and chili plots in the country. Of the total 286,000 kg of FOLIKILL 1.5 DP used during the year, then 216,343 kg (76%) are attributed to tomato crops and 69,657 kg (24%) to chili. These amounts are then multiplied by the percentage of active ingredient contained in the product (1.5% chlorpyrifos).

Finally, the amount of each active ingredient is added by crop type. For ease of interpretation, the results were expressed in the following groups: coffee, sugarcane, fruits (avocado, cocoa, citrus, plantain, mango, banana, watermelon), basic grains (rice, beans, corn, sorghum), vegetables (squash, chili, pear squash, potato, cucumber, cabbage, tomato, zucchini) and others (cotton, etc.). The results are presented in A.I. 1 (Additional Information 1).

[2] The data can be solicited at michel.wildi@gmail.com.
[3] Mmixtures of various chemical components (additives, active ingredients, solvent) at different concentrations

Agrochemical use during the Sugarcane Production Cycle.

The identification of chemicals used in sugarcane fields was carried out through cross-checking information from literature, the List of Registered Products (MAG, 2019) and semi-structured interviews with engineers and agricultural operators. The methodology of the qualitative interviews is specified in chapter 5.2.1.

2.3 Results

2.3.1 Pesticide and Fertilizer Import Dynamics.

From September 2018 to August 2019, El Salvador imported $55,133,442 in biocides (domestic use), pesticides and fertilizers (agricultural use). Pesticides represent 46% of this total ($25,357,711); 42.2% are for fertilizers ($23'270'038) and 11.8% for biocides ($6,505,693) used in households (MAG, 2019a). In terms of pesticides, herbicides account for the largest share of this import trade ($13,814,479), followed by insecticides ($6,645,339) and fungicides ($3,409,103) (MAG, 2019b).

For informational purposes, the quantities of commercial products imported into the El Salvador in 2019 amounted to 80,230 tons of fertilizers, 4,729 tons of pesticides and 1,498 tons of biocides. Pesticides include 3,016 tons of herbicides, 1,254 tons of insecticides, 138 tons of fungicides, and other products (e.g., agricultural adjuvant) (MAG, 2019a).

Import data for fertilizers, herbicides, insecticides, and fungicides indirectly reflect their use through market demands, although there is probably a time lag of a few weeks between the date of import and the date of application due to the movement of merchandise. Monthly imports of these products are shown in the graphs below (Figure 2, Figure 3, raw data available I.A. 2) to analyze the dynamics of their use. The amounts of imported fertilizers are 18 times higher than those of pesticides. Fertilizer imports follow a logical "sawtooth" pattern throughout the year, with a peak in July and an amount imported 7 times higher than the average of the other months of the year.

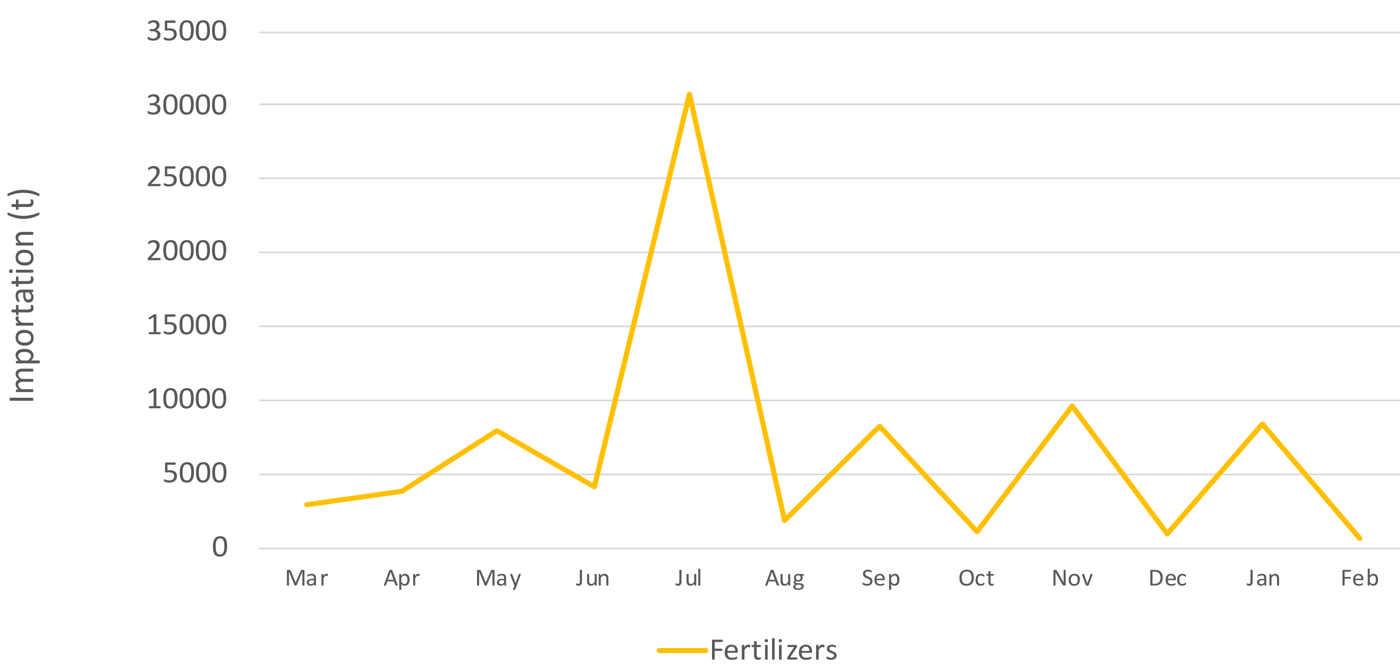

Figure 2 Import dynamics of fertilizer in El Salvador from March 2018 to February 2019 (data sources MAG, 2019).

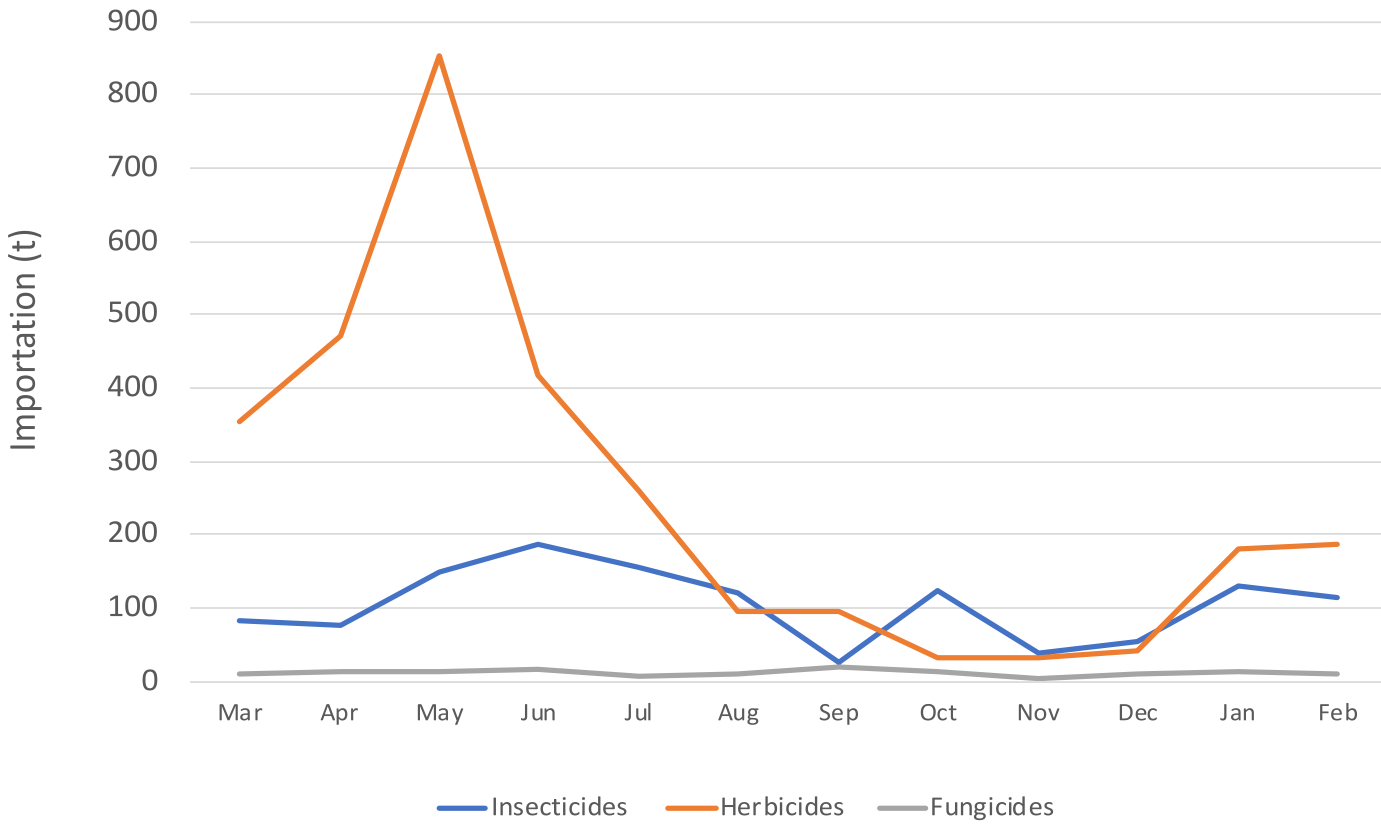

Figure 3 Import dynamics of insecticides, herbicides, and fungicides in El Salvador from March 2018 to February 2019 (data sources MAG, 2019).

Herbicides are the most imported pesticides in the country with the maximum during the months of April, May, and June are the second months with the highest levels of imports. Insecticides present a different dynamic with 3 import peaks, including January, June, and October. Fungicides correspond to three peaks in the year, including September, January and June.

In general, imports of fertilizers and pesticides are strongly associated to the weather with a maximum of imports especially in the raining season; when corn, beans, sorghum, and other crops are planted (G. Sandoval, personal communication, 2019).

In sugar production, fertilizers are applied 150 days after harvest between March and July (Medardo & Molina, 2016). Moisture is essential for plants to absorb fertilizers more easily through their root systems and to prevent the products from evaporating before they enter the soil and plants (Sandoval, 2019). This is also the case for pesticides, which are imported during the months of April, May, and June, at the beginning of winter; when they are most requested by producers and governmental and non-governmental institutions (Sandoval, 2019).

2.3.2 Quantities of Active Ingredients used in 2018-2019.

The agricultural product registry of El Salvador includes 1,429 commercial products, involving 893 pesticides for agricultural use, 434 fertilizers and includes 102 biocides for domestic use (MAG, 2019a).

The 3603 commercial products imported and used in the country between September 2018 and August 2019 were analyzed for their content of active ingredients with pesticide action and used in agriculture (insecticides, herbicides, fungicides, and rodenticides).

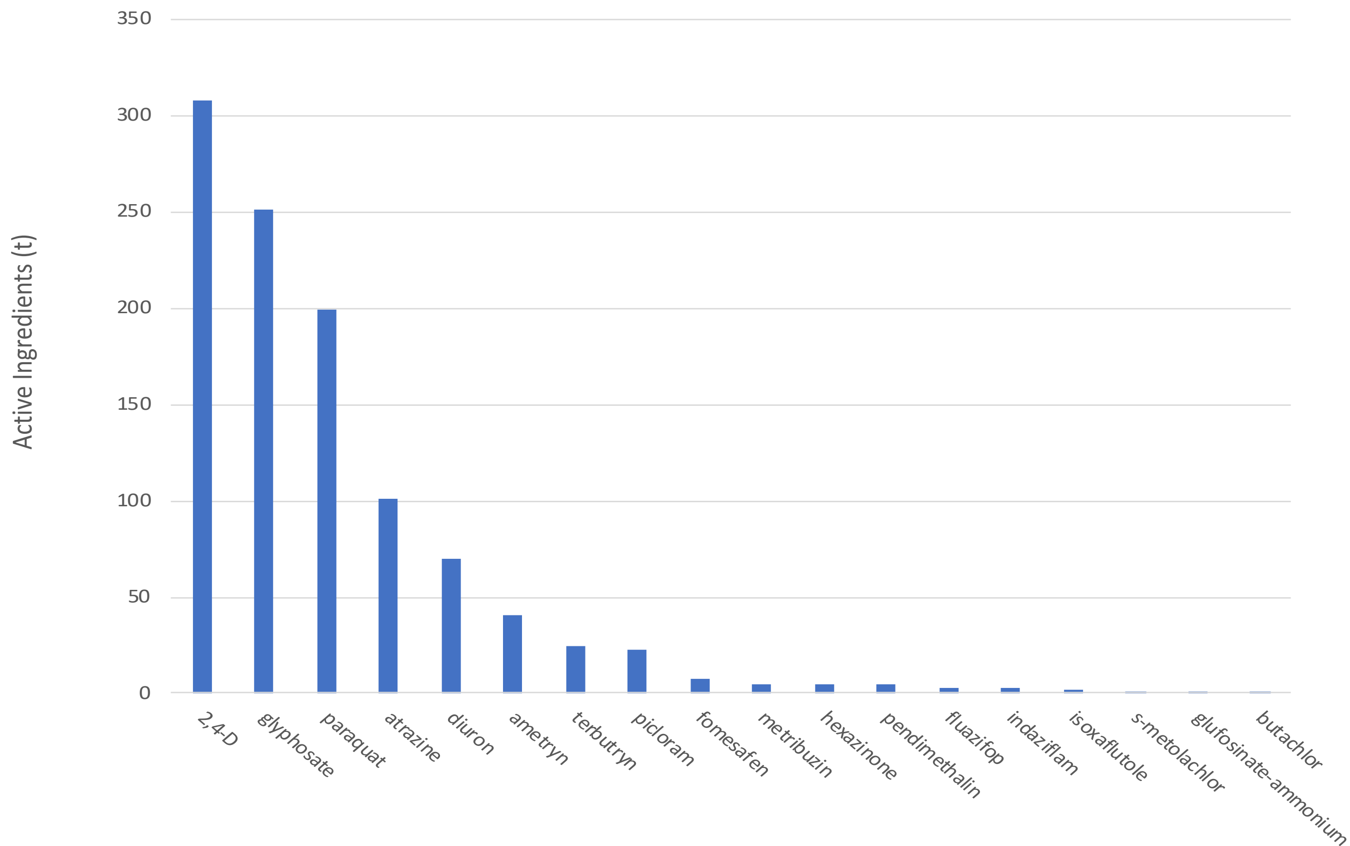

Figure 4 List of active substances of herbicides used in El Salvador in quantities greater than 1 ton per year (sources of analyzed data MAG, 2019).

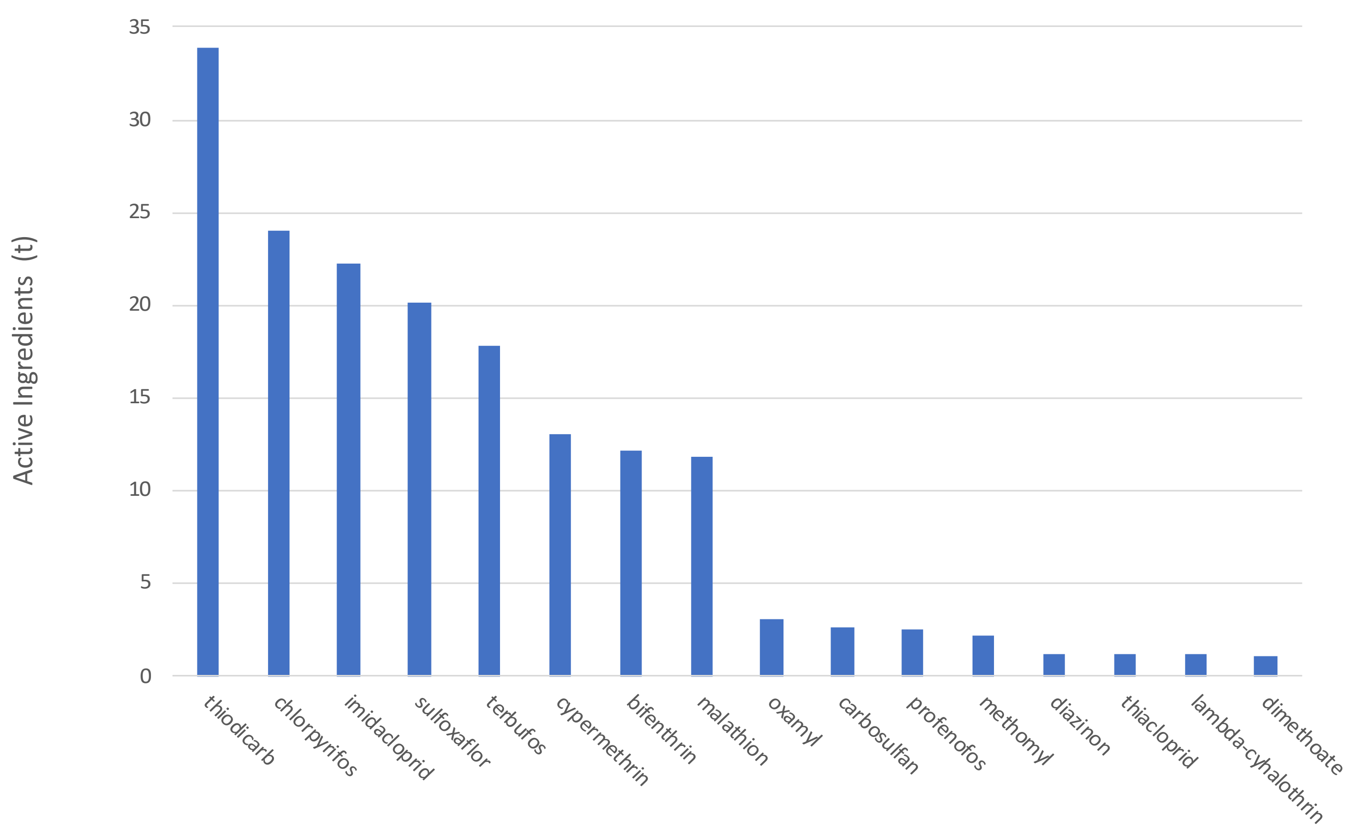

Figure 5 List of insecticides by active substance used in El Salvador per year in quantities greater than 1 ton per year (data sources MAG, 2019).

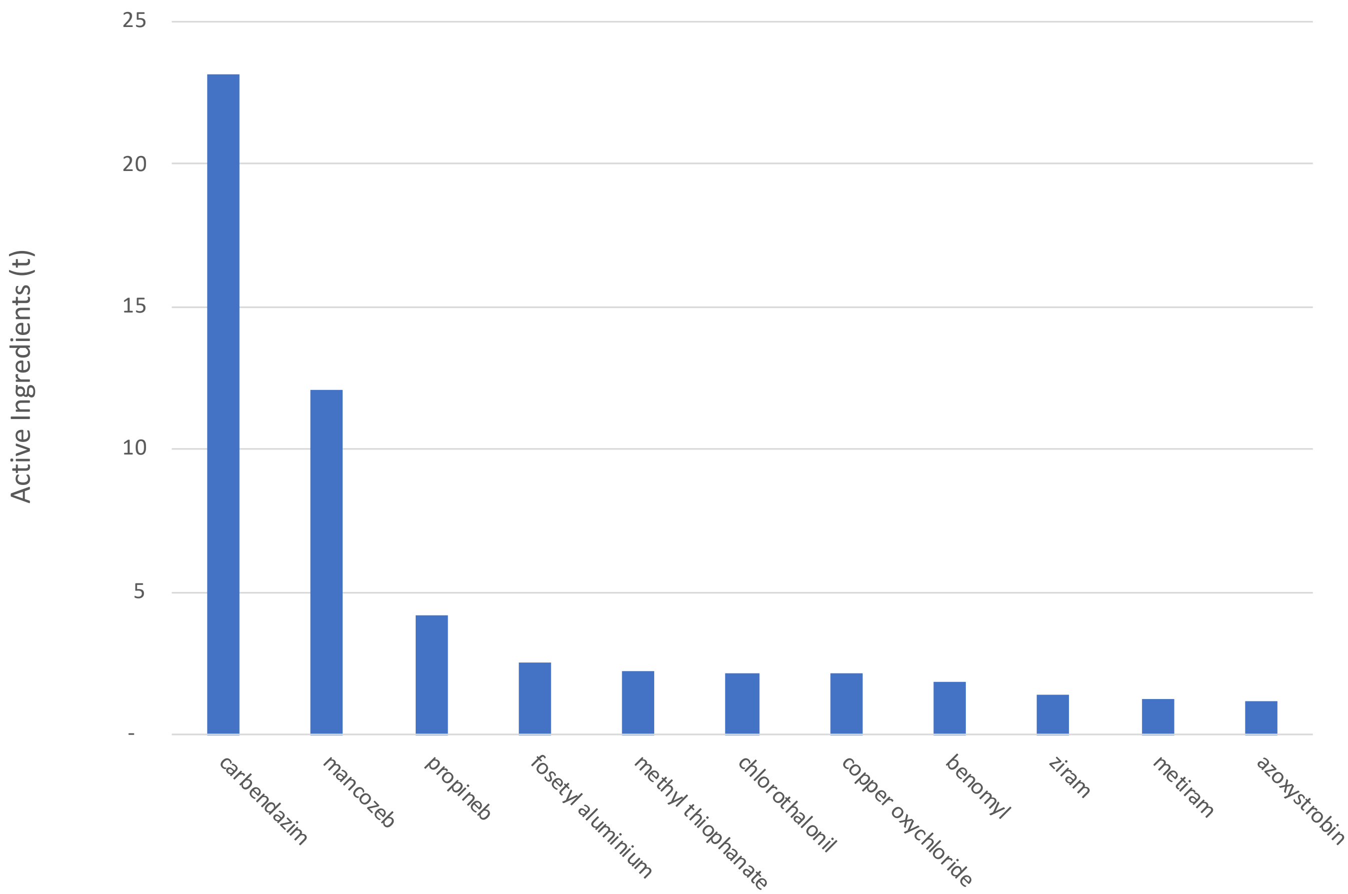

Figure 6 List of fungicides by active substance used in El Salvador per year in quantities greater than 1 ton per year (data sources MAG, 2019).

The active substances with herbicidal activity used in quantities greater than one ton are shown in Figure 4. The three most used active substances are 2,4-D (308 tons, phenoxy), glyphosate (251 tons, aminophosphonic) and paraquat (200 tons, bipyridyl). In the second largest group are atrazine (108 tons, triazines), diuron (70 tons, urea) and ametryn (47 tons, triazine).

Regarding insecticides (Figure 5), the most used is thiodicarb (carbamate) with a use of 34 tons (based on MAG data analysis, 2019). It is followed by chlorpyrifos (24 tons, organophosphate), imidacloprid (22 tons, neonicotinoids), sulfoxaflor (20 tons, sulfoximine) and terbufos (18 tons, organophosphate) (MAG, 2019b).

With respect to fungicides (Figure 6), the active substances most used are carbendazim (23 tons, benzimidazole) and mancozeb of the thiocarbamate family (12 tons).

The following figures show the total consumption of herbicides, insecticides, and fungicides by crop type (Figures 7,8). These numbers are an estimate based on the type of crop for which a commercial product is registered, the active ingredient concentrations of the product and the area cultivated by crop type as explained in the methodology. The types of crops considered are coffee, sugarcane, fruits (avocado, cocoa, citrus, banana, mango, plantain, watermelon), basic grains (rice, beans, corn, sorghum), vegetables (squash, chili, chayote, potato, cucumber, cabbage, tomato, zucchini) and others (cotton, etc.).

Figure 8 shows that the highest consumption of herbicides is dedicated to the production of basic grains (60%), sugarcane (29%) and coffee (10%). The total consumption of active ingredients with insecticidal activity is also mainly concentrated in the production of basic grains (65%), followed by coffee (12%) fruits (11%)

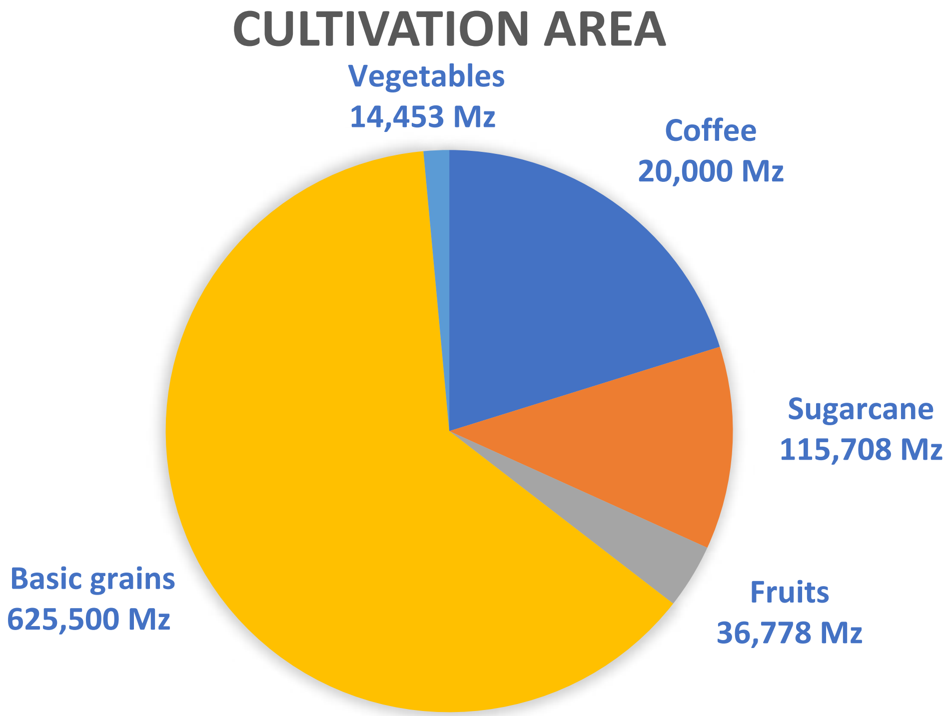

Figure 7 Total area under cultivation in El Salvador (MAG, 2019)

and finally sugarcane (6%) and vegetables (6%). As for fungicides, the main consumer is coffee crops (55%), then basic grains production (23%) and finally fruits (13%) and sugarcane (1%).

It is important to note that MAG statistical yearbook 2018-2019, basic grains production corresponds to 62%, coffee 20%, sugarcane 12%, fruit trees 4% and vegetables 1% of the total cultivated area in El Salvador (1,001,032 manzanas) (Figure 7).

This means that, per unit of cultivated area sugarcane crops absorb about 2.6 times more herbicides than basic grains. In terms of insecticides, fruit plantations absorb 11% of total, although they only account for 4% of the cultivated area. Most fungicides used are applied on coffee crops and a small proportion is used on sugarcane fields. This is because coffee plantations are located at high altitudes and are more prone to fungal infections.

Within the same use group, such as herbicides some active ingredients are used more for certain types of crops than for others. Staple grain crops represent for between 50% and 72% of the consumption of the 3 most used herbicides (2,4-D, glyphosate and paraquat) (Figure 9). Sugarcane crops occupy more 2,4-D and glyphosate than paraquat, which is used more in staple grain crops.

As for insecticides (Figure 10), thiodicarb is used almost exclusively on staple grain crops. Chlorpyrifos is also used in staple grain production (57%), followed by vegetables (18%), sugarcane (14%) and coffee (10%). Imidacloprid is mainly used for staple grain (81%), followed by sugarcane (12%) and coffee (4%).

Consumption of the three main active ingredients with fungicidal action is found mainly in coffee plantations, which account for 51%-71% of their uses (Figure 11). In the case of carbendazim, use is concentrated in second place in basic grains (15%) and fruit trees (11%). As for mancozeb, it is used in second place for fruit trees (24%) and then for vegetables (15%). Propineb is used secondarily on staple grains as carbendazim.

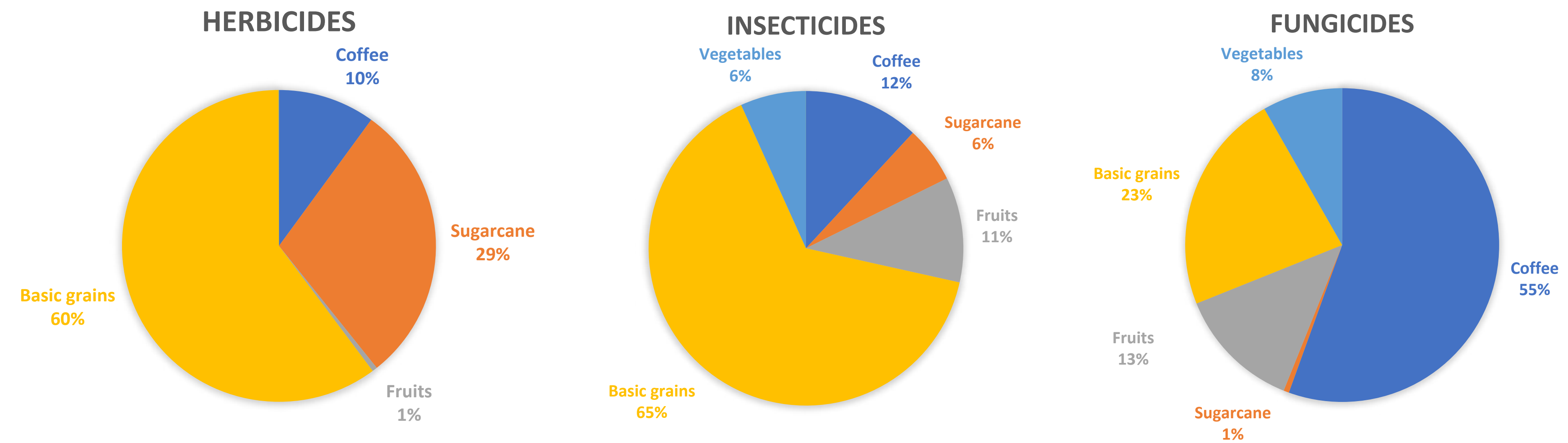

Figure 8 Total consumption of active ingredients of substances used as herbicides, insecticides, and fungicides by crop type.

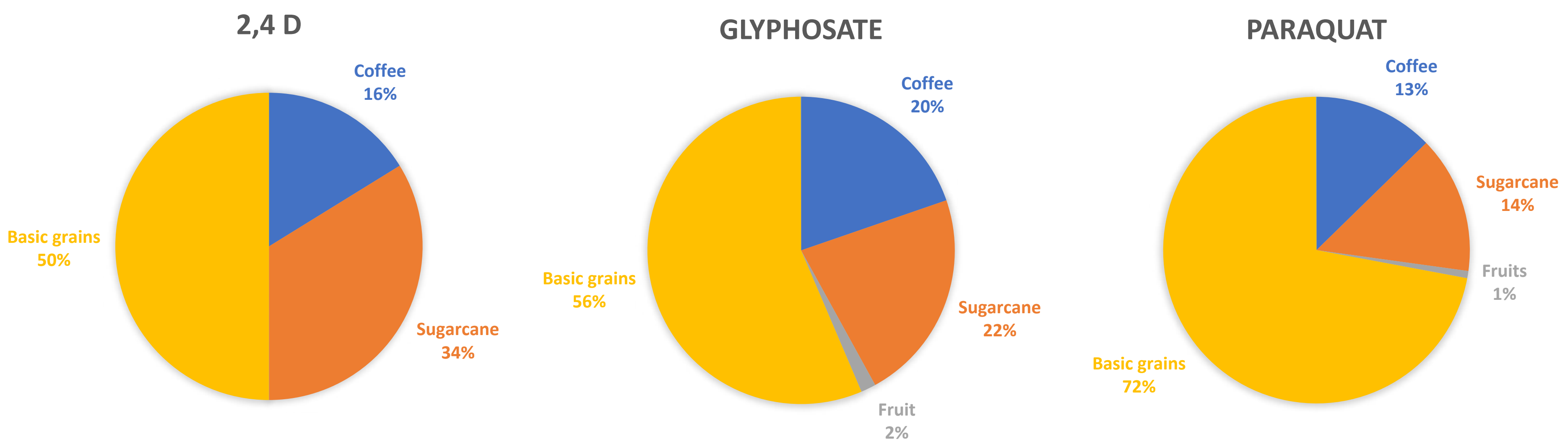

Figure 9 Consumption of the three main active ingredients used as herbicides.

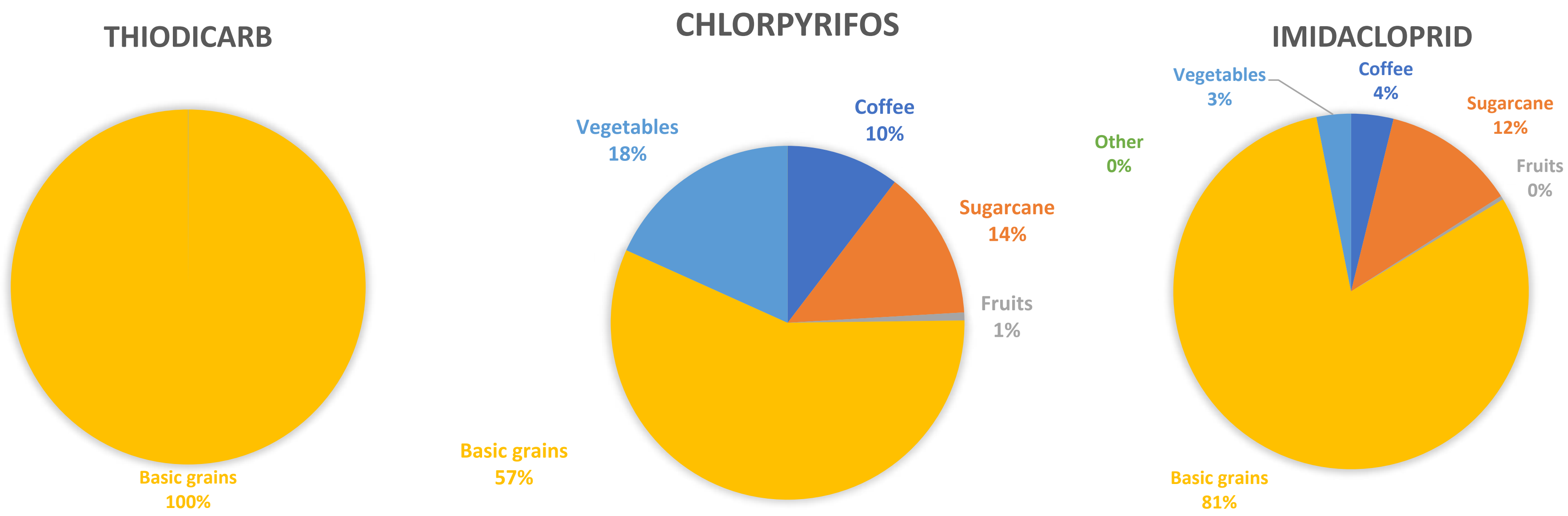

Figure 10 Consumption of the three main active ingredients used as insecticides.

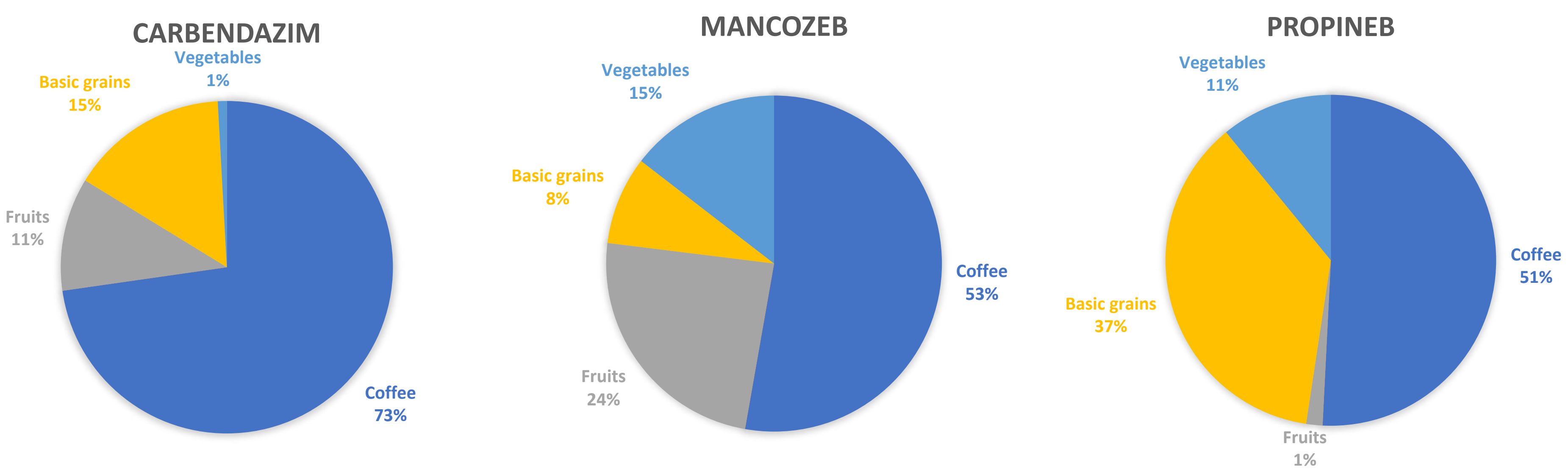

Figure 11 Consumption of the three main active ingredients used as fungicides.

2.3.3 Use of Agrochemicals during the Sugarcane Production Cycle

The sugarcane production cycle consists of different stages in which chemicals of synthetic or natural origin can be used on crops. Fertilizers are applied to the fields to enrich the soil with essential elements to promote crop growth. Pesticides can be used for various purposes, including controlling weed growth in competition with crops, controlling certain pests or as a ripening agent[4].

Sugarcane is a semi-evergreen herbaceous plant with a growing cycle of 5 to 7 years (Hughes et al., 2016; Moret, 2014). Cycles beginning with a planting are referred to as "virgin" and the following 5 to 7 cycles are referred to as "regrowth" cycles. The crop and phenological cycle include several stages, including soil preparation, planting of cuttings, sprouting, root development, stem emergence (tillering), vegetative growth, maturation, germination, and harvest. The following cycles begin with sprout emergence (Moret, 2014; NAD, 2019a).

Soil preparation involves several plowing steps aimed at optimizing the air-water ratio in the soil, providing good physical conditions for root anchorage, manure incorporation, destruction of unwanted grasses, and promotion of microorganism activity (NAD, 2019a).

Soil enrichment in large-scale production is generally not done by manure, but by mineral fertilizers (Figure 12) such as nitrogen fertilizers (urea, ammonium nitrates or ammonium sulfates), phosphorus (ammonium phosphate) and the addition of potassium salts (KCl) (Hughes et al., 2016). Soils can also be enriched with some essential elements such as boron, copper, iron, manganese, zinc, and sulfur (NAD, 2019b). These chemical elements in the form of salts are applied in solid form directly into the soil or in liquid form after dissolution in water (Disagro, 2011). Depending on the cultivation methods, a first soil treatment with phosphorus and lime (CaO) is carried out 2 months before planting the cuttings (RITA, 2015).

Throughout the tillering phase, sugarcane is very demanding in terms of fertilizers and a new fertilizer application can be made 30 days and 60 days after germination (RITA, 2015). During its growing period, different phytosanitary treatments are applied for the control of different pests such as the Pinta fly (Aeneolamia postica) or the screwworm (Diatraea saccharalis) (Hughes et al., 2016). This fly is treated with

Figure 12 Type of fertilizer found around sugarcane fields (UNES© photo).

[4] An organic compound that, when applied in small amounts, inhibits, promotes, or modifies in some way, physiological processes of the plant (Arcila, 1990). In sugarcane, these compounds act as growth regulators that favor higher sucrose concentration." (p. 154, Medardo & Molina, 2016)

insecticides containing for example, thiamethoxam or the neonicotinoid imidacloprid (Hughes et al., 2016). Grub is treated with insecticides such as triflumuron (Bayer CAC, 2019a), carbofuran and bifenthrin (Hughes et al., 2016). Sugarcane can be subject to multiple pests of other types (different types of borers, whiteflies, termites, mealybugs, grasshoppers) and diseases (bacterial, viral, fungal) that may involve other types of pesticides (NAD, 2019c; Werner, 2018).

In the growing season, constant weeding is practiced with different herbicides used individually or in combination, such as 2,4-D, atrazine, glufosinate-ammonium, glyphosate, paraquat and triazine (Bayer CAC, 2019b; Hughes et al., 2016).

Harvesting, also called "zafra", takes place from November to April (HRW, 2004). From 28 to 49 days before harvest, ripening agents are applied to stop cane growth, wilt leaves, and concentrate sugar (Hughes et al., 2016). The products generally applied aerially are Roundup Weather-MAX® and Roundup Power MAX II® with glyphosate as the main active substance (Oregon et al., 2017). One day before harvest, fields are burned to remove plant foliage prior to cutting (HRW, 2004). The technique of harvesting without burning the field is called "zafra green" and corresponds in 2011-2012 to 2.5% and in 2012-2013 to 7.2% of the country's sugarcane crops (MAG, 2012, 2013; MARN, 2013c). The same sugarcane plant has a useful life of 5 to 7 harvests before being renewed (Hughes et al., 2016).

Table 5 compiles the substances used for sugarcane production reported in different studies conducted in Central America, Africa, and Australia (Armas et al. 2005; Davis et al., 2013; Donga et al. 2018, Lehtonen 2009; Mitchell et al. 2005; Ongley, 1997; Pankhurst, 2006) as well as two FAO´s documents that include the inventory of pesticides used on sugar crops (Ongley, 1997) and the management of weeds used on sugar crops (Labrada et al. 1996).

The list of substances reported in the literature has been updated from the 2019 register of agricultural products and fertilizers obtained from the Dirección General de Sanidad Vegetal y Animal (General Directorate of Plant and Animal Health). The active substances are shown in table 5 according to type of use and by chemical group.

In El Salvador, 59 active substances are registered for use in sugarcane cultivation. These 59 substances consist mainly of herbicides (35) and insecticides (17), some of which have nematicide and acaricide effects, and finally fungicides (4) and rodenticides (3).

Only 3 registered herbicides are contact herbicides, meaning that they only damage the treated plant part (Au, 2003). This type of herbicide should be applied in sufficient quantities to cover the entire foliage of the target weed (M. Singh & Sharma, 2008, p. 16). Three contact herbicides have been registered in El Salvador, including paraquat which induces free radicals in the treated plant that interfere with lipid synthesis. Most of the registered herbicides are selective or translocation herbicides. This means that these molecules enter through the root system or in the weed foliage migrate to another part of the plant to exert their effect. Selective herbicides act by disrupting the cellular functioning of the plant for example, by inhibiting photosynthesis (e.g., diuron, atrazine), modifying protein structures or dysregulating cell division, protein synthesis (e.g., asulam) or lipid synthesis (Au, 2003).

The insecticides used for sugarcane treatment belong to the main chemical groups of carbamates, neonicotinoids, organophosphates and pyrethroids. The action in humans of most of these compounds is directed at the nervous system by inhibiting the enzyme involved in synaptic transmission (acetylcholinesterase) or by deregulating the sodium channels involved in electrical transmission in the central and peripheral nervous system. These inhibitors prevent the transmission of nerve impulses, leading to paralysis and death. Some other insecticides used inhibit the synthesis of chitin necessary for the formation of insect exoskeletons such as benzoylureas or disrupt the molting of insect larvae such as tebufenozide.

In fungicides, we find strobilurins, which are cellular respiration inhibitors directed at mitochondrial cytochromes. We also found that sterol inhibitors are necessary for cell membrane formation such as triazoles and cell division inhibitors such as benzimidazole. Three rodenticides can be applied in sugarcane fields such as brodifacoum, coumatetralyl, flocoumafen. All are anticoagulant agents.

Table 5 List of Active Substances included in the National Registry of Crop Protection Products used in the production of sugarcane and their action mode.

Active ingredients	CAS	Chemical group	Mode of action	Reference
Fungicides				
Carbendazim	10605-21-7	Benzimidazol	Systemic. Inhibition of mitosis and cell division.	(K. Lewis et al., 2016)
Pyraclostrobin	175013-18-0	Estrobilurina	Systemic. Respiration inhibitor.	(K. Lewis et al., 2016)
Azoxystrobin	131860-33-8	Estrobilurina	Systemic. Respiration inhibitor.	(K. Lewis et al., 2016)
Cyproconazole	94361-06-5	Triazol	Systemic. An inhibitor of ergosterol biosynthesis.	(K. Lewis et al., 2016)
Herbicides				
2,4-Dichlorophenoxyacetic acid	94-75-7	Phenoxy	Systemic. Increases biosynthesis and ethylene production causing uncontrolled cell division and thus damaging vascular tissue.	(EXTOXNET, 2019; K. Lewis et al., 2016)
Acetochlor	34256-82-1	Chloroacetamide	Systemic. Inhibition of cell division.	(K. Lewis et al., 2016; van Almsick, 2009)
Ametrine	834-12-8	Triazine	Systemic. Inhibits photosynthesis (photosystem II).	(K. Lewis et al., 2016)
Amicarbazone	129909-90-6	Triazolinone	Contact. Inhibition of photosynthesis (photosystem II).	(K. Lewis et al., 2016)
Asulam	3337-71-1	Carbamate	Systemic. Causing slow chlorosis.	(K. Lewis et al., 2016)
Atrazine	1912-24-9	Triazinea	Systemic. Inhibits photosynthesis (photosystem II).	(K. Lewis et al., 2016)
Bentazone	25057-89-0	Thiadiazine	Systemic. Absorbed by roots and translocated. Oxidative damage due to lack of vitamin E, destruction of chlorophyll.	(K. Lewis et al., 2016)
Carfentrazone	128621-72-7	Triazolinone	Contact. Cell membrane interruption.	(K. Lewis et al., 2016)
Clethodim	99129-21-2	Cyclohexandione oxime	Systemic. Inhibits the synthesis of amino acids.	(K. Lewis et al., 2016)
Clomazone	81777-89-1	Isoxazolidinone	Systemic. Inhibition of carotenoid synthesis.	(K. Lewis et al., 2016)
Diuron	330-5a4-1	Urea	Systemic, absorbed by the roots, it acts by strongly inhibiting photosynthesis.	(K. Lewis et al., 2016)
Ethoxysulfuron	126801-58-9	Sulfonylurea	Sistémico. Inhibe la síntesis de aminoácidos.	(K. Lewis et al., 2016)
Fluazifop	69335-91-7	Aryl propanoate	Systemic	(K. Lewis et al., 2016)
Glyphosate	1071-83-6	Phosphonoglycine	Systemic. Inhibits the synthesis of amino acids.	(K. Lewis et al., 2016)
Glufosinate Ammonium	77182-82-2	Phosphonic	Contact and partially systemic. Inhibition of photosynthesis and glutamine synthase.	(K. Lewis et al., 2016)
Hexazinone	51235-04-2	Triazinone	Systemic, non-selective. Inhibits photosynthesis (photosystem II).	(K. Lewis et al., 2016)
Imazapic	104098-48-8	Imidazolinone	Systemic. Inhibits the synthesis of amino acids.	(K. Lewis et al., 2016)

Active ingredients	CAS	Chemical group	Mode of action	Reference
imazapyr	81334-34-1	Imidazolinone	Systemic. Inhibits the synthesis of amino acids.	(K. Lewis et al., 2016)
Indaziflam	950782-86-2	Fluoroalkyltriazine	Systemic, non-selective. Inhibits cellulose biosynthesis.	(K. Lewis et al., 2016)
Isoxaflutole	141112-29-0	Oxyacetamide	Systemic. Inhibits the synthesis of amino acids.	
MCPA				
(2-methyl-4-chlorophenoxyacetic acid)	94-74-6	Aryloxy alkanoic acid	Systemic. Interferes with protein synthesis, cell division and plant growth.	(K. Lewis et al., 2016)
Mesotrione	104206-82-8	Tricetone	Systemic. Inhibits the synthesis of amino acids.	(K. Lewis et al., 2016)
Metribuzin	244-209-7	Triazinone	Systemic. Inhibits photosynthesis (photosystem II).	(K. Lewis et al., 2016)
Metsulfuron methyl	74223-64-6	Sulfonylurea	Systemic. Inhibits the synthesis of plant amino acids.	(K. Lewis et al., 2016)
Oxifluorfen	42874-03-3	Dimethylether	Systemic. Selective with contact action. Causing irreversible damage to the cell membrane.	(K. Lewis et al., 2016)
Paraquat	4685-14-7	Bipyridyllium	Contact. Broad spectrum, non-residual activity with contact and some desiccant action. Photosystem I inhibitor.	(K. Lewis et al., 2016)
Pendimethalin	40487-42-1	Dinitroaniline	Systemic. Selective, absorbed by roots and leaves. Inhibition of mitosis and cell division. Inhibition of microtubule assembly.	(K. Lewis et al., 2016)
Picloram	1918-02-1	Pyridina	Systemic. Selective, systemic, absorbed by roots and leaves and translocated. Plant growth inhibition.	(K. Lewis et al., 2016)
S-metolachlor	87392-12-9	Chloroacetanilide	Systemic. Inhibition of cell division.	(K. Lewis et al., 2016)
Terbutryn	886-50-0	Triazine	Systemic. Inhibits photosynthesis (photosystem II).	(K. Lewis et al., 2016)
Topramezone	210631-68-8	Benzoylpyrazole	Systemic. Oxidative damage due to lack of vitamin E, destruction of chlorophyll.	(K. Lewis et al., 2016)
Trifloxisulfuron	145099-21-4	Sulfonylurea	Systemic. Inhibits the synthesis of plant amino acids.	(K. Lewis et al., 2016)
Insecticides				
Acephate	30560-19-1	Organophosphate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	(K. Lewis et al., 2016)
Bifenthrine	82657-04-3	Pyrethroid	Contact. Prevents the closure of voltage-gated sodium channels in axonal membranes.	(K. Lewis et al., 2016)
Carbofuran	1563-66-2	Carbamate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	(K. Lewis et al., 2016)
Carbosulfan	55285-14-8	Carbamate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	(K. Lewis et al., 2016)

Active ingredients	CAS	Chemical group	Mode of action	Reference
Chlorantraniliprole	500008-45-7	Anthranilic diamide	Exhibits larvicide activity as an orally ingested toxicant by targeting and disrupting Ca2+ balance; causes impaired regulation, paralysis, and ultimately death	(K. Lewis et al., 2016)
Fipronil	120068-37-3	phenyl pyrazole	Broad spectrum with contact and stomach action. GABA chloride channel antagonist.	(K. Lewis et al., 2016)
Cypermethrin	52315-07-8	Pyrethroid	Contact. Prevents the closure of voltage-gated sodium channels in axonal membranes.	(K. Lewis et al., 2016)
Chlorpyrifos	2921-88-2	Organophosphate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	(K. Lewis et al., 2016)
Imidacloprid	138261-41-3, 105827-78-9	Neonicotinoid	Systemic with contact and stomach action. Acetylcholine receptor agonist (nAChR).	(K. Lewis et al., 2016)
Lambda cyhalothrin	68085-85-8	Pyrethroid	Contact. Prevents the closure of voltage-gated sodium channels in axonal membranes.	(K. Lewis et al., 2016)
Novaluron	116714-46-6	Benzoylurea	Chitin synthesis inhibitor, insect growth regulator.	(K. Lewis et al., 2016)
Tebufenozide	112410-23-8	Hydrazine	It accelerates the molting of lepidopteran larvae, which stop feeding within a few hours of exposure and then go through a lethal molt.	(K. Lewis et al., 2016)
Terbufós	13071-79-9	Organophosphate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor. Insecticide and nematicide.	(K. Lewis et al., 2016)
Thiamethoxan	153719-23-4	Neonicotinoid	Systemic with contact and stomach action. Acetylcholine receptor agonist (nAChR).	(K. Lewis et al., 2016)
Thiocyclam-h-oxalate	31895-22-4	Trithiane	Selective, it blocks nicotinic acetylcholine in the central nervous system.	(K. Lewis et al., 2016)
Triflumuron	64628-44-0	Benzoylurea	Chitin synthesis inhibitor, insect growth regulator.	(K. Lewis et al., 2016)
Rodenticides				
Brodifacoum	56073-10-0	Coumarin	Inhibits the enzyme vitamin K epoxy reductase. It is an anticoagulant.	(K. Lewis et al., 2016)
Coumatetralyl	5836-29-3	Coumarin	Inhibits the enzyme vitamin K epoxy reductase. It is an anticoagulant.	(J. Routt Reigart et al., 2013)
Flocoumafen	90035-08-8	Coumarin	Inhibits the enzyme vitamin K epoxy reductase. It is an anticoagulant.	(K. Lewis et al., 2016)

The following graphs summarize the quantities of the main herbicides and insecticides applied in sugarcane fields in 2019. According to the calculations made by cultivated areas, the herbicides applied in most of the sugarcane fields are diuron (69.3 tons), 2,4-D (68.5 tons) and glyphosate (50.8 tons) (Figure 13).

The insecticides mainly applied in the sugarcane fields are chlorpyrifos (3.3 tons), imidacloprid (2.7 tons) and terbufos (1.9 tons) (Figure 14). As for fungicides, these are triadimenol (340 kg) and pyraclostrobin (12 kg).

2.4 Conclusion

The value of annual agrochemical imports in El Salvador is equivalent to US$55 million in pesticides and fertilizers. The most used pesticides are 2,4-D, glyphosate and paraquat for herbicides and thiodicarb, chlorpyrifos and imidacloprid for insecticides. In Central America, El Salvador (1,515 tons) is a modest consumer of pesticides compared to Costa Rica (10,547 tons) and Guatemala (10,547 tons) (Bravo et al., 2011). However, these numbers depend on the area cultivated, the type of crop and the way it is grown. For example, in 2004 El Salvador consumed 70% more pesticide per cultivated hectare than Nicaragua, but 12 times less pesticide per cultivated hectare than its counterpart Costa Rica (Bravo et al., 2011). Agrochemical use in El Salvador is interrupted by crop cycles that include massive fertilizer use in July and pesticide use between April and August.

Regarding absolute consumption, basic grains production is the leading consumer of herbicides and insecticides in the country, and this is explained by the fact that these crops account for 65% of the cultivated areas. However, herbicide consumption per unit area is approximately 2.6 times higher in sugarcane fields than in basic grains. Coffee crops are the largest consumers of fungicides. This disparity in herbicide use in sugarcane compared to basic grains in El Salvador is important to note because it implies that the sugarcane worker is much more exposed to the effects of these chemicals than the basic grains worker, although both can suffer from their effects.

Conventional sugarcane crops use synthetic pesticides and mineral fertilizers during land preparation, plant growth and often prior to harvest to increase sugar yields. Of the 287 pesticide formulations registered for sugarcane crops by MAG, 134 were imported and used between August 2018 and September 2019. Most active ingredients used are herbicides (diuron, 2,4-D, paraquat) followed by insecticides (chlorpyrifos, imidacloprid and terbufos).

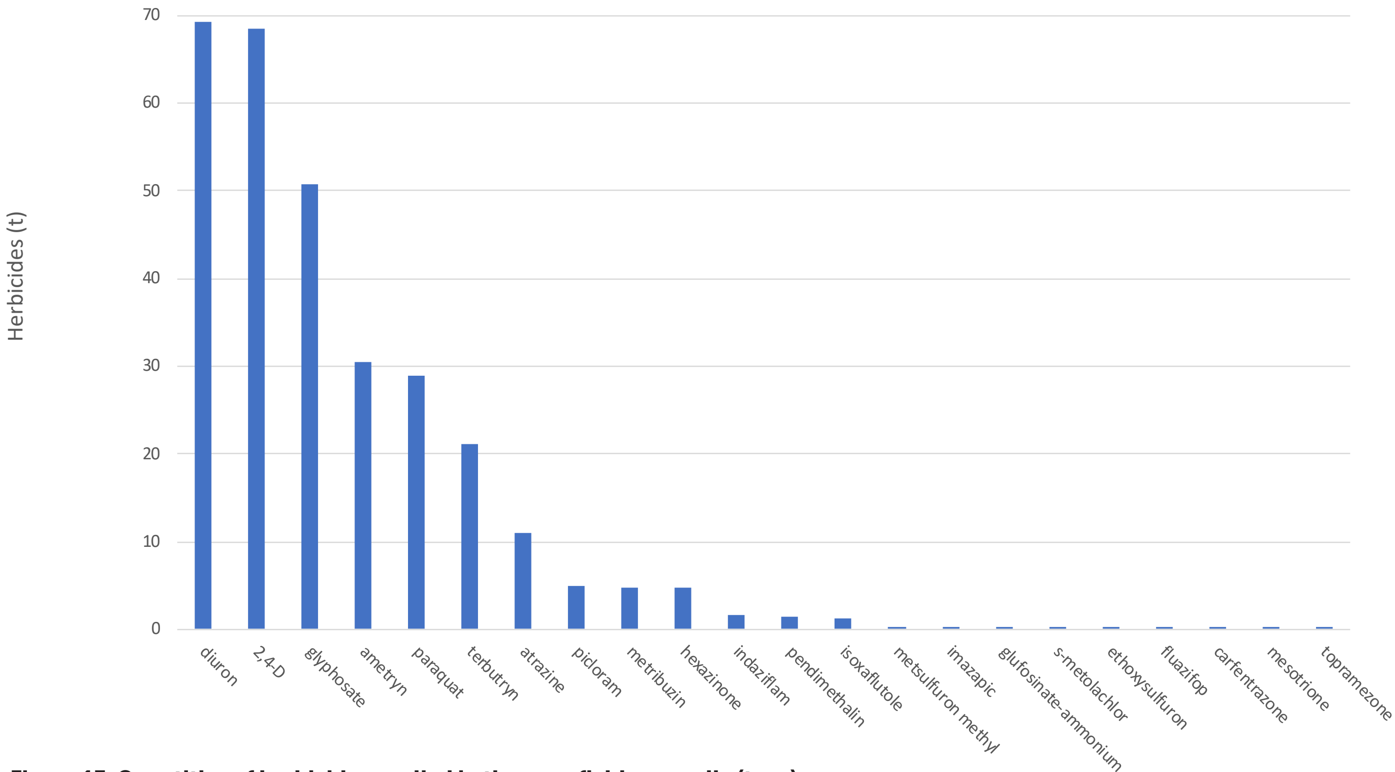

Figure 13 Quantities of herbicides applied in the cane fields annually (tons).

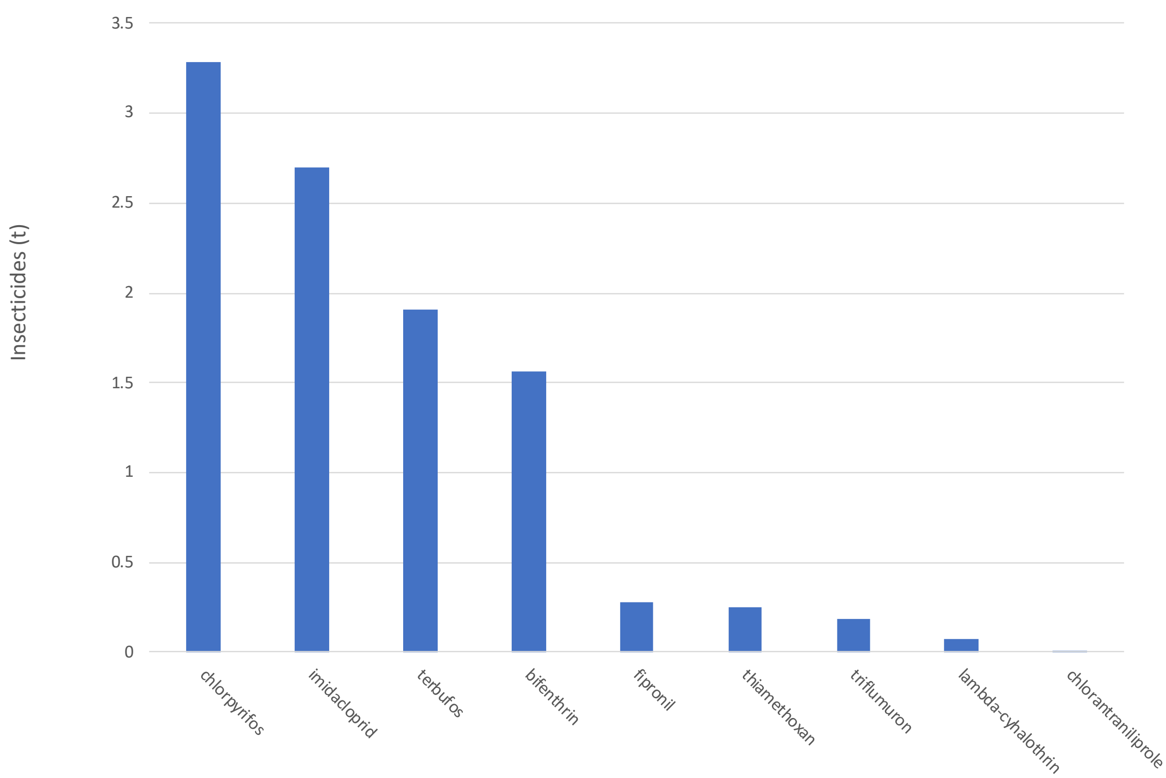

Figure 14 Quantities of insecticides applied in the cane fields annually (tons).

3 Identification of the Hazards of the Active Substances used in Sugarcane Plantation

3.1 Introduction

Hazard identification of active substances is the first step in the risk assessment of chemicals. It involves the identification of the inherent hazards of each substance to human health and the environment. The next step after hazard identification is the characterization of human and environmental exposure to these substances. Hazard identification followed by exposure characterization defines the risk associated with the use of pesticides or other chemicals.

The first step in this chapter was to define the different hazard indicators for human health and the aquatic environment including, surface waters and aquifers and to obtain an overview of the substances of greatest concern a scoring system was developed to highlight the substances. It is important to note that exposure in other environmental phases such as soil, air and food has not been considered in this study

3.2 Methodology

3.2.1 Identification of Human Health Hazards

Different parameters for acute and chronic toxic effects were considered to identify the hazards of each active substance. The general parameters selected are based on the criteria to be provided for human health risk assessment when registering pesticides in the United States (Damalas & Eleftherohorinos, 2011) and in Europe (ECHA, 2019). Hazard identification is the evaluation of the inherent ability of a substance to cause adverse human health effects (ECHA, 2019). Many of the potential toxic effects tested in the European Union and the United States are the same, although legally recognized standardized laboratory tests may differ. As part of this work, no assessment of the reliability and relevance of the toxicological study results was carried out because the results included in this work are from official agency reports or scientific reports from agencies such as the World Health Organization (WHO), the European Food Safety Authority (EFSA), the European Chemicals Agency (ECHA), the United States Environmental Protection Agency (US-EPA), where toxicological data quality assessment has already been carried out. An exception was made for variables of evaluation that were not found in the official reports and that seemed important in the Salvadoran context, such as nephrotoxicity or deleterious effects on the kidneys. The reasons for this are based on the large and increasing incidence of chronic kidney disease in El Salvador, especially that known as CINAC (Chronic Interstitial Nephritis in Agricultural Communities), which is widespread in communities associated with sugarcane cultivation (Vandervort et al., 2014) and other agricultural communities in El Salvador (e.g., Orantes et al., 2017).

Unfortunately, it has not been possible to compile official positions such as the immunotoxicity of substances, because this information is not available or there is hardly available and no database has been found that systematizes such information. According to ECHA (2013), indicators of the effect of substances on the immune system are currently being discussed in different scientific groups (ECETOC, IPS, etc.). The only integrated effects that are partially related to immunotoxicity are the cases of skin and respiratory organ sensitization reported in the ECHA database. In addition to the commonly considered criteria for assessment, the evaluation of effects on the liver and the biliary system was carried out when assessing the cumulative effects of certain pesticide groups, including neurotoxic effects and effects on reproduction and development (EFSA, 2013).

Criteria for identifying human health hazards include acute, subchronic and chronic effects. Some of these effects may be considered purely acute (e.g., lethal doses) or chronic (e.g., carcinogenicity), while others may have short- and long-term effects (e.g., neurotoxicity).

Acute toxicity:

Is judged by the lethal dose at 50% of the population (LD50) of rats (skin and oral) in laboratory tests. The toxicity threshold has been established according to the category of the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). Category 3 corresponds to a description "toxic if swallowed" and "toxic in contact with skin" corresponding to an LD50 (oral) 50-300 mg/kg bw (body weight) and an LD50 (dermal) 200-1000 mg/kg bw. These thresholds were selected because they are the "hazard" threshold in the GHS system. LD50 data were obtained from the World Health Organization (WHO) document on the classification of hazardous pesticides (WHO, 2010b). Missing substances have been completed from the United States Environmental Protection Agency pesticide registration review dossiers. (US-EPA, 2019) and the Pesticide Properties Database (K. Lewis et al., 2016).

Irritation and corrosivity:

The irritant or corrosive potential of a substance is assessed according to the GHS classification of the ECHA database (ECHA, 2019). Irritation is assessed according to the ability of a substance to cause local inflammation after a single exposure. Corrosivity of a substance is assessed according to its ability to destroy tissue (ECHA, 2013).

Skin and respiratory system sensitization:

Skin sensitization caused by a substance determines its ability to cause allergic reactions (ECHA, 2013). Hypersensitivity of the respiratory system does not refer to a specific mechanism of toxicity but to symptoms such as asthma (ECHA, 2013). The corrosivity of a substance is assessed in terms of its ability to destroy tissue (ECHA, 2013).

Endocrine disruptors:

For this hazard assessment criterion, the European Commission (EC) definition has been used. According to Okkerman & van der Putte (2002): "An endocrine disruptor is a substance or exogenous mixture that alters the function(s) of the endocrine system and therefore causes adverse health effects in an intact organism, or in its progeny or (sub)populations".

The 435 substances evaluated in this research for the European Commission were compared and included in the database. Pesticides that meet the characteristics of category 1 (at least one study shows that it is an endocrine disruptor in an intact organism) or 2 (potential endocrine disruptor based on in vitro, in vivo, or structural analysis tests) have been reported as endocrine disruptors. Substances in categories 3a (no scientific basis for listing an endocrine disruptor) and 3b (no data) have not been marked for this hazard characteristic.

Carcinogenicity:

Is a parameter for judging whether a substance or mixture of substances induces or increases the incidence of cancer. Cancer is characterized by an "uncontrolled growth of altered cells with the ability to migrate from their original site to another location in the body" (Stepa et al., 2019). The 34 substances were searched in the database of the International Agency for Research on Cancer (IARC, 2019), European Chemicals Agency (ECHA, 2019), pesticide properties database (K. Lewis et al., 2016) and the specific files of the U.S. Environmental Protection Agency. The selected pesticides are substances classified as carcinogenic (IARC Class 1. or US-EPA Class A.), probably carcinogenic (IARC Class 2A or B. US-EPA) and possibly carcinogenic (IARC Class 2B or C. US-EPA). Substances in categories that are not classifiable as carcinogenic (IARC or D US EPA Class 3) and probably not carcinogenic (IARC or E US EPA Class 4) have not been flagged for this hazard characteristic.

Mutagenicity:

The mutagenicity of a substance is its ability to induce genetic modifications in the exposed organism. Some of these mutations have no effect, while others may adversely affect the target cell. If the affected cell is a germ cell, it can affect several generations causing fertility problems, malformations, genetic diseases, etc. It can also lead to cancers (Stepa et al., 2019). The 34 substances were searched in the Chemical Carcinogenesis Research Information System (CCRIS, 2019) to verify if there are positive results of standardized mutagenicity tests. If so, additional research was conducted in an official organ registry file to consult the interpretation made by a specialist on this characteristic (US-EPA and Australian Pesticides and Veterinary Medicines Authority) (APVMA, 2019).

Reproductive Toxicity:

Is defined as "all the harmful effects that a substance may have on the reproductive cycle, the reproductive functions of males and females and on the fetus"(Nikolaidis, 2017). The reproductive toxicity data were imported directly from the external scientific report published in 2013 to the European Food Safety Authority (EFSA, 2013). The evaluation criteria of this report are based on effects on embryo/fetal development until sexual maturation and effects on sexual function and fertility (EFSA, 2013). Missing substances were searched for in the U.S. Environmental Protection Agency's substance-specific files, the World Health Organization report, and the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment reports (OEHHA, 2019) and the Pesticide Properties Database (K. Lewis et al., 2016).

Neurotoxicity:

Is defined as (Nielson et al., 2012) "any adverse effect on the structure or function of the nervous system related to exposure to a chemical". Neurotoxicity may be indicated by morphological changes (structural) in the central or peripheral nervous system or specific sensory organs, neurophysiological (e.g., electroencephalographic changes), behavioral (functional) and/or neurochemical (e.g., neurotransmitter levels) changes. Symptoms of neurotoxicity may appear immediately after exposure or later. The list of 34 active substances has been updated in terms of their neurotoxic effects according to the scientific report submitted to the European Food Safety Authority (EFSA, 2013). The missing substances have been completed according to the US EPA approval files.

Effects on the liver:

Including the biliary system: Substances with a harmful effect on the liver and biliary system were compiled based on the evaluation of the scientific report (EFSA, 2013). The studies considered in this work are substances targeting the liver and bile with reported effects such as degeneration and cell death, hypertrophy, cholestasis, among others (EFSA, 2013). Only substances with evidence of adverse effects on the liver and biliary system were selected.

Nephrotoxicity and kidney effects:

This indicator is based on research conducted in the TOXNET (Toxicological Data Network) of the United States National Library (TOXNET, 2019). Retained substances with a potentially toxic effect on the kidneys are substances that directly damage this organ through atrophy, necrosis, deterioration. Toxicological studies reporting loss of kidney function and increased incidence and severity of kidney disease were also included.

3.2.2 Human Health Scoring System

The 12 human health toxic effect criteria detailed in the previous chapter including carcinogenicity, mutagenicity, reproductive toxicity, endocrine disrupting, kidney, liver, neurotoxicity, acute toxicity, skin irritation/corrosion, eye irritation/corrosion, skin sensitization, respiratory hypersensitivity was integrated into a scoring system. In general, for each of the criteria a score of 1 point was given if the substance met the threshold established in the previous chapter. Two exceptions were made. First, for the criteria "Eye irritation/corrosion" and "Skin irritation/corrosion" a score of 0.5 was given for irritant substances and a score of 1 for corrosive substances, i.e., a higher degree of hazard. Secondly, to integrate proportionality in terms of toxic potential, substances in GHS toxicity classes 1 (fatal), 2 (lethal) and 3 (toxic) were scored with 3 points, 2 points and 1 point. The scores for each active substance were calculated per use class and the final score was determined (Table 6).

3.2.3 Hazard Identification for the Aquatic System

The hazard identification is mainly based on the persistence, bioaccumulation, and toxicity (PBT) indicators used by the European Chemicals Agency (ECHA, 2017b) and the US Environmental Protection Agency (US EPA, 2008). The use of PBT substances or so-called very persistent and very bioaccumulative substances (vPvBs) is of great concern because they can persist in the environment for long periods of time, accumulate in living organisms and affect the proper functioning of the ecosystem (EMA, 2014).

In addition to these basic parameters, the mobility capacity of each substance from the soil to the aquifer was also included. This parameter was added according to the methodology for prioritizing emerging substances of the NORMAN network (Network of reference laboratories and related organizations for monitoring and biomonitoring of emerging environmental substances).

The definition and thresholds used to distinguish a substance as toxic, persistent, very persistent, bioaccumulative or very bioaccumulative are given below:

Persistence:

The lifetime of a chemical in different environmental compartments such as marine and freshwater, sediment, and soil. The persistence of a substance also characterizes the type of degradation it undergoes (hydrolysis, photolysis, biodegradation, etc.). The thresholds used are those used for pesticide registration in the European Union (ECHA, 2017b) supplemented by those of the NORMAN network. Substances are evaluated according to their half-life in these compartments, meaning the time required to degrade 50% of the substance. A substance is considered persistent if its half-life is greater than one of these thresholds, i.e., >60 days in marine waters; >40 days in freshwaters and estuaries; >180 days in marine sediments; >120 days in freshwater or estuarine sediments or >120 days in soil. A substance is very persistent if its half-life is:> 60 days in marine, fresh or estuarine waters: > 180 days in fresh, salt, or estuarine water sediments;> 180 days in soil (ECHA, 2017b), in other words >60 days in all aquatic environments and >180 days in all solid environments. To these thresholds was added the threshold of potentially persistent according to the NORMAN network threshold with a half-life in water (fresh, marine, estuarine) of > 20 days or > 60 days in sediment (fresh, marine, estuarine) (NORMAN, 2013).

Bioaccumulation:

According to ECHA (ECHA, 2017a, p.10): "Accumulation is a general term for the net result of absorption (uptake), distribution, metabolism and excretion (ADME) of a substance in an organism." Bioaccumulation in aquatic organisms is estimated based on the bioconcentration factor (BCF), which is the ratio of the concentration of the substance in the aquatic organism to the concentration of the substance in water. It is noted that bioaccumulation considers all exposure pathways (e.g., dietary) and BCF only considers that of the aqueous phase (ECETOC, 1995). The ECHA thresholds are characterized by a BCF > 2000 for bioaccumulative substances and a BCF > 5000 for substances considered to be very bioaccumulative. To these bioaccumulation criteria have been added those of the NORMAN network (NORMAN, 2013). In accordance with the NORMAN network, a substance is potentially bioaccumulative if the BCF > 500 (NORMAN, 2013).

Toxicity:

In line with ECHA (ECHA, 2017b), a substance is considered toxic if it meets one of the following criteria: NOEC (No Observed Effect Concentration) or EC10 (adverse effect concentration for 10% of organisms) for marine and freshwater aquatic organisms <0.01 mg/L; substances that are carcinogenic (category 1A, 1B), germ cell mutagenic (category 1A, 1B) or toxic to reproduction (category 1A, 1B or 2); substances identified according to European regulations as having specific target organ toxicity. To these toxicity criteria have been added those of the NORMAN network (NORMAN, 2013) for toxicity to aquatic organisms.

As stated in the NORMAN network, a substance is very toxic if the PNEC < 0.01 µg/L (Predicted No Effect Concentration), toxic if the PNEC < 0.1 µg/L and potentially toxic if the PNEC < 1 µg/L (NORMAN, 2013).

This information has been gathered for each of the 39 active substances in the following order of sources:

1. C&L Inventory Database - ECHA, European Chemicals Agency (ECHA, 2020).

2. Pesticides database of the European Commission (EC, 2019a).

3. NORMAN database (Network of reference laboratories, research centers and related organizations for monitoring of emerging environmental substances) (NORMAN, 2020).

4. Finally, to complete the missing information, mainly data on the persistence of substances,

investigations were performed on the official files reviewed. These are mainly the EFSA (European Food Safety Authority) and US EPA (United States Environmental Protection Agency), files of the European Commission for the elaboration of environmental quality standards.

Mobility:

Substances that can potentially infiltrate the aquifer are identified conforming to their persistence (DT50 soil or water) and their potential not to adsorb on organic carbon and clays present in the soil (mobility). Mobility is estimated using the adsorption coefficient of the substance with organic carbon (Koc) or the octanol-water coefficient (Kow) (Kozel & Wolter, 2018).

3.2.4 Scoring System for the Aquatic System

To obtain an overview of substances with the characteristics of most concern for the environment, a PBMT score was computed according to the NORMAN method. A score of 0.5 was assigned to substances characterized as potentially persistent, potentially bioaccumulative, potentially toxic and potentially mobile. A score of 1 was assigned to substances characterized as persistent, bioaccumulative, toxic and mobile. A score of 2 was assigned to substances characterized as very persistent, very bioaccumulative, very toxic and very mobile.

3.3 Results

3.3.1 Identification of Hazards and Substances of Concern for Human Health

For the acute toxicity indicator, seven substances were identified that exceed the threshold characterized as toxic if the substance is ingested or meets the skin. Of these 7 substances, 3 are considered fatal (terbufos, flocoumafen, coumatetralyl) and 4 are considered toxic (paraquat, fipronil, lambda cyhalothrin, chlorpyrifos). Flocoumafen and coumatetralyl are rodenticides with anticoagulant activity, therefore they are at the top of the list (Table 6).

The herbicides on the list of substances under consideration generally have a moderate to low acute toxicity (lethal dose), which could be explained by the fact that these substances have a toxic action designed to inhibit plant metabolism (inhibition of photosynthesis) (Table 5, chapter 2.3.3).

Among the herbicides, only paraquat is considered toxic according to its acute toxicity level. Active substances classified as toxic or lethal are mainly insecticides such as fipronil, lambda cyhalothrin and chlorpyrifos. These insecticides are mainly nerve agents targeting key enzymes such as acetylcholinesterase and inhibiting sodium channels involved in axonal transmission, also present in humans (Čolović et al., 2013; Corbel et al., 2009).

The most frequent effects (Figure 15) for the 39 active ingredients considered in descending order are harmful effects on the reproductive system (27 substances), liver and biliary system (24), endocrine disruptors (16). The fourth reported effect includes substances toxic to the kidneys (13 substances), including 10 herbicides (2,4-dichlorophenoxyacetic acid, glyphosate, paraquat, diuron, mesotrione, ametryn, atrazine, fluazifop, picloram, topramezone) and 3 insecticides (fipronil, imidacloprid and thiamethoxan). The intense use of herbicides in sugarcane cultivation and the incidence of CINAC seem to be explained by the effect of herbicides on the kidneys.

Sixth and seventh among the reported effects are neurotoxicity and carcinogenicity. Glyphosate has been put in brackets because its carcinogenicity is still under discussion in different expert groups such as the International Agency for Research on Cancer (IARC) and the European Food Safety Authority (SCAHT & Ecotox Centre, 2018).

The possible and probably carcinogenic substances include 7 herbicides (2,4-D, glyphosate, diuron, s-metolachlor, isoxaflutole, pendimethalin, terbutryn) and 1 insecticide (fipronil).

Not all the listed effects on human health can be considered equally, while the fact that a substance is carcinogenic should already serve to significantly limit worker exposure, if not to replace it with a less hazardous alternative (EASHW, 2004). Another example is the mutagenic potential of some substances such as paraquat, lambda cyhalothrin and hexazinone. In fact, if these genetic mutations occur in germ cells, they can be inherited over several generations and can lead to reduced fertility, malformations, genetic diseases, and embryonic death (Stepa et al., 2019). However, to prioritize active substances with multiple hazard characteristics, a scoring system discussed in subchapter 3.2.2 has been implemented.

The system of punctuation indicates that the active substances that reveal, based on the scoring system and current scientific knowledge, the greatest multiplicity of hazardous characteristics for human health are herbicides: 2,4-D (7), paraquat (5.5), glyphosate (5-6), s-metolachlor (5) and diuron (5). Similarly, the insecticides with the most hazardous characteristics for human health are lambda cyhalothrin (7), fipronil (6), terbufos (6), imidacloprid (5) and chlorpyrifos (4).

3.3.2 Identification of Hazards and Substances of Concern to the Aquatic System

Information on the uses of the 39 active substances (fungicides, herbicides, insecticides, insecticides, growth regulators and rodenticides) is provided in Appendix 10.3 (List of environmental hazards) of this document.

From the information gathered and the analyses performed, seven substances are very persistent which include four herbicides (indaziflam, 2,4-dichlorophenoxyacetic acid, terbutryn and paraquat), two insecticides (imidacloprid and chlorantraniliprole) and one rodenticide (flocoumafen). To these 7 substances are added 10 substances considered persistent as defined in the previous chapter among them 6 herbicides (atrazine, hexazinone, metribuzin, ametryn, topramezone, picloram) and 4 insecticides (chlorpyrifos, fipronil, thiamethoxan, lambda-cyhalothrin).

According to the indicator of bioaccumulation, three substances are classified as very bioaccumulative (flocoumafen, chlorpyrifos, imazapic) and two substances as bioaccumulative (atrazine, carfentrazone). Triflumuron and pyraclostrobin are considered potentially bioaccumulative.

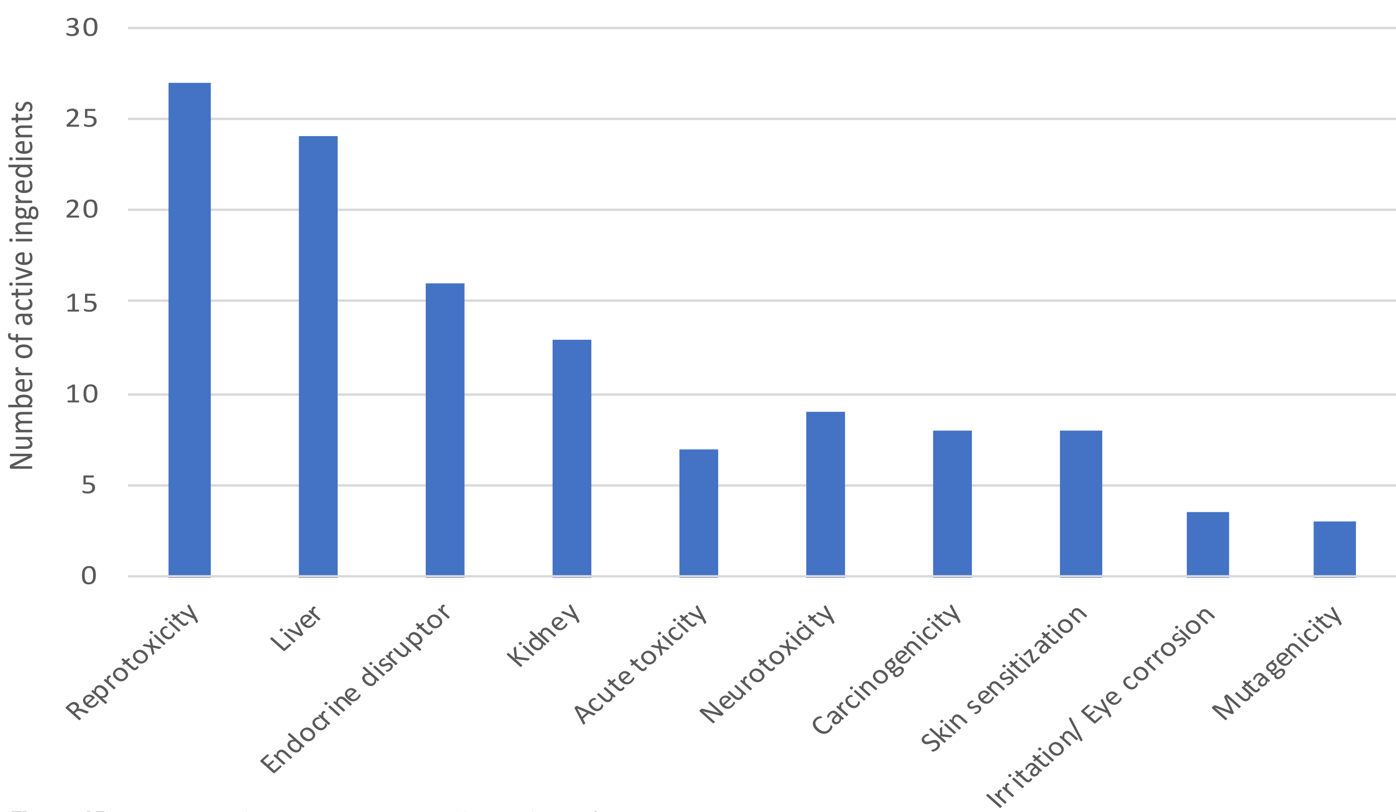

Figure 15 Frequency of acute and chronic effects of the 39 active substances characterized.

Table 6 Scoring and classification according to the hazard indicators of the active substances. Columns marked with a "1" are substances that meet the hazard class criteria established in this research for the indicators of carcinogenicity, mutagenicity, reproductive toxicity, endocrine disruptor, renal toxicity, hepatic toxicity, neurotoxicity, acute toxicity, skin corrosivity, eye corrosivity, skin and respiratory sensitization. Substances marked with a "0.5" are those that cause skin or eye irritation. Substances in the "acute toxicity" column marked with a "2" or "3" are lethal substances (toxic and very toxic).

Actives ingredients	CAS	Total points	Carcinogenicity	Mutagenicity	Reproductive toxicity	Endocrine disruptor	Kidney	Liver	Neurotoxicity	Acute toxicity	Irritation/skin corrosion	Irritation/eye corrosion	Sensibilización de la piel	Respiratory hypersensitivity
Fungicides														
Pyraclostrobin	175013-18-0	2	0	0	1	0	0	1	0	0	0	0	0	0
Herbicides														
2,4-D	94-75-7	7	1	0	1	1	1	1	1	0	0	1	0	0
Paraquat	1910-42-5	5.5	0	1	0	1	1	1	0	1	0	0.5	0	0
Glyphosate	1071-83-6	5-6	(1)	0	1	1	1	1	0	0	0	1	0	0
S-metolachlor	51218-45-2	5	1	0	1	1	0	1	0	0	0	0	1	0
Diuron	330-54-1	5	1	0	1	1	1	1	0	0	0	0	0	0
Mesotrione	104206-82-8	4	0	0	1	0	1	1	0	0	0	0	1	0
Isoxaflutole	141112-29-0	4	1	0	1	0	0	1	1	0	0	0	0	0
Carfentrazone	128621-72-7	4	0	0	1	1	0	1	0	0	0	0	1	0
Pendimethalin	40487-42-1	4	1	0	0	1	0	1	0	0	0	0	1	0
Fluazifop	69335-91-7	3	0	0	1	0	1	1	0	0	0	0	0	0
Ethoxysulfuron	126801-58-9	3	0	0	1	0	0	1	0	0	0	0	1	0
Metribuzin	21087-64-9	3	0	0	1	1	0	1	0	0	0	0	0	0
Ametrine	834-12-8	3	0	0	0	1	1	0	0	1	0	0	0	0
Atrazine	1912-24-9	3	0	0	1	1	1	0	0	0	0	0	0	0
Picloram	1918-02-1	3	0	0	0	1	1	1	0	0	0	0	0	0
Hexazinone	51235-04-2	2.5	0	1	1	0	0	0	0	0	0	0.5	0	0
Clethodim	99129-21-2	2	0	0	1	0	0	1	0	0	0	0	0	0
Topramezone	210631-68-8	2	0	0	1	0	1	0	0	0	0	0	0	0
Metsulfuron methyl	74223-64-6	2	0	0	1	0	0	0	0	0	0	0	1	0
Glufosinate Ammonium	77182-82-2	2	0	0	1	0	0	0	1	0	0	0	0	0

Actives ingredients	CAS	Total points	Carcinogenicity	Mutagenicity	Reproductive toxicity	Endocrine disruptor	Kidney	Liver	Neurotoxicity	Acute toxicity	Irritation/skin corrosion	Irritation/eye corrosion	Sensibilización de la piel	Respiratory hypersensitivity
Indaziflam	950782-86-2	2	0	0	0	0	0	1	1	0	0	0	0	0
Imazapic	104098-48-8	1	0	0	0	0	0	1	0	0	0	0	0	0
Terbutryn	886-50-0	1	1	0	0	0	0	0	0	0	0	0	0	0
Imazapir	81334-34-1	0.5	0	0	0	0	0	0	0	0	0	0.5	0	0
Insecticides														
Lambda cyhalothrin	68085-85-8	7	0	1	1	1	0	1	1	1	0	0	1	0
Fipronil	120068-37-3	6	1	0	1	0	1	1	1	1	0	0	0	0
Terbufos	13071-79-9	6	0	0	1	1	0	0	0	3	0	0	1	0
Imidacloprid	138261-41-3	5	0	0	1	1	1	1	1	0	0	0	0	0
Chlorpyrifos	2921-88-2	4	0	0	1	1	0	0	1	1	0	0	0	0
Thiamethoxan	153719-23-4	3	0	0	1	1	1	0	0	0	0	0	0	0
Triflumuron	64628-44-0	2	0	0	1	0	0	1	0	0	0	0	0	0
Tebufenozide	112410-23-8	2	0	0	1	0	0	1	0	0	0	0	0	0
Chlorantraniliprole	500008-45-7	0	0	0	0	0	0	0	0	0	0	0	0	0
Growth regulator														
Ethephon	16672-87-0	3	0	0	1	0	0	1	1	0	0	0	0	0
Trinexapac-ethyl	95266-40-3	2	0	0	1	0	0	1	0	0	0	0	0	0
Rodenticides														
Flocoumafen	90035-08-8	4	0	0	1	0	0	0	0	3	0	0	0	0
Coumatetralyl	5836-29-3	3	0	0	1	0	0	0	0	2	0	0	0	0

The substances considered highly toxic to the environment are 2 herbicides (indaziflam, metsulfuron methyl), 4 insecticides (imidacloprid, fipronil, lambda cyhalothrin, terbufos) and 1 rodenticide (flocoumafen). To these 7 highly toxic substances are included 10 other active ingredients considered toxic among them 8 herbicides (2,4-D, terbutryn, paraquat, hexazinone, metribuzin, imazapyr, isoxaflutole, pendimethalin) and 2 insecticides (chlorpyrifos, triflumuron). Potentially toxic substances total 10 including one fungicide (pyraclostrobin) and 9 herbicides (atrazine, carfentrazone, ametryn, topramezone, diuron, ethoxysulfuron, s-metolachlor, clethodim, fluazifop).

Substances considered "highly mobile", i.e., not strongly adsorbed on soil, and easily desorbed by rainfall and reaching watercourses or aquifers include 26 substances. This total includes 18 herbicides (see list in appendix 11.3), 3 insecticides and 2 growth regulators. Seven substances are considered "mobile" including 1 fungicide, 4 herbicides and 2 insecticides.

The graph below (Figure 16) summarizes the number of active ingredients with one or more of the hazardous properties. Special attention should be paid to PBT and vPvB (very persistent and very bioaccumulative) substances. PBT substances are of great concern because they are particularly hazardous to human health and the ecosystem. These substances can persist in the environment (water, soil, sediment), accumulate in the tissues of living organisms, and cause acute or chronic toxicity. Substances identified as PBTs by the criteria of this research are flocoumafen and chlorpyrifos. Substances that are very persistent and very bioaccumulative are also considered to be of high concern because their long-term effects are unknown. Only floucomafen is characterized in this way.

With the purpose of to understand the implications of PBT or vPvB assessment, the example of European legislation was used, since such legislation does not exist in El Salvador. At the European Union level, PBT and vPvB pesticides are not authorized for marketing without a more comprehensive risk assessment (Fabrizi, 2014).

However, chlorpyrifos has been banned at the European level for its genotoxic, neurotoxic and reprotoxic effects (EC, 2019b) because accessible data did not justify its persistence. Floucomafen is not allowed due to its vPvB characteristics (EU, 2016).

Substances that meet 2 of the 3 PBT criteria are candidates for substitution (EC, 2009). According to the analysis, this corresponds to 9 more substances in addition to those already considered, among them: 2,4-D, fipronil, hexazinone, imidacloprid, indaziflam, lambda cyhalothrin, metribuzin, paraquat and terbutryn.

Moreover, it has been added an analysis of pesticides with physicochemical characteristics that could contaminate drinking water resources in aquifers and/or pass drinking water treatment barriers. The indicators used are based on the proposal of Rüdel et al. (2020) to measure persistent, mobile, and toxic substances (PMT) as well as very persistent and very mobile substances (vPvM) in the class of substances of high concern. The list of substances includes 8 PMT substances with toxic activity can be found in drinking water and 5 vPvM substances. vPvM substances can circulate in water cycle and cause contamination that is difficult to remediate (Rüdel et al., 2020).

The substances at the top of the environmental hazard identification list (Table 7) are the herbicides indaziflam (6), terbutryn (5), 2,4-D (5), atrazine (4,5), imazapic (4), metribuzin (4), hexazinone (4), metsulfuron methyl (4). The insecticides of most concern are imidacloprid (6), fipronil (5), chlorpyrifos (5), chlorantraniliprole (4,5) and terbufos (4). The rodenticide floucomaphene (6) is also at the top of the list.

3.3.3 Summary of Hazards to Human Health and the Environment

In order to summarize the hazards identification of each substance to human health and the environment, the substances have been consigned in the following graph based on the score assigned to them in the previous chapters (Figure 17). This graph gives an overall perspective of the active substances of high concern for human health (right area of the graph) and for the aquatic ecosystem (upper area of the graph).

A horizontal green dotted line has been added on the Y-axis. This boundary corresponds to substances with at least 2 of the 4 possible environmental hazard

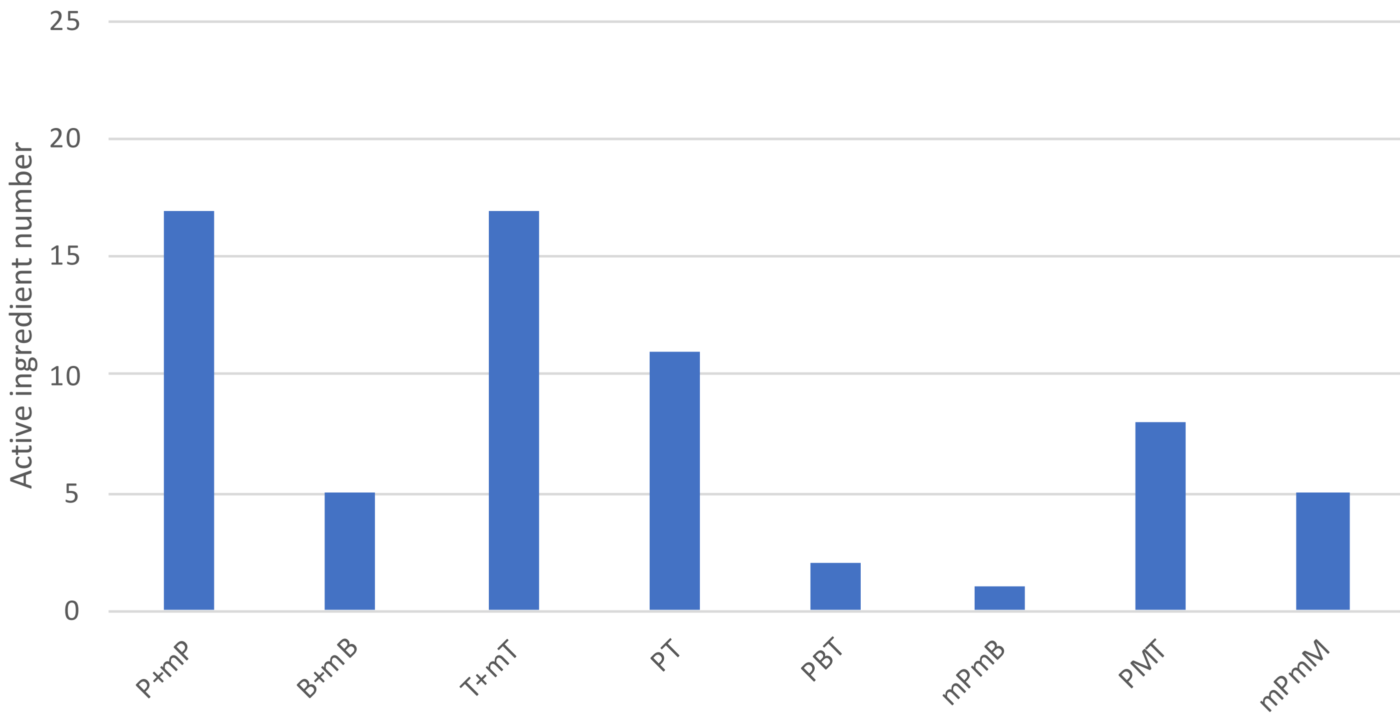

Figure 16 Number of substances characterized as T+vT (toxic and very toxic), P+vP (persistent and very persistent), B+vB (bioaccumulative and very bioaccumulative), PT (persistent and toxic), PBT (persistent, bioaccumulative, toxic), vPvB (very persistent and very bioaccumulative), PMT (persistent, mobile, toxic), vPvM (very persistent and very mobile).

characteristics (PMBT). A vertical red dotted boundary has also been added on the X-axis. This boundary corresponds to substances that are very toxic to human health or have at least 2 health hazard characteristics. The rectangle at the top right of the graph formed by the intersection of the two boundaries corresponds to substances of concern to the aquatic system and human health. There are 13 substances with hazard characteristics of concern to human health and the aquatic system. Regarding herbicides, 2,4-D, paraquat, ametrine and atrazine are the most widely used. As for insecticides, the most widely used are imidachloprid, chlorpyrifos, terbufos and fiponil.

This representation is indicative, but it does not take into consideration all the hazardous' characteristics to the environment and human health that need to be further examined thoroughly on a case-by-case basis. For example, some pesticides can cause an increased incidence of certain specific diseases (e.g., Parkinson's disease) have not been specifically considered in this assessment. There are also specific adverse effects on the ecosystem (e.g., disappearance of bees) by certain groups of substances (e.g., neonicotinoids) were not considered. It should also be noted that not all effects can be considered equivalent, e.g., the case of substances considered as CRMs, PBTs or vPvBs. These considerations are discussed in the conclusion. In any case, this graph seems to indicate the minimum degree of damage to health and the environment these agrochemicals can produce. If a higher score is assigned to effects such as carcinogenicity, then the score for some of these chemicals would increase and highlight their greater hazard.

3.4 Conclusion

The objective of this chapter was to identify intrinsic characteristics of each active ingredient that can be used, in sugarcane crops and are imported into the country. The substances were analyzed first in terms of their hazards to human health and then to the aquatic system and aquifers. An attempt was also made to assign the degree of hazard of each of the chemicals analyzed in terms of their effect and the amount of product used in El Salvador.

Table 7 PBMT criteria score result for active substances with pesticide effect.

Active ingredients	CAS	PBMT Total Score	Persistence	Bioaccumulation	Toxicity	Mobility
Fungicides						
Pyraclostrobin	175013-18-0	2	0	0.5	0.5	1
Herbicides						
Indaziflam	950782-86-2	6	2	0	2	2
Terbutryn	886-50-0	5	2	0	1	2
2,4-Dichlorophenoxyacetic acid	94-75-7	5	2	0	1	2
Atrazine	1912-24-9	4.5	1	1	0.5	2
Imazapic	104098-48-8	4	0	2	0	2
Metribuzin	21087-64-9	4	1	0	1	2
Hexazinone	51235-04-2	4	1	0	1	2
Metsulfuron methyl	74223-64-6	4	0	0	2	2
Carfentrazone	128621-72-7	3.5	0	1	0.5	2
Topramezone	210631-68-8	3.5	1	0	0.5	2
Ametrine	834-12-8	3.5	1	0	0.5	2
Isoxaflutole	141112-29-0	3	0	0	1	2
Paraquat	1910-42-5	3	2	0	1	0
Picloram	1918-02-1	3	1	0	0	2
imazapyr	81334-34-1	3	0	0	1	2
Ethoxysulfuron	126801-58-9	2.5	0	0	0.5	2
Diuron	330-54-1	2.5	0	0	0.5	2
S-metolachlor	51218-45-2	2.5	0	0	0.5	2
Mesotrione	104206-82-8	2	0	0	0	2
Pendimethalin	40487-42-1	2	0	0	1	1
Fluazifop	79241-46-6	1.5	0	0	0.5	1
Clethodim	99129-21-2	1.5	0	0	0.5	1
Glyphosate	1071-83-6	1	0	0	0	1
Glufosinate Ammonium	70393-85-0	0.1	0	0	0	0.1
Insecticides						
Imidacloprid	138261-41-3	6	2	0	2	2
Fipronil	120068-37-3	5	1	0	2	2
Chlorpyrifos	2921-88-2	5	1	2	1	1
Chlorantraniliprole	500008-45-7	4.5	2	0	0.5	2
Terbufos	13071-79-9	4	0	0	2	2
Thiamethoxan	153719-23-4	3.5	1	0	0.5	2
Lambda cyhalothrin	68085-85-8	3	1	0	2	0
Tebufenozide	112410-23-8	2.5	0	0	0.5	2

Active ingredients	CAS	PBMT Total Score	Persistence	Bioaccumulation	Toxicity	Mobility
Triflumuron	64628-44-0	2.5	0	0.5	1	1
Growth regulator						
Ethephon	16672-87-0	2	0	0	0	2
Trinexapac-ethyl	95266-40-3	2	0	0	0	2
Rodenticides						
Flocoumafen	90035-08-8	6	2	2	2	0
Coumatetralyl	5836-29-3	2.1	0.1	0.5	0.5	1

Information on 12 indicators of acute and chronic effects on human health was compiled from risk assessment files from Europe and the United States and reports from international research centers and groups. The analysis revealed that a simplified analysis of the hazards of substances based on the acute toxicity indicator alone is not sufficient. In fact, only 7 of the 39 active substances analyzed have a toxic or fatal potential. However, when analyzing the other effects, 27 substances have a toxic effect on reproduction, 24 on the liver and biliary system, 16 have a potential effect as endocrine disruptors and 16 exert toxicity on the kidneys.

Seven active ingredients (potentially 8 with glyphosate) of the 39 used in El Salvador are possible or probable carcinogens. Of these 8 potentially carcinogenic substances (if glyphosate is included), 6 also have a reprotoxic effect (2,4-dichlorophenoxyacetic acid, diuron, fipronil, glyphosate, isoxaflutole, s-metolachlor). Based on the information gathered, none of the substances has the three CMR characteristics (carcinogenic, mutagenic and reprotoxic). From literature searches, only the herbicides paraquat, hexazinone and the insecticide lambda cyhalothrin have shown mutagenic effects.

The same exercise was repeated for the hazard indicators for environment considered in the European and American regulatory frameworks, such as persistence, bioaccumulation, and toxicity. To these indicators were added those proposed by the German Environment Agency, including the ability of the substance to reach the aquatic system and aquifer.

The analysis of these indicators revealed 11 PT substances (persistent and toxic), 2 PBT substances (persistent, bioaccumulative and toxic) and one vPvB substance (very persistent, very bioaccumulative). Of the 39 substances, 9 can end up in aquifers, 8 of which are toxic and 5 are very persistent and highly mobile. Given these same physicochemical qualities (mobile and persistent), these substances would be difficult to remove during water treatment for drinking water purification.

Hazard identification is only the first part of the risk assessment for human health and the environment. Therefore, the potential effect these substances may exert will depend on a multitude of factors such as exposure routes, duration, frequency, dose, potency of the substance under consideration (ECHA, 2013). This study has made it possible to identify the most hazardous substances for human health and the environment that are being applied in El Salvador. The recognition of these substances should be the first step in future studies that seek to identify the sources, mobility, and fate of these substances, as well as their possible elimination from the Salvadoran environment. With the purpose to characterize the exposure of humans and the environment to these pesticides, a case study was carried out in the lower zone of the Paz River.

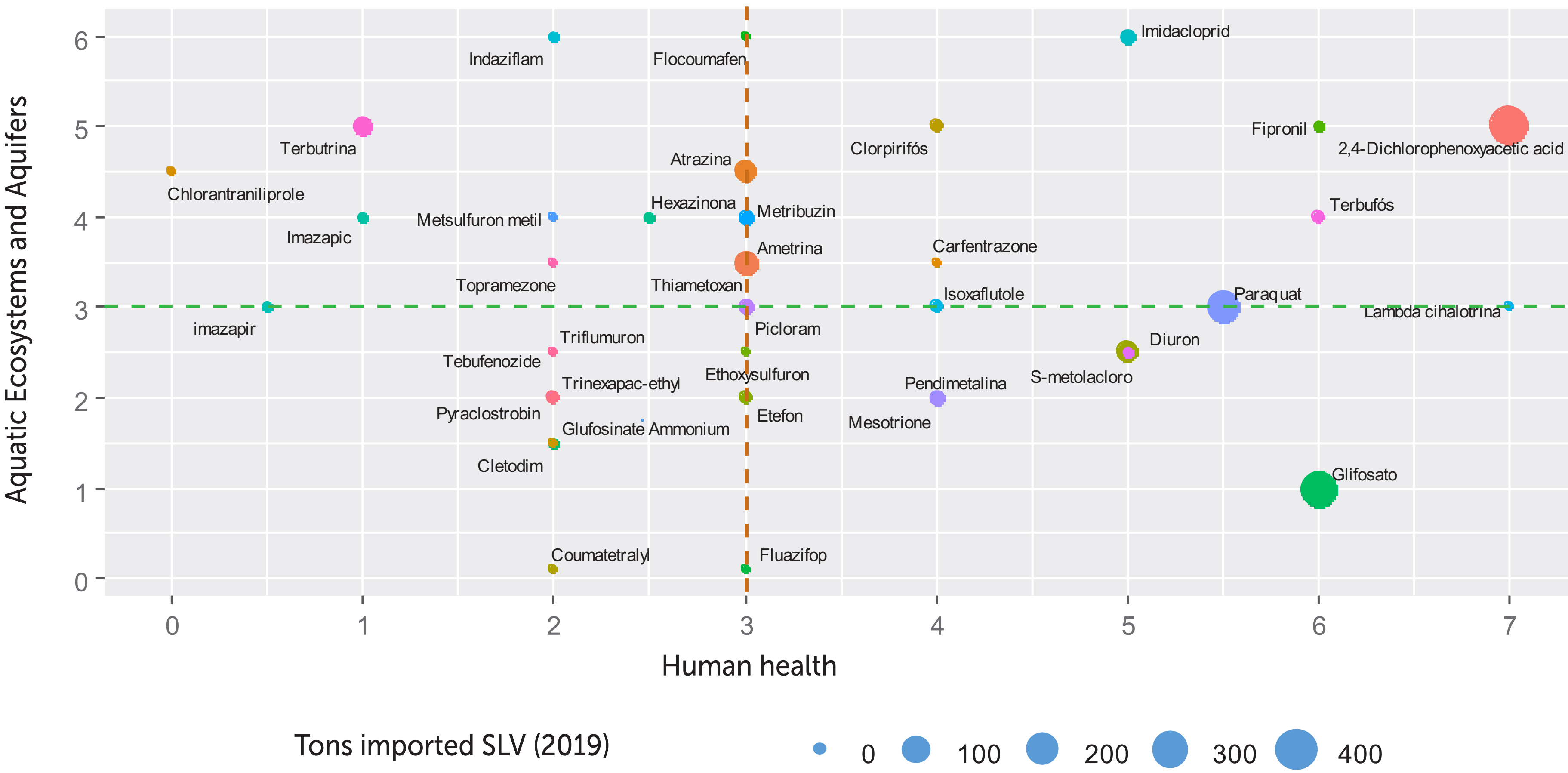

Figure 17 Results of the analysis of environmental and human health hazards. On the x-axis, scores are obtained for health hazards and on the y-axis, scores are obtained for hazards to the aquatic ecosystem and aquifers. The size of the points is proportional to the tons of products imported to El Salvador in the year 2018-2019 (MAG, 2019a).

4 Description of El Aguacate sub-basin of the Paz River and the Mangrove of Garita Palmera

4.1 Introduction

The previous chapter was dedicated to the identification of pesticides' hazards that can be used on sugarcane crops. The risk analysis of these products is not limited to sugarcane, as these products are also used on other crops. A central element in determining the risk to human health and the environment is to analyze how and under what conditions these products are used on this type of crop.

To answer this question, a case study was conducted in the lower zone of the Paz River (Figure 18). Although these investigations focus on the analysis of the risks caused using pesticides, it is essential to understand the context in which they occur. It would be simplistic to consider that the problem of pesticides can only be summarized in their direct effects on their users or the environment. It is necessary to place this problem in the context of the socio-economic reality of the region. For this purpose, this chapter is devoted to both the socio-economic and the physical and climatic description of the area. The last subchapter of this baseline reports on the results obtained during the analysis of local territorial conflicts related to the sugar industry and the use of pesticides.

4.2 Methodology

The biophysical, socioeconomic, and hydrological description of the study area is based on the bibliographic compilation of reports made on this area by other authors.

The analysis of the actors in the territory and of the conflicts related to the presence of sugar crops in the territory was carried out according to the method of "conflict-context analysis" (Marthaler & Gabriel, 2010). This method was used for two different purposes. First of all, this method made it possible to analyze the opportunities and risks associated with the research process in the territory with fragile and conflict-affected contexts. Secondly, it made it possible to analyze the actors involved, the sources of conflicts and reconciliations, and to gather information on the socio-environmental impacts of sugarcane cultivation.

This analysis was carried out during one day with representatives of 11 communities (10 women, 11 men) in the study area. The people who participated in the conflict analysis in the study area belonged to a large group of stakeholders: local farmers and fishermen, families living around the sugarcane fields and environmental protection associations and local autorities.

4.3 Results

4.3.1 Socioeconomic Description of the Area of Study

The area of study is located in the lower zone of the municipality of San Francisco Menéndez, department of Ahuachapán, in the western part of the country. The lower zone of this municipality is home to three cantons: La Hachadura, Garita Palmera and El Zapote, where more than 18 communities are established in which around 15 thousand people live, most of which have a constant interaction with the natural resources from the sub-basin El Aguacate river, the mangrove of Garita Palmera and El Zapote, the Paz riverbed (bordering Guatemala) and the tropical rainforest of El Zanjón El Chino, for the development of their livelihoods and use of resources.

The territory of the El Aguacate sub-basin is characterized by a dynamic economy that includes cross-border trade, subsistence agriculture, sugarcane production, the flow of remittances from abroad, tourism and artisanal fishing in the sea and mangroves; the main economic activities are subsistence agriculture, trade, and artisanal fishery.

Cross-border trade is determined by the flow of goods in the urban center of Cara Sucia, since customs and migratory activities at the La Hachadura border facilitate the exchange of goods in a formal and informal manner, being this urban center the point of reference for the peripheral cantons and settlements of San Francisco Menéndez, such as the southern region of Jujutla. Most families receive remittances from abroad, particularly from the United States, placing San Francisco Menéndez in the first 25 municipalities in the country that channel a large part of the total remittances that enter the country annually[5], since only in the first 3 months of 2020, the municipality managed to capture 13.4 million dollars in remittances.

Fishing in the Garita Palmera mangrove forest is one of the main livelihoods for some 1,700 families in 6 communities bordering the salt forest[6], since the different services provided by the salt forest facilitate income generation, food security, recreation, supplies for construction, medicine, etc., as well as representing a key means for natural disaster mitigation and adaptation to climate change (Table 8). The following is a prioritization of the elements of the mangrove's ecosystem of which the families make use of the natural service.

In the coastal zone of the territory, there are 3 communities (El Tamarindo, Garita Palmera and Bola de Monte) that have a fishing population of 48.2% in relation to the total number of people in their community, which is around 2,403 people in these communities. The most extracted species in this part of the mangrove are fish and crustaceans, 87.9% for food security, while fishermen prefer to extract them from the sea for commercial purposes. More than 80% of the coastal communities use the wood for construction

[5] Central Reserve Bank, Statistical Report on Family Remittances January - March 2020.

[6] Biophysical and Socioeconomic Study of the Garita Palmera Mangrove, MARN, 2016.

Table 8 Natural services of local ecosystems in the Aguacate river sub-basin. Source: MESAMA Advocacy Plan, UNES, 2019.

Ecosystem	Food	Housing	Economic income	Medicine	Recreation	Disaster prevention
Rivers			X		X	
Estuaries-Mangroves	X	X	X	X	X	X
Beaches			X	X	X	
Mouth	X		X		X	X

and firewood for cooking. El Aguacate River tributary is the only freshwater aquifer that supplies the ecosystem functions of the forest.

At the agricultural level, production dynamics vary depending on social strata and land concentration modalities, for example, the poorest families with little access to land, produce mostly basic grains and minor species as a means of subsistence; middle strata or with greater purchasing capacity, produce fruit, vegetables, sesame and plantain, in some cases, these strata are organized in cooperatives and a sector with agro-industrial capacity and greater concentration of land, produces and is part of the sugarcane market[7], establishing relationships with the Izalco Central Sugar Mill and the Salvadoran Sugar Association (CASSA) for the commercialization of this product in the national and regional market. On the other hand, livestock activity is characterized by cattle managed under free grazing, horses in free grazing and stables, pigs mostly in free range, with a low number of stables, and poultry in free range.

4.3.2 Hydrographic Description and Land Use

The El Aguacate sub-basin (also known as Brazo of Paz River) is part of the Paz River watershed that originates in the Quesada Mountains in the department of Jutiapa in Guatemala (EcuRed, 2019). The Paz River watershed has a total area of 2,647 km^2, of which 34% is located in El Salvador and 66% in Guatemala (Gallo & Rodríguez, 2010).

In the past, the main course of the Paz River delimited the border with Guatemala and passed through the wetlands of Bola de Monte and El Botoncillo, where it flowed into the Pacific Ocean (Figure 18). At that time, the Paz River also fed year-round into the El Aguacate River, which supplies freshwater to the Garita Palmera wetlands (G. Ramirez Villanueva, personal communication, 2020).

However, the lack of management of the upper and middle zones of the Paz Basin in terms of land use and water resources altered the hydrological balance and sediment dynamics of the Paz River (Gallo & Rodriguez, 2010). The upper part of the catchment area has a higher erosion potential than the middle part. All eroded material is deposited in the lower part of the catchment causing river blockage. This phenomenon also leads to the loss of soil and its nutrients by leaching in the upper part of the watershed (EcuRed, 2019). This change in sedimentary dynamics is one of the causes of the aggradation of the bed of the former perennial river El Aguacate, located in the lower zone of the Paz River basin (G. Ramirez Villanueva, personal communication, 2020).

After two extreme weather events, including hurricane Camille (1964) and hurricane Fifi (1974), the Paz River left its original channel (13°47'52.25 "N - 90° 7'2.06 "W) and flowed into an irrigation canal in Guatemalan territory (Gallo & Rodríguez, 2010). This phenomenon created what is now called the Nuevo Paz sub-basin located in Guatemalan territory (Gallo & Rodríguez, 2010). Currently, the former Paz Riverbed and the Zanjón del Aguacate receive water only during periods

[7] http://www.consaa.gob.sv/zonas-productoras-de-cana-de-azucar-en-el-salvador/

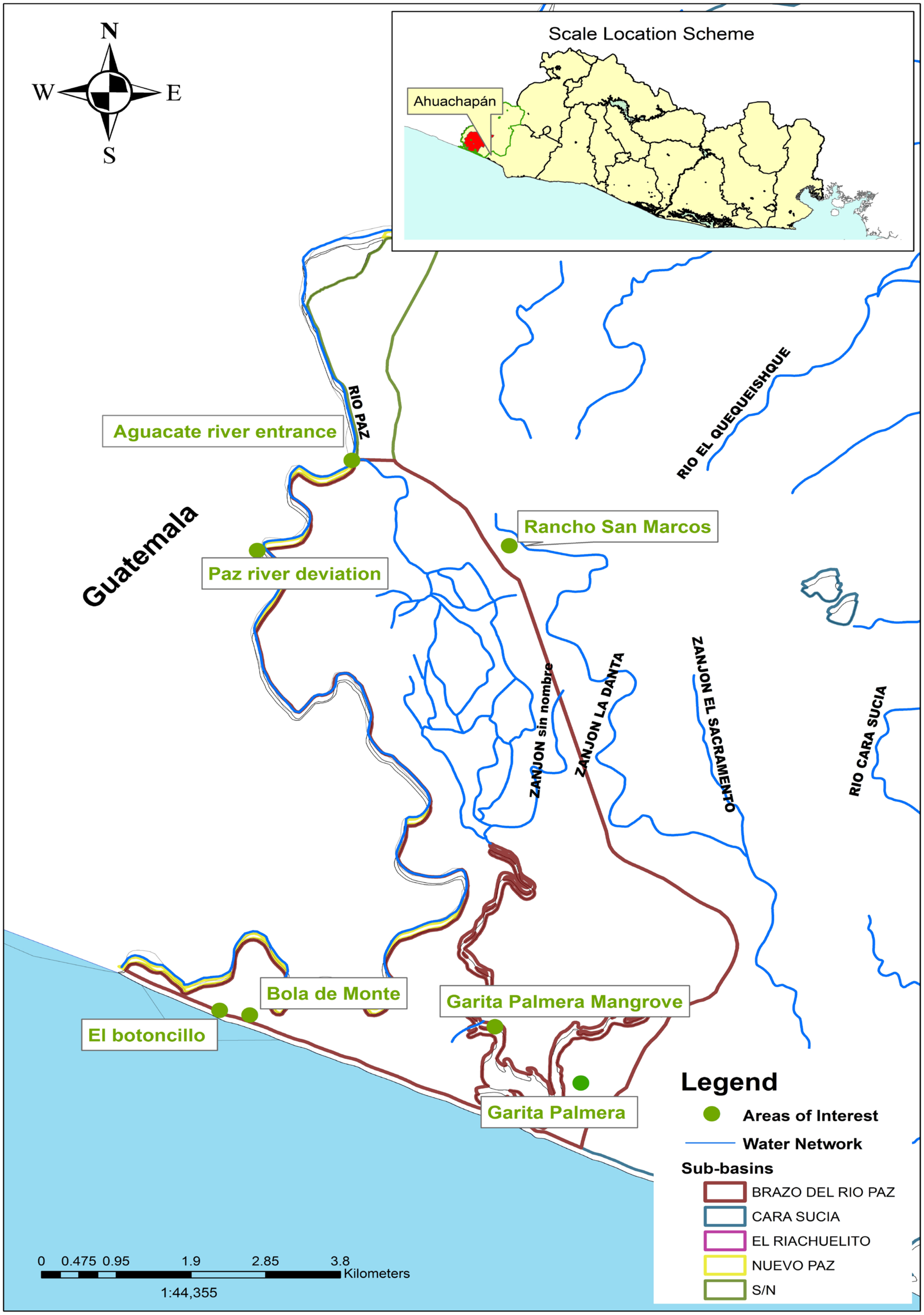

Figure 18 Water network of the El Aguacate micro-watershed delimited with the thick blue border at the center of the map. The point of influence of the Paz River ("El Aguacate River entrance") and the diversion of the Paz River into Guatemalan territory that occurred in 1974 are marked on the map. The water network of the ditch is characterized by strong morphological modifications of the natural riverbed for the irrigation activities of the cane fields.

Figure 19 A) Transport of pumped water from Río Paz to the cane field (April 2019, N13 47.480, W090 06.941). B) Diversion of the Aguacate River by digging ditch with an excavator to irrigate the cane fields (April 2019, N13 46.540, W090 05.572).

of very heavy rainfall during climatic events called "temporales" (Wildi, 2019).

This deviation from the original course of the river has repercussions on the freshwater reserves available in the lower zone for domestic and agricultural use, but also threatens the wetlands of Bola de Monte, Garita Palmera and Botoncillo. According to Gallo & Rodríguez (2010) approximately 2,600 million cubic meters of freshwater per year no longer flow in these ecosystems.

The lack of fresh water in the Garita Palmera wetland is also aggravated by two other phenomena. The first, mentioned above, due to the accumulation of sedimentary material that prevents water from entering the Zanjón and the second, is the excessive use of these waters in the irrigation of the cane fields that occurs throughout the dry period from February to May (Figure 19A) (Maximus*, 2019). As can be seen in the map (Figure 18) and in the photographs (Figure 19B) the morphology of this river has been highly modified.

The following graph (Figure 20) illustrates the average accumulated precipitation (mm) per month for the study area, which is characterized by an abundant annual precipitation of 1,700 mm. However, the distribution of precipitation is very uneven, with a dry season between December and April and a rainy season between May and November. Precipitation between May and October accounts for 95% of annual precipitation (Buckalew et al., 1998).

Of the 30 km² area of this micro-watershed, approximately one third of its total area is dedicated to sugarcane cultivation (Basagoitia Quiñonez & Flores, 2016). Other crops in the area include maize, plantains, coconuts, yucca, and watermelons. Cows are also raised on pasture (Wildi, 2019). The map below shows land use by crop type (Figure 21).

A data analysis conducted by Basagoitia Quiñonez in 2016 shows that the micro-watershed is divided into 18.9 km2 of crop mosaic, basic grains, plantains, pastures, and banana trees, 8.5 km2 and 1.2 km2 of mangroves. The monospecific forest in transition and urban tissue represents only 1.1 and 0.2 km2 of the watershed (Basagoitia Quiñonez & Flores, 2016).

From the results of the EVALHID rainfall-runoff model, there is an overexploitation of water from the microbasin aquifer equal to 450,000 m3 (Basagoitia Quiñonez & Flores, 2016). Water extraction from this aquifer comes, in terms of water volume, 81% for sugarcane irrigation, 11% for livestock activity and other crops, and 8% for domestic use.

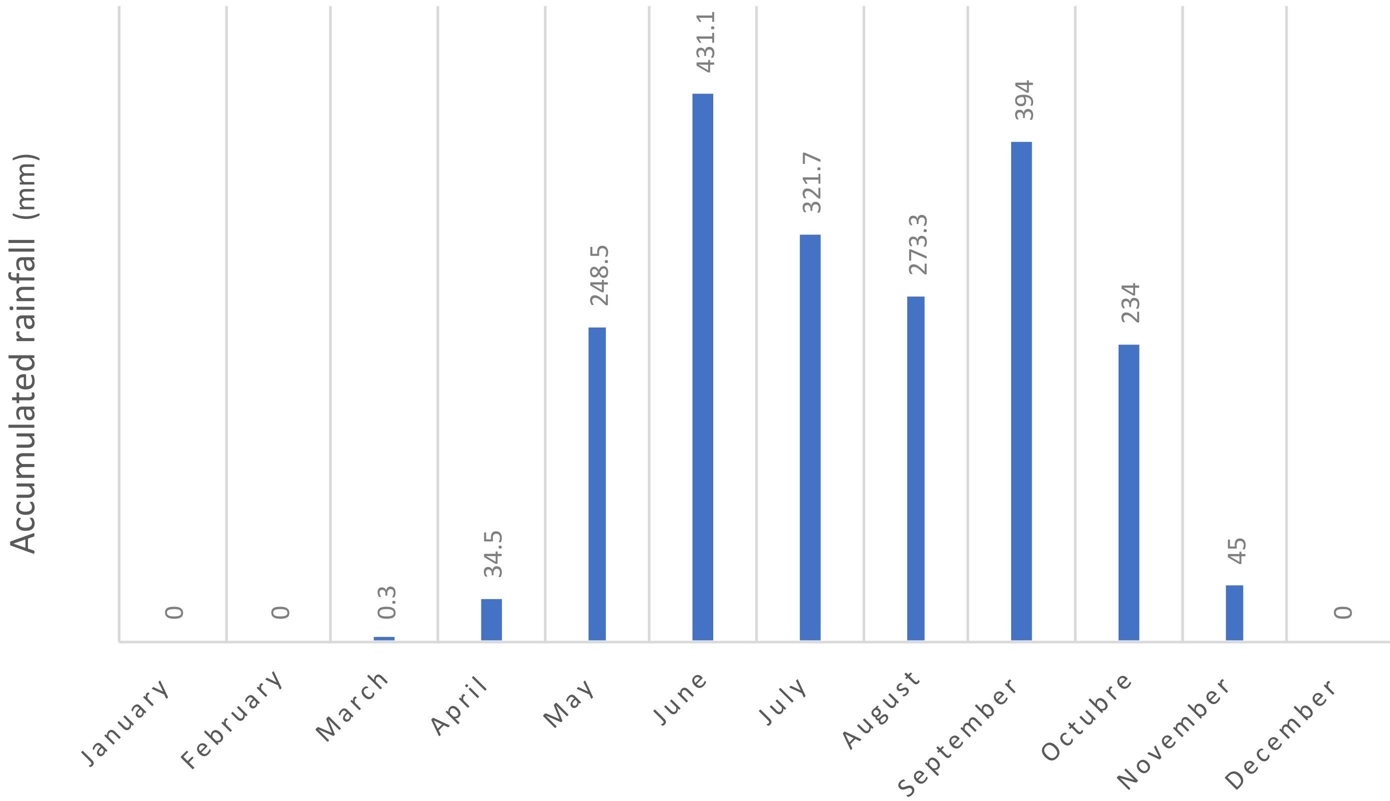

Figure 20 Distribution of precipitations during the year from data collected from 1970 to 2014 at the Ahuachapán, La Hachadura and Cara Sucia gauging stations (Basagoitia Quiñonez & Flores, 2016).

4.3.3 Biophysical Description of Garita Palmera Wetland

The Garita Palmera wetland is part of the Barra de Santiago - El Imposible Conservation Area. This Conservation Area is in the extreme southwestern part of the country that belongs to the Coastal Plain and Coastal Chain (Figure 22). It is one of the sites with the highest species richness and occurrence of restricted species (MARN, 2010).

The main geomorphological characteristic of Garita Palmera is its sand bar that runs parallel to the coastline and is slightly more than 4.5 km long and varies in width from 200 to 400 m. This environment is characterized by saline sediments frequently anaerobic and muddy, and anmoor soils are defined, whose formation is linked to these environments and whose composition is basically humidified organic matter mixed with clay under anaerobic conditions. Anmoor is formed in temporarily flooded environments, being a good geomorphological indicator of potentially floodable areas (Geologists of the World 2012 cited in Vásquez Jandres et al., 2017).

The Garita Palmera wetland is directly influenced by the Paz River and El Aguacate River sub-basin. However, it is also indirectly influenced by river systems and ditches that drain from El Imposible National Park's territory of influence. Nine different sub-basins ranging from 14 to 64 km2 in extension and originating in the mountainous part of El Imposible are in that zone (Requena Quintanilla 1993 cited in Vásquez Jandres et al., 2017). The most important rivers of indirect influence are Cara Sucia River and San Francisco River.

The behavior of the rivers is well differentiated with a strong physiographic control in the different parts of the riverbed. In the high areas, where the rivers are encased and with strong slopes, erosion and transport processes dominate; while in the middle areas the rivers gradually lose their erosive capacity and slope, so the riverbeds are no longer so encased and have a more meandering behavior (Geologists of the World 2012 cited by Vázquez Jandres 2017)

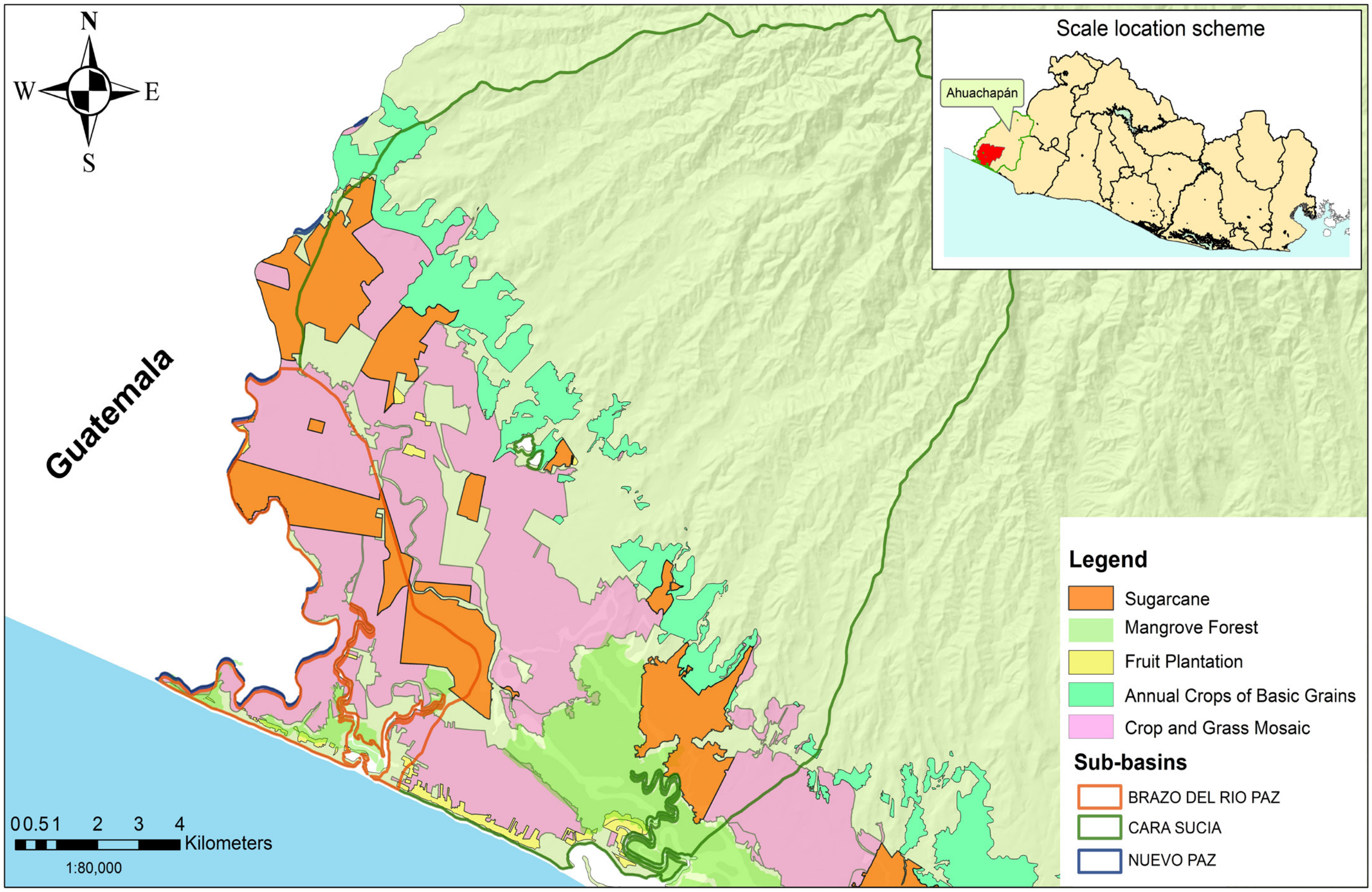

Figure 21 Land use map of the lower Río Paz area based on MARN 2012 data.

The Garita Palmera estuarine/mangrove system has a total surface area of 488 ha, of which 368 ha correspond to the estuary and mangrove, 60 ha marine and 71 ha of palm groves and other floodable lands; an average depth in the marine portion of up to 6 meters (no data is available for the estuary portion, but most likely the depth does not exceed 6 meters), and water mirror elevation of 0 meters above sea level. The ecosystem / life zone is subtropical humid forest.

This area is composed of three portions, considering the fragmented process of this place. The first two completely fragmented portions are found parallel to the road that leads to the hamlet and communities of Garita Palmera. These are characterized by the dominance of "red mangrove" (Rhizophora mangle) in its innermost part with little structural development and sometimes in association with "sincahuite" trees (Laguncularia racemosa), which is considered a seminal forest. In conditions with evident anthropogenic disturbance.

The main area of mangrove covers and primary network, and secondary channels, is formed by the mouth, which is typically a very dynamic sandy bar subject to hydro morphological and oceanographic changes determined by sea currents, tides, water load and atmospheric factors such as precipitation, wind direction, and ambient temperatures. All these conditions create an unstable dynamic in this sector.

The mouth of Garita Palmera is estimated at an area of 1.2 km2 with a width and depth varying according to the tidal pattern of 200 m and depth between 0.5 - 2 m, in its inner portion is observed mangrove forest (350 m from the mouth) with semi-dense and dense sectors of "red mangrove" in acceptable conditions of conservation. Mostly the sectors known as Bajo Caballo

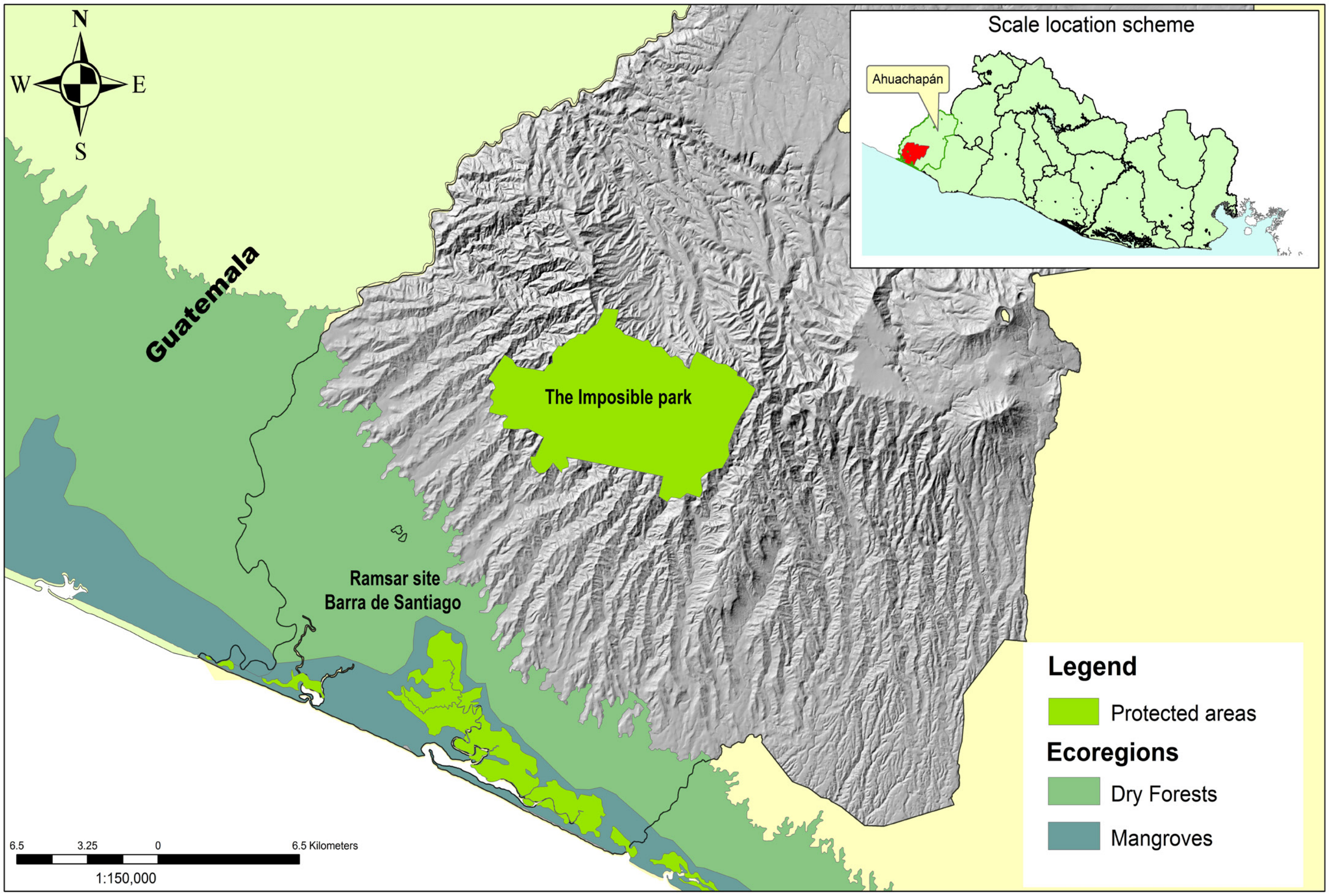

Figure 22 Barra de Santiago- El Imposible Conservation Area

and El Baral, and to a lesser extent sectors known as Los Cayucos (13°43'34.06 "N - 90° 4'59.57 "W).

It is important to mention that there is a zoning pattern with gradients of greater flooding, dominated by "red mangrove" and "sincahuite" sometimes in association. In the less flooded parts, the species "botoncillo" (Conocarpus erectus) and "Istaten" (Avicenia germinans) dominate. In general terms, the mangrove forest has considerable structural development. On the other hand, it is important to emphasize that the main fluvial source comes from the Paz River and the El Aguacate River sub-basin.

The marine strip corresponds to a sandy beach front (fine) with a gentle slope and an approximate length of 5.5 km. On the other hand, this strip also includes strictly oceanic waters outside the mouth, bordering the 3 nautical miles.

The zone is composed of an ecotone area, and a deciduous forest represented by the "royal palm" (Brahea salvadorensis). The traditional strip is mostly formed by "huiscoyol" (Bractris major).

4.3.4 Analysis of Stakeholders and Conflicts in the Territory

More than 30 organizations have been identified (Figure 23) that operate in the territory and are directly or indirectly related to the pesticide issue. A selection of the main actors was made, and they were organized in accordance with their type of relationship with the issue. The first group of identified actors is made up of national institutions such as MAG, in charge of pesticide import authorization, sustainable and economic agricultural development; MARN, in charge of reducing environmental degradation and MINSAL, which guarantees its citizens a comprehensive health service in harmony with the environment (MAG, 2019c; MARN, 2019; MINSAL, 2019).

The second group of identified actors is composed by local, national, and international suppliers of pesticides (legally established or operating illegally) such as manufacturers, distributors, and resellers (agroservices).

The third group of differentiated stakeholders are users, including local farmers who use agrochemicals for food production, plantain producers and the sugar industry. This stakeholder group consists of people directly exposed to agrochemicals during their preparation and/or use.

The fourth group of stakeholders consists of individuals and groups of individuals indirectly exposed using these pesticides. This group includes the communities surrounding the crops and fishermen's associations.

The last group of stakeholders operating in the territory is formed by local associations, NGOs, municipal offices, and environmental police in charge of environmental protection.

The conflicts-sensitive analysis in the territory has highlighted the problems, causes, intensity, risk of escalation and elements of reconciliation. They are summarized in the following table (Table 9).

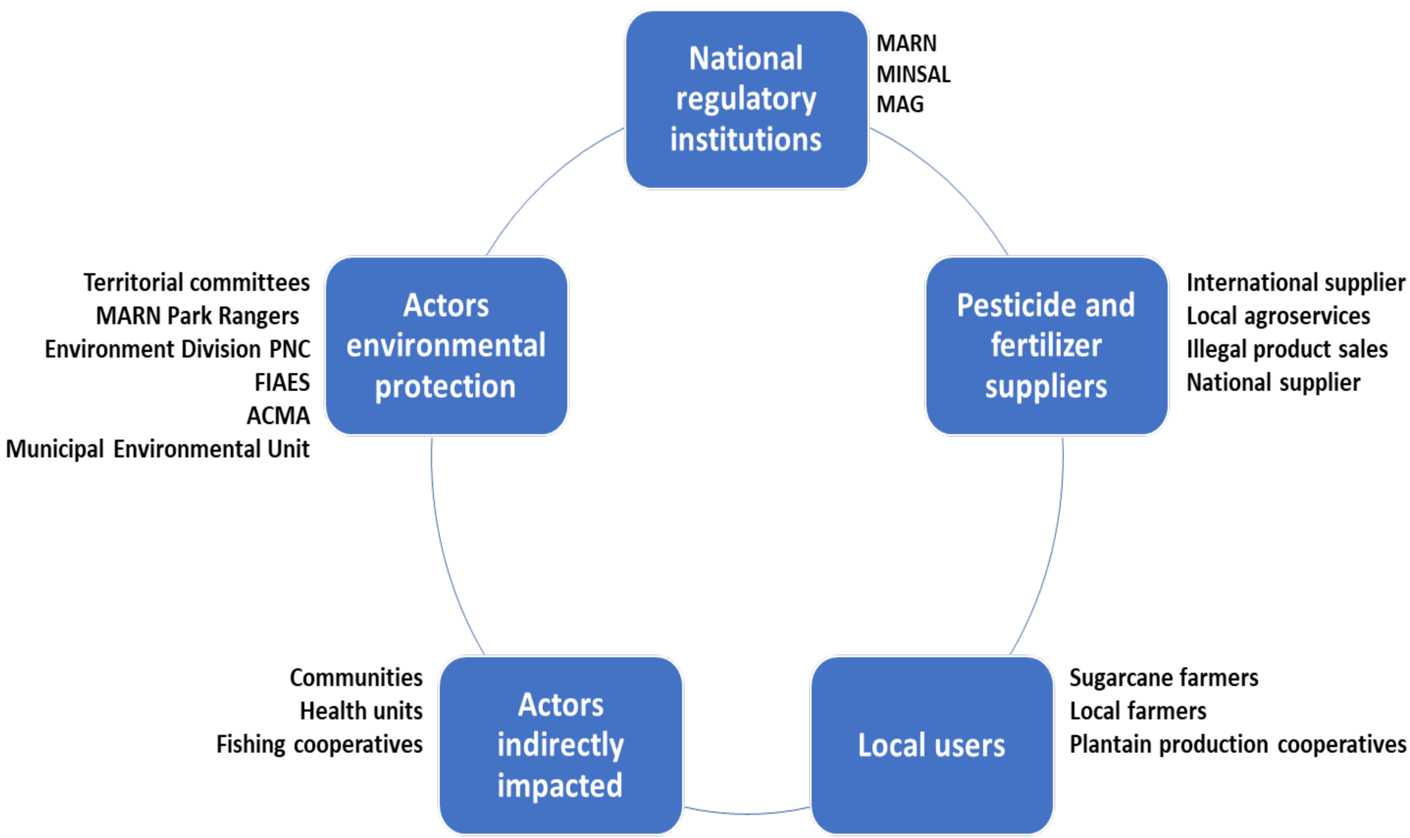

Figure 23 Articulation of the different stakeholder groups related to the issue of pesticides at national and territorial levels, starting with national regulatory institutions, pesticide suppliers, users, stakeholders indirectly affected by their use and stakeholders interested in environmental protection.

Table 9 Analysis of problems, causes and actors involved in conflicts in the territory with a high degree of tension.

Problems encountered	Causes mentioned	Stakeholders involved
Loss of access to land for subsistence production	Purchase of land for sugarcane plantation. High land rental prices to local farmers	• Sugar industry • Local producers
Early ripening and loss of subsistence production (corn, plantain, yucca, watermelon, etc.).	Derived from ripening agents (glyphosate, trinexapac-ethyl) during application from aircraft in sugarcane fields.	• Sugar industry • Local producers
Decrease in amounts of fish, shrimp, crabs caught in mangroves	High mortality due to pesticide runoff into rivers and mangroves and possible entry of excess sediment, loss of freshwater supply.	• Sugar industry and other users of pesticides • Local fishermen
Salinization of domestic water wells in the community	Overexploitation of water resources in aquifers and surface waters for irrigation purposes.	• Sugar industry • Communities
Lack of freshwater inflow into mangroves	Irrigation of large extensions. Deviation of rivers for irrigation purposes.	• Sugar industry • Local fishermen • Environmental protection association
High mortality in some communities due to renal failure	Pesticide applications	• Sugar industry • Communities
Accidents, burns/irritation, poisoning during pesticide use	Lack of information for suppliers and training of users with the use of appropriate equipment, uncontrolled sale of pesticides	• Local producers • Agroservices • Health Units
Criminalization of leaders of local environmental organizations	Divergent interests between communities and industry	• Sugar industry • Local producers • Local fishermen • Environmental protection association

This analysis of the conflicts and problems faced by the communities reveals the threats to their living environment and to the food sovereignty of the 9,000 people living in this watershed. In fact, five of the eight main problems faced by the population are related to access to land for staple grain production, loss of crops due to the spread of ripening agents, and loss of access to fresh water in domestic wells.

Two problems faced by the population are related to the use of pesticides and their impact on the health of workers. The last phenomenon faced by the population is, to some extent, the cause and consequence of the tensions between the different actors, the criminalization of community actors defending their rights by certain actors in power.

The sugar industry is one of the main actors and motors of most of the problems and conflicts faced by local communities. The positive aspects reported by the communities about this industry are the source of employment it generates, as well as some compensations granted by the company such as the construction of asphalt roads or classrooms.

4.4 Conclusion

The description of the socioeconomic elements of the lower Paz River zone revealed different elements. First of all, the communities living in the area mainly depend on subsistence agriculture and fishing for their survival. Their sources of income come from selling their products in the Cara Sucia market, obtaining remittances and for some, working in the sugarcane fields. Access to land for the peasants and the conservation of natural spaces are therefore vital conditions for their survival in this area, yet they are the most threatened by the sugar industry.

Mangrove areas are particularly important because they protect the people of these communities from adverse weather events, prevent them from disasters, and are a source of income, food, medicine, and recreation in their daily lives.

The pressure on freshwater resources in the area is extremely high. This is explained by an uneven rainfall regime, with most of the precipitation concentrated during the months of May to October. Since the diversion of the Paz River in the 1970s, the El Aguacate ditch only receives water during high intensity rainfall events.

The conflict analysis highlighted three problems that are directly and indirectly related to the use of pesticides in the communities:

1. The aerial application of ripening agents in the sugarcane fields and affects the surrounding subsistence crops of the communities.

2. The impact on the health of workers and peasants who apply pesticides (accidents during application and mortality due to chronic kidney disease).

3. The impact on the aquatic ecosystem due to fertilizer and pesticide runoff and its consequent impact on the fishing population.

The analysis also reveals a dichotomy between the communities and the sugar production sector. In one hand, the communities are highly dependent on the sugar industry as a source of paid labor. On the other hand, the same industry is directly or indirectly responsible for the loss of access to farmland (land grabing)), the degradation of their environment and ecosystems, the loss and degradation of water resources, and the deterioration of the communities' health, harming their quality of life and life expectancy due to chronic kidney disease of unknown causes.

The above analysis highlights the need for governmental supervision of surface and subterranean water use with fair regulations that do not benefit already enriched, privileged and powerful sectors, at the expense of the suffering and impoverishment of the most vulnerable sectors.

5 Human Exposure to Pesticides

5.1 Introduction

Pesticides have three main routes of entry into the human body: through ingestion, inhalation, and the dermal route (OCSPP US EPA, 2015b). Human exposure to pesticides can be characterized in terms of exposure to hazards chemicals in the workplace (occupational exposure) and exposure that occurs outside of one's work (non-occupational exposure).

Occupational exposure is given by direct contact with pesticides, this mainly includes agricultural workers, workers who synthesize and formulate pesticides and domestic fumigators (Damalas & Eleftherohorinos, 2011). These workers are more susceptible to acute poisoning (Fenske & Day, 2005).

The process of using pesticides consists of several phases that, if not carried out properly and according to good practices, can expose humans, their surroundings, and the environment to high risks. Mejía et al. (2015) describes each of these stages, which consist: of:

1. Purchase and selection
2. Transport
3. Storage
4. Formulation
5. Application
6. Solide waste management and residues

The selection and purchase of pesticides are important for two reasons. First, it is a matter of choosing a product that is legal, appropriate in terms of its intended use and minimizes hazards to people and the environment. At that point, the seller must inform the user of the appropriate protective equipment to be used to minimize the user's exposure. The seller must specify the conditions of use and the doses to be applied to minimize exposure of the environment, bystanders, and residents (Mejía et al., 2015).

The second step is the safe transport of pesticides. At this stage, spills must be prevented due to accidental damage to packaging by sharp objects or by sunlight. It should also be avoided the contact with children, animals and food, and reduce the risk of fire during transport. (Mejía et al., 2015)

The third step is pesticide storage. If this is not done properly in a separate, enclosed, ventilated room that is not subject to flooding, it can further expose the user, the user's family, and the environment. In fact, if the products are stored in the home, the family may be exposed to pesticides through inhalation of pesticide vapors, but also through the skin if they touch pesticide-contaminated jars or if the jars are improperly closed, or by accidental or deliberate ingestion (suicide) (Mejia et al., 2015; Quinteros & López, 2019).

The fourth stage is preparation and mixing (formulation). At this stage, both the environment and humans are exposed to pesticides. This problem is aggravated by exposure to concentrated substances at this stage. Exposure to the vapors of the concentrated products and accidental spillage on the skin, as well as the risk of splashing during the mixing phase of the product with the large volume of water, represent only some of the hazards to which one is exposed. The number of times the operator must recharge the backpack spray pump, the presence of several active substances and adjuvants, the concentrations of the products in the mixture and the use of protective equipment are variables that must be considered in this phase (Mejía et al., 2015).

The fifth step (application of the pesticide) is the most delicate since the pesticide is released into the environment. The worker's exposure depends on the protective equipment, the hours of daily exposure, the number of days of application per year, the climatic conditions and the calibration of the equipment used. The cleaning conditions of the spraying equipment and protective equipment after use are also elements that must be considered in the exposure (Mejía et al., 2015).

The final step is the disposal of pesticide wastes (containers) and remnants (residual pesticide). Potential exposure occurs mainly in the reuse of pesticide containers for water transport, food storage and in the inadequate disposal of wastes and remnants. Generally, wastes are disposed of in the open air at the application site without prior treatment. Before disposal, containers should be washed to remove pesticide residues and should be cut or perforated to prevent other persons from reusing them, and finally they should be placed in a special container for later collection. As for the remnants, these should be disposed of by applying them in surrounding vacant lots or in piles of weeds in nearby land (Mejía et al., 2015). All these methods to minimize the risk of pesticides are not usually followed in El Salvador.

Non-occupational exposure to pesticides is multifactorial and includes occupational exposure, application site drift, residential use, and ingestion (Deziel et al., 2015). Dietary (ingestion) exposure is characterized by consumption of water and food contaminated with pesticides and their degradation products (OCSPP US EPA, 2015b). Non-occupational exposure also includes exposure associated with frequent and potentially contaminated locations inside and outside the home (Damalas & Eleftherohorinos, 2011). The population may be exposed by inhalation or contact to concentrations significant to their health in their homes due to household use of certain biocides, entry of contaminated equipment or clothing, and inhalation of contaminated dust (Deziel et al., 2015; Whitemore et al., 1994). Outside the home, the population may be exposed to pesticides due to pesticide drift. This exposure can occur through windblown dust and contact with contaminated soil (bystander) (Damalas & Eleftherohorinos, 2011).

Considering these theoretical aspects, the objectives of this chapter are:

1. To characterize the exposure of sugarcane workers to chemicals and other harmful substances.

2. To determine the working conditions and the distribution of responsibilities in the sugarcane fields.

3. Characterize the exposure of communities living around the fields to chemicals and other harmful substances emitted during the sugarcane growing cycle.

5.2 Methodology

5.2.1 Survey Interview

The analysis of the sensitive context to the conflict discussed in the previous chapter revealed that tensions between communities and sugar industry actors are extremely high. Due to the fact that some community leaders are already under death threats because of their work for the defense and fight for their rights; community actors decided that the collection of information from sugarcane workers and neighboring communities would be done through private interviews directly in the interviewee's home.

Interview surveys were conducted with three sugarcane workers (Damien*, Eleonor*, Maximus*), one sugarcane agronomist (Carlos*), one comunity leader (Pascal*), three women (Osa*, Aline*, Berta*) with boys and girls that live around the sugarcane fields to portray pesticide exposure. Aliases were given to each interviewee and appear with a name followed by an asterisk (*).

The interviews conducted in this research permitted us to inquire deeper into the problem to include the organization of work in the fields and the various responsibilities, identify obstacles and opportunities to improve practices and socially contextualize the workers. A specific interview guide was developed to each type of actor interviewed, consisting mainly of open-ended questions that included a personal presentation, the production cycle, field work organization, working with the products and compensation provided by the company. Interviews were conducted in the communities El Castaño, El Chino, El Palmo, El Porvenir, Rancho San Marcos, San Marcos Cañales and Santa Teresa (municipality of San Francisco Menéndez, Ahuachapán). The interviews were recorded with the consent of the interviewee. During the transcription of the interviews, no information or testimony was included that could allow the identification of the person and, therefore, compromise their place of work or physical integrity.

Through the compilation and cross-checking of the information obtained through the 8 interview surveys, a schedule of exposure of sugarcane workers (occupational exposure) and surrounding communities (non-occupational exposure) was established. The interview transcripts are available in A.I. 3 (Additional Information 3).

5.3 Results

5.3.1 Exposure of Men and Women Workers to Pesticides and other Harmful Substances in Sugarcane Crops

It is possible to distinguish three main phases in which exposure can be characterized by different exposure groups (Table 10). The first phase of pesticide exposure occurs from November to January, when the soil of an existing crop is prepared for the new growing season or for planting a new crop (every 5 to 12 years) (Carlos*, 2019; Maximus*, 2019). Fertilizers, pre-emergence herbicides and certain products with a dual insecticidal and fungicidal action are applied at this time (Carlos*, 2019). Fertilizers and the fungicide/insecticide product are distributed in solid form in the crop furrow (Carlos*, 2019; Pascal*, 2019). Depending on the area, a group of women is hired to do this work with a bag of fertilizer hanging on their back and a bag containing the biocide suspended on their waist. Then they distribute these two products with their bare hands. The pre-emergence herbicide is then applied directly to the soil by backpack sprayer (Carlos*, 2019).

The second exposure phase takes place throughout the crop maintenance stage, which usually begins in late May or early June through August (Carlos*, 2019; Damien*, 2019; Eleonor*, 2019). A team of ten people, usually including a quarter of women, is recruited by a quadrille leader (caporal) for a period of 3 months, 6 days a week, 4 to 6 hours a day (Carlos*, 2019; Damien*, 2019; Eleonor*, 2019)

Before starting work in the fields, operators do not have a medical examination and do not receive training or personal protective equipment. During the workday, they are dressed in boots, pants, long cotton shirt and a cap (Figure 24) (Damien*, 2019; Eleonor*, 2019).

If the landowner has hired technical assistance from the sugar cane mill ("Ingenio"), an agronomist will provide the products, calculate the rates to be applied and demonstrate the calibration of a backpack spray pump (Carlos*, 2019). If the landowner does not call for technical assistance, then the foreman (caporal) organizes the products and rates to be applied according to his habits (Carlos*, 2019). When an engineer is present, the two-person backpack pumps are calibrated to avoid overuse of the product in the field (Carlos*, 2019). In fact, operators are paid by the task, they must spray a 250-liter barrel containing a mixture of up to 5 different products on 1 to 1.5 manzanas (1.05 hectares) and receive $6 in return (Damien*, 2019; Eleonor*, 2019). Some operators then modify the mouthpiece of the backpack spray pump so that more of the mixture is applied in less time (Carlos, 2019). According to an engineer who has done this work, after the calibration demonstration, the foreman and his workers are free to do whatever they want (Carlos*, 2019). That is, sociologically, neither those who work, nor the caporal are willing to receive recommendations from an engineer about the work they have been doing for a long time in their own way (Carlos*, 2019).

The third phase of exposure to pesticides and other substances, such as fine particles and polycyclic aromatic hydrocarbon (PAH), takes place during the zafra phase. The harvest or zafra takes place from late November to April, depending on the variety harvested (early, medium, and late varieties) (Carlos*, 2019). Sugar mill engineers visit sugarcane field owners to take sugarcane samples to measure different parameters such as content and sucrose fraction (Brix degree) (Carlos*, 2019). Depending on the sugar content, the

Table 10 Calendar of exposure to pesticides and other harmful substances in relation to the sugarcane production cycle.

	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
Harvest or zafra												
Ripening	x	x	x	x	x						x	x
Burning of sugarcane fields	x	x	x	x	x						x	x
Crop preparation and maintenance												
Pre-emergence Herbicides	x	x	x					x				
Post-emergence Herbicides								x	x	x		
Fertilizers	x		x					x				
Insecticides						x		x	x	x		
Fungicides	x	x	x					x	x	x		
Rodenticides				(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	

Figure 24 Protective and spraying equipment (backpack sprayer pump) used in the cane fields consisting of boots, pants, long cotton shirt and a cap.

factory gives the order to start the harvesting process. Refining plants promote or require the use of ripening agents 4 to 7 weeks before harvest to increase the sugar content of the cane and facilitate the work of the cutters (Carlos*, 2019; Maximus*, 2019).

The landlords are not always in favor of using ripening products, as it can easily cause them to lose 20% of their crop and reduce the plantation's operating time. Due to the size of the canes, the application of ripening agents can only be done by air (Carlos*, 2019).

The spraying of sugarcane fields by airplane or helicopter takes place in the early morning hours between 5 and 8 am when there is no breeze (Carlos*, 2019). During this process, 5 people are needed on the ground to mark the rows of the field with a flag (flaggers) several meters high (see Figure 25) to guide the application of curing agents for aircraft. In this process, ground personnel are literally sprayed from head to feet across the entire surface of their bodies in contact with the spray mixture (Carlos*, 2019; Eleonor*, 2019; Pascal*, 2019). When spraying curing agents, workers do not wear chemical protection masks. Absorption via exposure route is estimated to be not only through the skin but also by inhalation, as pesticide workers through the lungs, without any evidence to the contrary, is 100% of the inhaled aerosol, i.e., estimated to be 10 times higher than dermal absorption (WHO, 2010a). The mixture contains primarily an herbicide with the active ingredient glyphosate with the potential growth regulator trinexapac-ethyl and, if necessary, the flowering inhibitor ethephon (Medardo & Molina, 2016).

For the past year, specialized companies such as Drontek® have been offering the service of drones for the treatment of fields using ripening agents. (Carlos*, 2019; Maximus*, 2019). In 2018, the use unmanned aerial vehicles has been limited to sugarcane fields in El Salvador. Currently, about 30% of sugarcane crops are treated by drones (Dinero, 2018). At the moment, only wealthy landowners can use this technology that consumes less pesticides and water (Carlos, 2019). According to interviews conducted in the 7 communities of the Rio Paz sub-basin, most fields are still treated by aircraft (Aline*, 2019; Damien*, 2019; Eleonor*, 2019; Maximus*, 2019; Pascal*, 2019).

After aerial application of ripening agents, the fields are burned to get rid of irritating leaves and facilitate cutting the next day. The cut canes are taken to the refinery (Figure 26).

Figure 25 Sugarcane fields. The approximately 4 m high flag in the center of the field is used for guidance of the airplanes applying the ripening agents. The fields are burned after 4 to 7 weeks after the application of the ripening agents.

5.3.2 Distribution of Responsibilities and Working Conditions, Induced Impacts on Women in the Communities.

This subchapter does not pretend to be exhaustive but refers only to certain social and organizational aspects that can contribute to the understanding of the obstacles to change certain practices in pesticide's application.

In the communities where surveys and interviews were conducted, work in the sugarcane fields is almost the only source of paid work (Aline*, 2019; Berta*, 2019; Damien*, 2019; Eleonor*, 2019; Maximus*, 2019; Osa*, 2019). The organization of sugarcane cultivation involves different jobs and responsibilities. Communities are involved in two main tasks that include crop maintenance and zafra.

Generally, a different group of workers are involved in cutting and harvesting sugarcane. The information gathered during the interviews indicated that the different roles and responsibilities in the sugarcane fields are as follows:

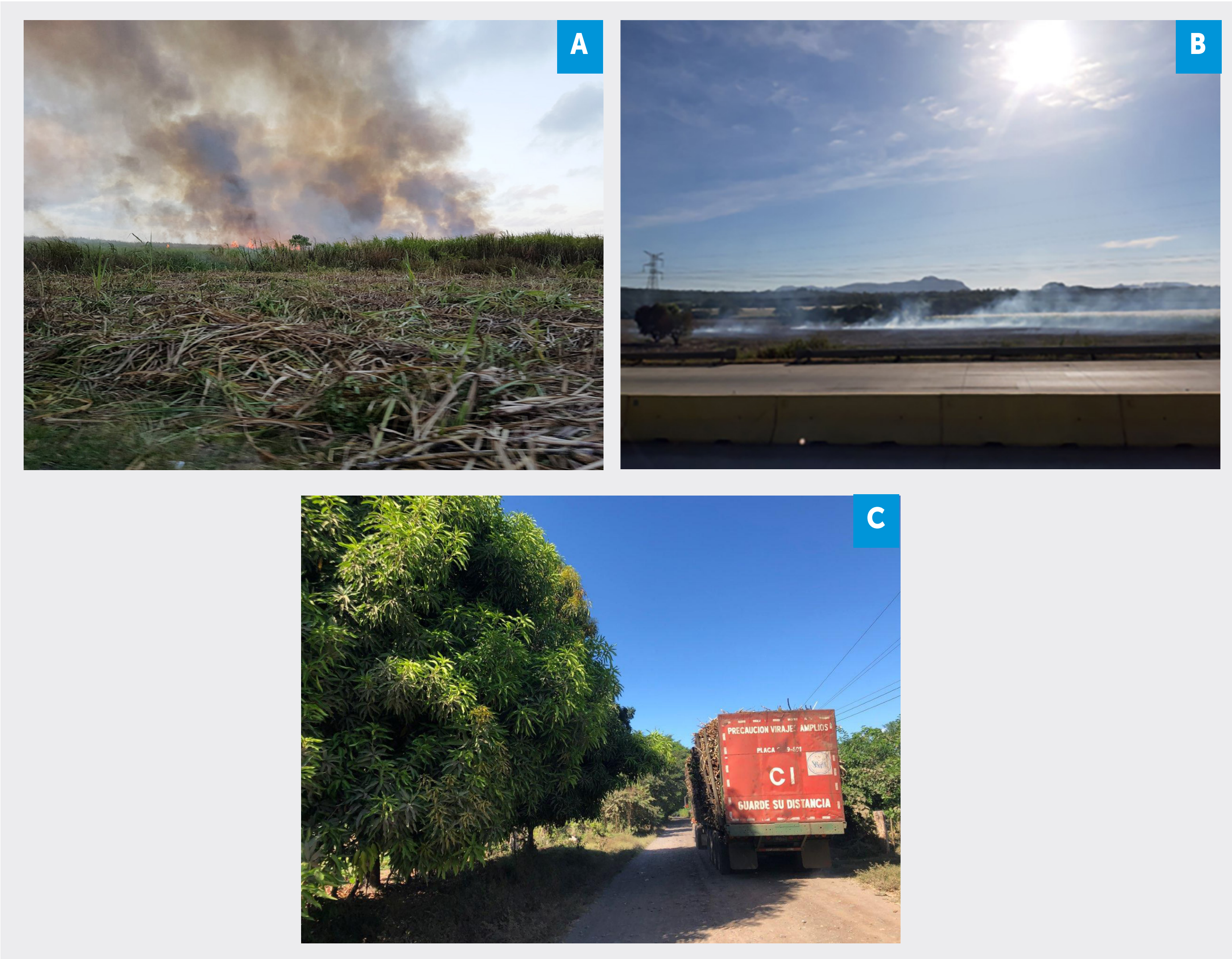

Figure 26 A. Fire ignited in sugarcane fields in the late afternoon, the day before harvest B. Sugarcane fields after calcination C. Transport of raw sugarcane to the mill.

1. Sugar mill - refining plant:

Refining plants coordinate with crop owners the timing of cutting and harvesting sugarcane (Carlos*, 2019). They send their own agronomists to the different growing areas of the country to take sugarcane samples (Carlos*, 2019). The sugarcane is then analyzed in the mill's laboratory to determine various parameters (e.g., Brix levels, fiber percentage, purity). Based on the results of the analysis, the mill establishes the schedule for the application of ripening agents and then the cutting of the cane (Carlos*, 2019).

Engineers are responsible for organizing the stages of cutting, harvesting, transporting, and refining sugarcane. They organize the transportation of groups of cutters to the different producing regions of the country. The factories are in charge of supplying cutting equipment (churumbas[8], cumas, lima, chimpinillera[9], sleeves, hat, shoes) and emergency medical assistance (Berta*, 2019; Maximus*, 2019). For large properties, the refinery also offers various technical assistance services, such as the application of ripening agents by drones or the application of pesticides and fertilizers

[8] In El Salvador, bag where the seed is loaded.

[9] Shin guard

by knapsack pump. An agronomist engineer is then dispatched with the range of pesticides, calculates the doses to be applied and demonstrates to workers the calibration of the instruments (Carlos*, 2019).

2. Owner of the sugarcane field.

The owners of the sugarcane fields are individuals and legal entities such as cooperatives and some case companies that have property rights. In the case that it is not the factory that hires the employees, the owner of the crop is usually the head of the personnel who carry out the cutting or the application of pesticides. Some parcel owners are shareholders of the refinery plant (Carlos*, 2019).

3. Mandador[10]

This person works for the owner of the parcel. He is the coordinator and responsible for the cane field. He organizes the workdays, recruits' personnel to carry out tasks like pesticide's application, plot security and irrigation. He is in charge of paying employees at the end of the workday.

4. Foreman (caporal).

This person is the team leader during the execution of the work. This person determines the tasks to be performed, registers the hours, and evaluates the amount of work done to proportion the salary. When applying pesticides, he is responsible for supervising the preparation of the pesticide mixture in the barrels.

5. Sugarcane cutter.

This is the person employed by the owner or the factory to cut and harvest sugarcane. These people are relocated throughout the country to carry out the harvest.

6. Agricultural employees.

These personnel perform non-specific work and are hired in the communities living near the fields to prepare the soil, plant the cane, apply fertilizers and pesticides, and mark the areas for aerial spraying.

Working as a cutter is probably the most physically and psychologically exhausting job.

"Someone who hasn't done it before doesn't do it. It is like if you are a corralero, someone is looking for you and you know that you can milk. But they tell you: "Look, you are going to milk, and you have never done it, but if you can't, you can't" and the cane is like that, because that matter is a bully. Because you don't think you're going to be there since 7 am when we start and there are times when we go out until 4-5 in the afternoon."

Maximus* (2019) sugarcane cutter.

"My God, am I going to stay here?" he asked but everyone was going ahead, but he wanted to finish his duty and he started to shiver and shake, so a collegue ask him "and you, do you feel bad?", "yes" he said, he saw him pale. He said, "Suck this candy", and so he spent 8 more days and left for not staying in the camp."

Aline* (2019) sugarcane cutter's wife.

The testimonies collected (1 cutter and 3 wives of sugarcane cutters) indicate that sugarcane cutters are either employed by a sugar mill or employed by the owner through the mandador. Some cane cutters sign a contract with the mill for the duration of the harvest because the work involves many risks.

"They hit their foot, they cut their foot, they hit their hand, they cut a hand, several times, for example, last year, my husband told me that there was a boy whose foot was cut off, so it is a risk they run."

Osa* (2019) sugarcane cutter's wife.

[10] Person who takes care of a farm and assists the employer in its administration

Sugarcane cutters working directly for the crop owner did not delay signing contracts (Aline*, 2019; Maximus*, 2019). Sugarcane cutters work for the entire zafra season, i.e., for 6 months. They are paid per task (ton or area harvested) or per day of labor.

Interviewees reported that they earn between $6 and $9 per day depending on whether the owners respect the work agreement (Berta*, 2019; Maximus*, 2019). Workers can earn $20.00 per day under optimal conditions and in theory up to $30.00 In all cases collected, workdays start between 3:30 and 4:30 a.m. and end between 7 and 8 p.m. (Aline*, 2019; Berta*, 2019; Maximus*, 2019). Workers use certain medications or active ingredients for pain and energy (Aline*, 2019). Groups of sugarcane cutters move to different areas of the country to work, some return at night after a day's work and others live in areas close to the fields (Aline*, 2019; Maximus*, 2019). Workers sleep in camps where they pay for lodging, food, and laundry. Wives of workers report that their husbands do not eat enough, among other things because some chemicals (Iodine) are added to the food at the expense of the workers (Aline*, 2019; Berta*, 2019; Osa*, 2019). During the six months of the harvest, they have 24 hours off every 20 days to see their families (Aline*, 2019; Berta*, 2019; Osa*, 2019).

"They come at 21st and 22nd days of work, for example, if they come late on the 22nd, they spend the 23rd and then they go on the 24th, in other words, they take a rest day every month"... "if they come like that, you see, since the food is not good for them, they come very thin. No, this work is extremely hard for them."

Berta* (2019) sugarcane cutter's wife.

"It's hard because my little girl cries for two hours, it feels bad when they go there. But when they come, they bring money, and we say that we are going to buy the things we need. Well, in my case, sometimes there is no money, sometimes we lend money to spend the days when they go there because, to pay for electricity, water, cable, and things that one has to pay by law, practically the first payment only serves to pay off debts."

Aline* (2019) sugarcane cutter's wife.

The employer keeps 4 days of salary out of 20 for workers to return to work (Osa*, 2019).

"Interviewer: So, there are people who don't want to go back to work, because the work is too heavy.

Osa: Yes, the work is killing."

Osa* (2019) sugarcane cutter's wife.

Agricultural employees who apply pesticides are hired by the sugarcane field owner's mandador by word of mouth. Unlike the cutters, pesticide applicators are usually people from the communities adjacent to the cane fields (Damien*, 2019; Eleonor*, 2019). They work 12 weeks a year and 6 days a week. The mandador pays them per task to apply a barrel of pesticides for the equivalent of $6 (Eleonor*, 2019). Women also do this work and are sometimes pregnant because many women must support their families alone or the husband's salary is not enough (Damien*, 2019; Eleonor*, 2019). In the communities interviewed, pesticide's application job is the only source of work, even for young people (Damien*, 2019). Workers do not know the effects of the products they apply, are not trained and some are illiterate (Damien*, 2019; Eleonor*, 2019). When the owner provides protective equipment, it is not used due to weather and slows down the pace of work (Damien*, 2019; Eleonor*, 2019). The interviewees mentioned that they would do another job if there were other opportunities.

Workers cannot talk about their working conditions or report abuses for fear of losing their jobs

"There is a lot of need because $6 is hardly any money. The salary set by the government is $7, but since they are the ones who pay, they keep paying $6, that's why the corruption here is not going to end."

Eleonor* (2019) agricultural employee, plaguicide applicator.

"We can talk, but who listens to us? There is no one. We can make remarks that they only come to kill us, but

that lingers in the air. As an example: The salary. When they made a salary increase for the farmer and said, "if they talk, we are going to throw them out", and because the people are always in need, they keep their mouth shut."

Eleonor* (2019) agricultural employee, plaguicide applicator.

In other words, it is evident that the community workers are dependent on the owners and the sugar mills and that the working conditions mean that the sugarcane cutters and pesticide's applicators put their physical health at risk to meet the basic needs of their families in the short term.

As an additional element of analysis, it should be noted that this distribution of responsibilities and working conditions responds to a large extent to the sexual division of labor, in which men are assigned public spaces for their performance and women are limited to private spaces (home and domestic tasks). Similarly, this distribution has a differentiated impact on the health of women and men. In some cases, the effects are due to the physiological characteristics of women, while in other cases, the effects derive from the level of exposure they are exposed to when performing part of the activities related to reproductive work. Women living in agricultural areas are affected differently than men due to physiological and exposure factors. In effect, pesticides generate different risks for women because of their impact on the hormonal cycle, reproductive toxicity (e.g., infertility), prenatal toxicity (death of the fetus, malformations, etc.) and postnatal toxicity (lactation), cancers (breast cancer), etc. (Bretveld et al., 2006; Cohen, 2007; Garcia, 2003; Watts, 2013).

In addition to occupational exposure, women are also exposed through the places they frequent and the domestic activities for which they are often responsible. Exposure occurs through direct drift from pesticides applied near the home (Ames et al., 1993). Women are also exposed during house cleaning due to windblown pesticide-contaminated dust, cleaning contaminated work clothes, contact with contaminated pets (Deziel et al., 2015). Moreover, women are responsible for bringing food to those who are working in the sugarcane fields, exposing themselves to pesticides without any protection when entering the field to deliver the food. Women like all other family members are also exposed through ingestion of contaminated food and water (Damalas & Eleftherohorinos, 2011) Similar is true for childhood, which is also affected differently from adults. From the prenatal stage through adolescence, children are more biologically sensitive to pesticide's toxicity due to their physiology (body mass, skin surface area), their metabolism (gastrointestinal absorption, higher ventilation rate than adults) and the fact that their nervous, hormonal, respiratory and immune systems are still developing (Watts, 2013). Before birth, fetuses are already exposed to pesticides through the placenta. After birth, children are exposed through breast milk, working in fields with pesticides, at school, in parks, at home and by accidental ingestion (Watts, 2013; WHO, 2004).

It should be added that job insecurity has an indirect impact on the person responsible for the household, most of whom are women, since they are assigned the tasks of reproductive work -unpaid- (care, child rearing and economic management of the household) during their partner's absence. In addition, they assume the tasks of caring for their partners when the latter have health problems that the same working conditions have caused them.

In addition, due to the economic vulnerability of the family, women must seek remunerated economic activities to supplement the family income, which for them implies a double or even triple workday, often compromising their health when they are involved in spraying pesticides or cutting sugarcane.

Pesticide's applicators are paid by tasks, which amplifies over-application of pesticides and discourages the use of protective equipment that slows down the speed of the work.

Furthermore, crop owners do not take responsibility for any health problems that their workers developed during their time of labor activity (Damien*, 2019; Eleonor*, 2019; Maximus*, 2019) or for damage to community crops during aerial application (Aline*, 2019; Berta*, 2019; Osa*, 2019). That power relationship excludes any possible negotiation with their employer to improve those conditions.

Based on the cases reported and the definition of the El Salvador Labor Code (art. 17) , the employer is the owner of the crop (a natural or legal person such as a company) or the mill. In the case of persons applying pesticides, the employer reported in these surveys was the owner of the crop. In this case, the owner of the crop has the legal obligation to: "Provide the worker with the materials necessary for the work; as well as the appropriate tools and implements for the performance of the work, when it has not been agreed that the worker will provide the latter" (Article 29d). According to the Good Agricultural Practices Guide p.58 (Medardo & Molina, 2016), it is a legal obligation: "Record of delivery and return of PPE"(Personal Protective Equipment), "Visual evidence of PPE use by workers and of the condition of PPE", "Interview with workers demonstrating practical knowledge of the proper use of PPE", "Record of worker training on use of PPE, storage of pesticides and other agricultural supplies, safe use of pesticides and disposal of containers."

5.3.3 Exposure to Pesticides and other Harmful Substances of Populations surrounding Sugarcane Fields.

In this research conducted by UNES, information was collected through interviews with four mothers (Osa*, Aline*, Berta* and Pascal*) living in neighboring communities to characterize the exposure of bystanders.

The populations around the sugarcane fields (Figure 27) are also affected by agricultural practices during the three main phases considered in the previous chapters. Some communities are in the middle of the sugarcane fields and some of the houses are located less than 15 meters from the crops or within the width of a road.

As mentioned above, during early season soil preparation after fertilization, pre-emergence herbicides are applied to bare soil (November-January). Once plantlets have emerged at the beginning of the rainy season (early June), herbicides and systemic insecticides (e.g., imidacloprid, lambda cyhalothrin) are applied to control yellow cane aphid. Neighboring houses report a strong odor after application. This suggests pulmonary exposure for a few hours after application for households in the vicinity of crops. Based on the cases interviewed in this study, it is people from the communities who are hired to apply the pesticides. However, after application, the clothes contaminated with pesticide are mixed with the clothes from the rest of the household and cleaned together. The people who clean the clothes, often women encountered the pesticide residues.

During the harvest season, the four women interviewed reported the passage of airplanes spraying ripening agents in the cane fields. This operation took place in the morning around 8 a.m. and lasted two hours. It was reported that the aerosols are breathed into the village by men, women and children who are in school at the time. No measures are taken to alert the people in advance and the villagers continue their usual activities without taking shelter in an enclosed room or outside these aerosol clouds. Some cases of acute poisoning of children accidentally sprayed by aircraft have been reported. On many occasions, this practice even affects the school cycle of students due to the different allergic skin and respiratory reactions generated by the contact and exposure to these ripening agents, educational centers are forced to suspend classes and send students back home.

In addition to inhalation and dermal exposure, there is a high probability that villagers are also exposed by ingestion of contaminated food and water. The same damage to food crops (e.g., chilis, squash, papayas) already reported in Chapter 4.3 from drift of aerially applied pesticides. Since local people depend on these crops as a source of food, they may be exposed to these pesticides when they consume them. This is confirmed by the agronomist interviewed, who affirms that all crops within about 200 m of the treated areas are also sprayed by the ripening agents. Drift distance depends on a multitude of factors such as weather conditions, pesticide mixture used, spray equipment and practices. It can be greater than 1,600 m in case of temperature inversion (Fishel & Ferell, 2019). Well

[11] "The person who renders the service or performs the work is called a worker; the person who receives and remunerates him is called the employer."

Figure 27 The families in this community have their houses between the road where the trucks pass during the harvest and the sugarcane fields.

water used by households in communities living near sugarcane crops (El Chino, San Marcos Cañales) comes from surface aquifers. Measurements in four wells in these communities have shown that the aquifers are located between 2.9 and 5.9 m from the surface. These aquifers are porous and are composed of sand and other gross erosion materials. These materials produce a high infiltration of surface water into the aquifer but have a low filtration or chemical retention capacity in the infiltration water and therefore highly susceptible to contamination (MARN, 2013b).

However, insufficient data is available on pesticide contamination of water and food consumed by communities. The measurement campaign conducted under El Salvador's National Integrated Water Resources Management Plan in 2015 did not measure pesticides in groundwater (MARN, 2017b). In June 2014, a paraquat measurement campaign was conducted in 13 artesanal wells in the communities Las Brisas in San Miguel. The measured concentrations ranged between the detection limit of the analytical method used 0.62 mg/L and 8.89 mg/L. At least 7 of the 13 wells had concentrations 4 to 28 times higher than Salvadoran standards for drinking water (A. López et al., 2015). The analytical method was not accurate enough to judge the contamination status of the remaining 6 wells in view of the health risk.

From 4 to 7 weeks after the application of the ripening agents, the canes are burned in the evening around 5 pm to facilitate harvesting the following day (Figure 28) (Maximus*, 2019). Smoke and fine particles produced by combustion enter neighboring houses, causing soot and ash to settle in the various rooms of the house (Pascal*, 2019). Fine particles less than 10 μm (PM10) emitted during the combustion process can enter the lungs and even the bloodstream (OAR US EPA, 2016). The most hazardous particles to health are fine particles less than 2.5 μm (PM2.5) (OAR US EPA, 2016).

Some scientific studies have been conducted on the exposure of workers and villagers to fine particles released during sugarcane burning. Le Blond et al. (2017)

measured PM_{10} concentrations in the air of communities surrounding the fields before, during and after burning in Ecuador and Brazil. These measurements showed an increase in PM_{10} from 18-37 (µg m^{-3}) before burning to 1,807 (µg m^{-3}) during burning and 123 (µg m^{-3}) during cutting in the villages around the fields (Le Blond et al., 2017).

PM_{10} concentrations during cutting are due to the resuspension of particles in the air during the work. Cançado et al. (2006) monitored fine particulate matter produced by sugarcane burning for one year. The monitoring was conducted in a city of 250,000 inhabitants in Brazil, 80% of which is surrounded by sugarcane plantations. In the case of this city, the burning of sugarcane plantations contributes to 60% of the total aerosol mass.

During the combustion period, PM_{10} concentrations increase on average from 28.9 (µg m^{-3}) to 87.7 (µg m^{-3}) and $PM_{2.5}$ concentrations increase from 10.0 (µg m^{-3}) to 22.8 (µg m^{-3}) (Cançado et al., 2006). These figures are given as an indication because the concentrations of fine particles found in the air are highly dependent on climatic and meteorological conditions, such as wind, temperature, and humidity of the ambient air. On the other hand, it is the fine particles that have the highest surface area per gram of material, and therefore have the greatest affinity for retaining pollutants.

It is possible that part of the pollutants is burned or evaporated during the combustion process. However, there is also the possibility that a fraction of them is retained in the fine particles of the combustion. More research on this problem should be carried out.

5.4 Conclusion

The way sugarcane cultivation is practiced in the communities visited is very intensive in terms of the use of water, soil, fertilizers, and pesticides. As seen in this chapter, the production cycle involves the use of agrochemicals in the phases of soil preparation, crop handling and just before harvest.

It has also been observed that villagers hired to spray sugarcane fields do not receive the proper induction and training, protective equipment and medical attention required to work with fertilizers and pesticides. These working conditions are difficult to change because workers are in a very vulnerable situation facing the power of those who hire them. The way their work is organized and paid also makes it impossible to work in a way that guarantees workers' health. Payment per task favors the excessive use of pesticides and leads to dangerous behavior when using these products. Various labor rights violations have also been reported and there appears to be a gap in state controls on the observance of labor rights. Workers' rights are not respected.

Figure 28 A. Intentional burning of sugarcane plots the night before harvest. B. Sugarcane sugar fields ready for harvest ©UNES

Given the employer-employee relationship in sugarcane crops, the employer is responsible for providing adequate protective equipment and ensuring compliance with the General Law on Risk Prevention in the Workplace (ALRES, 2010) and occupational safety standards for the use of agrochemicals (ISDEM, 2012). These legal frameworks include employment conditions for people using pesticides and personal safety standards. Rules regarding employment conditions include medical examination, prohibition of employing personnel under 18 years of age, women of childbearing age, mentally retarded persons, physically ill persons (liver, kidneys, asthma) and illiterate persons working with these substances (ISDEM, 2012). Workers should also be trained in the safe use of the products and appropriate personal protective equipment. The equipment should be adapted according to the hazardousness of the products used. Depending on the products used by operators in the sugarcane fields (e.g., 2,4-D and glyphosate), the employer must provide during spraying: gloves (Nitrile, Butyl or Neoprene), mask with filter (NIOSH R95 or R100 type plus Organic Vapors cartridge), lineless rubber boots, protective suit coveralls, safety glasses. (Annex 2, p. 111, Medardo & Molina, 2016).

The obstacle to improving practices is associated with the social and economic conditions of the people working in the fields, which create a bond of servitude with their employer that prevents discussion and denunciation. Considering the hierarchical organization in the sugarcane fields, the employer must check the application of employment standards. Given the operational nature of the caporal's role, the caporal should verify the way in which pesticides are applied and compliance with the manufacturer's dosage. As instructed by the team leader or agronomist, the worker should correctly calibrate his instrument and wear the PPE provided by the employer.

The effects of pesticide application, mainly by air, are strongly felt in the communities living around the sugarcane fields. **Women and children are affected by pesticides differently than men. This is due to morphological, physiological reasons and to social issues related to the sexual division of labor, the assignation of gender roles and the subsequent distribution of household duties.** At present there is hardly any data on the extent of these contaminations generated in soil, rivers, well water, and food.

Interview surveys show various legal aspects of aerial application of pesticides that may endanger the health of residents are not respected. These are mainly violations of Article 7, paragraphs 12 and 18 of Decree No. 423 instructive of aerial applications of agricultural input (MAG, 2011)[12]. Paragraph 7 is not respected because the planes pass over the houses releasing part of the spraying in houses and schools and the safety distance of 300 m is not respected. In addition, the sugarcane plots are adjacent to the houses. Pesticide contamination in the food production of the communities' inhabitants has also been reported many times. MAG agreement 18 is also not respected in the sense that there is no notification of aerial application 72 hours prior to application. Consequently, people do not take the necessary measures to protect themselves. The hours of application can also compromise the health of children on their way to school during application hours. There is evidence that children have been sprayed.

[12] "Agricultural aircraft must not spray pesticides over the airspace less than three hundred meters away from the following places: rivers, lakes, lagoons, fountains, estuaries, ponds, apiaries, stables, hospitals, schools, villages, towns, public places, sheepfolds, trails, beachess".

6 Exposure of the Aquatic and Wetland System

6.1 Introduction

To characterize environmental exposure to pesticide emissions in sugarcane fields, it is necessary to monitor their concentrations in the different environmental compartments. As mentioned above, sugarcane fields are sprayed with agrochemicals at least three times a year, including during soil preparation, crop maintenance and before harvest. Some pesticides are incorporated in solid form directly into the soil, others are sprayed by knapsack pump or sprayed by airplane. The type of substance used and the way it is applied influence the probability that these substances will reach the aquatic system and may cause adverse effects.

The objectives of this chapter are:

1. To collect data on the existing concentrations of pesticides measured in the environment in El Salvador.
2. To make an initial evaluation of pesticide concentrations in the study area.

Based on the environmental concentrations found, an initial environmental risk assessment can then be made (Chapter 8).

6.2 Environmental Concentration in the Estuarine Environment of El Salvador

The data on the concentrations of pesticides measured in the different environmental compartments of El Salvador in river and estuarine waters, sediments and different marine organisms were recompiled. The available data consulted are no less than 9 years old. Therefore, data are mainly available for organochlorines and to a lesser extent organophosphate. The main data come from the documents entitled "Aldrin, BHC, DDT y Heptacloro en aguas superficiales y subterráneas de la zona algodonera" (Calderón, 1981), "Surface and Groundwater Contamination in selected Watersheds in Southwestern El Salvador" (Requena & Mayton, 1991), "Informe del estado del medio ambiente marino en el área Pacífico de El Salvador" (Rubio, 1994) and "Muestras de sedimentos de la plataforma costera de El Salvador libres de niveles significativos de plaguicidas" (Barraza, 2003).

South-western coastal zone and Barra de Santiago Ramsar Site

Regarding the wetlands of the southwestern coast, mainly comprised of: Barra de Santiago, Garita Palmera, San Juan, Metalío, Santa Rita, Zanjón El Chino and Bajo Río Paz, few studies have been carried out on pesticides and their impact on the estuarine/fluvial environment and mangroves. Only two studies have been documented (Calderón, 1981; Requena & Mayton, 1991), mostly referring to the Barra de Santiago wetland and some measurements in surrounding rivers in some of the geographical areas mentioned above.

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Requena & Mayton (1991) stated the high concentrations of methamidophos that were found in some of the water samples could have produced the high mortalities of shrimp, fish and other fauna associated with this region, reported by the inhabitants of the area. They also mention that the low concentrations of pesticides found in water were probably due to the sampling period did not correspond with the high pesticide applications.

All concentrations measured in the Cara Sucia River exceed the permissible limits for water solubility and toxicity according to Paz Calderón (1981).

Unfortunately, of the main wetlands that conform the southwestern coast and that make up the Barra de Santiago Ramsar Site (containing estuarine systems, river courses, coastal and inland lagoon systems such as: Barra de Santiago, Garita Palmera, Bajo Rio Paz, San Juan, Metalío, Santa Rita and Zanjón El Chino) there are no documented studies apart from the two mentioned above. These two studies cover the little documented information from the southwestern wetlands to the Gulf of Fonseca.

Table 11 Measured concentrations of organochlorines and organophosphates in the south-west coastal zone and Barra de Santiago

Location	Pesticides	Concentration	References	Human Health Guideline Value	References
Surface water analysis (µg/L)					
Aguachapío River	α-BHC	0.01	Requena & Mayton (1991)	2	(WHO, 2006)
Cuilapa River	methamidophos	0.34	Requena & Mayton (1991)	a	(WHO, 2006)
	α-BHC	0.33	Requena & Mayton (1991)	2	(WHO, 2006)
	γ-BHC	0.01	Requena & Mayton (1991)	2	(WHO, 2006)
Cara Sucia River	aldrin, dieldrin	140.33 (37-341)	Paz Calderón (1981)	0.03	(WHO, 2006)
	DDT	152.1 (56.07-105.33)	Paz Calderón (1981)	1	(WHO, 2006)
average value August-January (min. max)	Heptachlor and hep. epoxide	7.27 (0-10.8)	Paz Calderón (1981)	a	(WHO, 2006)
	α e γ-BHC	56 (19.2-127)	Paz Calderón (1981)	2	(WHO, 2006)

Location	Pesticides	Concentration	References	Human Health Guideline Value	References
El Naranjo River	α-BHC	0.33	Requena & Mayton (1991)	2	(WHO, 2006)
El Rosario River	α-BHC	0.07	Requena & Mayton (1991)	2	(WHO, 2006)
Ezcanal River	α-BHC	0.01	Requena & Mayton (1991)	2	(WHO, 2006)
Guayapa River (Up-wharf)	α-BHC	Up: 0.01 Down: 0.01 Wharf: 0.005	Requena & Mayton (1991)	2	(WHO, 2006)
La Palma River	α-BHC	0.07	Requena & Mayton (1991)	2	(WHO, 2006)
Sediment analysis (µg/kg d.w)					
Barra de Santiago	paraquat	34	Requena & Mayton (1991)	not applicable	
	α-BHC	0.5	Requena & Mayton (1991)	not applicable	
	DDE	0.7	Requena & Mayton (1991)	not applicable	
	dieldrin	53	Requena & Mayton (1991)	not applicable	
	DDD	0.06	Requena & Mayton (1991)	not applicable	
Fish analysis (µg/kg d.w)					
Mugil sp "lisa"					
Barra de Santiago	paraquat	40	Requena & Mayton (1991)	-	-
	DDE	30	Requena & Mayton (1991)	-	-
	o,p'-DDT	10	Requena & Mayton (1991)	-	-
Catfish					
Barra de Santiago	α-BHC	10	Requena & Mayton (1991)	-	-
	γ-BHC	30	Requena & Mayton (1991)	124	See chapter 6.4.3 (US EPA, 2000)
	DDE	90	Requena & Mayton (1991)	-	-
Mollusk Analysis (µg/kg d.w)					
Anadara sp "curil"					
Barra de Santiago	α-BHC	10	Requena & Mayton (1991)	does not exist	-
	γ-BHC	10	Requena & Mayton (1991)	124	See chapter 6.4.3 (US EPA, 2000)
	Heptachlor	10	Requena & Mayton (1991)	5.35	See chapter 6.4.3 (US EPA, 2000)
	DDE	10	Requena & Mayton (1991)	-	-
Crustacean Analysis (µg/kg d.w)					
Ucides occidentalis "punche"					
Barra de Santiago	α-BHC	500	Requena & Mayton (1991)	-	-
	DDE	10	Requena & Mayton (1991)	-	-
Callinectes sp "jaiba"					
Barra de Santiago	aldrin	10	Requena & Mayton (1991)	-	-

a Unlikely in drinking water

Acajutla - Los Cóbanos Area

Pesticide records are reported for the Acajutla - Los Cóbanos area (Table 12), but it is important to emphasize that this report by Michel & Zengel (1998), covers with higher priority other toxicants derived from the oil spill, which were analyzed for petroleum hydrocarbons, chlorinated organic compounds, pesticides, and trace elements. Most of the oysters analyzed contained only low levels of PAHs, except for those collected close to an industrial discharge channel that were up to 100 times background levels. Only black mud accumulated in the main harbor contained PAHs at levels of environmental concern. Pesticides in oysters and fine-grained sediments were below detection levels in most samples. PCBs were also low; trace elements in sediments and oysters varied widely, reflecting differences in loadings and degree of bioavailability. Zinc and copper in oysters were elevated to levels normally considered representative of moderately contaminated sites, while arsenic, cadmium, chromium, lead, and nickel were not elevated at most sites. These results were generally associated with potential sources of contamination identified through a questionnaire on product storage, handling and waste disposal from facilities operating in the area which covered part of the Los Cóbanos reef system.

The system is surrounded by different fluvial courses, one of the main ones being the mouth of the Sensunapán river. Among the stations related to fluvial courses, the Acajutla-Los Cóbanos connection, which is a rocky platform, and a system of rocky reef portions has been considered.

At these stations they measured organochlorine pesticides obtaining the following results of concentrations per station (Table 12).

In addition to the mentioned study, only punctual data are recorded in the estuarine waters of Barra Salada which is also a fragmented mangrove system but of great importance in the reef interaction of Los Cóbanos.

In the Barra Salada system, methyl-parathion concentrations of 0.01 and ethyl-parathion concentrations of 0.01 mg/kg were detected in measurements made in 1986, 1988 and 1989 (Rubio 1994). In the cliff coast of the Balsamo Mountain range, no documentation or articles were found on pesticides associated with fluvial courses in this type of system.

The Paracentral and Eastern Coastal Plain

The paracentral and eastern coastal plain is characterized by the largest extensions of mangroves and estuarine systems (Jaltepeque and Jiquilisco), fragments of small inland wetlands, as well as riparian vegetation typical of fluvial ecosystems such as the Bajo Lempa, Grande de San Miguel River and to a lesser extent the Jiboa river. All these sectors in the seventies were used for several extensions of cotton cultivation.

At the present time, all these sectors are subject to sugarcane cultivation, containing a wide extension of hectares. Despite the relevance of the mentioned ecosystems, there are few studies on the subject and some specific data.

Rubio (1994) detected high concentrations of organochlorine compounds in the Jiboa River, with higher concentrations at the mouth of the river.

Domínguez & Paz (1985), cited by Rubio (1994), determined organophosphorus and organochlorine pesticide residues in fish, crustaceans, and mollusks in

Table 12 Concentration in upstream rivers in the Acajutla - Los Cóbanos area.

Location	Pesticides	Concentration	Human Health Guideline Value	References
Surface water analysis (µg/L)				
El Almendro River	Total DDT	up: 260 down: 260	206	See chapter 6.4.3 (US EPA, 2000)
Huiscoyol River	Total DDT	up: 38 down:18	206	See chapter 6.4.3 (US EPA, 2000)

the Jaltepeque estuary. The results are presented in the following table (Table 14):

Of all the groups of organisms studied, curiously the lowest concentration or zero concentration corresponds to the species Caranx sp with 0.0 ppm concentration of the organophosphate Paradoxon and the highest concentration was detected for the organochlorine BHC 1.47 mg/kg d.w in the same genus of fish mentioned above.

This was followed by the organochlorine compound heptachloro-epoxide with a concentration of 1012.2. mg/kg b.w. in Anadara sp tissue.

Unfortunately, the information is limited in terms of spatio-temporal period, lethal concentrations, limits of detection and quantification (not detailed). However, it is important to mention this is the only study available and it refers to living organisms from this geographical area.

Wetlands of the Eastern Region

This case is specifically focused on Jiquilisco Bay and the Gulf of Fonseca respectively, in terms of surface area and mangrove coverage, primary and secondary estuarine channels and remnants of alluvial swamps are the ones with the largest surface area. Both wetlands support the most important artisanal fishery in El Salvador and in the case of Jiquilisco Bay is where the most important shrimp farming (series of ponds in large quantities of marine shrimp culture) of marine shrimp (L. vannamei and L. stylirostris) of El Salvador is concentrated. It is also home to the largest extraction of “black shells”, “curiles” (genus Anadara sp) in the country.

As with the previous wetlands, research on pesticides is minimal and there is only occasional data.

López Zepeda (1977) cited by Rubio (1994), conducted a study of organochlorine pesticide residues in some

Table 13 The concentration level measured in the Jiboa River (Rubio, 1994).

Location	Pesticides	Concentration
Surface water analysis (µg/L)		
Jiboa River upper and middle part and mouth Average value August-January (min. max)	α e γ-BHC	36.95 (0-96)
	aldrin, dieldrin	45.2 (24-101)
	DDT	110.1 (21.9-292)
	Heptachlor and hep. epoxide.	13.6 (0-76)

fish, mollusks and crustaceans in the Bay of Jiquilisco as shown in Table 15, the highest concentrations were detected in DDT in the group of fish as follows: Cynoscion sp "curvina" 2.33 mg/kg b.w.; Mugil sp "chimbera" 1.86 mg/kg b.w.; Pomadays sp "ruco" 1.79 mg/kg b.w.; second for the mollusk group: Anadara sp "curil" 0.75 mg/kg b.w. and Mytella sp "churria" 0.62 mg/kg b.w.

The seasonal periods in which the work was carried out and permissible concentration limits for aquatic species are not reported in the mentioned study.

Table 14 Organophosphorus and organochlorine pesticides present in the Jaltepque Estuary: (Taken and adapted Dominguez & Paz 1985).

Taxa	Pesticides	Concentration (µg/kg d.w)	Comments
Fish analysis (µg/kg d.w)			
Arius sp	BHC	202.9	
	DDT-totals	89.0	
	Endrin-Aldrin	0.0	
	Heptachlor-Epoxide	141.8	
	Paradoxon	153.7	Arius sp "bagre" (catfish) benthic species frequently found feeding in sedimentary bottoms.
Caranx sp	BHC	1470.0	
	DDT-totals	2302.0	
	Endrin-Aldrin	100.0	
	Heptachlor-Epoxide	0.0	
	Paradoxon	0.0	Caranx sp "jurel" species with pelagic characteristics in their adult, pre-adult and juvenile forms enter estuaries occupying the water column.
Pomadays sp	BHC	14.7	
	Endrin-Aldrin	105.2	
	Heptachlor-Epoxide	1249	
	Paradoxon	0.3667	Pomadasys spp "ruco" epibenthic species that usually occupies the middle column of the water body.
Crustacean analysis (µg/kg d.w)			
Callinectes spp	Paradoxon	0	Callinectes sp "jaiba" benthic organism with relatively short movements, pre-adult larval stages depend 100% on the estuary.
Litopenaeus sp	Paradoxon	16.8	Litopenaeus sp "shrimp" Epibenthic species of moderate mobility within estuaries. Larval, juvenile and pre-adult forms within the estuary, adults migrate to the open sea.
Analysis of mollusks (µg/kg d.w)			
Anadara sp	DDT-totals	16.7	
	Endrin-aldrin	3	
	Heptachlor-Epoxide	1012.2	
	Paradoxon	122.2	Anadara sp "curil" benthic organisms of muddy bottoms entirely sessile. 100% of its life cycle depends on estuarine/mangrove interaction. Ideal organism for pesticide and heavy metal detection studies.

Therefore, the present analysis is limited. Another study that was carried out with emphasis on marine shrimp farms (L. vannamei) cultivated and located mainly in Bahía de Jiquilisco western sector by Nomen et al. (2012), with emphasis on determining organochlorine and organophosphorus pesticides in cultivated shrimp, soil, sediment in ponds and sediment and water around the ponds. Samples were taken during the dry season (January-March) and rainy season (June-August).

Nomen et al. (2012) reported that in soil samples around the ponds heptachlor, endrin, dieldrin. p,p'-DDE and p,p'-DDT were found in concentrations above the limits of quantification (LOQ) and p,p'-DDE was found in concentrations in the range of 3.85 to 19.61 mg/L.

The study concluded that organochlorine compounds are present in Jiquilisco Bay trapped in sediment, which have been reported since 1980. They were not found in cultivated shrimp, nor in water or sediment within the studied ponds.

Normen et al (2012) determined organochlorine and organophosphorus pesticides in "marine shrimp" farming areas. This article reports levels of ↱ -HCH, p,p'-DDT, p,p'-DDE, p,p'-DDD, endrin, dieldrin, heptachlor, parathion, methyl parathion and ethoprophos in soil (20 cm), sediment (3 cm), "marine shrimp" (L. vannamei) and water in three ponds and sediment (5 cm) and water around the ponds in Jiquilisco Bay. Sampling was conducted during the dry season (January-March) and rainy season (June-August).

The presence of pesticides in water, shrimp and pond sediment samples was not detected at any station. In soil samples around the ponds heptachlor, endrin, dieldrin, p,p'-DDT and p, p'-DDD were found in concentrations above the limits of quantification (LOQ) and p,p'-DDE were found in concentrations ranging from 3.85 to 19.61 µg/kg. In samples of estuarine water feeding the ponds, dieldrin was detected in the range of 0.085 µg/L and 0.182 in the dry season.

Rubio (1994) reported methyl parathion concentrations of 10 µg/L and parathion of 10 µg/L in estuarine waters of Jiquilisco Bay. The same author reports critical values for the coastal stretch of the Río Grande de San Miguel, especially the mouth of the river for: aldrin group 3770.67 µg/L, heptachlor 159.81 µg/L, DDT group 63.39 µg/L and BHC 53.13 µg/L. For the Bahía de Jiquilisco wetland this is particularly important because the mouth of Grande de San Miguel River is part of the mouth known as El Bajón de la Culebra (Eastern Sector of the Bahía de Jiquilisco).

A study conducted by the U.S. Army Corps of Engineers (1998) found chemical contamination by pesticides. Specifically, they point to large cotton growing areas in the southern coastal plains. In Grande de San Miguel River they detected concentrations of 3150 µg/L of DDT.

Therefore, any anthropogenic action of diverse agro-industrial productive nature and others that generate different types of discharges can directly or indirectly influence the three countries.

Table 15 Pesticides detected in some fish, mollusks, and crustaceans in Jiquilisco Bay. Taken from López-Zepeda (1977) cited by Rubio (1994)

	DDT	**Endrin**	**Dieldrin**	**Ethyl parathion**
Fish analysis (µg/kg d.w)				
Cynoscion sp	2.33	0.16	0.04	-
Mugil sp	1.86	0.27	0.05	-
Pomadays sp	1.79	0.07	0.52	-
Crustacean analysis (µg/kg d.w)				
Litopenaeus sp	0.56	-	-	-
Mollusk analysis (µg/kg d.w)				
Anadara sp	0.75	0.05	0.03	-
Mytella sp	0.62	0.03	0.02	0.01
Asteroideos analysis				
Oreaster sp	0.35	0.06	0.02	-

In the study by Matta et al. (2002) entitled "Hurricane Mitch Reconstruction/Gulf of Fonseca. Contaminant Survey and Assessment", the authors analyzed organochlorine and organophosphate pesticides in samples of surface water, sediment and biota ("catfish": Bagre panamensis and Arius seemani; "fiddler crab": Uca sp and "churria": Mytella sp).

Matta et al. (2002) in the study of pesticides and heavy metals in the Gulf of Fonseca post Micth by NOAA-AID, sampled surface water, sediments, and biota (Bagre panamensis panamensis, Arius seemani and Galeichthys jordani, "catfish" and Uca sp "fiddler crab") in El Salvador, Honduras, and Nicaragua. Twenty-five stations for El Salvador, 25 for Nicaragua and 25 for Honduras were established throughout the Gulf. The samples were processed in the Geochemistry Laboratory of Texas AAM University, obtaining the following observations of total DDT: the most detected chlorinated pesticides are DDT metabolites (DDE and DDD), the highest DDT concentrations were detected in La Unión, which exceeded 2 mg/kg d.w followed by San Lorenzo (HON), El Tamarindo (SV) and Estero Torcillos (NIC-HON).

In this investigation, El Tamarindo was the station where the highest DDT concentrations were found in fish and sediment. In addition, high concentrations of DDT were found in mussels (Mytella sp) with 11.9 µg/kg d.w and in sediment with 118 µg/kg. High concentrations (160 µg/kg d.w) of diazinon (organophosphate) were also found in fish in Bahía de la Unión.

Study of El Salvador's Oceanic Platform

The only oceanic study including the Salvadoran continental shelf was carried out during the visit of the research vessel "Urraca" where Barraza (2003), collected sediment samples from 10 to 400 meters' depth of water within the continental shelf. It is important to mention, after 50 meters' depth species richness decreases with few dominant species appearing.

Eight sediment samples were collected and sent for analysis at the FUSADES integrated quality laboratory to determine the levels of organochlorines and organophosphates. The results indicated that the concentration of these compounds in the eight samples analyzed is absent or below the detection levels of the methods used (less than 2.97 parts per billion, NOAA US EPA), which do not represent harm to marine biodiversity or to marine organisms associated with the ocean bottom, such as sole, grouper, snapper, sea bass, catfish, shrimp, crab, langoustine, etc., which is considered an important and positive finding on the environmental quality of the Salvadoran ocean bottom.

6.3 Methodology

6.3.1 Sampling Strategy and Plan

The development of this sampling plan is based on the prioritization of substances of concern in the aquatic environment as described in the sections of Appendix 11 (11.4 Prioritization of substances of concern to be monitored in the aquatic system), the selection of the environmental matrix (11.5 Environmental matrix to be sampled) and selecting the analytical laboratory (11.6 Selection of analytical laboratory).

Pesticide contamination is so-called diffuse source (as opposed to point source) contamination. Diffuse sources of pollutants are complex to monitor because the sources are multiple and vary in space and time.

The sampling strategy includes different aspects such as the environmental matrix sampled, list of selected substances (number and relevance), duration of the measurement, frequency, number, distribution of the sampling points and laboratory efficiency. For example, pesticide measurement experiments in Switzerland have shown that the best method to measure maximum pesticide concentrations is to take frequent samples during rainy periods (Wittmer et al., 2014).

On the other hand, it was demonstrated in this research that a point sample tends to underestimate the concentrations found in the environment (Wittmer et al., 2014) and is poorly representative of the real conditions. Laboratory performance means the analytical recovery rate of substances obtained during contaminant extraction using solvents of the contaminant in the environmental matrix and the detection limits and quantification of the applied analytical methods.

As mentioned in Chapter 5.3, there are three main periods when cane fields are sprayed: during soil preparation (November to January), crop maintenance while growing (June to August) and before harvest (September to March). After application to crops and soils, pesticides are transported to other environmental compartments by runoff, air, erosion, and water infiltration. For these reasons, water samples are taken during the rainy period after spraying to get an idea of the level of contamination at the time of the potentially highest load of pesticides and fertilizers.

This preliminary sampling campaign includes the collection of prospective samples from 4 different environments (surface and groundwater, sediments, and fish) to obtain a screening of the contamination levels of certain pesticides, fertilizers, and heavy metals in the study area. The measurement campaign includes 6 wells in the communities, 3 stations distributed in Zanjón El Aguacate (tributary of the Paz River) and 6 stations in Garita Palmera wetland (Table 11). Analysis of fish caught in the coastal zone and in Garita Palmera wetland was also included in the campaign.

The following map (Figure 29) shows the location of the different measurement points considered. The six points selected for groundwater measurement are marked by E1 (Paz y Progresso II), E2 (Rancho San Marcos), E3 (San Marcos Cañales), E4 (El Chino), E5 (ISTA) and E6 (El Palmo La Danta).

Different parameters were analyzed in these wells that give access to these superficial aquifers and a profile of major ions was made between the station at higher elevation (E1), which constitutes the reference point and the points at lower elevation or downstream of the sugarcane fields (E5, E6). Paraquat, organophosphorus and triazines were analyzed at E2, E3 and E4. These stations are in porous aquifers (formed by sedimentary alluvium) and therefore more vulnerable to contamination from the sugarcane fields.

The river El Aguacate contains 3 measuring stations, the first at the Paz River intake (E7), the second halfway to the Garita Palmera wetland (E8, El Diamante bridge) and the third near its mouth in the Garita Palmera wetland (E9) (Figure 29).

Since the climatic events of 1974 and the detour of Paz River from its initial course El Aguacate only receives water during heavy rainfall events called "temporales". Water samples from the wells and the river were taken during the first rain events after the typical spraying of the cane fields from late July to October. Sediment samples were taken during the dry period to obtain adequate conditions for sediment deposition and less turbid water to find the streams. Details of each measurement point are summarized in Table 16.

6.2.3 Sampling Method

For a campaign to measure organic microcontaminants (pesticides), the use of plastics (PE, PVC, etc.) should be avoided in any utensils that encounter the sample and transport containers. Sample collection and storage is done with stainless steel-teflon (polytetrafluoroethylene) or glass tools. Samples should be kept at 4-8°C and transported within 24 hours to the laboratory.

At each of the measurement stations listed in Table 11, a protocol sheet is filled out with the name of the operator, date and time, GPS coordinates, description and diagram of the site, physicochemical parameters of the water, meteorological conditions of previous days, deviations from the sampling and transportation protocol.

River and well water samples are collected in two borosilicate bottles (4L) provided by the laboratory. Sampling is the part of the measurement process that induces most of the variability in the result and must be conducted following the protocol.

River Water Sampling

River water sampling was based on the recommendations of the French Loire-Brittany Water Agency guide (AE-LB, 2006).

Downstream of the sampling point the parameters of temperature, pH, conductivity, turbidity, dissolved oxygen, and Ox/Red potential were taken and recorded in the field sheet or field diary.

For increasing the representativeness of the sampling, composite samples of 8 liters were taken at each site. They were formed by successively adding 1 liter of water every 15 minutes to two borosilicate glass bottles

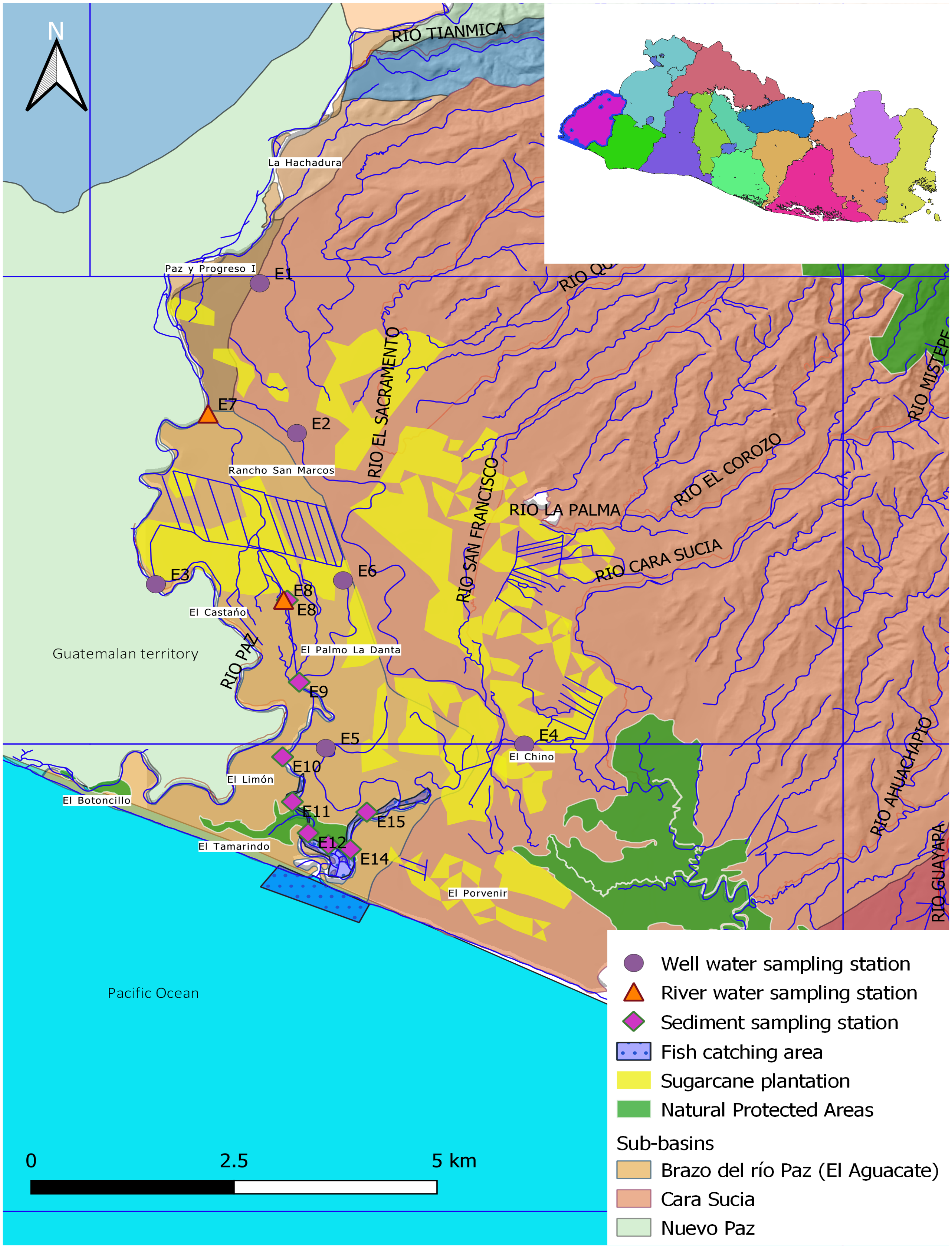

Figure 29 Map of the study area including measurement stations (E1-E9), hydrographic network, type of aquifers and sugar cultivation areas. Source: prepared based on MARN GIS coverages (2011) and land use map Basagoitia Quiñonez & Flores (2016).

4L contained in coolers. The sampling time per station was 1 hour.

The bottle was filled completely and without air bubbles. A precalcined aluminum square is placed between the lid and the glass neck to avoid water contact with the plastic. The bottle was kept in a refrigerator at a temperature between 4° and 8°C to retard microbial decomposition.

Samples were received by the laboratory within 24 hours of its collection. Paraquat and glyphosate were analyzed within 4 days and triazines and organophosphate within 1 month of sample delivery.

Well Water Sampling.

Well sampling is based on the Standard Operating Procedure of the Scientific, Engineering, Response and Analysis Services Contract (SERAS, 2007). Well sampling takes place from the highest point upstream (potentially least contaminated) to the lowest point downstream (potentially most contaminated).

Well water sampling covers some specificities different from surface water. Indeed, depending on the level of utilization of the well, the water available on the surface is standing water that does not represent the water in the aquifer. For this reason, before collecting the sample for analysis, the well should be purged 3 to 5 times of its volume. During its purging, the temperature, pH, turbidity, and conductivity parameters are measured until stable values are obtained. This ensures that enough water has entered the aquifer into the well and that the sample will be representative of the aquifer. In all cases, the water sent by the analyses must have a turbidity of less than 50 NTU.

Samples were received by the laboratory within 24 hours of sampling. Paraquat and glyphosate were analyzed at 4 days and triazines and organophosphates were analyzed one month after sample delivery.

Sediment Sampling

Sediment sampling in El Aguacate River and wetland was based on the Swiss harmonized sediment sampling method for quality assessment according to ecotoxicological evaluation criteria (Casado-Martinez et al., 2016). However, river samples were collected with a bailer and wetland samples were collected with a 1.20 m long PVC tube with a diameter of 10 centimeters.

Sediment sampling included a composite sample of at least 3 different points per site to obtain a representative sample of the study area. No person enters the water body until the deposition zones have been identified. The sediment areas collected should be submerged throughout the year (also during periods of low current), contain as large a fraction of fine particles as possible, and be in a deposition zone that is a low flow zone such as a concave and/or vegetated area.

A person enters the river downstream of the sampling points to avoid sediment remobilization. Sampling is done in the downstream direction to avoid undesirable effects due to sediment remobilization. The depth, current and nature of the substrate of the cross section to be sampled are determined before entering the river. The first 2-10 cm of sediment is collected in an uncontaminated bucket with a scoop at least three points per cross section to form a compound sample representative of the cross section. At each sampling point, surface water was emptied into the scoop before collecting the sediment in the bucket.

If the sampling is conclusive (e.g., sufficient fine sediment in the bucket), remove stones, leaves and other branches manually from the bucket with gloves. The peculiarities of the sample in terms of color (color change on contact with air), odor and consistency are noted on the field sheet. Homogenize the contents of the bucket with a spatula until a homogeneous consistency, texture, and color of at least 3 L is obtained. Sieve to 2 mm without adding water and collect the sieve in a second uncontaminated bucket. Fill the aluminum trays to the brim and close them with aluminum foil. Everything is placed vertically in the cooler.

As with the river water samples, all sampling equipment is rinsed 3 times with water from the site. The physicochemical parameters of the water are also measured, and a schematic diagram of the site and sampling points is made.

Table 16 Description of sampling stations. Without greater knowledge of aquifer dynamics, pesticide samples were taken in the wells closest to the sugarcane fields. For fertilizer (and other major ions) analyses, only the point in the least contaminated aquifer (uppermost point of the basin) and the wells down the sugarcane fields with higher concentrations of total dissolved solids were considered. Regarding sediment analysis, AMPA analysis was done only at the sites closest to the sugarcane fields since they degrade rapidly.

Station code	Coordinates	Communities	Pesticides and fertilizers analyzed	Sampling period
Well water				
E1	N13 49.928, W090 05.810	Community: Paz y Progreso II Reference Point	Phosphate Nitrates, Nitrites Sulfates	Rainy season May-November
E2	N13 48.325, W090 05.44	Community: Rancho San Marcos	Triazines Paraquat	Rainy season May-November
E3	N13 46.709, W090 06.844	Community: San Marcos Cañales	Triazines Paraquat	Rainy season May-November
E4	N13 44.993, W090 03.175	Community: El Chino	Triazines Paraquat	Rainy season May-November
E5	N13 44.956, W090 05.152	Community: Colonia ISTA	Phosphate Nitrates, Nitrites Sulfates	Rainy season July-October
E6	N13 46.75 W090 04.98	Community: El Palmo la Danta	Phosphate Nitrates, Nitrites Sulfates	Rainy season May-November
El Aguacate River water and sediments				
E7	N13 48.532, W090 06.324	El Aguacate River Intake Reference Point	In water: Glyphosate, Paraquat, Organophosphate	Rainy season May-November
E8	N13 46 32.320, W090 05 32.164	El Diamante Bridge after the sugarcane fields	In water: Glyphosate, Paraquat, Organophosphate In sediment: Organochlorines, AMPA, Paraquat, Heavy metals	Rainy season May-November Dry season November-April
E9	N13 45 39.692, W090 05 24.998	El Castaño Bridge after the sugarcane fields	In sediment: Organochlorines, AMPA, Paraquat, Heavy metals	Dry season November-April
Garita Palmera wetland sediments				
E10	N13 44 51.7205, W090 05 34.9041	Los Mangos	Organochlorines, AMPA, Paraquat, Heavy metals	Dry season November-April
E11	13° 44′ 22.9094″ N, 090° 05′ 29.1064″ W	El Perol	Organochlorines, Organophosphates, Paraquat Triazines Heavy metals	Dry season November-April
E12	13° 44′ 02.8993″ N, 090° 05′ 19.6747″ W	El Enganche	Organochlorines, Organophosphates, Paraquat Triazines Heavy metals	Dry season November-April

Station code	Coordinates	Communities	Pesticides and fertilizers analyzed	Sampling period
E13	13° 43' 55.3755" N, 090° 05' 07.5614" W	Bajo El Caballo	Organochlorines, Organophosphates, Paraquat Triazines Heavy metals	Dry season November-April
E14	13° 43' 52.3915" N, 090° 04' 54.4276" W	Los Cayocos	Organochlorines, Organophosphates, Paraquat Triazines Heavy metals	Dry season November-April
E15	13° 44' 16.2704" N, 090° 04' 44.5863" W	El Cuje	Organochlorines, Organophosphates, Paraquat Triazines Heavy metals	Dry season November-April

Fish Sampling

Fish capture: Specimens of three families of fish were captured, which were as follows: Family Ariidae, specifically 8 adult specimens of the genus Arius guatemalensis ("black catfish") were captured, using hooks N° 4 in the estuarine arm known as "El Perol", the specimens were measured and weighed using a tape measure graduated in centimeters. The length (L.T.) and weight expressed in grams (g) were taken using a digital scale with a capacity of +/- 1 gram and recorded on the field sheet.

In addition, 9 specimens were caught from the family Mugilidae, specifically from the species Mugil curema in the estuarine sector known as "La Cuchilla". For this purpose, 3.25-yard and ½ inch long nets of stretched mesh and 020 thread were used.

Finally, 3 specimens of the Lutjanidae family were collected: 2 individuals of Lutjanus guttatus ("moon snapper") and 1 of L. novemfasciatus ("red snapper") using #4 hooks and pearl thread with shrimp bait. These catches were made 2 km off the coast of Garita Palmera in the area known as "the sunken boat."

It is important to clarify that all the fish product was purchased from local artisanal fishermen. The length and weight of each fish was measured, and its species was determined to separate the samples according to species.

Processing of samples: each specimen caught was washed, gutted, and the head and tail were cut off. Subsequently, the muscle fraction of each individual was cut into small pieces of 5cm x 4cm and stored in sterilized and sealed ziplock plastic bags. Each bag was properly identified, labeled, and coded. Each bag was immediately frozen in a freezer. Morphological characteristics were taken such as: fins, fin size, soft rays, type of teeth, fresh coloration, and gill arches. For fish identification, the following taxonomic key was used Robertson & Allen (2015).

6.4 Results

6.4.1 Water and Sediment Quality of El Aguacate River

Stations E7, E8 and E9 (see Figure 29 and Table 16) in El Aguacate River were monitored between October 2020 and January 2021. Water quality was assessed at the end of the rainy season (October 14, 2020) between station E7 at El Aguacate intake and station E8 downstream of the cane fields. Both stations were characterized for their physicochemical parameters and concentrations of glyphosate, paraquat and organophosphorus. Station E8, downstream of the sugarcane fields was also analyzed for its major ion content.

The flow of El Aguacate River on the sampling day was 224 ($\pm$13) liters per second. The days prior to sampling were characterized by low rainfall (4 mm the night

Table 17 Physicochemical parameters with standard deviation (±SD) in El Aguacate River.

El Aguacate River	E7 Station upstream sugarcane fields	E8 Station downstream sugarcane fields
Physicochemical parameters		
Temperature (°C)	31.3 (± 0.2)	29.2 (± 0.2)
pH	8.3 (± 0.1)	7.1 (± 0.1)
Dissolved oxygen (mg/L)	8.2 (± 0.2)	4.8 (± 0.3)
Redox potential (mV)	94.9 (± 1.2)	29.9 (± 2.1)
Conductivity (µS/cm)	400.2 (± 2.7)	1006.3 (± 4)
TDS (mg/L)	200.4 (± 1.5)	502.0 (± 2.9)
Turbidity (NTU)	32.0 (±10.6)	27.0(± 20.7)
Transparency (cm)	30 (±10)	>15 cm*

before), although this was still the rainy period. The last rainfall with significant amounts was on October 5 with 45 mm. However, it was noted that this year's rainfall regime was particularly disturbed by the passage of tropical storms "Amanda" (May 30-31, 147 ±20 mm accumulated in 48 hours in the study area) and "Cristobal" (June 1-12, 417 ±38 mm of rain in 12 days) which induced several floods in the area. Rainfall levels for May and June this year (683 mm), recorded in the community monitoring network, is a factor of 2.5 higher than in previous years (258 mm according to CLV (2018).

The day of sampling was sunny. The following table shows the results obtained for water quality obtained at the entrance of El Aguacate River (E7) and at the station downstream of the sugarcane fields (E8).

The pH measured in the water upstream of the reed beds corresponds to normal values for surface water (8.3). The pH value drops by 1.2 points downstream of the sugarcane fields but remains within the values that allow the development of aquatic species (6.5-9). This acidification is due to heavy rainfall (a natural phenomenon) and to soil acidification induced using certain nitrogen fertilizers (Barak et al., 1997). The reduction in dissolved oxygen and redox potential, and the increase in TDS could indicate the introduction of a reducing or oxygen-consuming component to the water, such as the introduction of organic matter into the river.

The redox potential is a measure of the river's ability to purify itself of pollutants and organic matter. It depends on the oxygen present in the system whether it can help the degradation of these molecules. Healthy surface waters should have a positive potential of 300-500 mV (Søndergaard, 2009). The redox potential and pH are also important in determining the speciation pattern of metals and metalloids and the reduction or oxidation of different organic molecules (Plant et al., 2003; Williams & Fraústo da Silva, 2006).

The oxygen level at the entrance of El Aguacate River corresponding to that of the Paz River is particularly good with a value of 8.2 mg/L, which is above the theoretical 100% at this temperature and conductivity (7.38 mg/L). This result can be explained by the high phototrophic productivity at this time of day (11:05 am). The oxygen level at the measuring station at 4500 m downstream of this station drops drastically with a value of 4.8 (mg/L), i.e., only 63% oxygen saturation. In the case of warm waters (tropical climate), the WHO water quality criterion sets a value of 5-6 mg/L for biota as the minimum dissolved oxygen concentration (Enderlein et al., 1996). Exposure to lower values makes fish more susceptible to disease and environmental stress (Wilson, 2010). Low oxygen and pH values can increase the toxicity of metals (Zn, Pb, Cu) to aquatic organisms (Enderlein et al., 1996). Dissolved oxygen values below 3 mg/L are lethal to most fish species (Wilson, 2010).

This oxygen saturation indicates a higher oxygen demand than produced by photosynthetic organisms. Biological oxygen demand increases with the microbiological decomposition of organic matter in the stream. In agricultural areas, uncontrolled growth of aquatic algae, and subsequently of organic matter, indicates an overabundance of nutrients (nitrate, phosphorus) due to leaching of fertilizers. This process is called accelerated eutrophication.

Conductivity is an indicator of the total concentration of dissolved ions in the water, including cations (Na+, K+, Ca+, Mg2+ etc.) and anions (CO32-, NO3-, PO42-, SO42-, etc.). The increase in their value between the station above and the station below the sugarcane fields indicates contamination. The conductivity increases by a factor of 2.5 after sugarcane fields (1006 µS/cm) compared to the value at the entrance of El Aguacate river (400 µS/cm). This increase may be due to fertilizer leaching, which increases nitrate, phosphate, and potassium concentrations in the water.

The measurement of total dissolved solids (TDS) corresponds to the concentration of dissolved ions in the water. In clean seawater, it corresponds to the salinity values. In this river, other molecules in ionic form probably also contribute to the total TDS load, such as urea and other fertilizers. The TDS value reported by the sonde is calculated from the conductivity values, there is also a factor of 2.5 between upstream and downstream.

Turbidity is another way of measuring water transparency. It depends on the presence of mineral particles (clays, limes) and organic particles (phytoplankton, microorganisms, dissolved organic compounds). To protect aquatic life, the CCME recommends an increase of no more than 8 NTU over a short period of time or 2 NTU over a long period of time compared to background values (CCME, 2002). The measured turbidity values (29.5 NTU) are on average 24.75 NTU higher than the average of values reported in dry periods at 4 sites in the Paz River (B-01 to B-04-RPaz in MARN, 2017), indicating very pronounced erosion in the watershed.

Turbidity values are not significantly different between the stations above and below the sugarcane fields. The precision of the turbidity measurement by the transparent tube does not allow us to highlight a significant difference. It should also be noted that there was a sedimentation basin upstream of the sampled site in El Aguacate River (station E7). The level of transparency measured with the Secchi disk (30 cm) at the entrance of the river is at a limit value characterized by excessive turbidity for fish survival (Boyd, 2004).

To complete this assessment, a water sample was analyzed to determine its major ion composition (results in mg/L Table 18). The sulfate concentrations are ten times higher than the values measured at the reference value for the site upstream of the watershed. Sulfates are not directly toxic, but can form strong acids in the water, which could explain the lower pH values compared to water from the upstream site.

This high abundance of sulfates could be explained by the use of chemical fertilizers in the fields. However, the results indicate a good buffering capacity (high alkalinity) that allows pH stabilization. The measured total phosphate levels represent a serious threat of hypertrophy that could further decrease oxygen levels in the dry period when temperatures and ion concentrations increase due to evaporation.

Observations in the station located downstream the sugarcane plantation (E7) revealed the following: in the river substrate, fine sand mixed in certain backwaters with mud, brown coloration (with a mixture of whitish color), a slight presence of foam was observed. There was no iron sulfide, nor clogging, with solid waste, organic and inorganic waste could be distinguished with heterotrophic organisms, green algae (macrophytes) were present in small quantities. With respect to aquatic vegetation, only "water lettuce" was identified. Other observations suggest that the algae were rich in nutrients, "chimbolos" (family Policidae) were observed, and the surrounding vegetation was highly disturbed with sugarcane fields, "higerrillos" (Ricinus commnunis) and "hemelina" (Hamelia sp).

Samples taken upstream and downstream of the sugarcane fields did not detect glyphosate, paraquat and organophosphate. The limit of quantification (LOQ) for glyphosate by the analytical method used was 64 µg/L. This LOQ is low enough to indicate that these water samples do not represent a risk to aquatic species from this herbicide. This assessment was based on the latest chronic environmental quality criterion developed by the Swiss Ecotoxicology Centre set at 120 µg/L (Ecotox Centre, 2016a).

The detection limit for paraquat analysis is 106 µg/L. The Australian Government proposes a guideline value

Table 18 Results of major ion analysis of El Aguacate River at station E8.

	Concentration (mg/L)	Guideline values for environment (mg/L)	Comments	Interpretation
Calcium ($Ca^{2}+$)	77.2	-	-	-
Chloride (Cl^{-})	34.95	-	-	-
Carbonate and bicarbonate (CO_3^{2-}/HCO_3-)	434.32	> 20 mg/L	For protection of aquatic life should not be lower than 20 mg/L[1]	Good buffering capacity of water – Very alkaline water
Potassium (K^{+})	9.23	-	-	-
Magnesium (Mg^{2+})	24.9	-		
Sodium (Na^{+})	39.4	-	-	-
Nitrite (NO^{2-})	-	<0.05 mg/L N[2]	Absence of nitrites	-
Nitrates (NO_{3-})	2.38 o 0.54 (mg/L N)	<1.5 mg/L N[2]	At this concentration, there are no evident harmful effects on biocenoses.	Contamination from fertilizer runoff.
Orthophosphates (PO_4^{2-})	0.45 o 0.15 (mg/L P)	<0.04 mg/L P[2]	Hypertrophic level - Risk of environmental asphyxia	Contamination from fertilizer runoff.
Sulfates (SO_4^{2-})	384.1	-	May form toxic sulphides in an anaerobic environment - It can form strong acids that reduce the value of the pH.[3]	Contamination from fertilizer runoff.

[1] US EPA, 2002, p. 2002
[2] Stucki, 2010
[3] DEP Kentucky, 1997

for the protection of the aquatic system of 0.5 µg/L (AGI, 2000). Although this guideline value is not reliable due to the lack of toxicological data, the detection limit does not rule out a risk to aquatic organisms.

The organophosphates measured in the river water are below the detection limit mentioned in Table 19. However, most of the detection limits are above the ecotoxicological limits, so a risk cannot be ruled out.

6.4.2 Water Quality in the Wells

The depth and the level of the aquifers as a function of sea level on the day of sampling are indicated in the first lines of the table below (Table 20). The measurement points have been ordered from left to right according to their elevation above sea level starting from the well at the upstream end to the well at the downstream end.

To situate the level of the aquifers according to their variations in the year, the annual average of the measurements over 12 months, as well as the maximum and minimum recorded are also shown in the same table based on monthly data from February 2019 to January 2020.

All points in the sampled aquifer are shallow, especially points E2 to E6 (2 to 3.1 meters). Point E1 is the reference station located in the upper part of the basin (about 24

Table 19 Contaminants analyzed, laboratory analytical performance (LOD limit of detection: LOQ limit of quantification), reference values for the protection of the aquatic environment, analytical results of selected sites.

Contaminant	Analytical performance		Interpretation	Sites	
	LOD (µg/L)	LOQ (µg/L)	Guideline values for aquatic environment (µg/L)	Station above the cane fields E7	Station below the cane fields E8
Aminophosphonate					
Glyphosate	21	64	120a	Nd	Nd
Bipyridyls					
Paraquat	35	106	0.5b	Nd	Nd
Organophosphate					
Chlorpyrifos	6	17	4.6×10^{-4}a	Nd	Nd
Diazinon	7	21	0.1699c	Nd	Nd
Dichlorvos	12	38	0.132d	Nd	Nd
Ethyl parathion	5	16	0.013c	Nd	Nd
Ethion	36	118	0.028d	Nd	Nd
Malathion				Nd	Nd
Methyl parathion	8	25	0.1c	Nd	Nd
Pirimiphos Methyl	7	21	0.055c	Nd	Nd
Triazophos	15	45	-	Nd	Nd

Nd: Not detected
a: Chronic exposure quality criteria of the Swiss Ecotoxicology Centre (Ecotox Centre, 2021).
b: Chronic water quality criteria in China (Tt et al., 2019).
c: Criterion Continuous Concentration of the United States Environmental Protection Agency (OCSPP US EPA, 2015a).
d: Acute toxicity value of the United States Environmental Protection Agency (OCSPP US EPA, 2015a).

Table 20 Description of sampled wells including: piezometric level as a function of soil (soil water depth in meters), piezometric level as a function of altitude, mean annual piezometric level (standard deviation), minimum recorded piezometric level, maximum piezometric level.

Well stations	E1 Paz y Progreso II	E2 San Marcos Ranch	E3 San Marcos Cañales	E4 El Chino	E5 Colonia ISTA	E6 El Palmo la Danta
Water depth	6.1	2.5	3.1	2.0	2.5	1.98
Aquifer level (msnm)	23.88	9.50	5.90	2.00	12.47	NA
Annual aquifer level (SD	23 (0.7)	7.9 (0.7)	4.2 (0.8)	0.8 (0.9)	11.4 (0.9)	NA
Minimum aquifer level	22.16	6.93	2.65	-0.97	9.80	NA
Maximum aquifer level	24.50	9.25	5.50	2.40	12.82	NA

NA: Not available

meters above sea level). The water at this point comes from an aquifer of volcanic origin and is not vulnerable to surface contamination. In contrast, points E2 to E6 are in porous aquifers composed of unconsolidated sand and gravel (MARN, 2013b). These types of aquifers are very productive (good profitability in terms of available water volumes and are easily recharged). However, they are also much more sensitive to surface contamination (e.g., fertilizers and some pesticides). The aquifers in the communities of San Marcos Cañales and El Chino are close to sea level (5.9 and 2 meters). The sampling month (October 2020) corresponds almost to the maximum level recorded in the period from February 2019 to January 2020.

The following table (Table 21) summarizes the physicochemical parameters including temperature, pH, conductivity, and total dissolved solids. Each parameter is accompanied by the average recorded in May 2019, February, and October 2020.

From the limited data available, temperature and pH values are close to the annual average. The waters are neutral to slightly acidic (pH below 7). This could be explained by the precipitation (acidic water) that occurred in the days before sampling and the elements present in the soils (dissolved ions).

Conductivity and TDS in the Rancho San Marcos (1005 μS/cm), El Chino (1744 μS/cm) and El Palmo La Danta communities are high compared to the reference station (E1 470 μS/cm). The Colonia ISTA and El Chino stations have significant phreatic level conductivity fluctuations during the year (±400 μS/cm).

The redox potential of the sampled wells shows oxidizing values for wells E2 to E6 and reducing conditions for E1. E2 to E6 are located in porous coastal aquifers, which explains the aerobic conditions (McMahon, 2010). In contrast, the aquifer of volcanic origin at the upstream point exhibits anaerobic and reducing conditions.

The following table (Table 22) resumes the results obtained for the major ion analyses in three community wells (E1, E5, E6). E1 represents the reference point that characterizes the type of water present in the aquifer upstream of the crops. The water is sodium bicarbonate type (GIH UES, 2021) because its composition is mainly formed by bicarbonate as anions and sodium as cation.

An increase in nitrate and phosphate concentrations from upstream to downstream of the basin could indicate contamination by NPK fertilizers. Nitrates are absent in the reference waters upstream of the basin (E1) and are found in the aquifers downstream (E4).

Table 21 Physicochemical parameters of the aquifers on the day of measurement and the average recorded from May 2019 to October 2020. The parameters reported are temperature, pH, conductivity, total dissolved solids, and redox potential

Well stations	E1 Paz y Progreso II	E2 San Marcos Ranch	E3 San Marcos Cañales	E4 El Chino	E5 Colonia ISTA	E6 El Palmo la Danta
T(°C)*	24.5	29.2	30	29.6	28.4	26.1
Average May 2019-October 2020 (standard deviation)	29.4 (0.1)	29.2 (0.1)	30.1 (0.3)	29.7 (0.5)	29 (0.4)	NA
pH	6.7	7.0	7.2	6.9	7.0	7.33
Average May 2019-October 2020 (standard deviation)	6.7 (0.2)	7.2 (0.1)	7.4 (0.1)	7.1 (0.1)	7.3 (0.2)	NA
Conductivity (μS/cm)*	470	1005	802	1744	549	3000
Average May 2019-October 2020 (standard deviation)	481 (30)	1033 (19)	825 (15)	1329 (388)	1158 (407)	NA
TDS (ppm) *	235	504	401	872	271	1503
Media annual (Standard deviation)	266 (51)	570 (111)	456 (89)	710 (130)	651 (294)	ND
Redox Potential (mV)*	-0.3	17.7	28.8	12.5	22.1	50.1
Media annual	NA	NA	NA	NA	NA	NA

NA: Not available
*The day of measurement

Table 22 Measured concentrations of majority ions (mg/L).

Well stations	E1 Paz y Progreso II	E5 Colonia ISTA	E6 El Palmo la Danta
Ca^{2+}	23.55	31.08	83.95
Cl^{-}	38.45	60.68	594.21
CO_3^{2-}/HCO_3^{-}	226.92	204.95	732.00
K^{+}	47.20	74.90	24.30
Mg^{2+}	7.30	5.78	26.75
Na^{+}	25.80	27.50	290.00
NO_2^{-}	-	-	-
NO_3^{-}	-	10.30	0.30
PO_4^{2-}	0.39	1.31	2.34
SO_4^{2-}	33.17	85.74	619.05

Phosphates increase by a significantly higher factor (3.4) than all other ions (0.8-1.6). However, the analyses of majority ions do not show exceedances of drinking water standards for nitrates (50 mg/L) and nitrites (3 mg/L) (E. Álvarez & Rodríguez Pacas, 2001) and even have low concentration values that can be explained by the rainy season.

However, the physicochemical parameters found, and the concentrations of certain majority ions make well water unacceptable for human consumption. Not due to toxicological factors, but for taste acceptability criteria. The WHO recommends a TDS load of <600mg/L and sulfate concentrations of <250mg/L and sodium of <200 mg/L (WHO, 2006). These factors explain why communities such as El Chino and El Palmo La Danta no longer use water from their wells for drinking or cooking. It should also be noted that sodium and chlorid increase considerably from E1 to E6, indicating that there may be some influence of seawater (marine intrusion) to the surficial aquifer. The Na/Cl ratio in meq for E1, E5, E6, is 1.04, 0.70 and 0.75, respectively. If compared with the Na/Cl ratio for seawater which is 0.78, it is clear that E5 and E6 probably do have some seawater contribution.

The next table (Table 23) presents the concentrations in milliequivalents per liter to calculate the ionic balance and ionic ratios based on the methodology presented by Zúñiga et al., 2010 for the study of salinization in the coastal zone of Antioquia (Colombia).

The error in ion balance ranges from 11% to 18%, which is quite high but still an acceptable level based on Nordstrom et al., 2009. An ion balance that is not in equilibrium may be the result of a lack of analysis of minority elements present in high concentrations (e.g., trace metals), of an error in acid water analyses (contribution of H+ ions) (Zúñiga et al., 2010).

The rNa/rCa and rNa/rCa+Mg ion ratios increase dramatically from 0.95 and 0.76 between the Paz y Progreso II reference site to 3.01 and 2.38 at El Palmo la Danta, showing an increase in sodium ions. This is also the case for rCl/rHCO3 which rises from 0.29 to 1.4 showing an increase in chloride levels in the water. Inland waters contain a ratio of 0.1 to 5 and 20 to 50 in seawater. A study conducted in this area found that this salinization does not come from saline intrusion from the sea, but from land use and irrigation (Campos Hernández, 2016). However, as mentioned before, the Na/Cl ratio in meq of wells E5 and E6 are similar to seawater.

FAO recommendations irrigation should be limited from low to medium in sites with TDS between 450-2000 mg/L, electrical conductivity between 700-3000 µS/cm, sodium ionic concentration > 3 (meq), chloride ionic concentration between 4-10 meq (Ayers & Westcot, 1994). These indices show that low or medium restriction measures should be taken at the beginning of the dry season to ensure long-term protection of soils and crops in the communities of Rancho San Marco, El

Table 23 Ionic concentrations expressed in milliequivalents per liter, ionic balance, ionic ratios for selected chemical elements.

	E1 Paz y Progreso II meq/L	E5 Colonia ISTA meq/L	E6 El Palmo la Danta meq/L
Ca^{2+}	1.18	1.55	4.20
Cl-	1.08	1.71	16.76
CO_3^{2-}/HCO_3^-	3.72	3.36	12.00
K^+	1.21	1.92	0.62
Mg^{2+}	0.30	0.24	1.10
Na^+	1.12	1.20	12.61
NO_2^-	0.00	0.00	0.00
NO_3^-	0.00	0.17	0.00
PO_4^{2-}	0.01	0.03	0.05
SO_4^{2-}	0.69	1.79	12.89
Ionic balance	-1.70	-1.37	-6.40
Load unbalance (CI)	-18.21	-11.45	-10.63
rMg/rCa	0.26	0.15	0.26
rNa/rCa	0.95	0.77	3.01
rNa/rCa+Mg	0.76	0.67	2.38
rCl/rHCO3	0.29	0.51	1.40
rSO4/rCl	0.64	1.04	0.77

Chino and El Palmo La Danta.

Table 24 shows the results obtained in the analysis of paraquat and organophosphorus triazines in the well water during the rainy season.

The 3 samples taken did not detect glyphosate or paraquat. The limit of quantification for glyphosate was 64 µg/L. This limit is low enough to conclude, based on these results that these water samples do not represent a risk for human consumption of glyphosate at the 5 mg/L limit cited in WHO (2006).

The limit of quantification for paraquat analysis is 106 µg/L. The Canadian government establishes a maximum acceptable concentration for this pesticide in drinking water of 7 µg/L (Canada, 2005). The limit of quantification for this analysis does not completely discard a risk to human health.

The same observation can be made for chlorpyrifos and atrazine, which have limits of quantification slightly higher than the values in the health protection guidelines. It is also not possible to rule out a risk to human health for simazine and terbuthylazine because their quantification values are 59 and 15 times higher than the guideline values.

6.4.3 Fish and Sediment Analysis of the Garita Palmera Wetland

Four fish samples were analyzed for bioaccumulative pesticides, such as organochlorines. Some insecticides with hydrophobic characteristics, such as organophosphates were also analyzed.

Depending on the size of the fish, composite samples were prepared to obtain a sufficiently large net mass for analysis and to increase representativeness. Fishermen who caught snappers were unable to differentiate the two species (Lutjanus guttatus, L. novemfasciatus). Therefore, these two species were separated for the analyses.

The table below (table 25) shows for each fish sample, mean length, mean weight per species and the weight of the analyzed sample after dissection. Each pesticide analyzed is accompanied by the laboratory’s limit of

Table 24 Results of pesticide analysis of well water, including laboratory analytical performance and human health guideline values.

Contaminant	Analytical performance		Interpretation	Sites		
	LOD (µg/L)	LOQ (µg/L)	Guideline values for human health (µg/L)	E2 Rancho San Marcos	E3 San Marcos Cañales	E5 El Chino
Bipiridilos						
Paraquat*	35	106	7b	Nd	Nd	Nd
Organophosphate						
Chlorpyrifos	6	17	30	Nd	Nd	Nd
Diazinon*	7	21	-	Nd	Nd	Nd
Dichlorvos	12	38	-	Nd	Nd	Nd
Ethyl parathion **	5	16	-	Nd	Nd	Nd
Ethion	36	118	-	Nd	Nd	Nd
Malathion**			-	Nd	Nd	Nd
Methyl parathion **	8	25	-	Nd	Nd	Nd
Pirimiphos Methyl ***	7	21	-	Nd	Nd	Nd
Triazophos *	15	45	-	Nd	Nd	Nd
Triazines						
Ametrine	138	419	-	Nd	Nd	Nd
Atrazine	92	280	100a	Nd	Nd	Nd
Simazine	118	358	2a	Nd	Nd	Nd
Terbuthylazine	104	317	7a	Nd	Nd	Nd
Terbutryn	122	370	-	Nd	Nd	Nd

*It is unlikely to occur in drinking water.
**Appears in drinking water at concentrations much lower than those of concern to health.
*** Not recommended for use in vector control in drinking water.
a: WHO, 2006
b: Canada, 2005

detection (LOD) and limit of quantification (LOQ). Since the pesticides of concern have not been detected, a risk to human health can only be ruled out if the LOQ is below the toxicity threshold. The RfD (Reference Dose) toxicity thresholds are from the document "Guidance for Evaluating Chemical Contaminant Data for Use in Fish Warnings" (US EPA, 2000).

To calculate a limiting concentration in fish, the Rfd was used with the scenario of a subsistence fisherman who eats 170 (g) of fillet per day and has a mass of 70 kg. These parameters were estimated from the daily consumption and weight of adults from the same document U.S. EPA 2000.

Comparison between the calculated limits and the limit of quantification shows that consumption of these fish does not represent a risk to human health at the levels of the organochlorines dieldrin, endrin, endosulfan, heptachlor, HCB, DDT, lindane and the organophosphates chlorpyrifos, diazinon and ethion.

Sediment samples were collected at eight sites during the dry period between January 12th and 14th. Sites E8 and E9 are located along the El Aguacate River and sites E10 to E15 are located downstream of the river mouth in the Garita Palmera wetland, as shown in Figure 29. The following table resumes the main sediment characteristics and oxygen level in the water column (Table 26).

All the sediments sampled contained a high to remarkably high proportion of fine particles because the sites sampled are in depositional zones with a slow flow regime. The sample taken at E8 (directly downstream of the sugarcane fields) differs the most from the other

Table 25 Results of the analysis of fish samples collected in the wetland and coastal zone of Garita Palmera. LOD: Limit of detection of the pesticide, LOQ: Limit of quantification. RfD: Estimated reference dose of the pesticide for daily human exposure that does not represent a risk of adverse health effects during the lifetime of the pesticide. Calculated limit value: Estimated limit value of the concentration in nets for subsistence fishermen.

	Analytical performance		Interpretation		Fishes			
Contaminants	**LOD (mg/kg)**	**LOQ (mg/kg)**	**Chronic RfD (mg/kg-d)**	**Calculated limit value in fish (mg/kg)**	**Black sea catfish Cathorops sp**	**White mullet Mugil curema**	**Spotted rose Lutjanus guttatus**	**Pacific dog snapper L. novemfasciatus**
Number of individuals					8	14	1	2
Average weight per individual in grams (±SD)					320.8 ±77	33.4 ± 6.5	1240	629.5 (±75.7)
Average size per individual in centimeters (±SD)					30.2 ± 6.5	13.9 ± 1.2	44	34± 0
Weight of fillet sample (g)					1352	241	720	693
Organochlorines								
Aldrin	6.10E-05	1.00E-04			Nd	Nd	Nd	Nd
Dieldrin	7.00E-05	1.20E-04	5.00E-05	2.06E-02	Nd	Nd	Nd	Nd
Endrin	8.30E-05	1.70E-04	3.00E-04	1.24E-01	Nd	Nd	Nd	Nd
Endrin aldehyde	5.50E-05	1.10E-04			Nd	Nd	Nd	Nd
Endrin ketone	4.90E-05	1.00E-04			Nd	Nd	Nd	Nd
Endosulfan sulfate	6.30E-05	1.30E-04	6.00E-03	2.47E+00	Nd	Nd	Nd	Nd
Heptachlor	2.20E-05	4.00E-05	1.30E-05	5.35E-03	Nd	Nd	Nd	Nd
Heptachlor epoxide	2.20E-05	4.00E-05			Nd	Nd	Nd	Nd
Hexachlorobenzene HCB	1.07E-04	2.10E-04	8.00E-04	3.29E-01	Nd	Nd	Nd	Nd
Methoxychlor	6.70E-05	1.30E-04			Nd	Nd	Nd	Nd
p, p´-DDT	8.80E-05	1.80E-04			Nd	Nd	Nd	Nd
p,p'-DDD	3.80E-05	8.00E-05			Nd	Nd	Nd	Nd
p,p'-DDE	5.60E-05	1.10E-04			Nd	Nd	Nd	Nd
Total DDT	1.82E-04	3.70E-04	5.00E-04	2.06E-01				
α-endosulfan	1.90E-05	4.00E-05			Nd	Nd	Nd	Nd
α-HCH	4.40E-05	9.00E-05			Nd	Nd	Nd	Nd
β-endosulfan	3.00E-05	6.00E-05			Nd	Nd	Nd	Nd
β-HCH	9.70E-05	1.90E-04			Nd	Nd	Nd	Nd
γ-HCH	1.17E-04	2.30E-04	3.00E-04	1.24E-01	Nd	Nd	Nd	Nd
δ-HCH	2.50E-05	5.00E-05			Nd	Nd	Nd	Nd

	Analytical performance		Interpretation		Fishes			
Contaminants	**LOD (mg/kg)**	**LOQ (mg/kg)**	**Chronic RfD (mg/kg-d)**	**Calculated limit value in fish (mg/kg)**	**Black sea catfish Cathorops sp**	**White mullet Mugil curema**	**Spotted rose Lutjanus guttatus**	**Pacific dog snapper L. novemfasciatus**
Organophosphates								
Chlorpyrifos	5.70E-03	1.73E-02	3.00E-04	1.24E-01	Nd	Nd	Nd	Nd
Diazinon	7.00E-03	2.12E-02	7.00E-04	2.88E-01	Nd	Nd	Nd	Nd
Dichlorvos	3.80E-03	1.16E-02			Nd	Nd	Nd	Nd
Ethyl parathion	5.10E-03	1.55E-02			Nd	Nd	Nd	Nd
Ethion	1.18E-02	3.57E-02	5.00E-04	2.06E-01	Nd	Nd	Nd	Nd
Malathion	8.20E-03	2.48E-02			Nd	Nd	Nd	Nd
Methyl parathion	3.40E-03	1.04E-02			Nd	Nd	Nd	Nd
Pirimiphos Methyl	7.10E-03	2.14E-02			Nd	Nd	Nd	Nd
Triazophos	1.48E-02	4.51E-02			Nd	Nd	Nd	Nd

Table 26 Qualitative description of the sediments sampled at the different sites and of the oxygen level in the water column.

Sites		Sediment description	Oxygen mg/L
E8	El Diamante Bridge	Dark grey, sandy-gravelly, ferrous odor, presence of fish, macrophytes	4.53
E9	El Castaño Bridge	Brown the first centimeters, then black, fine muddy, without living organisms.	
E10	Los Mangos	Black, muddy, strong sulfur odor, no living organisms	3.59
E11	El Perol	Black, muddy, sulfur odor, without living organisms	4.68
E12	El Enganche	Gray, muddy-sandy, sulfurous, without living organisms	5.47
E13	Bajo El Caballo	Gray, sandy, sulfurous, without living organisms	5.84
E14	Los Cayucos	Gray, sandy-muddy, sulfurous, without living organisms	4.23
E15	El Cuje	Gray, sandy-muddy, without living organisms	5.46

sites with a higher sand fraction and lower organic matter fraction. The sites with the highest organic matter were in the transition zone between El Aguacate river and its entrance into the Garita Palmera wetland (E9, E10 and E11). These sediments are characterized by a strong sulfur odor, indicating an anaerobic environment due to the presence of hydrogen sulfides. Only the upstream site contained organisms visible to simple sight. Based on the last visit to site E8 to take water samples (October), it appears that the transition period between the end of the rains and the beginning of the dry season is the most favorable time for the development of aquatic life in the river with the presence of reptiles, fish (chimbolos) and macrophytes.

Table 27 shows the results obtained for the analysis of AMPA, paraquat, organochlorines, organophosphates, triazines, trace metals and organic matter. The results for organochlorines are compared with the Threshold Effect Concentrations (TEC) developed for the estuarine environment cited in MacDonald et al. (1996). These values were supplemented with consensus TEC cited by (MacDonald et al. (2000) developed for freshwater and Threshold Effect Benchmark (TEB) developed from ecotoxicity bioassays on epibenthic species by Nowell et al. (2016). These TEB guidelines have been standardized for an organic matter content of 10%. For AMPA there are no quality criteria, therefore the predicted no-effect concentration cited in Bonansea et al. (2017) was used. In the short term, the risk of paraquat to benthic species is low (US EPA, 2019). However, the duration of this pesticide is very persistent and accumulates in sediments (approximately 30 years), for this the long-term risk is largely unknown (US EPA, 2019). The guideline value used in this study was calculated by applying a safety factor of 1,000[13] on the NOAEC[14] determined in a short-term toxicity test in the most sensitive species (Hyallela azteca) (US EPA, 2019).

Laboratory analysis detected paraquat at all 8 sites sampled with levels between the limits of detection and quantification (Table 27).

The other pesticides searched for in the sediment were not detected. However, an ecotoxicological risk can only be ruled out when the limits of quantification (LOQ in the Table) are below the guideline values for environmental protection. Otherwise, the risk cannot be ruled out. Considering the latter statement, according to the results presented by the laboratory the concentration levels of AMPA, dieldrin, endrin, heptachlor epoxide, p, p'-DDDT, p,p'-DDDD, p,p'-DDE and **γ**-HCH do not constitute a significant risk to benthic organisms.

A risk for the pesticides **α**-endosulfan, **β**-endosulfan, chlorpyrifos, methyl parathion and atrazine cannot be discarded because the limits of quantification are above the limits of the guideline values for the protection of the environment. It is also not possible to rule out a risk from paraquat due to the lack of scientific evidence on long-term effects and the guideline value used is indicative and close to the level of detection.

[13] In accordance with the European Commission's Technical Guidance document for setting environmental quality standards (EC, 2011).
[14] NOAEC: No observed adverse effect concentration

Table 27 Results of pesticide and trace metal levels measured in the sediments of El Aguacate River and Garita Palmera wetland.

Contaminants	Analytical performance		Interpretation	Sites							
	LOD (µg/kg)	LOQ (µg/kg)	Guidline values (µg/kg)	E8 El Diamante Bridge	E9 El Castaño Bridge	E10 Los Mangos	E11 El Perol	E12 El Enganche	E13 Bajo El Caballo	E14 Los Cayocos	E15 El Cuje
Aminophosphonate											
AMPA	17	53	280a	Nd	Nd	Nd	Na	Na	Na	Na	Na
Bipyridyls											
Paraquat	4	12	30e	Detected	Detected	Detected	Detected	Detected	Detected	Detected	Detected
Organochlorinates											
Aldrin	0.06	0.10		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Dieldrin	0.07	0.12	0.72a	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Endrin	0.08	0.17	2.67b	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Endrin aldehyde	0.06	0.11		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Endrin ketone	0.05	0.10		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Endosulfan sulfate	0.06	0.13	-	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Heptachlor	0.02	0.04		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Heptachlor epóxide	0.02	0.04	0.6b	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Hexachlorobenzene HCB	0.11	0.21		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Methoxychlor	0.07	0.13		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
p, p´-DDT	0.09	0.18	1.19a	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
p,p′-DDD	0.04	0.08	1.22a	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
p,p′-DDE	0.06	0.11	2.07a	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
α-endosulfan	0.02	0.04	0.0096c	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
α-HCH	0.04	0.09		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
β-endosulfan	0.03	0.06	0.032c	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
β-HCH	0.10	0.19		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
γ-HCH	0.12	0.23	0.32a	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
δ-HCH	0.03	0.05		Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd

Contaminants	Analytical performance		Interpretation	Sites							
	LOD (µg/kg)	LOQ (µg/kg)	Guidline values (µg/kg)	E8 El Diamante Bridge	E9 El Castaño Bridge	E10 Los Mangos	E11 El Perol	E12 El Enganche	E13 Bajo El Caballo	E14 Los Cayocos	E15 El Cuje
Organophosphates											
Chlorpyrifos	5.70	17.30	0.041c	Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Diazinon	7.00	21.20	0.19c	Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Dichlorvos	3.80	11.60		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Ethyl parathion	5.10	15.50		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Ethion	11.80	35.70		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Malathion	8.20	24.80		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Methyl parathion	3.40	10.40	0.052c	Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Pirimiphos Methyl	7.10	21.40		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Triazophos	14.80	45.10		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Triazines											
Ametrine	118	358		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Atrazine	92	280	13c	Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Simazine	118	358		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Terbuthylazine	104	317		Na	Na	Na	Nd	Nd	Nd	Nd	Nd
Terbutryn	122	370		Na	Na	Na	Nd	Nd	Nd	Nd	Nd

a: Threshold Effect Concentrations (TEC) for the estuarine environment: below which no adverse effects are expected (MacDonald et al., 1996).
b: Consensus-based Threshold Effect Concentrations (TEC) : below which no adverse effects are expected (MacDonald et al., 2000).
c: Threshold Effect Benchmark (TEB) : define a concentration below which adverse effects are unlikely (Nowell et al., 2016).
d: Predicted No Effect Concentration (PNEC) : concentration with no expected effects (Bonansea et al., 2017).
e: Estimated value applying a safety factor of 1000 (EC, 2011) on the 10-day acute survival toxicological parameter in the freshwater amphipod Hyallela azteca. (NOAC ((no-observed adverse effect concentration)): 30 mg/kg dry weight) (US EPA, 2019).

6.5 Discussion on Exposure to Different Pesticides

The characterization of the exposure of the aquatic environment to pesticides through environmental concentration data is limited for El Salvador. As observed from the search for existing information on pesticide levels measured (Chapter 6.2), most of the studies conducted to measure pesticide levels are between 20 and 40 years and focus exclusively on organochlorines. The following subchapters discuss certain characteristics of exposure by pesticide or pesticide family and the limitations associated with the characterization of environmental exposure in the country.

2,4-D (2,4-dichlorophenoxyacetic acid)

2,4-dichlorophenoxyacetic acid is the active ingredient most used on crops in El Salvador (308 tons). According to the estimates in this report, it is the second most used in sugarcane fields (69 tons). National laboratories do not have the technical means to measure its residues (e.g., LC-MS-MS; liquid chromatography coupled to tandem mass spectrometry) in the environment and there are no available data on Measured Environmental Concentration (MEC) at the national level to assess environmental exposure to this active ingredient. Based on the sugarcane production cycle (Chapter 2.3.3) and the recommendations of the distributor of the most widely used commercial product (Herbamax 60 SL), the herbicide is applied directly to crop soils. The applied doses of this herbicide in sugarcane fields are 1.7 (coffee) to 3.5 times more (sorghum) than in other types of crops (Quilubrisa, 2017). This means that the estimate of 69 tons of annual use in sugarcane fields is probably lower than the amount used.

Allan et al. (2017) monitored herbicides in wetlands adjacent to sugarcane fields in Queensland, Australia. Concentrations of 2,4-D measured at the 7 sites sampled ranged from <0.1 (ng/L) corresponding to the LOQ to 856 (ng/L) (Allan et al., 2017).

Surface water monitoring data from Canada, the United States, Australia, Greece, Mexico, and Spain cited by Islam et al. (2018) varied from 0.05 µg/L for Lake Chapala in Mexico (Reynoso et al., 2014) to 12 µg/L for urban waters in major cities in California (Ensminger et al., 2013, pp. 2008-2011). This suggests that the actual concentrations in water and sediments in the investigated area are probably higher than the non-detect levels reported in this work.

Diuron

As estimated in this report diuron is the most used herbicide in sugarcane fields (63.3 tons) and the 5th most used herbicide in the country (69.6 tons). No data are available on environmental concentrations in El Salvador. National laboratories are currently unable to measure its residues. Diuron can be applied once before and after weed emergence. Its application rate in sugarcane is 3.3 times that of corn when used in pre-emergence and 2.6 times that of corn in postemergence (applied after crop emergence or germination) in sugarcane fields (Adama, 2011).

Lewis et al, 2009 conducted extensive monitoring between 2005 and 2008 in 3 trapping areas on the Great Barrier Reef in Australia. Particular attention was paid to the influence of land use, including sugarcane fields, on pesticide residues found in the 600 samples collected from the 76 sites sampled. The most frequently analyzed herbicides at the sugarcane field drainage sites are diuron (2005-2008 mean concentrations between sites 0.07-2.69 µg/L), atrazine (0.05-0.77 µg/L), hexazinone (0.01-0.54 µg/L) and ametryn (S. E. Lewis et al., 2009).

Glyphosate and Aminomethylphosphonic Acid (AMPA)

At the national level, glyphosate is the second most used molecule in El Salvador (250 tons) and is estimated to be the third most used molecule in sugarcane fields (50 tons). It is used postemergence on weeds in doses similar to other crops and must be applied directly to them to avoid damaging the crops. It is also applied pre-harvest by air as a ripening agent at lower doses (0.75-1.5 L/Mz) for weed control (1-5 L/Mz). However, aerial application of this pesticide substantially increases wind drift, which directly exposes surrounding ecosystems and workers.

Only two laboratories are able to measure glyphosate and one laboratory is also able to measure its degradation product AMPA. The 2 water samples taken from El Aguacate River during the rainy season for the analysis of glyphosate in water did not detect these molecules. The detection limit for glyphosate in this laboratory is 21 µg/L.

In river waters, glyphosate has been detected at low concentrations including in rivers adjacent to the transgenic soybean field in Argentina (100- 700 µg g/L, 5 sites) (Peruzzo et al., 2008), in rivers in the United States (median 0.03 µg/L, maximum 476 µg/L 1826 sites) (Struger et al., 2008), in lakes in Switzerland (0.015-0.035 µg/L, 2 sites) or in rivers and streams in Canada (mean < 17 µg/L, maximum 40.8 µg/L, 500 sites) (Hanke et al., 2008). These results can be explained by the fact that glyphosate tends to adsorb in soils and degrade rapidly (soil DT50[15] is 15 days) to AMPA.

For this reason, AMPA was analyzed in sediments from three sites along El Aguacate River during dry season. The detection limit for AMPA in sediments from the contract laboratory is 17 µg/kg and it was not detected in the samples. Analogous investigations in the sediments of the Suquía River (Córdoba, Argentina) in urban areas and areas of intensive agriculture showed concentrations between <LOD (below detection limits) to 261 µg/kg of AMPA in sediment (Bonansea et al., 2017). According to this study to obtain a more representative monitoring of glyphosate and AMPA contamination in El Aguacate River, sediment samples should be taken at least 4 times per year in duplicate. The extraction of residues for analysis should be performed on fresh sediment to avoid possible losses of these products during drying.

Neonicotinoids

Imidacloprid is the insecticide of this family used in sugarcane fields in an estimated amount of 2.7 tons of active substances out of the total of 22.3 tons consumed. The recommended doses in food crops of the most widely used commercial product (Bayfidan Duo) containing imidacloprid are the same for sugarcane as for potato or rice (35-52.5 kg/mz).

From the literature search, no data on neonicotinoid concentrations in the country have been published. This could be explained by the fact that there is no laboratory authorized to measure them. This is of particular concern as the three neonicotinoids imidacloprid, clothianidin and thiamethoxam have been banned for use in Europe since 2018 because of their likely implications for bee die-off (EC, 2017).

Neonicotinoids were investigated in soils, sediments, and waters in the coastal zone of Belize where sugarcane, melon, banana, and sorghum are grown (Bonmatin et al., 2019). Of the 107 samples analyzed the frequency of detection was 68% in soils, 47% in sediments and 12% in waters. The most frequently measured neonicotinoid in sediments is imidacloprid, with mean concentrations of 0.068 µg/kg. The detection limits of this investigation are between 0.002 and 0.02 ng/kg (dry weight).

Organochlorines

The importation, distribution and commercialization of most organochlorine pesticides was prohibited in El Salvador in 2001 by Agreement No. 151 (MAG, 2000, p. 52). Only endosulfan is still allowed on certain crops. According to import data 1,416 liters of commercial products containing this pesticide have been used this year, but this product is not intended for use on sugar crops.

The detection limits for organochlorines in these analyses range between 0.02 µg/kg and 0.12 µg/kg for the sediments and fish analyzed, respectively. The 8 sediment samples and the 4 fish samples analyzed did not show concentrations above the detection levels.

The only data available for this study area are from the Cara Sucia River basin adjacent to El Aguacate micro-watershed. Measurements made in 1981 in this river showed alarming concentrations of aldrin/dieldrin, DDT, Heptachlor and BHC (Calderón, 1981). In 1991, sediment and fish (white mullet and catfish) analyses conducted in the wetland downstream of the Cara Sucia River and Barra de Santiago had also shown

[15] The degradation rate of pesticides is usually expressed as semi-disintegration.

alarming concentrations of dieldrin, BHC and DDT degradation products. However, sediment analyses conducted in 2004 in the coastal zone of the country including 4 stations perpendicular to Barra de Santiago had not detected organochlorines. The results of the Garita Palmera analyses are not extrapolated to Barra de Santiago. However, the results obtained for sediments and fish tend to show that organochlorine concentrations are potentially no longer a major concern in this area because their active ingredients have been banned for twenty years and their residual concentrations in the environment tend to decrease. As stated in Carvalho et al. (2002), organochlorines were largely mediated by organophosphates or carbamates (not measured in this study), which should be of greater concern for monitoring.

Organophosphates

Analyses of chlorpyrifos concentration found in streams in the agricultural region of Pampa Humeda (Argentina) cited by Alvarez et al. (2019) showed that the 75th percentile of the 109 samples in which this pesticide was detected (193 samples) is between 0.0005 µg/L and 0.0979 µg/L. Such concentrations could not have been detected with the analytical means of this investigation.

A similar investigation was carried out in the mangrove-lagoon ecosystem of Altata-Ensenada del Pabellon (Sinaloa State, Mexico) in a catchment area (360 km2) dominated by sugar production and vegetable crops (Carvalho et al., 2002). Sediment samples were also taken at eight locations for a total of 35. All samples revealed the presence of chlorpyrifos at concentrations between 0.4 and 8 µg/kg. According to this author, this compound has a DT50 (160 days) long enough to accumulate in the sediment and form a deposit (Carvalho et al., 2002). However, a seasonal variation in chlorpyrifos concentrations was observed depending on whether farmers had recently applied it or not.

Recently research has been conducted in the Quebrada La Mula micro-watershed (Costa Rica), which is dominated by rice and sugarcane crops (Carazo-Rojas et al., 2018). The measurement campaign in this micro-watershed was conducted three times a year for 5 years. Chlorpyrifos was detected once in water in 135 samples and twice in sediment in 129 samples with concentrations of 0.258 and 18.240 µg/kg (Carazo-Rojas et al., 2018).

Paraquat

Paraquat is the third most used active ingredient in the country (199 tons) and the fifth most used in sugar production (29 tons). Its loss of efficacy and the increasing tolerance of weeds to its toxicity leads sugar growers to make greater use of herbicides such as 2,4-D, diuron or glyphosate (Carlos*, 2019). The application rate of the most applied commercial product containing paraquat is the same among crops (3 L/Mz) (Quilubrisa, 2004).

This pesticide was not found in any of the three wells sampled. In previous studies conducted in the communities of Las Brisas San Miguel (El Salvador) concentrations of this compound were found in domestic wells at levels of great concern (4 to 28 times the toxicological levels) (A. López et al., 2015). Las Brisas are surrounded by corn crops for which paraquat use is still widespread in contrast to sugarcane fields where more effective herbicides (2,4-D and diuron) are used (Carlos*, 2019). It should also be noted that paraquat has a greater tendency to absorb into the soil and then wander into rivers and does not have the tendency to leach into aquifers. Of the 971 wells sampled between 1983 and 1990 in the United States only 11 wells in permeable aquifers were contaminated (US EPA, 2013).

For surface waters, reports from US monitoring data cited in Judkins & Wente (2019) this herbicide is rarely detected. From the US Water Quality Portal database, paraquat was only detected in water 14 times out of 1381 published results (64 sites) at concentrations between 0.24 and 3.6 µg/L. These data must be put in perspective with the fact that pesticide detection in rivers depends on time intervals and frequency of measurements as explained in the methodology section. For example, paraquat (67.7% of the 68 samples) was measured periodically in rivers in Mai Chau province in Vietnam (Thi Hue et al., 2018) with concentrations between 4.70 and 134.08 ↾g/l. The analytical techniques used by this author are also between 233 and 700 times more sensitive than those used in this research. The concentrations of this herbicide in the rivers of Vietnam were higher during the dry season due to water evaporation, which makes the concentrations higher. Currently, El Aguacate is a seasonal river that only flows through the Garita Palmera mangroves during the wet season. Therefore, it is not possible to monitor it in the summer.

Paraquat was detected at all 8 sites sampled but at concentrations below the limit of quantification. The long-term effects of benthic species exposure of this herbicide on benthic species are largely unknown (US EPA, 2019). Results from laboratory sediment toxicity bioassays show that crustaceans (Hyallela azteca) are more sensitive than insects (Chironomus riparius) to this compound (US EPA, 2019).

Because of its high level of use and persistence (more than 30 years), paraquat should be monitored in the country's soils and sediments to know the level, dimension, and extent of contamination.

Triazines

Triazines are a particularly important group of chemicals to be controlled in sugar growing areas. According to the estimates in this report, sugar plantations consume 30.1 tons of ametryn (of the 46.6 tons consumed in total in the country), 21.1 tons of terbutryn (of the 24.8 tons consumed in total) and 2.1 tons of atrazine (of the 108 tons consumed in total).

Based on the literature review, no data on triazine concentrations have been published for the country, even though it is a highly responsive contaminant in the countries where it has been measured. The concentrations measured in the three wells analyzed and in the 5 sediment samples are below the detection limits of 138 μg/L (ametryn), 92 μg/L (atrazine) and 122 μg/L (terbutryn).

Atrazine is a widespread contaminant in waters and aquifers. The highest concentrations are found in sediments. In aquifers, it was found in 41% of the wells analyzed in Iowa (USA) and its degradation product (deetylatrazine) in 35% of the cases (Kolpin et al., 1997). However, the detection limits were 1,840 times lower than in this study. In the 837 well water samples collected by Kolpin et al. (1996), the mean concentration was 0.15 ug/L.

Miles & Miles & Pfeuffer (1997) monitored 26 sampling stations in irrigation canals of sugarcane, citrus, and vegetable crops in south Florida (Lake Okeechobe). Of the 70 pesticides and degradation products analyzed, triazines were the most frequently detected pesticides (ametryn 117, atrazine 274 times out of 744 detections). The highest values were measured in sediments with maximum concentrations of 100 μg/kg ametryn and 50 μg/kg atrazine. The detection limits in this investigation for triazines were 1.6 μg/kg (Miles & Pfeuffer, 1997).

As previously cited in the Lewis et al. 2009 study in Australia, triazines are the most common group of substances found in sugarcane fields upstream of coastal ecosystems. The mean concentrations reported in this research (600 samples) are 0.05-0.77 μg/L for atrazine, 0.01-0.54 μg/L for hexazinone and ametryn (concentration not specified) (S. E. Lewis et al., 2009).

6.6 Conclusions

The bibliographic research carried out to compile the existing data on the levels of contamination produced in the environment by the use of pesticides in El Salvador, shows that very few efforts have been made to investigate this topic in the last 30 to 40 years. In the 1980s and 1990s, studies conducted in coastal ecosystems reported significant contamination in waters, sediments, and biota (mollusks, shrimp, fish, etc.) of certain bioaccumulative and carcinogenic organochlorine insecticides. In recent years, the use of pesticides has intensified in the country and a probably higher level of contamination than in the past should be expected. The decree published in April 2001 (No. 151), almost completely restricted to import, distribute and market most organochlorine pesticides, except endosulfan. In 2006, a study of sediments in the coastal areas of the country revealed undetectable levels of organochlorine concentrations (Barraza, 2003). In this investigation, similar results were obtained for organochlorine contamination in 4 different fish species and 8 sediment samples in the Garita Palmera wetland.

The major concern in this research is the total absence of available data on the levels of pesticide contamination currently used in the country and its impact on aquifers, rivers, lakes, sediments, and soils.

The preliminary sampling campaign carried out in this research has allowed us to point out the different failures or challenges that explain this serious problem of monitoring and access to information.

First, only three laboratories are authorized to perform analyses of a limited number of pesticides. Unfortunately, there is no independent research laboratory that does not have political interests, that does not respond to the economic interests of this guild or where the analyses requested of it do not represent a risk of conflict of interest. Although the scientific integrity of these laboratories can be preserved, the trust placed in them by the various environmental stakeholders is low.

Secondly, the analytical resources available to laboratories do not allow the analysis of most of the active ingredients used in the country. Only 6 active ingredients out of 39 registered for sugarcane crops could be analyzed in practice. This is problematic considering most widely applied products in the country and in sugarcane fields, such as 2,4-D, diuron, imidacloprid or terbufos, cannot be monitored. Table 32 of Appendix 11.4 shows the substances that should be measured as a priority in sugarcane fields based on their hazardousness and exposure.

Thirdly, in the previous chapter it was shown through the few analyses performed in this research, that the available analytical methods do not have the necessary sensitivity to detect and control residues in environmental matrices (apart from organochlorines and paraquat). This demonstrates the need to invest the necessary resources to acquire and train personnel in more efficient equipment (e.g., LC-MS-MS: liquid chromatography coupled to tandem mass spectrometry) to control contamination levels in the country. It is also essential that the analytical methods used, including sample preparation, extraction, and analysis techniques, are based on standardized methods recognized by international organizations. Each laboratory should be prevented from developing its own techniques, as this limits the comparability of results between laboratories.

Sediment analysis of El Aguacate River and the whole Garita Palmera wetland area has shown the presence of paraquat. The presence of this herbicide in the Natural Protected Area is of concern because it is very persistent and its long-term effects on benthic organisms are unknown.

Numerous scientific investigations have shown that pesticide residues are found in the ecosystems adjacent to the sugarcane fields, such as mangroves, coastal ecosystems, and coral reefs.

Based on research in other countries, the most frequently measured pesticides in coastal ecosystems downstream of sugarcane fields are mainly herbicides, such as diuron, atrazine, hexazinone and ametryn, but also the insecticides chlorpyrifos and imidaclorprid (Bonmatin et al., 2019; Carvalho et al., 2002; S. E. Lewis et al., 2009; Miles & Pfeuffer, 1997).

Chapter 8 will address the ecotoxicological effects of different pesticides on coastal mangrove ecosystems. The chemical risk assessment of the measurements made in the Garita Palmera wetland will also be discussed.

7 Human Health Effects and Risk Assessment

7.1 Introduction

The compilation of observed health and environmental effects and risk assessment are the last steps after hazard identification and exposure characterization. The objectives of this chapter are:

1. Calculate the health risk quotients for people applying pesticides in sugarcane fields.

2. To compile the acute and chronic health effects described by pesticide applicators in El Salvador.

7.2 Methodology

7.2.1 Calculation of the Risk Quotient for Pesticide Applicators

The World Health Organization's human exposure assessment model for insecticide spraying (WHO, 2010a) was applied to characterize the risk for pesticide applicators. The model variables were supplemented with information collected from applicators and values reported in the literature.

There are three critical stages of exposure during application, which are (WHO, 2010a):

1. Mixing and loading of the pesticide formulation.

2. Application of the pesticide by backpack spray pump.

3. Washing and maintenance of the knapsack spray pump.

The WHO exposure model was applied based on the most used active ingredients (2,4-D) and its complementary active ingredient recommended by some distributors (atrazine) (Bayer Crop Science, 2019). Herbicides have been taken as an example because they are the most used products in sugarcane (Reis et al., 2019). Workers interviewed by UNES reported the use of herbicides with the trade names Gesaprim (atrazine 90WDG), Karmex (Diuron 80WG), Tordon (Picloram 6.4 SL, 2,4-D 24SL), Hedonal (2,4-D 60 SL) and Randup (Glyphosate). According to interviewees, these products are used in a mixture including up to 4 different products in the same preparation (Eleonor*, 2019).

2,4-D is sold in liquid form at a concentration of 600 g/L (Hedonal 60L, Herbamax 60 SL, Palanka 60 SL, Elimina 60L, Totem 60 SL) and atrazine in solid form at a concentration of 900 g/kg (Gesaprim 90WDG) (MAG, 2019a).

For each step from preparation to pesticide application, we considered a 60 kg person, to include most women who also do this work. (WHO, 2010a). People who apply pesticides to sugarcane crops do it for three months of the year and 6 days a week (Damien*, 2019; Eleonor*, 2019).

This corresponds to 72 days of pesticide application on crops per year. Workers apply pesticides for 4 to 5 hours per day. It was also observed that sugarcane crop workers maintain their own bean or milpa fields (Maximus*, 2019). Operators have been working since the age of 18, and some started younger when the ILO (International Labor Organization) international labor standards had not yet established the minimum age limit. Workers are provided with boots, pants, long-sleeved shirt, and cap. They use a backpack pump. None of the interviewees mentioned the use of cotton protective suits with water-repellent coating, waterproof apron, gloves, polycarbonate safety glasses or face masks. It was also reported that operators work with pesticide mixtures. These results agree with the quantitative study conducted in Bajo Lempa (Mejía et al., 2014).

The first step in an application day is the preparation of the 250-liter barrel of the mixture to be applied in the field without any additional protective equipment such as boots, long-sleeved shirt, and pants (Carlos*, 2019; Damien*, 2019; Eleonor*, 2019). The operator's hands are then exposed to the concentrated products. For the model we assume that the operator prepares the barrel once a day from the concentrated products, so the Predicted Systemic Dose (PSD) for this person is calculated following the equation (WHO, 2010a):

$$PSD \left(\frac{\text{mg ingred.act.}}{\text{kg bdy.wt.*day}}\right) = \frac{VF_{dermal}\,(\text{mL})*CF(\frac{\text{mg}}{\text{mL}})*A*DE(\text{days})}{BW(\text{kg})*AT(\text{days})} \quad (1)$$

VF_{dermal}: Volume of formula in hands (8.4 mL) multiplied by number of barrels prepared (1)

CF: Concentration of active ingredient (AI.) in the pesticide formulations (600g/L 2,4-D)

DE: Duration of exposure in days (72d)

A: Dermal absorption (10%)

BW: Body weight (60 kg)

AT: Average time (1 year =365 days)

Second, the operator must fill his backpack spray pump (20 liters) 12 times with the contents of the 250-liter barrel per day (Carlos*, 2019). The equation is the same (as 1) but VFdermal is equal to 8.4 mL plus 12 fills and CF also changes as the product is diluted in 250 l. According to the vendor, it is recommended to add 3.3 kg/ha (2.32 kg/Mz) of Gesaprim 90WDG (SYNGENTA AGRO S.A., 2015) which equals 2.1 kg of atrazine per manzana and 2.45 (l) of Hedonal 60 SL per manzana (Bayer Crop Science, 2019) which amounts to 1.47 kg/Mz of 2,4-D. A 250 (l) barrel is sprayed on an manzana, as interviewees reported. If the operator respects the recommended dosage, then this equates to a concentration (CF) after dilution in the 250 l of 5.88 g/l of 2,4-D (2.45 (l)*600(l)*250 (l)-1) and 8.4 g/l of atrazine (2.1 (kg/Mz) *250 (l/Mz)-1).

Third, when applied outdoors with a hand-held backpack spray pump the inhalation route of exposure is considered insignificant due to the low volatility of these products (WHO, 2010a). In interviews, operators report getting soaked after application and burning their backs due to irritation from equipment leaks. The hands (840 cm2), forearms (1,140 cm2) and back (3,550 cm2) correspond to a total area of 5,530 (cm2) covered by a 0.01 cm (55.3 ml) film.

$$PSD\left(\frac{\text{mg ingred.act.}}{\text{kg dy.wt.*day}}\right) = \frac{VA_{dermal}\,(mL)*CA\left(\frac{mg}{mL}\right)*A*DE(days)}{(PC(kg)*TP(days))} \qquad (2)$$

VA_{dermal}: Volume of body spray (55.3 ml) per day
CA: Concentration of active ingredient (AI.) in the aerosol
DE: Duration of exposure (72 days)
A: Dermal absorption (10%)
BW: Body weight (60 kg)
AT: Average time (1 year=365 days)

To interpret the PSD, the AOEL (Acceptable Operator Exposure Level) was used for both active substances. The AOEL is defined as the maximum dose to which an operator can be exposed without adverse health effects (91 /414/EEC, 1991). The adverse health effects used to derive these toxicological assessment criteria should also include other criteria such as neurotoxicity, reproductive toxicity, and non-mutagenic carcinogenicity (de Heer et al., 2007).

The AOEL for 2,4-D is equal to 0.02 (mg active ingredient/ kg b.w. per day) (EC, 2019a) and 0.01 (mg active ingredient/ kg b.w. per day) for atrazine (K. Lewis et al., 2016).

In this way it is possible to calculate the risk quotient (RQ) for the operator during these three months of pesticide application work on sugarcane crops (WHO, 2010a):

$$RQ = \frac{DSP_{2,4D}}{AOEL_{2,4D}} + \frac{DSP_{atrazine}}{AOEL_{atrazine}} \qquad (3)$$

A risk quotient < 1 means that the risk for the operators is acceptable.
A risk quotient > 1 means that they incur a risk to their health (WHO, 2010a).

7.2.2 Acute and Chronic Health Effects in El Salvador

The compilation of the effects registered during the use of pesticides in the fields is based mainly on the testimonies of the applicators interviewed. These testimonies were supported by quantitative data from previous research in the country.

7.3 Results

7.3.1 Risks to Pesticide Applicators

The Predicted Systemic Dose (mg active ingredient/ kg b.w.*day) calculated over 72 working days per year with a backpack pump for sugarcane workers are presented in Table 28.

Table 29 presents the results of risk quotient calculation of the applicator described in equation (3), considering the Predicted Systematic Dose and the acceptable exposure level of this person. This risk quotient should not exceed a value of 1.

The risk quotient for barrel preparation, backpack spray pump filling and during field application are 98 to 157 times the acceptable level. This estimate did not consider other activities these operators might carry out such as pesticide application for their own food production. Exposure due to consumption of contaminated food or water during the year was also not considered.

7.3.2 Acute Human Health Effects

Acute effects reported by community workers at the end of a working day of pesticide application are skin irritation, burning on the back, severe fatigue, sometimes nausea and vomiting (Damien, 2019; Eleonor, 2019).

> *"Burning on the skin, at night it itches the back. But people have also been poisoned and they do not respond or anything. From the kidneys disease several people have already died."*
>
> (Eleonor*, 2019 agricultural collaborator, pesticide applicator).

One worker reported that he lost consciousness during application and was transported to the hospital (Eleonor*, 2019). It should be noted that some of these symptoms may also have been amplified by the strenuous working conditions induced by physical

Table 28 Predicted systemic dose (mg active ingredient/kg b.w.*day) calculated according to equations (1) and (2) and the scenario (working with 2,4-D and atrazine) described in the methodology for the three phases of work in sugarcane fields where operators are in direct contact with the pesticides.

	Barrel preparation	Loading of knapsack spray pumps	Field application	Total
2,4-D	1.66	0.19	1.28	3.13
Atrazine	solid	0.28	0.70	0.98

Table 29 Calculated risk quotient for community operators applying pesticides in sugarcane fields using a mixture of two commonly used herbicides.

	Barrel preparation	Loading of knapsack spray pumps	Field application	Total
2,4-D	83	10	64	157
atrazine	-	28	70	98

exertion, permanent sun exposure and dehydration during the 4-5 hours of application. Workers reported drinking little water (<2L) as they could not carry a water bottle during application (Eleonor, 2019).

"I was fumigating for a while and in the summer, they sent me to the sugarcane fields, where I was going to die. There by the ranch where we arrived, a part where it was sandy and hot, and of course as the body has perhaps a residue of poison, you feel fatigued. At about 2 o'clock in the afternoon I fell with cramps and vomiting, they began to inject me with serum and injections for vomiting. I was already dying; everything was stiffening up."

(Eleonor*, 2019 agricultural collaborator, pesticide applicator).

Surrounding communities reported to us strong odors, itchy nostrils, and cold symptoms when pesticides were applied by airplane (Aline*, 2019; Berta*, 2019; Osa*, 2019; Pascal*, 2019). A case of acute poisoning of a child accidentally sprayed by an airplane was reported; the causes of his coma and then hospitalization was multifactorial (Pascal*, 2019). Similar cases of community poisoning after aerial spraying of a pesticide, such as aerial application of paraquat in California, have been reported in the literature reviewed (Ames et al., 1993). A study in 11 U.S. states reported 2,945 cases of acute poisoning that were caused by pesticide application in the years 1998 to 2006 (Lee et al., 2011). Of the total cases, 14% of these poisonings involved children and 24% were due to aerial spraying (Lee et al., 2011).

In El Salvador, with respect to acute effects due to pesticides between 2012 and 2015, the government's National Epidemiological Surveillance System reported 5,988 cases pesticide poisoning. This corresponds on average to an incidence rate of 94.6 poisoning cases per 100,000 inhabitants. In 4 years of studies, 48% of poisoning cases were suicide attempts, 24.6% accidental poisonings and 26.9% workplace poisonings, i.e., 25.5 cases per 100,000 inhabitants (Quinteros & Lopez, 2019). In the scientific literature, the lowest values reported as 18.2 cases per 100,000 inhabitants for developing countries (Calvert et al., 2004) with values of 17.8 for Thailand and 17 for Belize (Thundiyil et al., 2008).

The main active ingredients responsible for workplace poisonings are bipyridyls (paraquat) with 33.3% of cases and organophosphates (methyl parathion, terbufos) with 33.6% of cases followed by carbamates (methomyl) with 12.2% and pyrethroids (cypermethrin) with 7.1% of cases (Quinteros & López, 2019). In general, the highest number of pesticide poisonings coincides with the period of agricultural crops (Quinteros & López, 2019).

7.3.3 Chronic Effects on Human Health

According to the bibliographic review on the chronic effects of pesticide use on the health of the Salvadoran population, there is only research that establishes a probable relationship between chronic kidney disease (CKD) and pesticide use. The main function of the kidneys in the human body is to filter the blood to remove toxins and excess water to produce urine. Chronic kidney disease (CKD) is a disease that develops slowly and over a long period of time (NIDDK, 2017).

It is characterized by "a drop-in glomerular filtration rate below 60 ml/min/1.73 m2 and/or the presence of structural renal damage (proteinuria, polycystic disease…) for more than 3 months" (Lidsky-Haziza & Bouatou, 2017). This disease includes different stages from I to V depending on the level of glomerular filtration rate and urine albumin concentrations (Lidsky-Haziza & Bouatou, 2017; UMVF, 2014). Only stages III to V are described as chronic renal failure (CRF) (UMVF, 2014).

In Central America, the Pan American Health Organization (PAHO) has estimated that between 1997 and 2013, 60,000 people died of kidney failure including 22,537 in El Salvador (Hoy et al., 2017). Traditional risk factors for this disease are diabetes, hypertension, cardiovascular disease, and family history (NIDDK, 2017; Ribó Arnau et al., 2014).

"One is already ruined; the body is left with that residue. When I get tired, I feel like I am vomiting, so I think it must be because of the same thing. The same thing happened with the late Tomas K. who died. He got the same thing, vomiting. A few days later they took him for tests, and it turned out that he was already sick with kidney disease."*

(Eleonor*, 2019 agricultural collaborator, pesticide applicator).

In the country, kidney failure is the second cause of death in men and the fifth in women (C. M. Orantes et al., 2019; Rodriguez et al., 2013, pp. 2012-2013). El Salvador and Nicaragua have mortality rates associated with the disease that are 4 times higher than the global average (Orantes-Navarro et al., 2017; Rodriguez, 2014). According to the study conducted by the National Institute of Health, the prevalence of CKD in the Salvadoran population is 12.6% (17.8% men, 8.5% women) and even 18% (23.9% men, 13.9% women) in agricultural communities (MINSAL, 2015b; C. Orantes et al., 2014). One of the main contributors, 33% of the national total, comes from a form of chronic kidney disease of unknown cause (or etiology) or called non-traditional risk factors (MINSAL, 2015b; Rodriguez, 2014). This new form of kidney disease also affects children and adolescents, as documented in a study conducted in three agricultural communities in El Salvador, with prevalence rates of 3.8% for boys and 4.3% for girls (Orantes-Navarro et al., 2016).

Non-traditional kidney disease came to the fore in the 1990s in farming communities in tropical countries, including those in Central America (El Salvador, Nicaragua, Costa Rica, Panama), Asia (India) and Africa (Egypt) (Jayasumana et al., 2016). In El Salvador, the presence of this form of kidney disease was detected in 2002 in a cross-sectional study of 205 end-stage nephropathy patients. This study revealed that 67% of the cases did not originate from known risk factors and were mostly characterized by a population of male farmers living in the coastal zone, who were exposed without adequate protection to pesticides in the workplace (Trabanino et al., 2002). For these reasons, this form of kidney disease of unknown causes has been named CINAC: Chronic Interstitial Nephritis in Agricultural Communities and includes chronic kidney disease of unknown or uncertain origin, chronic kidney disease of unknown ethology, agrochemical nephropathy, Mesoamerican endemic nephropathy, chronic tubular, and interstitial kidney disease, Uddanam endemic nephropathy or Sri Lankan agricultural nephropathy. The kidneys of patients with CINAC are characterized by tubular and interstitial lesions, glomerular sclerosis but no protein in the urine (Jayasumana et al., 2016).

Unsafe and unhealthy working conditions (see Chapters 5.3.1 and 5.3.2) are the complementary determinant that would explain the prevalence of CINAC, including strenuous working conditions (fatigue and excessive use of analgesics) and indiscriminate use of agrochemicals. In addition, the hot and humid work environment induces heat stress and dehydration would concentrate toxins in the kidneys (Hoy et al., 2017; Orantes-Navarro et al., 2017). In a large majority of references, CINAC is found in communities growing rice (Sri Lanka and India) or in sugarcane and staple grain cultivation (Central America) (Herrera et al., 2014; Herrera Valdés et al., 2015, 2019; Jayasumana et al., 2016; Jayasumana, Gunatilake, et al., 2014). A geospatial analysis of the relationship between hospital cases in El Salvador of chronic kidney disease of non-traditional causes and crop types revealed interesting results. The most significant statistical model for explaining hospital admission rates was the presence of sugarcane, cotton, and basic grains crops (Vandervort et al., 2014)

The results of a recently published investigation strongly suggest a common ethology for CINAC cases reported worldwide. **Based on the biopsy of 34 kidneys of CINAC-affected individuals from Sri Lanka, El Salvador, India, and France and on tests performed in rats, the researchers were able to demonstrate that the patients were subjected to a toxic mechanism similar to tubular calcineurin nephrotoxicity.** Calcineurin is an enzyme that binds Ca2+ and the protein calmodulin and inhibits calmodulin activity. Calmodulin is involved in the regulation of a variety of cellular activities. In other words, certain substances such as lithium, clominofen, lomustine and certain pesticides (paraquat, glyphosate and pyrethroids) directly or indirectly inhibit calcineurin, which then induces tubular nephrotoxicity (Vervaet et al., 2020). **The toxic origin of this kidney disease in El Salvador is believed to be caused by the combination of agrochemicals and dehydration.** This hypothesis was reconfirmed by a very recently published multiple linear regression model (C. Orantes et al., 2020).

This result is more alarming since, an epidemiological study conducted in El Salvador in 2015 found that 12.6% of the adult Salvadoran population (23% of men) is highly exposed to agrochemicals in the workplace (Orantes-Navarro et al., 2019). These statistics are even more important in the rural context where 66.5% of men and 33.1% of women are exposed (C. Orantes et al., 2014).

Other acute upper respiratory tract infections are the leading cause for men and the second for women in outpatient clinics corresponding to 818,489 cases per year based on MINSAL statistics (MINSAL, 2018; PAHO, 2008). Respiratory system diseases associated with air quality include unspecified pneumonias, unspecified asthma, unspecified bronchiolitis, unspecified chronic obstructive pulmonary disease. El Salvador recorded more than 14,000 hospitalizations per year in 2014 and 2015, of which 4 and 4.5% of these patients died due to air contamination. Acute effects of air contamination include coughing, shortness of breath, bronchial hyperreaction, eye irritation, and cardiac arrhythmia. Chronic effects include loss of lung capacity, development of childhood lung disease, early death of people with lung and heart disease (MINSAL, 2015a). According to the inventory of pollutant emissions in El Salvador (Herrera Murillo, 2011), 45,466 tons of PM10 and 30,651 tons of PM2.5 are emitted per year in the country. The main sources of PM10 are wood combustion (40%), open burning of waste (19.3%) and agricultural tillage (6.1%) (Herrera Murillo, 2011).

There are no estimates for the country of the contribution of sugarcane and other crop burning to this total or of the direct effects on the population. It can be reasonably assumed that crop burning corresponds to part of 40% of wood combustion, since it is also a biomass. However, epidemiological research on this subject has been conducted mainly in Brazil, but also in Ecuador, Ethiopia, and the island of Maui.

One of these studies focused on the effects of this practice on the health of sugarcane workers and the people living around these crops. The level of fine particulate was measured before, during and after burning in villages in Brazil and Ecuador. The fine particulate levels measured for workers and residents were below the WHO limits (workers: 5000 μg/m3, residents 50 μg/m3 for 24 hours). However, this investigation revealed that communities and workers are exposed to fine particulate concentrations not only during the fire, but also the following day, when potentially toxic cristobalite-containing ash is suspended during cutting work (up to 21.5 mg/m3). This exposure is important as workers spend long periods of time cutting sugarcane (Maximus, 2019). Based on calculations made by researchers, sugarcane burning would contribute to 3% of the mortality of those living near the fields (Le Blond et al., 2017). These authors conclude that the exposure of people around the fields should be considered both an acute and chronic respiratory health hazard.

Other studies have emphasized the impact of sugarcane burning on the health of the population, including:

Paraíso et al. (2015) conducted a study where they included monthly data on sugarcane crop fires and the frequency of hospital admissions for respiratory diseases in the 645 municipalities of São Paulo, Brazil. The researchers demonstrated a significant relationship between hospitalization of children under 5 years of age for respiratory diseases and the number of fires in sugarcane fields.

Mnatzaganian et al. (2015) compared the rate of respiratory distress (1,256 reports) over one year in an area impacted and an area not impacted by sugarcane burning on the island of Maui. The researchers highlighted the relationship between the area of burned sugarcane and the number of acute respiratory distress.

Dengia & Lantinga (2018) compared in two states of Ethiopia the number of patients hospitalized for upper respiratory tract infections for sugarcane burning with others during non-burning periods. The results showed that there are 18% to 56% less lung infection through the non-burning period of these crops.

Cançado et al. (2006) monitored fine particulate matter for one year in the city of Piracicaba (Brazil), where 80% of its watershed is occupied by sugarcane crops. This research showed that the particles generated by the sugarcane fire were the most important factor in the consultation rate of respiratory diseases in children and seniors. It also showed that for an increase of 42.9 (μg/m3) of PM10 and an increase of 10.2 (μg/m3) of PM2.5, there was an increase of 21.4% and 31.03% in hospitalization of children and seniors for respiratory problems, respectively.

This research shows that fine particulate contamination from burning could also be one of the significant factors contributing to the high epidemiological data on upper respiratory system diseases in El Salvador. However, this hypothesis should be verified by specific measurement campaigns on the emission of fine particles from this practice together with epidemiological data.

7.4 Conclusions

The exposure model revealed a risk quotient 100 times higher than the WHO acceptable risk. Epidemiological studies on acute cases of poisoning and on certain chronic effects, such as renal diseases of unknown origin could be the tip of the iceberg as far as public health is concerned.

The causes of this situation are: lack of use of personal protective equipment, failure of pesticide application equipment, lack of knowledge about the products used (especially about their chemical composition and health implications), lack of training in the use of these products (including inappropriate dosage) and lack of consideration of the operator's medical condition by the employer. The working conditions imposed on workers expose them to pesticide mixtures that do not necessarily respect the recommended doses and lead them to work quickly and inappropriately. Exposure of the human body to toxins associated with inadequate hydration and lack of adequate working conditions probably have synergistic effects on workers' health.

The results of the research previously carried out in El Salvador and the research conducted during this investigation show that the exposure of workers to the agrochemicals they use is of great concern and highly hazardous. This conclusion could be understood based on the description of the practices, an examination of the toxic effects experienced afterwards by the workers, epidemiological data on poisoning and the use of the WHO exposure model.

8 Effects and Risk Assessment for the Aquatic System and Wetland

8.1 Introduction

This chapter focuses on the evaluation of Measured Environmental Concentrations (MEC) in the water, sediment, and fish of the Garita Palmera wetland. A literature search was also conducted to characterize the effects that certain insecticides and herbicides have on the estuarine environment and mangrove ecosystems.

8.2 Methodology

Sediment and Water Risk Assessment

The risk assessment is based on the first level of assessment stipulated in the technical guidance of the Water Framework Directive (EC, 2011). This first level of assessment is based on the assessment of MEC and Environmental Quality Criteria (EQC). These two values are used to calculate the risk quotient (RQi) as follows:

$$RQ_i = \frac{MEC_i}{EQC_i}$$

RQ_i: Risk quotient for contaminant i

MEC_i: Measured ambient concentration for the contaminant i .

EQC_i: Environmental quality criteria for the contaminant i

If $RQ_i > 1$, risk is considered intolerable for aquatic organisms.

If $RQ_i < 1$, risk is considered tolerable for aquatic organisms.

Depending on the performance of the laboratory, the limit of quantification (LOQ) of the analyzed pollutant must be taken into account. If the contaminant is below the limit of quantification, the following must be considered:

If $LOQ_i < MEC_i$ then it can be concluded that the risk induced by contaminant i for the given sample is tolerable.

On the other hand, if $LOQ_i > MEC_i$ it is not possible to evaluate the risk until better analytical performance.

Risk Assessment of Fish Consumption

The risk assessment of fish consumption in mangroves is based on the guidance "Guidance for Evaluating Chemical Contaminant Data for Use in Fish Warnings" (US EPA, 2000). To calculate a limiting concentration in fish (LCF) for this ratio, the Rfd (chronic reference dose) was used considering the scenario of a subsistence fisherman who eats 170 g of fillet per day and has a mass of 70 kg. These parameters were derived from daily consumption and adult weight from the same US EPA (2000) document.

In this case, if LCF < Measured Concentration in Fish and LCF > LOQ then the risk to human health from this contaminant is considered tolerable.

On the other hand, if LCF< Measured Concentration in Fish, but LCF < LOQ, a risk cannot be excluded.

8.3 Effects of Pesticides on Different Estuarine/Marine and Mangrove Organisms

8.3.1 Effects of Insecticides

Tables 5 and 6 show different effects of organochlorine and organophosphate pesticides. Specifically, a total of 21 examples are shown (14 for organochlorines and 7 for organophosphates). Among the organisms used for the specific analyses, bivalve mollusks (oysters and crabs), fish followed by shrimp and crabs stand out. Pesticide toxicity and its effects cause changes in behavioral, biochemical, physical, and reproductive development (Lincer et al., 1976).

The following are some examples given by Lincer et al. (1976):

Some organochlorine pesticides, such as mirex are particularly toxic to estuarine organisms. e.g., juvenile marine shrimp and crabs died when exposed to this compound in 1 µg/L mirex.

Behavioral Aspects

Research on "fiddler crabs" showed loss of movement control which is vital for escape from predators, as well as for feeding and reproduction. Crabs of the species Uca pugnax have been observed surviving in detritus containing 10 mg/L DDT and with loss of coordination.

In Uca pugilator (fiddler crab), speed problems were detected after applications of 0.1 to 10 mg/L of dieldrin. In Callinectes sapidus (blue crab) only 22% survival was reported after 9 months of exposure to DDT concentrations of 0.5 and 0.25 µg/L (Lincer et al., 1976).

Aspects of Growth and Development

4 phytoplanktonic species were exposed to: DDT, Dieldrin and endrin. The effects were varied at different concentrations, causing severe damage in the inhibition of cell division, altering the photosynthesis process. DDE at low concentrations of 0.1 µg/L inhibited the growth of dinoflagellates of the species Exuviella baltica.

In different stages of Mytilus edulis ("clam"), developmental abnormalities such as blastomere disjunction, growth reduction and loss of tissue aggregation capacity were observed when tested with high concentrations of 5 organochlorines (mainly carbaryl and trichlorphon).

Cytology and Histopathology

Lincer et al. (1976) also mention that oysters (Crassostrea virginica) exposed to 1 ppb of DDT, Toxaphene and Parathion (combined) exhibited an abnormal infiltration of leukocytes and gonads and problems of hyperplasia of the germinal epithelium.

They conclude that these compounds have the capacity to alter defensive mechanisms, creating susceptibility in organisms to fungal, bacterial, and viral attacks. The organochlorine mirex was able to increase the incidence of viral infections in pink shrimp (Litopenaeus

Table 30 Effect of organochlorine pesticides on estuarine/marine organisms.

Treatment	Taxa	Effects observed	References
7 pesticides: 1 to 5 µg/L; 5 years of monitoring	"Clams" "Oysters"	Different species uptake pesticides in specific ranges.	(Lincer et al 1976)
Endrin, Aldrin, Heptachlor.	"Oysters"	Linear relationship between concentration and shell growth.	(Lincer et al 1976)
DDT in oil spray, 2 – 1.6 lb/A	"Isopods" " Amphipods"	High mortalities.	(Lincer et al 1976)
Methoxychlor	"Vaquita porpoises"	Affects fertilization and poor egg development.	(Jayaraj et al., 2016)
Endosulfan, concentration of 26.3 mg/L in 4 hours of exposure.	"Juvenile catfish"	100% mortality and necrosis of liver cells is observed.	(Z. Singh et al., 2016)
Endosulfan at concentrations of 0, 0.25, 1, 2, 3, 4 and 16 µg/L for 96 hours of exposure.	*"Fishes" Cichlasoma dimerus*	Corpuscular growth of hemoglobin hyperplasia in the interlamellar epithelium, blood congestion in the secondary lamellae, hypertrophy in the gills, testicular damage, and degeneration in the liver.	(Z. Singh et al., 2016)
Endosulfan at concentrations of 0.005, 0.05 and 0.5 µg/L for 15 days.	*"Clams" Ruditapes philippinarium*	Rupture of filaments at the level of gills and alteration of digestive glands.	(Z. Singh et al., 2016)
Dieldrin a 1.50 mg/L	"Fiddler crabs"	Correlation levels detected with poor adaptability, behavior, and mortality. With latent effects	(Lincer et al 1976)
DDT de 2-5 mg/L	"shrimp" "crabs" "fish"	From 35 to 100% mortality.	(Lincer et al 1976)
DDT <1 mg/L	"Oysters"	Feeding, paralyzed shell growth, erratic "shell" movements.	(Lincer et al 1976)
Mirex 1-5 Bait particles in standardized seawater / Mirex in flowing seawater 1.0 to 0.1 µg/L	juvenile "shrimp juvenile "shrimp juvenile "blue crabs" "Fiddler crabs".	-40-100% mortality. -Above 100% mortality of "shrimp" in Mixer-free water. -96% mortality -Mixer accumulation in the body.	(Lincer et al 1976)
Toxafeno	"fish" "shrimp" "crabs"	996 hours of TL50 exposure and histological damage was observed.	(Lincer et al 1976)
DDE	"ducks"	Eggshell thinning after 4 days over 40 ppm.	(Lincer et al 1976)
Chlordano	"seals"	Evidence of cancer and trauma meningoencephalitis.	(Javaraj et al 2016)

Table 31 Effect of organophosphate pesticides on estuarine organisms

Treatment	Taxa	Effects observed	References
Parathion	"Oysters"	Increased toxicity in relation to shell growth.	(Lincer et al 1976)
Range of 4 gutheon pesticides at 0.62 ppm	Eggs of "oysters" and "clams".	50% of the eggs developed normally.	(Lincer et al 1976)
Malathion Dursban with concentrations of 10 to 0.1 ppm	"Fishes"	Presence of Malathion was evidenced but not Dursban.	(Lincer et al 1976)
Paraoxon DDMP Parathion/Methyl Parathion	"Fiddler crab"	Selectivity of cholinesterase inhibition in tissue homogenization. Cholinesterase has been inhibited in small amounts of pesticides	(Lincer et al 1976)
Malathion, parathion	"fish" and "pink shrimp".	Revealed comparison of inhibited pain.	(Lincer et al 1976)
Parathion	"ducks"	Eggshell thinning effect.	(Lincer et al 1976)

duorarum). About 66% of the controls were infected by Baculorirus penai.

8.3.2 Effects of Herbicides

As can be seen from the pesticide modes of action in Table 5 (Chapter 2.3.3), many herbicides act by directly or indirectly inhibiting photosynthesis. When these herbicides are found in the aquatic environment, they mainly affect the primary producers in the ecosystem, which are the species most sensitive to these residues. For example, from laboratory ecotoxicological tests, the species most sensitive to glyphosate and 2,4-D are aquatic plants (Myriophyllum sibiricum) by growth inhibition, the marine alga Synechococcus sp. for diuron or the microalga Raphidocelis subcapitata for metachlor (Ecotox Centre, 2016a, 2016b, 2016c, 2017).

No studies are available on the effects of paraquat on mangrove ecosystems. From laboratory toxicity tests conducted by aqueous phase exposure, the most sensitive species are diatoms (Navicula pelliculosa, NOAEC: 0.16 µg/L), aquatic plants (Lemna gibba, NOAEC: 23 µg/L) and marine crustaceans (A. bahia, NOAEC: 39 µg/L) (US EPA, 2019). In the sediment compartment, tests are only available for the fly (Chironomus riparius) and amphipod (Hyallela azteca). The acute toxicity test on H. azteca (measuring survival and growth for 10 days, NOAEC: 30 mg/kg-d.w) shows effects at lower concentrations than the chronic test on the chironomid (mortality for 21 days, NOAEC: 90 mg/kg-d.w). These results show there are gaps in the long-term effects of paraquat on benthic and epibenthic organisms, as well as in the type of exposure through sediment (contact, ingestion, pore water). This is of particular concern because paraquat accumulates in sediments and is persistent (US EPA, 2019).

In a study conducted in mangroves in Australia, diuron was correlated with a severe and widespread die-off of 30 km2 of mangroves (Avicennia marina and Vierh. var. Eucalyptifolia). The diuron concentrations found in the mangrove water (4-10 ng/L) were associated with a decrease in photosynthetic activity of the microalgae. Concentrations found in the sediments were associated with a decrease in mangrove chlorophyll and a decrease in mangrove seedling health (Duke et al., 2005).

Bell & Duke (2005) measured the impact of 3 herbicides (atrazine, diuron and ametryn) on the photosynthetic activity of four different mangrove species. The species included mangroves with different physiologies such as "salt excretors" (A. marina and Aegiceras corniculatum) and "salt excluders" (Rhizophora stylosa and Ceriops australis). Seedlings of each type of mangrove harvested from the Moreton Bay wetland (Australia) were exposed in the laboratory to sediments with concentrations of 4, 40, 400 and 4,000 µg/kg herbicide. The mangroves were exposed for 72 days, and inhibition of photosynthesis, mortality and physical symptoms were observed. Two species were exposed to herbicides only through their root systems and two other species were exposed through their root systems and leaves (submerged in water).

The results of the experiment revealed mangrove species that are "salt excretors" are more sensitive to all herbicides. For the same concentration, the most toxic herbicide to mangroves is diuron followed by ametryn and atrazine. However, atrazine is the herbicide acted most rapidly on A. marina (leaf necrosis) (Duke et al., 2005).

8.4 Risk Assessment of Measured Pesticide Levels

Tables 35 through 38 in Appendix 11.7 summarize the risk assessment of pesticide concentrations in the water of El Aguacate River. Only the analysis of glyphosate has sufficient precision to rule out a risk to aquatic organisms in this sample. However, this point measurement is not very representative of the concentration variations that occur in the watercourses. Measurements should be performed continuously (autosampler) during the entire pesticide application period to calculate average (e.g., during 2 weeks of measurement) and maximum concentrations of glyphosate in El Aguacate stream. The laboratory analytical results do not allow risk assessment of paraquat and organophosphates because their limits of quantification are above the environmental quality criteria.

Aware that spot measurements of polar pesticides in river waters are not very representative of the real situation and that the number of analyses is limited, the use of passive sampling methods should also be considered. Chemcatcher® technology with Emperore Anion SR membranes would allow sampling of 2,4-D and Picloram and HLB-L membranes would also allow sampling of atrazine, diuron and ametryn (Lacey, 2020). Glyphosate can be sampled by another type of passive sampler called "POCIS" (Polar Organic Chemical Integrative Samplers) and paraquat by another solid-phase extraction technology called Oasis® WCX (Weak Cation exchange reversed-phase sorbent for strong bases and quaternary amines) (Lacey, 2020). These solutions were not applied in the context of this research for reasons of cost (high compared to the price of analysis in El Salvador), the difficulty of interpreting the data in view of the environmental risk and the diversity of the samplers to be deployed.

Water analyses at the end of the rainy season in the three wells of El Aguacate micro-watershed show that there is no risk to human health associated with the presence of chlorpyrifos. The detection limits for triazines and paraquat are not low enough to rule out a risk to human health. This is of particular concern since triazines are widely used in sugarcane fields and are easily found in aquifers.

Regarding sediment analysis. The risk assessment of AMPA and the organochlorines dieldrin, endrin, heptachlor epoxide, p,p'-DDT, p,p'-DDD, p,p'-DDE and γ-HCH (lindane) shows that there is no associated risk to benthic organisms according to the results reported by the laboratory. Analyses demonstrated El Aguacate River and the entire Garita Palmera wetland are contaminated with paraquat. The measured concentrations are below the guideline value determined for paraquat in this study. However, it should be noted that this guideline value should be based on chronic toxicity tests in at least three different species and trophic levels to be more reliable. The limits of quantification are not precise enough to assess the risk of **α**- and **β**-endosulfan and organophosphates.

It should be noted this year has been exceptional due to the hydrological conditions caused by the tropical storms (Amanda and Cristobal) influenced the area. These could have caused a "flushing" of sediments. It would be advisable to carry out new measurements for different hydrophobic pesticides in collaboration with a laboratory that has the necessary precision to carry out the chemical risk assessment.

The results reported for the analysis of fish from the Garita Palmera wetland show that there is no risk associated with fish consumption in terms of organochlorine and organophosphate contamination within the limits of current conditions.

8.5 Water quality - other problems encountered

In the 4.4 km between the intake and the measuring station El Diamante of the El Aguacate River, the oxygen levels available for the development of aquatic species are reduced by half and the total dissolved ion load doubles. According to the main ion analyses, this increase could be explained by the leaching of certain fertilizers applied in sugarcane (ammonium sulfate, potassium sulfate) and soil salinization due to inadequate irrigation techniques. The measured phosphorus level creates a risk of water hypertrophy. This implies an exaggerated growth of green algae, which once dead cause a significant decrease in oxygen levels due to their degradation by microorganisms. An anaerobic environment could lead to the reduction of large amounts of sulfate (SO42-) to hydrogen sulfide (H2S), which is toxic to aquatic organisms. This phenomenon was observed in sediments downstream of this site because of the sulfurous odor they gave off, indicating an anaerobic environment

Evaluation of the water quality of the communities' wells shows salt levels that make the water unsuitable for human consumption (appendix 11.6). For about 15 years, most families in the communities El Palmo La Danta and El Chino have been unable to use well water for personal consumption (well monitoring December 2020). This phenomenon is said to be caused to overexploitation of aquifers for irrigation of sugarcane fields (Figure 30) (Campos Hernández, 2016).

Further research will be needed to determine whether this salinity comes from saline intrusion, from contamination by geological layers drilled during the installation of irrigation wells, or whether the salinity comes from the removal of old saltwater deposits located in the lower zones of the aquifers. The use of aquifer water with a load too high of different salts increases soil salinity levels, which in turn increases the salinity of rivers and aquifers through leaching and infiltration. According to FAO recommendations and in view of water quality, irrigation should be limited in the area (Ayers & Westcot, 1994).

Figure 30 Wells are drilled approximately every 40 meters in the sugarcane fields to irrigate the fields between February and May.

8.6 Conclusions

Organochlorine and organophosphate insecticides have different effects on marine organisms including biochemical, physical, reproductive, and behavioral changes. The campaign to measure some insecticides in 4 different species of fish in the Garita Palmera wetland tends to show that organochlorines except for endosulfan, are no longer the priority pesticides to monitor in this area. This may be different in the area of the country where much more of these substances were used or where there are still contaminated sites. **However, much more emphasis needs to be placed on monitoring the pesticides currently used and their degradation products.** For example, more research should be conducted in the study area and other wetlands on the exposure levels of marine organisms to organophosphates and neonicotinoids which are the most widely used in the country.

However, it should not be forgotten that the major environmental concern for sugarcane fields related more in the use of herbicides such as 2,4-D, diuron and triazines. Research conducted in Australia suggests that different herbicides are responsible for the decline of mangrove ecosystems downstream of sugarcane fields (Bell & Duke, 2005; Duke et al., 2005). The problem in the Garita Palmera study area is that mangrove reforestation programs are in progress and if some of these herbicides are present in the sediment, they could inhibit growth and/or kill newly planted seedlings.

Various indicators show that the study area is heavily affected by aquifer water salinization problems, probably because of the massive use of fertilizers (remarkably high presence of sulfates) and an excessive irrigation regime. It is essential to take measures to regulate the amount of water pumped from the aquifers and that soil protection measures be put in place, otherwise these croplands could become unusable. It would be advisable to carry out soil quality studies to control salinity, pH, and erosion levels.

Based on field visits and measurements taken, El Aguacate River is in an advanced state of degradation. This river only receives water occasionally during the winter, but its oxygen levels only allow certain tolerant aquatic species to survive. Along with the El Chino River, it is the only freshwater inflow in the Garita Palmera wetland protected area. **Therefore, the El Aguacate River should become an integral part of the protected area of the Ramsar Site and a renaturation program of the river should be carried out, transformed in the meantime into an irrigation canal.**

9 Recommendations

Considerable efforts are needed at the regional and above all, at the national level to reduce the effects of pesticides on agricultural workers and the communities living around them, as well as on the environment. It is necessary to articulate different legal instruments for prevention, protection, vigilance, and sanction, accompanied by a real action plan to reduce the risks and impacts on human health and the environment associated with the use of pesticides.

A proposal for a general approach to reduce the impact of pesticides in developing countries (according to Konradsen et al., 2003) is as follows:

1. Eliminate highly toxic compounds.
2. Substitute the compounds for less toxic and equally effective alternatives.
3. Reduce use through better equipment.
4. Isolate people from the hazard.
5. Label products and train applicators in safe handling.
6. Promote the use of personal protective equipment.
7. Introduce administrative controls.

Various scientists promote "Integrated Pest Management" (IPM) as a solution that integrates the use of chemical pesticides as a last resort, if preventive measures, warning, forecasting and tolerance threshold systems, as well as biological and physical control are not sufficient (Swiss Federal Council, 2017). This model seems to have worked in many countries such as the Philippines, Indonesia, Nepal, Vietnam, Sri Lanka, and other developing countries. A model that is more community-based ("community IPM") in addition to a training program for farmers is cited in Atreya et al. (2011) as an example.

However, it should be noted that this type of approach requires a great deal of knowledge, literate farmers and in addition the success of this type of program is highly dependent on donor funding. It is also pertinent to ask whether this financial and training effort could be invested directly in a transition to organic or agroecological agriculture. IPM could be an option for industrial agriculture (e.g., for sugarcane), as the transition to an ecological mode of production is unlikely.

The following recommendations have been adapted to the Salvadoran context but are not intended to be exhaustive. Nevertheless, they should serve to initiate further reflection at different levels. Different farming areas in the country have their own characteristics that should be investigated and after a thorough analysis, plans could be proposed to improve or eliminate the use of hazardous pesticides and improve the working conditions of agricultural workers.

9.1 At the National level

9.1.1 The Creation of a National Platform to Defend People with CKD

Approximately 800,000 people (12.6% of the population) suffer from CKD in El Salvador, of which 33% are of unknown origin, although the latest published research shows a toxic origin (C. M. Orantes et al., 2014). It would be desirable to create a national platform among the different actors of civil society to defend their right to health, access to medical care and compensation for the victims of this chronic kidney disease. It should support promotion at the level of legislative, executive and judicial bodies in order to adopt the necessary measures to curb this growing epidemic in the country.

9.1.2 Reinforcement of Controls and Monitoring of Compliance with Labor Standards

During the interviews, several abuses and violations of Salvadoran legislation regarding the protection of workers were reported, including violations of occupational safety standards and employers' obligations. In this context, the Ministerio de Trabajo y Previsión Social (Ministry of Labor and Social Security) must carry out controls to ensure compliance with the following points:

Given the employer-employee relationship in sugarcane crops, the employer is responsible for providing adequate protective equipment and ensuring compliance with the General Law on Occupational Risk Prevention (ALRES, 2010) and occupational safety standards for the use of agrochemicals. Standards on employment conditions for fumigation include medical examination, prohibition of employing personnel under 18 years of age, women of childbearing age, mentally retarded persons, physically ill persons (liver, kidneys, asthma) and illiterate persons (ISDEM, 2012). Workers should also be trained on the safe use of pesticides, fertilizers and on the appropriate personal protective equipment. The equipment should be adapted according to the degree of hazard of the products used. Depending on the products used by operators in sugarcane fields (e.g., 2,4-D and glyphosate), the employer must provide their employees for spraying (Appendix 2, p. 111): gloves (nitrile, butyl or neoprene), a mask with filter (NIOSH R95 or R100 type plus cartridge for organic vapors), rubber boots, protective suit and safety glasses (Medardo & Molina, 2016).

Finally, MAG and/or MARN should guarantee permanent supervision in the use of pesticides.

9.1.3 Reinforcement of Controls and Monitoring of Compliance with Decrees No. 423 and No. 18

The interviews revealed that the various legal aspects of aerial spraying are not being respected, which endangers the health of local people, pesticides applicators and operators on the ground. These are mainly violations of Article 7 of Decree No. 423, paragraphs 12 and 18 about the aerial application of pesticides (MAG, 2011)[16]. The provisions of paragraph 7 are not in compliance because the planes fly over houses and schools, releasing part of the spraying, without respecting the minimum safety distance of 300 m. In addition, many sugarcane plots are adjacent to houses in the communities. In many interviews it was also reported the spread of pesticides by wind currents in the communities' food production

[16] Agricultural aircraft shall not spray pesticides in the airspace within 300 meters of the following places: rivers, lakes, lagoons, fountains, marshes, ponds, apiaries, stables, hospitals, schools, villages, towns, public places, tiangues, beach runways.

caused losses in their crops. Decree No. 18 is also not respected, as people are not informed 72 hours before aerial application. As a result, people do not take the necessary measures to protect themselves before the aircraft passes overhead. The time of application (6-8 am) can also endanger the health of children who go to school at that time. One of the testimonies collected states that a child was sprayed in this way when an airplane passed by and was subsequently hospitalized for acute poisoning.

The MAG and/or MARN should guarantee permanent supervision in the use of pesticides, compliance with the norms established in the legal frameworks, as well as the application of sanctions in case of violation of these norms.

9.1.4 Updating the Law on the Control of Pesticides, Fertilizers and Products for Agricultural Use (LCP)

The LCP should be updated to include the following:

a. The creation of an interdisciplinary technical committee (ecology, agronomy, agroecology, economics, social and behavioral sciences, health and toxicology, ecotoxicology, hydrogeology, pedology) composed of representatives from academia, the health system, Ministries of Health, Agriculture and Environment, civil society and local stakeholders, to:

- Review every four years the list of authorized active ingredients according to individual (toxicology), population (epidemiology) and ecosystem (ecology and ecotoxicology) effects for importation, use, and conditions of use.
- Conduct a comprehensive socio-economic analysis including public health costs (acute and chronic diseases, suicide, mortality, morbidity), loss of labor due to these diseases, precariousness of communities due to health costs, loss of water resources and biodiversity (fishery resources), loss of soil fertility and its medium- and long-term impact on agriculture, etc.

b. Prohibition of active substances with a particularly hazardous potential for human health.

In particular:

- Active ingredients responsible for most cases of acute poisoning in the country, including bipyridyls[17], organophosphates[18], carbamates[19] and pyrethroids[20].
- Active ingredients with a toxic effect on the kidneys.

c. Prohibition of active substances with a hazardous potential for the environment and biodiversity.

Among them:

- Active ingredients with high risk of contaminating aquifers such as triazines[21].
- Active ingredients very hazardous for pollinating insects such as neonicotinoids[22], pyrethroid bifenthrin, carbamates[23], organophosphates[24].

d. That the application of agrochemicals by air be prohibited as in Europe.

e. Prohibition of synthetic chemical pesticides for private use.

- Synthetic pesticides and biocides that are not used for sanitary or public health purposes (e.g., to control

[17] Paraquat, diquat.
[18] Terbufos, chlorpyrifos, diazinon, ethoprophos, phorate, acephate.
[19] Carbofuran, asulam, carbosulfan.
[20] Bifenthrin, lambda cyhalothrin, cypermethrin.
[21] Atrazine, ametryn, cyromazine, terbutryn, hexazinone.
[22] Clothianidin, imidacloprid, thiamethoxam.
[23] Carbaryl, carbofuran, methomyl, methiocarb, mexacarb, propoxur.
[24] Azinphos-methyl, chlorpyrifos, demeton, diazinon, dicrotophos, dichlorvos, dimethoate, fenthion, fenitrothion, fensulfothion, fonofos, malathion, methamidophos, methidathion, methidathion, methyl parathion, mevinphos, monocrotophos, naled, omethoate, oxydemeton-methyl, phorate, phosmet, phosphamidon, pyrazophos, tetrachlorvinphos.

dengue, malaria, zika, chikungunya, etc.) should be banned for domestic use.

f. Regulation, reduction of the use and commercialization of substances with eutrophying effect on the natural environment..

- The use of fertilizers responsible for accelerating the eutrophication of surface waters and contamination of aquifers (nitrate, phosphates, heavy metals) and soils must be reduced to levels acceptable under environmental laws and water for human consumption.

g. Measurement and purity standards for imported fertilizers.

- The heavy metal and arsenic content of fertilizers imported into the country should be controlled so as not to further reinforce the high concentrations of certain contaminants from existing geogenic sources. Imported fertilizers should be analyzed in El Salvador to verify that they have the necessary quality to not contaminate the country.

9.1.5 Updating of the Environmental Law (EL)

Several activities are needed to monitor contamination levels in El Salvador's environment:

a. Aquatic Ecosystem Monitoring System

- At the national level, MARN and some universities will implement a surface water monitoring system that includes biological indicators (macroinvertebrates, fish or diatoms) and physicochemical indicators, as well as emerging synthetic pollutants (pesticides, heavy metals, drugs, antibiotics and industrial products).
- Establishment of an independent monitoring body in charge to monitor the level of contamination in the different environmental compartement, to identify the contaminated sites of concern and those responsible for them.
- A list of priority chemical substances in terms of human and environmental health is established for monitoring in the different environmental media (water, soil, biota, sediment). These "priority" substances are those that threaten to or via the aquatic environment. The aim of the list is to reduce (or eliminate) contamination of surface waters (rivers, lakes, estuaries and coastal waters) by the listed pollutants.

b. Establishment of Environmental Quality Standards (EQS) for Priority Substances

- Environmental quality standards are applied for relevant environmental matrices (surface waters, estuaries, aquifers, soils, sediments or biota) according to the physicochemical behavior of the pollutant and its measured environmental concentrations based on data on effects such as acute and chronic toxicity to aquatic organisms, accumulation in the ecosystem, loss of habitats and biodiversity, as well as human health.

9.2 Implement an Action Plan to Reduce Health and Environmental Risks Associated with the Use of Pesticides and Fertilizers.

MAG, MARN and MINSAL should implement a plan to reduce the risks associated with the use of pesticides and fertilizers. The plan should focus to protect consumers, agricultural operators, people around the fields, ground and surface water, and organisms involved in soil fertility, as well as all organisms (such as bees) that play an important role in the conservation and sustainability of the environment. The plan should include a national training program on organic or agroecological production alternatives, a process of transition from conventional production to a more sustainable mode of production, quantitative goals for reducing the use and concentration of pesticides and fertilizers measured in environmental matrices (water, soil, sediment, biota), state support for agroecological food production, the valorization of organic products at the national level and for export (coffee, sugar, etc.), the introduction of ecological compensation zones proportional to the cultivated areas.

9.3 Minimum Requirements to be met for Sugarcane Production

Current sugarcane production in El Salvador is still mostly a conventional type of production that involves the systematic use of chemical fertilizers, the application of synthetic herbicides to the soil and irrigation. The choice of conventional, organic or agroecological mode of production depends on the country's agricultural policy. However, before the discussion of this strategic element, the fight against bad agricultural practices, dangerous for human health and the environment that endanger sustainable production, should be a short-term and priority objective. Bad practices consist of improper dosage and application of pesticides without protective equipment, massive and inappropriate use of fertilizers, inefficient and harmful irrigation techniques and the practice of pre-harvest burning

Three priority processes need to be initiated in the short term at the national level:

a. That the recommendations promulgated in the Technical Guide on Good Agricultural Practices for Sugarcane Cultivation (Medardo & Molina, 2016) in El Salvador become minimum requirements for any producer who sells his sugarcane to a mill, under the assumption that there is adequate monitoring by state authorities to ensure compliance with what is indicated in the guide.

b. That the practice of burning be prohibited at national level and the promotion of a green harvest be established through adequate incentives as the beginning to advance towards a type of cultivation that has the least ecological and social impact promoted by the competent authorities.

c. The termination of the aerial application of agrochemicals.

The green zafra has many advantages according to the 5-year cost-benefit analysis conducted for El Salvador by Fonseca et al. (2018). First, the reincorporation as stubble of 40% of agricultural harvest residues reduces the use of fertilizers such as urea and ammonium sulfates by up to 20% and reduces soil erosion. The other 60% can be reused for energy recovery. Unburned sugarcane provides 10% more juice when pressed and increases yields from 5 to 15 tons/ha. The current average yield, as reported in MAG 2018-2019 statistical yearbook, is 91.3 ton/Ha (63.8 tons/manzana; 1 manzana = 0.70 hectares). According to the authors the yield in the first green harvest year would be 135 tons/ha and 121 tons/ha between the second and fifth year. A change in the varieties grown corresponding to different agroecological profiles of the country's regions could increase yields to 170-190 tons/ha (Fonseca et al., 2018). Crop residues can also be resold for electricity production. However, green zafra doubles the cost of labor. Nevertheless, in the end, the cost-benefit analysis at a purely economic level is similar with or without burning. Although, green harvesting provides more jobs (0.48 jobs/ha/year) and is based on an incentive wage for workers that doubles ($6.6 per ton) what is currently earned. The environmental benefits are: capture of 70 tons of CO_2/ha, reduction of erosion, reduction of weeds, improved chemical and biological qualities of the soil.

9.4 Corporate Responsibility: Incentives to improve Water Management

In the absence of a water law setting limits and priorities for use, the unequal distribution and overexploitation of water resources by agribusiness, livestock and the industrial sector that uses water as a raw material, generates tensions among the poorest and most vulnerable communities. However, given the context of vulnerability of the communities and the threats to which they are subjected, it is not strategically feasible to develop an integrated management plan directly between them and the large producers. While waiting for the legal framework to be established and for the competent authorities to monitor compliance with the law, there is an incentive-based approach for companies to comply with the principles of good governance and sustainable management of water resources, taking into account the social, economic and ecological needs of the basin. In this regard, there is an international alliance called the Alliance for Water Stewardship (AWS) that is responsible for planning and implementing, a sustainable and integrated water resources management plan.

AWS is a global alliance of members that includes companies, NGOs and the public sector. Members contribute to the sustainability of local water resources by adopting and promoting a universal framework for sustainable water use. Members commit to a 5-step process, which includes: 1. Gathering technical scientific and stakeholder information at the site. 2 Engagement and planning 3. Implementation 4. Evaluation 5. Communication and dissemination.

Following an external audit by AWS, the company can obtain certification, which brings demonstrable benefits in terms of customer relations, increased investor confidence, greater social acceptability of its activities, improved brand perception and dialogue with regulators and policy makers[25].

9.5 Promote Alternative Production Methods

UNES believes that it is necessary to develop an agricultural strategy at the national level that promotes agroecology as a technological tool to implement a production system resilient to climate change. Priority should be given to local agricultural production to feed the population, promote a fair and solidarity economy and direct sales between producer and consumer. Considering the situation in the territory, the strategy should include a process of returning access to land to communities so they can practice local food agriculture environmentally friendly.

Alternative Method of Sugarcane Production

In sugarcane production, several alternatives to the conventional production method can be considered. The elaboration of a proposal of possible alternatives is complex and multifactorial and must take into account local and national social, economic and ecological aspects It is not the ambition of this research to provide complete and holistic solutions to this problem. However, efforts should be made to seek and apply alternative methods in line with the objectives of the Salvadoran environmental law that establishes it is important "the integrated management of pests and the use of natural fertilizers, fungicides and pesticides in agricultural activity, which maintain the balance of ecosystems, in order to achieve the gradual replacement of agrochemicals with bioecological natural products"(art. 50, EL, 2012).

In order to reduce environmental impacts, sugarcane production methods should consider the following elements cited in FAO (2003) and Pérez Iglesias et al. (2006):

1. Soil management and conservationo: Soils in sugar production are not adequately managed, leading to various phenomena such as soil loss by erosion, soil compaction, soil salinization by inadequate irrigation, acidification by the use of chemical fertilizers and the loss of organic matter (e.g., by the practice of burning). Several actions can be implemented to reduce these impacts. The first is the abandonment of deep tillage (to reduce erosion), incorporation of organic matter into the soil from green crop residues with compost, crop rotation, application of a liquid conditioner to increase the decomposition of crop residues and increase the water absorption capacity of the soil, covering the soil with organic matter, etc.

2. Reduction and change of irrigation systems: Excessive irrigation in sugarcane fields causes many problems for the soil such as salinization, leaching of soil nutrients, water saturation and an increase in sugarcane pests and diseases. There are different techniques to increase the soil's capacity to retain moisture, reduce evaporation and irrigate crops. The experiences cited in the FAO document, in first place the abandonment of tillage increases the soil's capacity to retain water by reducing the frequency of irrigation (from 10-12 to 20-25 days) and the amounts used by 50% (FAO, 2003). Secondly, the remains of the green harvest are left in the fields, which reduces evaporation and soil erosion during rainfall. Thirdly, the installation of drip irrigation systems, which is already used in sugar cultivation in other countries, is the most efficient means of irrigation.

[25] Details can be downloaded from the following website: https://a4ws.org/the-aws-standard-2-0/.

3. Biological control of insect pests: These techniques have been used in Cuba for 90 years and are aimed at controlling sugarcane pests by introducing a natural predator of the pest. We can mention for example the use of entomophagous insects, which are natural predators of sugarcane pests. These insects feed on insect larvae and pests. There are also entomopathogenic organisms (viruses, bacteria, fungi, nematodes, protozoa) that infect and kill insect pests.

4. Soil fertilization: Can be done through the use of crop residues, use of compost to increase organic matter and nitrogen in the soil (organic residues), association with other types of crops that improves nutrient availability, fixes nitrogen and soil structure. Soil treatment with the application of a liquid conditioner to increase the decomposition of crop residues.

5. Weed control: Weeds compete with sugarcane for soil nutrients, light and water. There are three means of control: physical (manual or mechanical weeding), chemical (herbicides), biological (use of competitive species). Organic crops do not use chemical herbicides. Weed control is carried out by preventive means (limiting contamination by weed-contaminated areas), the use of competitive varieties and physical weeding.

9.6 At the Community Level

Risk reduction for communities working in pesticide application in sugarcane fields involves different levels of complexity, as shown in figure (31). Communities working in this crop are very vulnerable from a socioeconomic and health point of view. The overwhelming majority of the inhabitants of these communities are farmers, but they have great difficulty accessing land to cultivate it. They are left with few options for paid work other than spraying the fields. The fight against poverty and the creation of alternative employment would be one of the most sensible, but also the most complex, solutions to break this dependence on this form of work. The organization of work in the sugarcane fields is one of the main obstacles to improving practices. In fact, communities suffering from the effects of the pesticides they apply cannot negotiate alone with their employer, boss or landowner for fear of losing their jobs or facing reprisals.

In this context, it is recommended that negotiations and pressure to enforce safety measures be carried out by a third-party organization (e.g., a union) or by the Ministerio de Trabajo y Previsión Social (Ministry of Labor and Social Security) on the owners or the employer. Similarly, imposed working conditions increase the exposure of workers and the environment to pesticides. This is because workers are paid per task, resulting in unsafe behavior in the use of agrochemicals, lack of hydration during work and over-application on treated surfaces. The precarious salary paid per task also forces the other members of the family to join in this work, since if only one member of the family works, the money is not enough to supply even the minimum adequate food.

This also leads to the incorporation of people with health conditions that are not recommended for this work (pregnant women, people susceptible to kidney disease). There is a lot of work to be done to defend the rights of workers. This leads directly to the fact that controls must be carried out by authorized government agencies to ensure the legal framework for the protection of personnel and the environment is respected (medical examinations, training, equipment, recording of weather conditions during application, etc.). In the short term, the measures to be implemented as soon as possible are the training of personnel in the use of pesticides and the provision of adequate personal protective equipment.

The sugarcane fields in the study area are located less than 300 meters away from homes, schools, playgrounds, community food production fields and surface waters. Therefore, it is impossible to ensure that aerial spray dispersion does not end up on women, children and men living in the surrounding area. It is also impossible to guarantee it will not cause damage to adjacent crops and protected areas. There are alternatives to aerial spraying and burning practices. Aerial spraying is not a necessary practice for sugarcane crops, however, it is used only to increase sugar yields for extraction and promote better profits for the plantation owner. Given the risk and damage this type of practice causes to the health of the population, to their food crops and to direct contamination of aquatic ecosystems, it is recommended a policy prohibiting this type of spraying be implemented.

Considering the current practice of aerial spraying, which does not comply with the legal framework of Decrees No. 18 and 423; it is recommended a governmental and anonymous monitoring system be established in the communities. This monitoring system should collect dates, times, photos, locations, weather conditions and information in case a notification was issued prior to pesticide application, to report abuses and present the evidences to the Environmental Court of the area. The State must create the conditions to follow up on anonymous complaints from the population.

Finally, a system for monitoring exposure and contamination of the population in the different environmental compartments (soils, aquifers, surface water, biota and sediments) should be established in collaboration with MARN, MINSAL and the country's universities. The latter to check contamination levels in the region and thus be able to reinforce the necessary measures to reduce emissions and exposure to these agrochemicals.

It is evident that laws to protect the environment are not effective if there are no control and monitoring mechanisms to determine when there are violations of the law and thus penalize the violators. Therefore, two important things need to be established in El Salvador:

- Strengthen the capacities of the personnel of the Environmental Division of the National Civil Police to monitor and document infractions linked to decrees and laws related to environmental protection (LMA, LANP, LSVA), water use (Legislative Decree No. 153) and the use of pesticides and fertilizers (LCP, Legislative Decree No. 18, No. 151, No. 423).

- The creation of mechanisms to confirm infractions, such as the establishment of adequate laboratories for the determination of pesticides and heavy metals in the different environmental phases. This is extremely important and essential for the protection, not only of agricultural workers and their families, but also of the population in general.

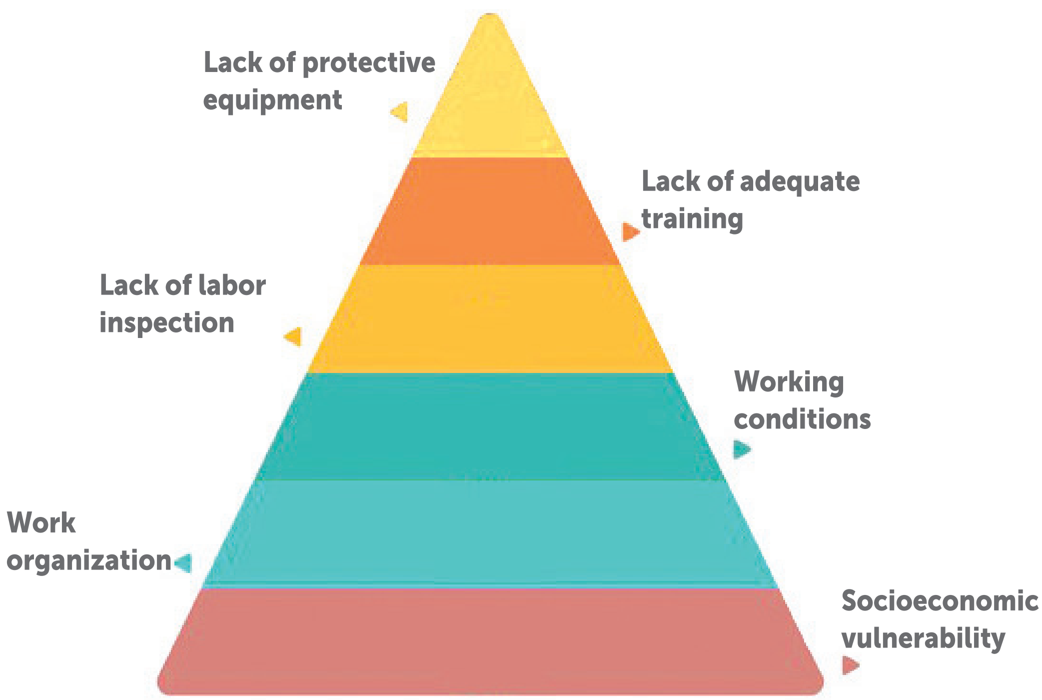

Figure 31 Factors impeding safer use of pesticides by communities when working in sugarcane fields.

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11 Appendixes

11.1 Methodological Chart: Analysis of the conflict-sensitive territory

Organization of the activity

General objective: The objective of this meeting is to present to the target communities the intentions of UNES relative to the planned research process on the issue of sugar production in the territory, in order to plan the steps with the population in line with a conflict sensitive approach.

Technical objective: Participants use the tools and concepts learned during the community diploma course on the principles of integrated water and contamination management to facilitate the analysis of the context of the conflict in the territory in relation to sugar production. Qualitative observations are collected on the positive and negative impacts of sugarcane monocultures.

Products: List of the main challenges faced by the communities in the territory, map of actors and relationships, list of sources of tension and conciliators, analysis of risks and opportunities, lists of observations on the territory.

Materials:

Scissors	Four packs of markers (red, blue, green, black)
List of assistants	Camera
List of per diems	Color sheets
Writing board	Adhesive tape
Projector - electric cable -computer	Flip charts

Agenda:

Welcome and presentation of the objectives of the meeting.
Introduction of the proposed research process.
Definition of the main challenges faced by the communities in relation to the research.
Identification of the key actors in the territory in relation to sugar production and their relationships.
Identification of sources of tension and reconciling elements.
Analysis of risks and opportunities through research.
Compilation of information on the socio-environmental impacts of sugar crops.
Synthesis and conclusions.

Content	Objectives moderators	Objectives participants	Methodology	Material	Time
Welcome and presentation of the objectives of the meeting	Present to the participants the program of the day and the objectives established. Demonstrate the continuity of the process after the end of the course.	Take note of the day's agenda and ask questions.	Power Point Presentation	Computer Projector Extension cord Slides	10 min
Introduction of the proposed research process.	The introduction arouses the interest of the participants, but also their questions, doubts and/or suspicions.	Participants are informed of the intentions, objectives and goals of UNES in the proposed research.	Power Point Presentation	Slides	15 min
Analysis of context fragility					
Definition of the main challenges faced by communities in relation to research.	Participants list the main conflicts that exist in the territory.	The participants list the relevant conflicts to which they are subject in their territories.	In small groups of 6 people, participants list the relevant conflicts present at the territorial level, judge their intensities (low/medium/strong) if there is a probability of escalation during the research process and at the time of publication, the media coverage of the report.	A flipchart with 3 different columns	20 min
Identification of key stakeholders in the territory in relation to sugar production and their relationships.	Participants identify all the actors involved in the topic and characterize their relationship.	The participants draw up a map of the actors and their relationships.	On colored maps of different sizes by importance or power, participants list the actors involved in the topic. The actors are placed on a flipchart and their relationships are characterized by different types of lines.	Colored paper, tape, marker pens	20 min
Identification of tension sources and reconciling elements.	Identify the sources of tension and the elements of bonding that unite people in this situation.	Participants identify sources of tension and conciliatory elements.	- What leads to tensions in the current situation? - What are the connecting elements? - What are the current threats to peace and stability? - To what extent do tensions affect women and men differently? - What do people do together despite tensions?	2 flipchart, one with the tensions sources and the other one with the conciliatory elements	20 min
Analysis of risks and opportunities through research.	Participants give their opinion, recommendation and accept or reject the research steps depending on whether they are harmful to the community.	Participants judge the risks and opportunities of each stage of the research and specify the contributions they would be willing to make.	A flipchart presents the planned steps for the research and complete participants according to the risks and opportunities they see during the process and the results.	A flipchart with opportunities and risks	20 min

Content	Objectives moderators	Objectives participants	Methodology	Material	Time
Compilation of information on the socio-environmental impacts of sugar crops.	Community observations and perceptions are collected and organized.	Participants fill out a colored piece of paper by observation and write on the back why they believe this impact is partially or totally related to the presence of sugarcane monocultures.	The "Beehive" Technique 1) The facilitator asks the participants to form groups of 6, wherever they are (i.e., in the same room). 2) The groups are invited to answer the question: What are my personal observations and the facts that I have observed about the direct relationship between sugarcane monocultures and their impact on my environment and what makes me say that they come from this type of crop? 3) The answers are written on colored paper and pasted on different flipcharts depending on the economic, environmental or social impact.	3 flipcharts with the main social, environmental and economic classes.	20 min
Debriefing and conclusion	The various aspects are reviewed in order for the committee to make a decision on the progress of the research and to define its support.	A leader summarizes the results of the different positions and takes a decision on the next step envisaged and how it will be carried out.	**Debriefing and conclusion**	The various aspects are reviewed in order for the committee to make a decision on the progress of the research and to define its support.	20 min

11.2 Chronology of events following the acceptance of Decree No. 473

Table 32 Events after the acceptance by GANA and the FMLN of the revision of the Pesticides Law.

Date	Events	References
September 5, 2013	Members of the FMLN and GANA agree to revise the pesticide and fertilizer control law, which bans 53 agrochemicals in El Salvador.	(CAD, 2013c)
September 10, 2013	The president and director of the Coffee Growers Association denounces this revision, which prohibits the use of endosulfan, used to combat the coffee berry borer, and the prohibition of herbicides because manual weeding is more expensive (labor). The Council Executive National (COENA) asks President Mauricio Funes to study the decree, which is considered a threat to food security and to the country's economy.	(CAD, 2013a)
September 11, 2013	The international agribusiness lobby CropLife (BASF, Bayer CropScience, Dow AgroSciences, DuPont, FMC Corporation, Monsanto, Sumitomo and Syngenta) reports that this revision could reduce agricultural production in El Salvador by 60%.	(CAD, 2013e)
September 19, 2013	President Mauricio Funes receives the decree.	(Funes, 2013)
October 1, 2013	President Mauricio Funes returned the decree with observations to the Legislative Assembly. The president mentioned that 42 substances included in the lists are already prohibited by national ministerial agreements and international conventions. According to the President, a technical committee will be created to evaluate the risk based on scientific principles of the other 11 active substances mentioned in the decree.	(CAD, 2013d)
October 3, 2013	The deputies of the Legislative Assembly continue to debate the other 11 substances without reaching an agreement. Angel Ibarra president of UNES) said that the 11 substances are the most sold in the country and the ones with the highest toxic risk.	(CAD, 2013f)
November 27, 2013	The Commission on Environment and Climate Change of the congress establishes a 1-year limit to ban the sale of paraquat and a 2-year limit for the remaining 52 substances. The Commission accepts the creation of a technical committee for the evaluation of substances.	(CAD, 2013b)
2015-2016	Imports of insecticides, herbicides and fungicides increased by 6% in Central America.	(CAD, 2017)
March 11, 2019	Central American companies have until December 20, 2020 to incorporate the new Globally Harmonized System labeling standards for products based on their toxicity and hazardousness.	(CAD, 2019b)
September 26, 2019	The Government of El Salvador invested US$3 million in the purchase of fungicides (40,775 liters) and insecticides (30,000 liters) for coffee growers.	(CAD, 2019a)

11.3 List environmental hazard per pesticide

Active ingredient	Persistence	Bioaccumulation	Toxicity	Mobility
Fungicide				
Pyraclostrobin	-	potentially B	potentially T	M
Herbicide				
2,4-Dichlorophenonxyacetic acid	mP	no	T	mM
Amethrin	P	no	potentially T	mM
Atrazine	P	B	potentially T	mM
Carfentrazone	no	B	potentially T	mM
Cletodim	no	no	potentially T	M
Diuron	no	no	potentially T	mM
Ethoxysulfuron	no	no	potentially T	mM
Fluazifop	no	no	potentially T	M
Glyphosate	no	no	probably no T	M
Glufosinate Ammonium	no	no	no	-
Hexazinone	P	no	T	mM
Imazapic	no	mB	probably no T	mM
imazapyr	no	no	T	mM
Indaziflam	mP	no	T+	mM
Isoxaflutole	No (degradation product P)	no	T	mM
Mesotrione	no	no	no	mM
Metribuzin	P	no	T	mM
Metsulfuron methyl	-	n	T+	mM
Paraquat	mP	-	T	no
Pendimethalin	no	no	T	M
Picloram	P	no	probably no T	mM
S-Metholachloro	no	no	potentially T	mM
Terbutryn	mP	no	T	mM
Topramezone	P	no	potentially T	mM
Insecticide				
Chlorantraniliprole	mP	no	potentially T	mM
Chlorpyrifos	P	mB	T	M
Fipronil	P	no	T+	mM
Imidacloprid	mP	no	T+	mM
Lambda cyhalothrin	P	n	T+	non
Tebufenonzide	no	no	potentially T	mM
Terbufos	no	no	T+	mM
Thiamethoxan	P	no	potentially T	mM
Triflumuron	no	potentially B	T	M
Ethephon	no	no	no	mM
Trinexapac-ethyl	no	no	no	mM
Coumatetralyl	no	no	no	-
Flocoumafen	mP	mB	mT	no

11.4 Prioritization of substances of concern to be monitored in the aquatic system

The process of selecting the substances to be monitored was carried out following the next steps. First, the 39 substances were separated by their uses as herbicides, insecticides, fungicides, rodenticides, and growth regulators. This was done in order to obtain representative active ingredients for each use group.

Within each group, the different active ingredients were prioritized (referred to as the "Priority Index") by summing the amounts used per year normalized by the maximum import value in the group and the resulting hazard score (Chapter 3.3) normalized by the maximum value in the group. The general formula used to calculate the priority index for active ingredient i is as follows:

$$\text{Priority Index}_i = \frac{Al_i}{Al_{max}} + \frac{Pu_i}{Pu_{max}} \quad (4)$$

Al_i : Amount imported of active ingredient i;

Al_{max}: Amount Maximum imported into the group.

Pu_i : Point score PBMT[26] of the active ingredient i;

Pu_{max}: PPoint score Maximum PBMT in the group.

This general index takes into account hazard indicators (PBMT) and an exposure indicator (amount used). Ideally, the concentrations of environmental measurements of the different active ingredients should also be considered, but these data are not available for El Salvador.

The histograms presented below (Figure 32) classify herbicides and insecticides in terms of the amounts used (A, B), the PBMT hazard score obtained in Chapter 3.3 (A', B') and, finally, by the overall index that integrates these last two parameters (A'', B'').

It can be seen from Figure 32 that the active ingredients to be monitored as a priority are not the same if their level of use or hazard characteristics are considered separately. Figures A''' and B''' classify the substances to be monitored as a priority based on PBMT indicators and quantities used.

[26] Persistence, Bioaccumulation, Mobility, Toxicity.

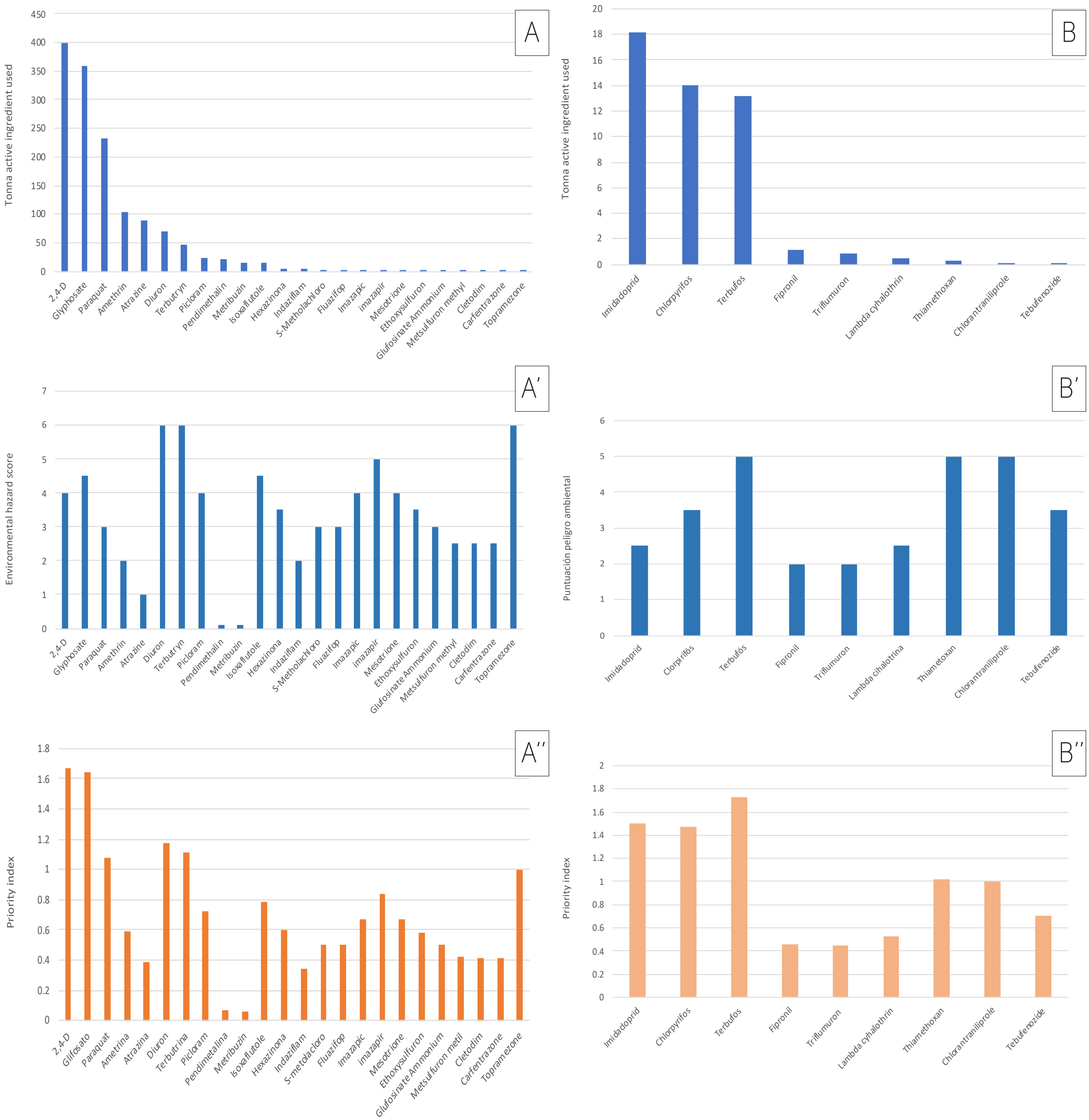

Figure 32 A) Classification of herbicides by their uses, B) Classification of insecticides by their uses, A') Classification of herbicides by their PBMT hazard index, B) Classification of insecticides by their PBMT hazard index, A'') Classification of herbicides by their priority index, B'') Classification of insecticides by their priority index, A'') Classification of herbicides by their PBMT hazard index, B'') Classification of insecticides by their priority index.

Table 33 lists all priority indexes to be monitored for each use group. The priority index is less relevant for groups containing only 1 or 2 active substances such as fungicides, growth regulators and rodenticides. This is because this indicator is proportional to the degree of use and hazard of the active substances present in each group.

11.5 Environmental Compartment to be sampled

After prioritizing the substances in each group, the environmental matrix (water, sediment, biota) in which the active ingredients are most likely to be found was defined. The first indicators to be considered to evaluate the behavior of a chemical released into the environment are the air-water distribution coefficient (Henry's law constant, KH (Pa m3/mol), solubility (Sw (mg/L), hydrophobicity (octanol-water constant KOW), soil adsorption coefficient (organic water partition coefficient mL/g) and biodegradation time in soils (soil DT50) (Gilliom et al., 2007).

Biodegradation times in water and in the sediment-water system (DT50) were also being sought, as they provide an indication of the relevance of measuring the original active ingredient with respect to these degradation products. For example, glyphosate is rapidly degraded in soils by microbial activities in AMPA (aminomethylphosphonic acid) (Hagner et al., 2019). This degradation product is strongly adsorbed in soils, which can be found in sediments in proportions often much higher than the mother molecule (Battaglin et al., 2014; Bonansea et al., 2017; Silva et al., 2018).

Initially, active substances with a log(Koc) or log(Kow) less than 3 were assigned to the aqueous phase and those with a log(Kow) greater than 5 to the sediment (EC, 2011). Substances between log(Koc) 3 and 5 were considered on a case-by-case basis.

Active substances with a log(BCF) greater than 2 were marked as can be found in the biota (EC, 2011). Active substances with a high probability of occurrence in groundwater were also identified in function of their persistence and mobility in soil

To confirm the tendency to find these chemicals in the different environmental compartments, the degree of occurrence of each chemical in surface water, groundwater, sediments and biota was also taken into consideration. The indicator of the presence of chemicals is the number of exceedances of the limit of quantification (LOQ) in the different environmental compartments.

These occurrence levels and the data corresponding to these different indicators were directly consulted in the NORMAN[27] network's "Substance Sheets" database (NORMAN, 2020). For substances for which measurements of environmental concentrations were not available, the assessment was based on the "environmental fate" chapters of the registration files of the U.S. EPA[28] and EU ECHA[29].

As shown in Table 33, most of the herbicides (19) are polar with a logarithm (Koc) lower than 3 and should be found mainly in the water phase such as 2,4-D, ametryn, atrazine, carfentrazone, clethodim, diuron, ethoxysulfuron, fluazifop, glufosinate-ammonium, hexazinone, imazapic, imazapir, isoxaflutole, mesotrione, metribuzin, metsulfuron methyl, picloram, s-metolachlor, topramezone. With the purpose of checking whether this trend is confirmed in environmental measurements, these active ingredients were searched for in the above-mentioned NORMAN database (NORMAN, 2020).

The herbicides truly found in surface waters are 2,4-dichlorophenoxyacetic acid, ametryn, atrazine, diuron, ethoxysulfuron, glufosinate-ammonium, hexazizone, isoxaflutole, picloram, metribuzin, and metolachlor. Data on the remaining substances are not available and have been marked with an (x) in the table below. As for insecticides, chlorantraniliprole, firpronil, imidacloprid, terbufos, thiamethoxan should also be found more in the aqueous phase based on their Koc values. Chlorantraniliprole, firpronil, imidacloprid and thiamethoxan were in fact overwhelmingly found in surface waters based on data summarized by the NORMAN network (NORMAN, 2020).

Thiamethoxan is highly mobile in soils and may also be of concern because of its potential to contaminate

[27] Network of reference laboratories, research centers and related organizations for monitoring of emerging environmental substances
[28] United States Environmental Protection Agency
[29] European Chemical Agency

groundwater (NY DEC, 2002). Terbufos, with a Koc between 500 and 5000 has been measured in surface water, sediments and biota. Its ability to bioconcentrate in aquatic organisms also makes it a hazard to higher trophic level organisms, including humans (PubChem, 2020b).

In accordance with the PMT and vPvM analysis in Chapter 3.3, nine pesticides have physicochemical characteristics that could cause these substances to leach into aquifers. Of these nine pesticides, six were actually found in aquifers in Europe, including 2,4-D, chlorantraniliprole, fipronil, hexazinone, imidacloprid and metribuzin. Sixteen other pesticides on this list of 39 active substances were also detected in European aquifers, including ametryn, atrazine, diuron, ethoxysulfuron, glyphosate, imazapyr, isoxaflutole, metsulfuron methyl, pendimethalin, picloram, pyraclostrobin, s-metolachlor, terbufos, thiamethoxan, triflumuron and trinexapac-ethyl.

The herbicides that are absorbed into soils and are most likely to be found in sediments are clethodim, glyphosate, glufosinate-ammonium, indaziflam, paraquat, pendimethalin and terbutryn. However, it should also be noted that clethodim can be very persistent in the aquatic system (water and sediment) but has a low probability of ending up in the aquatic system because it degrades rapidly in soils (US EPA, 1992).

Glyphosate adsorbs on soils rich in organic matter and can enter the aquatic system through erosion (US DA, 1984). Glufosinate-ammonium has ambivalent behavior and its adsorption to soil is low to high (9.6-1229) (NORMAN, 2020). However, it degrades rapidly in soil and its degradation products are mobile advantages. In some cases, its MPP[30] degradation product could reach the aquifer (EFSA, 2005).

Terbutryn may be found in sediments in function of its Koc value and degradation constants. However, it has also been mentioned that it may degrade to hydroxy-terbutryn, which may leach into aquifers (Meister, 1992). The three active ingredients with high probability to be found in sediments and persistent are indaziflam, paraquat and pendimethalin

No environmental data were found on lambda cyhalothrin, but it is moderately bioaccumulative and persistent and adsorbs strongly to the particulate phase (van Leeuwen et al., 2008). Simulation trials have shown high accumulation in insects and aquatic plants (Hamer et al., 1999; Moore et al., 2001). Tebufonozide is persistent and strongly adsorbed to soils and sediments (Sundaram, 1997). The pesticide also accumulates in aquatic organisms (BCF of 370) (PubChem, 2020a). The sediment and biota matrix should be prioritized for monitoring of these two substances.

Triflumuron was measured in surface water, sediments and biota. It accumulates in some fish but is rapidly excreted (EU, 2015). This active ingredient is slightly to moderately persistent (EU, 2015). Because of its very rapid degradation in water (DT50 2.9 days), it would be preferable to monitor it in sediments (DT50 23.9 days).

The fungicide pyraclostrobin is a molecule with affinity for organic carbon with log(Koc) between 3.8 and 4.2 (AVPMA, 2003). It has been monitored in surface water, sediments and biota (NORMAN, 2020). Because of its hydrophobicity and slower degradation in soils (12-166 days) and sediments (26-96 days), this fungicide should have a higher probability of being found in sediments. It accumulates in some fish with BCFs of 247, 691 and 1195, but is rapidly metabolized and eliminated in these organisms (AVPMA, 2003).

Two growth regulators are registered for use in sugarcane fields. Ethephon has low to moderate mobility in soils and degrades rapidly (DT50 5.1-8 days). If found in sediment it also degrades rapidly (DT50 5.3 days) (US EPA, 1995). No environmental measurement data were found for this product.

The mobility of trinexapac-ethyl in soil is pH dependent with an increase in mobility with increasing pH. The substance degrades very rapidly in aerobic soil (0.045-0.72 days) and relatively quickly in water (25.9 days) and is very unlikely to be found in sediment (EPAL, 2018).

[30] 3-methyl-phosphinico-propionic acid

The rodenticide flocoumafen was not imported into El Salvador between September 2018 and August 2019. If it would be used, it would be expected to be bound to soil or sediment organic carbon. Flocoumafen is highly persistent in soils and also in water and sediments. It is highly bioaccumulative in fish (24300 L/kg) (EC, 2016).

Coumatetralyl does not have the necessary data to assess its persistence in the aquatic system. It is rapidly degraded by light, but may persist for 30 to 86 days in soils. It is considered to have low mobility in sandy, clay and sandy loam soils.

Although the active ingredients that can potentially bioaccumulate according to BCF>100 are pendimethalin, glufosinate-ammonium and carfentrazone, only pendimethalin shows this type of behavior in the laboratory with a BCF of 5000 (EC, 2003). Carfentrazone is metabolized in fish tests (NRA, 2000).

Table 33 Priority index, relevant environmental compartment for sampling and biodegradation time of active ingredients.

				Environmental compartment				*Biodegradation (DT50)*[1]		
Active ingredient	**CAS**	**Chemical family**	**Priority index**	**Surface Water**	**Ground Water**	**Sediment**	**Biota**	**Soil**	**Water**	**Water-Sediment**
Herbicides										
2,4-D	94-75-7	Phenoxi	1.7	x	x			4.4	7.7	18.2
Glyphosate	1071-83-6	Phosphonoglycine	1.6		x	x		15	9.9	74.5
Diuron	330-54-1	Urea	1.2	x	x			118	9	9
Terbutryn	886-50-0	Triazine	1.1			x		74	27	60
Paraquat	1910-42-5	Bipyridyl	1.1			x		180	28	100
Topramezone	210631-68-8	Benzoylpyrazole	1.0	(x)				218	9.5	77.5
Imazapir	81334-34-1	Imidazolinona	0.8	(x)	x			11	-	-
Isoxaflutole	141112-29-0	Oxyacetamide	0.8	x	x			0.9	0.36	0.36
Picloram	1918-02-1	Pyridine	0.7	x	x			82.8	80.8	196.1
Imazapic	104098-48-8	Imidazolinona	0.7	(x)				120	-	-
Mesotrione	104206-82-8	Tricetona	0.7	(x)				11.6	6.6	11.1
Hexazinone	51235-04-2	Triazine	0.6	x	x			105	-	-
Amethrin	834-12-8	Triazine	0.6	x	x			9.2	No biodeg.	1780
Ethoxysulfuron	126801-58-9	Sulfonylurea	0.6	x	x			18	17	30
S-Metholachlor	51218-45-2	Chloroacetanilida	0.5	x	x			90	88	365
Fluazifop	69335-91-7	Aryl propanoate	0.5	(x)				7.4	7.2	24.5
Glufosinate Ammonium	77182-82-2	Phosphonic	0.5	x		(x)		21	-	-
Metsulfuron methyl	74223-64-6	Sulfonylurea	0.4	(x)	x			10	115	224.3
Cletodim	99129-21-2	Oxime cyclohexandiona	0.4	(x)		(x)		0.55	7	16.7
Carfentrazone	128621-72-7	Triazolinone	0.4	(x)				1	0.1	0.21
Atrazine	1912-24-9	Triazine	0.4	x	x			28	-	80
Indaziflam	950782-86-2	Fluoroalquiltriazine	0.3			x		177	> 1000	2.7 - 4.8
Pendimethalin	40487-42-1	Dinitroaniline	0.1		x	x	x	182.3	4	16

				Environmental compartment				***Biodegradation (DT50)***[1]		
Active ingredient	**CAS**	**Chemical family**	**Priority index**	**Surface Water**	**Ground Water**	**Sediment**	**Biota**	**Soil**	**Water**	**Water-Sediment**
Metribuzin	21087-64-9	Triazinone	0.1	x	x			7.1	41	50
Insecticides										
Terbufos	13071-79-9	Organophosphate	1.7	x	x		x	8	-	-
Imidacloprid	138261-41-3	Neonicotinoid	1.5	x	x			191	30	129
Chlorpyrifos	2921-88-2	Organophosphate	1.5	x		x	x	386	5	36.5
Thiametoxan	153719-23-4	Neonicotinoid	1.0	x	x			50	30.6	40
Chlorantraniliprole	500008-45-7	Diamida anthranilic	1.0	x	x			597	-	-
Tebufenozide	112410-23-8	Hidrazine	0.7			x	x	-	30	-
Lambda cyhalothrin	68085-85-8	Pyrethroid	0.5			x	x	175	0.24	15.1
Fipronil	120068-37-3	phenyl pyrazol	0.5		x		x	142	54	68
Triflumuron	64628-44-0	Benzoylurea	0.4		x		x	22	2.6	6.4
Fungicides										
Pyraclostrobin	175013-18-0	Estrobilurin	2	x	x	x	x	41.9	2	28
Growth regulator										
Ethephon	16672-87-0	Ethylene	2.0					13.1	2.4	2.8
Trinexapac-ethyl	95266-40-3	Cyclohexanecarboxylate derivative	1.1	x	x	x	x	0.16	4.2	4.5
Rodenticides										
Coumatetralyl	5836-29-3	Coumarin	2.0			x	x	89	-	-
Flocoumafen	90035-08-8	Coumarin	0.5			x	x	213	NA	NA

[1] The half-life (DT50) is defined as the time it takes for an amount of a compound to be reduced in half by degradation.

11.6 Choice of analytical laboratory

- A survey was carried out in different national laboratories to evaluate their analytical capabilities with respect to this list of substances. The laboratories consulted were the Laboratory of Residues of Chemical and Biological Substances MAG-OIRSA, Laboratory of National Public Health and the Laboratory of FUSADES.

- From the list searched, only the 5 active ingredients and 1 degradation product can be analyzed at the national level, including atrazine, chlorpyrifos, glyphosate, paraquat, terbutryn and AMPA. In general, the families of pesticides that can be analyzed in El Salvador are bipyridinium, carbamates, organochlorines, organophosphates, phosphonoglycines and triazines. The complete list of substances that can be analyzed is presented below (Table 34).

Table 34 List of active substances with pesticide effects that can be analyzed in El Salvador

Active Substance	Chemical Family	OIRSA-MAG	LNPHP	FUSADES
Diquat	bipyridyls	X		
Paraquat	bipyridyls	X		
Oxamyl	carbamates		X	
Naphthol	carbamates	X		
Aldicarb	carbamates	X	X	
Aldicarb sulfone	carbamates	X		
Aldicarb sulfoxide	carbamates	X	X	
Carbaryl	carbamates	X	X	
Carbofuran	carbamates	X	X	
Hydroxycarbofuran	carbamates	X	X	
Methiocarb	carbamates	X		
Methomyl	carbamates	X	X	
Oxamyl	carbamates	X		
Propoxur	carbamates	X	X	
Aldrin/Dialdrin	organochlorines	X	X	X
Chlordane	organochlorines			X
DDT / DDD / DDE	organochlorines	X	X	X
Endosulfan I Endosulfan II Endosulfan Sulfate	organochlorines	X	X	X
Gamma HCH (Lindane)	organochlorines	X		
Heptachlor	organochlorines	X	X	
Heptachloro-epoxide	organochlorines	X		X
Hexachlorobenzene	organophosphate	X		X
Lindane	organophosphate		X	X
Chlorpyrifos	organophosphate	X		
Diazinon	organophosphate	X		X
Dichlorvos	organophosphate	X		
Ethyl parathion	organophosphate	X		

Ethion	organophosphate	X		X
Malathion	organophosphate	X		X
Methyl parathion	organophosphate	X		X
Pirimiphos Methyl	phosphonoglicine	X		
Trazophos	phosphonoglicine	X		
AMPA	triazines	X		
Glyphosate	triazines	X	X	
Atrazine	triazines	X		
Simazine	triazinas	X		
Terbuthylazine	triazinas	X		
Terbutryn	triazinas	X		

Organophosphates, triazines, carbamates and organochlorines are analyzed by chemical family. The substances searched belong to different chemical families. For these reasons, the entire list of organophosphates and triazines is analyzed. To these two chemical families, isolated analyses of glyphosate, AMPA and paraquat have been added. Following the recommendations of an expert from the OIRSA-MAG laboratory, they have been added to the list of organochlorine analyses.

11.7 Organoleptic Quality of the Well Water in the Study Area at the End of the Rainy Season.

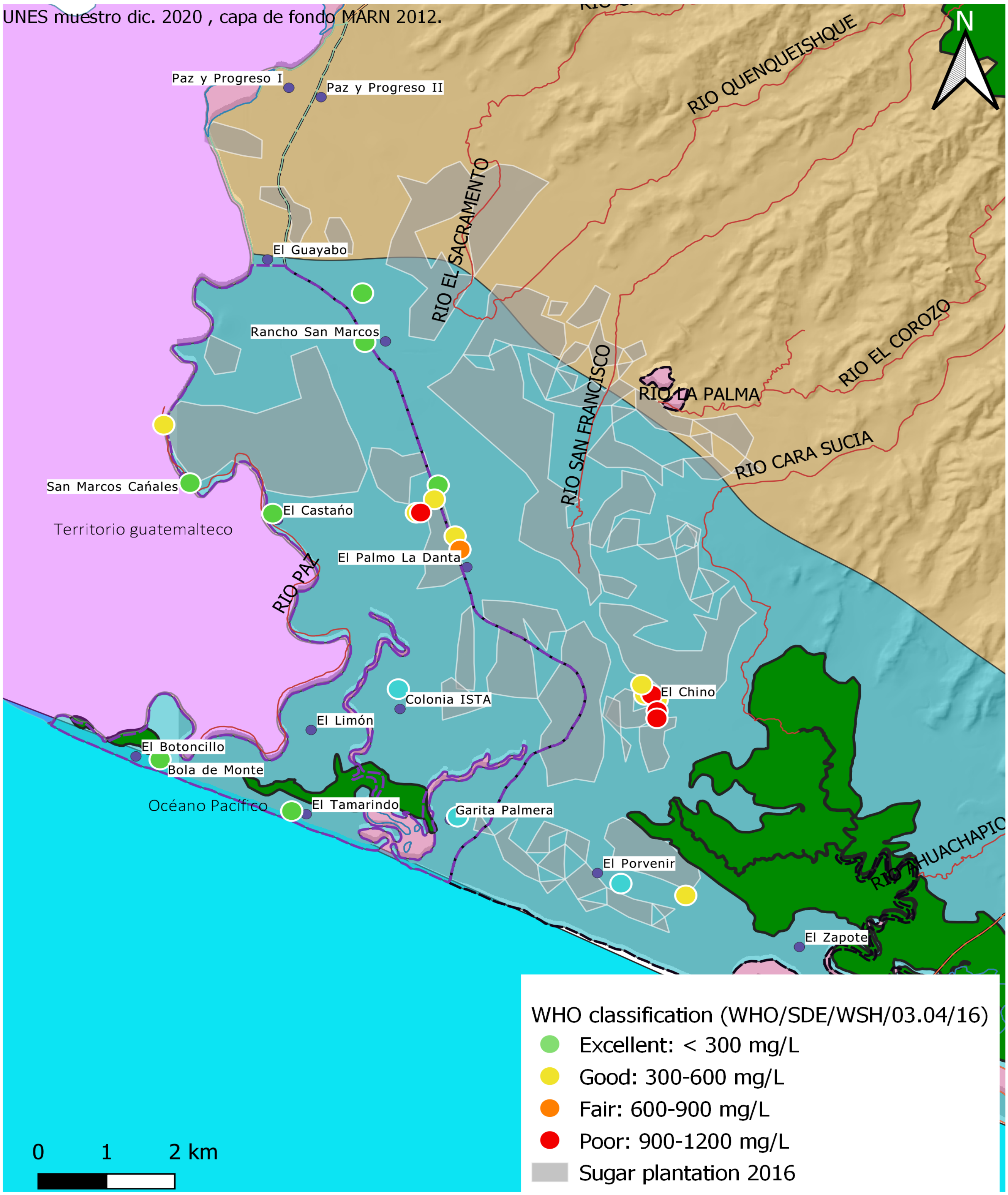

Figure 33 Organoleptic quality of water from domestic water wells in 9 communities of El Aguacate micro-watershed (December 2020).

11.8 Chemical risk assessment of sampled pesticides

Table 35 Spot samples of aminophosphate, bipyridyl and organophosphates in the water of El Aguacate River on October 14 at 1.30 pm until 2.15 pm at station E7 and at 11:05 am until 11.55 am at station E8.

Contaminants		**Interpretation**	**Sites**	**Risk**
	LOQ (µg/L)	**Environmental quality criteria**	**Station above the sugarcane fields E7-E8**	**RQi (risk quotient)**
Aminophosphonate				
Glyphosate	64	120a	Nd	<1, there is no risk
Bipyridyls				
Paraquat	106	0.5b	Nd	Cannot be evaluated
Organophosphates				
Chlorpyrifos	17	$4.6*10^{-4}$a	Nd	Cannot be evaluated
Diazinon	21	0.1699c	Nd	Cannot be evaluated
Dichlorvos	38	0.132d	Nd	Cannot be evaluated
Ethyl parathion	16	0.013c	Nd	Cannot be evaluated
Ethion	118	0.028d	Nd	No se puede evaluar
Malathion			Nd	
Methyl parathion	25	0.1c	Nd	Cannot be evaluated
Pirimiphos Methyl	21	0.055c	Nd	Cannot be evaluated
Triazophos	45	-	Nd	

Nd: Not detected
LOQ: Limit of quantification of pesticides
a: Quality criteria for chronic exposure of the Swiss Center for Ecotoxicology. (Ecotox Centre, 2021).
b: Chronic water quality criterion in China. (Tt et al., 2019)
c: Criterion Continuous Concentration of U.S. Environmental Protection Agency (US EPA, 2015).
d: Acute Toxicity Value of U.S. Environmental Protection Agency (US EPA, 2015).

Table 36 Spot samples of bipyridyl and organophosphates in water from three communities in El Aguacate subwatershed on October 14, 2020.

Contaminants		Interpretation	Sites	Risk
	LOQ (µg/L)	Guideline values (µg/kg)	Well E2, E3, E5	RQi (risk quotient)
Bipyridyls				
Paraquat*	106	7b	Nd	Cannot be evaluated
Organophosphates				
Chlorpyrifos	17	30	Nd	<1, there is no risk
Diazinon*	21	-	Nd	
Dichlorvos	38	-	Nd	
EEthyl Parathion**	16	-	Nd	
Ethion	118	-	Nd	
Malathion**		-	Nd	
Methyl Parathion**	25	-	Nd	
Pyrimiphos Methyl***	21	-	Nd	
Triazophos*	45	-	Nd	
Triazines				
Amethrin	419	-	Nd	
Atrazine	280	100a	Nd	Cannot be evaluated
Simazine	358	2a	Nd	Cannot be evaluated
Terbuthylazine	317	7a	Nd	Cannot be evaluated
Terbutryn	370	-	Nd	

* It is improbable to appear in drinking water.
** Occurs in drinking water at concentrations below those that are of health concern
*** Not recommended for use in the control of vectors in drinking water.
a : WHO, 2006
b : Canada, 2005

Table 37 Spot samples of aminophosphate, bipyridyl and organophosphates in the sediment of the Garita Palmera wetland on January 13, 2021.

Contaminants		Interpretation	Sites	Risk
	LOQ (µg/L)	Guideline values (µg/kg)	E8-E15	RQi (risk quotient)
Aminophosphonate				
AMPA	53	280a	Nd	<1, there is no risk
Bipyridyls				
Paraquat	12	30e	detectado	<1, but long-term effects are unknown
rganochlorines				
Aldrin	0.1		Nd	
Dieldrin	0.12	0.72a	Nd	<1, there is no risk
Endrin	0.17	2.67b	Nd	<1, there is no risk
Endrin aldehyde	0.11		Nd	
Endrin ketone	0.1		Nd	
Endosulfan sulfate	0.13	-	Nd	
Heptachlor	0.04		Nd	
Heptachlor epoxide	0.04	0.6b	Nd	<1, there is no risk
exachlorobenzene HCB	0.21		Nd	
Methoxychlor	0.13		Nd	
p, p´-DDT	0.18	1.19a	Nd	<1, there is no risk
p,p'-DDD	0.08	1.22a	Nd	<1, there is no risk
p,p'-DDE	0.11	2.07a	Nd	<1, there is no risk
α-endosulfan	0.04	0.0096c	Nd	Cannot be evaluated
α-HCH	0.09		Nd	
β-endosulfan	0.06	0.032c	Nd	Cannot be evaluated
β-HCH	0.19		Nd	
γ-HCH	0.23	0.32a	Nd	<1, there is no risk
δ-HCH	0.05		Nd	
Organophosphates				
Chlorpyrifos	17.3	0.041c	Na	Cannot be evaluated
Diazinon	21.2	0.19c	Na	Cannot be evaluated
Dichlorvos	11.6		Na	
Ethyl Parathion	15.5		Na	
Ethion	35.7		Na	
Malathion	24.8		Na	
Methyl Parathion	10.4	0.052c	Na	Cannot be evaluated
Pyrimiphos Methyl	21.4		Na	
Triazophos	45.1		Na	

Contaminantes		Interpretación	Estaciones	Riesgo
	LOQ (µg/L)	Guideline values (µg/kg)	Pozo E2, E3, E5	RQi (risk quotient)
Triazines				
Amethrin			Na	
Atrazine		13c	Na	
Simazine			Na	
Terbuthylazine			Na	
Terbutryn			Na	

a: Threshold Effect Concentrations (TEC) for the estuarine environment: below which no adverse effects are expected (MacDonald et al., 1996).
b: Consensus-based Threshold Effect Concentrations (TEC): below which no adverse effects are expected (MacDonald et al., 2000).
c: Threshold Effect Benchmark (TEB): define a concentration below which adverse effects are improbable. (Nowell et al., 2016).
d: Predicted No Effect Concentration (PNEC): concentration with no expected effects (Bonansea et al., 2017).
e: Value estimated by applying a safety factor of 1,000 (EC, 2011) on the toxicological parameter of 10-day acute survival in the freshwater amphipod Hyallela azteca (NOAC (no-observed adverse effect concentration): 30 mg/kg de dry weight) (US EPA, 2019).

Table 38 Specific samples of organochlorines and organophosphates in fish of Garita Palmera wetland on January 13, 2021

	Analytical performance		Detection in fishes	Risk
Contaminants	LOQ (mg/kg)	Value limits calculated on the fishes (mg/kg)		RQi (risk quotient)
Organochlorines				
Aldrin	1.00E-04		Nd	
Dieldrin	1.20E-04	2.06E-02	Nd	<1, there is no risk
Endrin	1.70E-04	1.24E-01	Nd	<1, there is no risk
Endrin aldehyde	1.10E-04		Nd	
Endrin ketone	1.00E-04		Nd	
Endosulfan sulfate	1.30E-04	2.47E+00	Nd	<1, there is no risk
Heptachlor	4.00E-05	5.35E-03	Nd	<1, there is no risk
Heptachlor epoxide	4.00E-05		Nd	
Hexachlorobenzene HCB	2.10E-04	3.29E-01	Nd	<1, there is no risk
Methoxychlor	1.30E-04		Nd	
p, p´-DDDT	1.80E-04		Nd	
p,p'-DDDD	8.00E-05		Nd	
p,p'-DDE	1.10E-04		Nd	
Total DDT	3.70E-04	2.06E-01		<1, there is no risk
α-endosulfan	4.00E-05		Nd	
α-HCH	9.00E-05		Nd	
β-endosulfan	6.00E-05		Nd	
β-HCH	1.90E-04		Nd	
γ-HCH	2.30E-04	1.24E-01	Nd	<1, there is no risk
δ-HCH	5.00E-05		Nd	
Organophosphates	0.00E+00		Nd	
Chlorpyrifos	1.73E-02	1.24E-01	Nd	<1, there is no risk
Diazinon	2.12E-02	2.88E-01	Nd	<1, there is no risk
Dichlorvos	1.16E-02		Nd	
Ethyl Parathion	1.55E-02		Nd	
Ethion	3.57E-02	2.06E-01	Nd	<1, there is no risk
Malathion	2.48E-02		Nd	
Methyl parathion	1.04E-02		Nd	
Pirimiphos Methyl	2.14E-02		Nd	
Triazophos	4.51E-02		Nd	

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"Construyendo una sociedad unida y sustentable"

Calle Camagüey 6G, Colonia Yumuri, San Salvador.

(+503) 2260-1465
(+503) 2260-1480

Correo: unes.elsalvador@gmail.com

@uneselsalvador
UNES_ElSalvador