UNIVERSIDADE FEDERAL DE MINAS GERAIS
Escola de Engenharia
Programa de Pós-Graduação em Saneamento, Meio Ambiente e Recursos Hídricos

Inara Fernandes Farah

PESTICIDES IN SURFACE AND GROUNDWATER: occurrence, environmental and human health risk, and removal efficiency by membrane technologies

Belo Horizonte
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Coorientadora: Lucilaine Valéria de Souza Santos

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"Pesticides In Surface And Groundwater: Occurrence, Environmental And Human Health Risk, And Removal Efficiency By Membrane Technologies"

INARA FERNANDES FARAH

Dissertação defendida e aprovada pela banca examinadora constituída pelos Senhores:

Profa Miriam Cristina Santos Amaral Moravia

Profa Lucilaine Valéria de Souza Santos

Profa Sílvia Maria Alves Corrêa Oliveira

Prof. Victor Rezende Moreira

Profa Gemima Santos Arcanjo

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Prof. Eduardo Coutinho de Paula Profª. Miriam
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E por sonhar comigo.
Esta conquista é tão minha quanto sua.

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RESUMO

A intensificação das práticas agrícolas em monoculturas, impulsionada pela crescente demanda por alimentos, tem causado significativa contaminação de águas superficiais e subterrâneas por pesticidas. Essa contaminação compromete os ecossistemas aquáticos e representa riscos à saúde humana, como disfunções endócrinas, imunológicas, reprodutivas e neurológicas. Os tratamentos convencionais de água, projetados para remover partículas suspensas e patógenos, são insuficientes para eliminar esses compostos, ressaltando a necessidade de tecnologias avançadas. Este estudo objetivou avaliar a ocorrência de pesticidas em fontes hídricas, os riscos ambientais e à saúde humana associados, além da eficiência de diferentes tipos de processos de membranas na remoção desses compostos. A metodologia baseou-se em revisões sistemáticas da literatura, análise de dados globais sobre a presença de pesticidas e a aplicação de Avaliações de Risco Ambiental e Avaliações de Risco à Saúde Humana. Os resultados apontaram 485 ocorrências de pesticidas em águas superficiais, com 42% sendo inseticidas, 35% herbicidas e 23% fungicidas. Entre os 112 pesticidas classificados como de alto risco ambiental, 63 carecem de regulamentação, enquanto os demais, embora regulados em algumas regiões, ainda representam riscos significativos devido à sua toxicidade e ao seu elevado potencial de bioacumulação. Tecnologias de membranas, como nanofiltração (NF) e osmose inversa (RO), demonstraram elevada eficiência na remoção de pesticidas em meio aquoso, com taxas médias de rejeição de 85% e 88%, respectivamente, e são eficazes na remoção ou redução dos riscos à saúde humana, incluindo a remoção de compostos altamente tóxicos e persistentes. A análise detalhada revelou que o desempenho das membranas depende tanto das características dos pesticidas, como hidrofobicidade, carga e massa molecular, quanto das propriedades das membranas, como composição, ponto de corte de peso molecular e carga superficial. Condições operacionais e fatores como o *fouling* também influenciam o desempenho, podendo comprometer a eficiência. Estratégias de pré-tratamento e otimização das condições operacionais, além da escolha da membrana adequada, foram identificadas como essenciais para maximizar a eficácia. Conclui-se que regulamentações mais abrangentes são indispensáveis para mitigar os impactos da contaminação por pesticidas. Além disso, recomenda-se a adoção de pesticidas verdes, o desenvolvimento de membranas otimizadas e a padronização de metodologias para facilitar a implementação de soluções mais sustentáveis e economicamente viáveis. Esses avanços são fundamentais para garantir a segurança hídrica e a efetividade dos sistemas de abastecimento diante dos desafios impostos pelos diversos poluentes de preocupação ambiental contaminantes emergentes.

Palavras-chave: agrotóxico; ocorrência; risco ambiental; risco à saúde humana; membranas.

ABSTRACT

The intensification of agricultural practices in monocultures, driven by the growing demand for food, has resulted in significant contamination of surface and groundwater by pesticides. This contamination compromises aquatic ecosystems and poses risks to human health, including endocrine, immunological, reproductive, and neurological dysfunctions. Conventional water treatment processes, designed to remove suspended particles and pathogens, are insufficient for eliminating these compounds, highlighting the necessity for advanced technologies. This study aimed to assess the occurrence of pesticides in water sources, the associated environmental and human health risks, and the efficiency of different membrane processes in removing these compounds. The methodology was based on systematic literature reviews, analysis of global data on pesticide presence, and the application of Environmental Risk Assessments and Human Health Risk Assessments. Results identified 485 pesticide occurrences in surface waters, of which 42% were insecticides, 35% herbicides, and 23% fungicides. Among the 112 pesticides classified as high environmental risk, 63 lack regulation, while the remainder, although regulated in certain regions, still pose significant risks due to their toxicity and high bioaccumulation potential. Membrane technologies, such as nanofiltration (NF) and reverse osmosis (RO), demonstrated high efficiency in removing pesticides from aqueous media, with average rejection rates of 85% and 88%, respectively. These technologies are effective in mitigating or reducing human health risks, including the removal of highly toxic and persistent compounds. Detailed analysis revealed that membrane performance depends on both pesticide characteristics—such as hydrophobicity, charge, and molecular weight—and membrane properties, such as composition, molecular weight cut-off, and surface charge. Operational conditions and factors like fouling also influence performance, potentially compromising efficiency. Pre-treatment strategies, optimization of operational conditions, and the selection of suitable membranes were identified as essential for maximizing effectiveness. The study concludes that more comprehensive regulations are indispensable for mitigating the impacts of pesticide contamination. Additionally, the adoption of green pesticides, the development of optimized membranes, and the standardization of methodologies are recommended to facilitate the implementation of more sustainable and economically viable solutions. These advancements are critical for ensuring water security and the effectiveness of supply systems in addressing the challenges posed by various pollutants of environmental concern, including emerging contaminants.

Keywords: pesticides; occurrence; environmental risk; human health risk; membranes.

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LIST OF ABBREVIATIONS, VARIABLES AND SYMBOLS

BM	Body Mass
C	Daily Water Consumption
DWEL	Drinking Water Equivalent Level
EC_{50}	Effective Concentration 50%
F	Contribution of Water to Exposure
LC_{50}	Lethal Concentration 50%
LD_{50}	Lethal Dose 50%
LOEC	Lowest Observed Effect Concentration
Log D	Logarithm of the Distribution Coefficient
Log K_{ow}	Logarithm of the Octanol-Water Partition Coefficient
Log P	Logarithm of the Partition Coefficient
MEC	Measured Concentration
MF	Microfiltration
MWCO	Molecular Weight Cut-Offs
NF	Nanofiltration
NOEC	No Observed Effect Concentration
PA	Polyamide
PES	Polyethersulfone
PNEC	Predicted No Effect Concentration
RfD	Reference Dose
RO	Reverse Osmosis
RQ	Risk Quotient
R(H)Q	Risk (Human) Quotient
TDI	Tolerable Daily Intake
UF	Ultrafiltration
WTP	Water Treatment Plants

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CHAPTER 1

1 INTRODUCTION

Pesticides, encompassing both chemical and biological agents, are fundamental to modern agricultural practices. Designed to combat pests, enhance productivity, and protect crops, their widespread use began during the Green Revolution in the mid-20th century. Since then, global reliance on pesticides has increased significantly, with current estimates indicating over 3.5 million tons applied annually (FAO, 2023). This intensive use, while beneficial for meeting food demand, has raised concerns about environmental persistence, bioaccumulation, and potential health risks (HUANG; LI, 2024; SABARWAL; KUMAR; SINGH, 2018).

The agricultural sector has undergone profound transformations, including the increased adoption of monoculture practices to meet growing global food demands. Monocultures, while efficient for large-scale production, create favorable conditions for pest infestations due to reduced biodiversity (HAAN et al., 2021). Consequently, farmers often resort to intensified pesticide use, with global consumption increasing by 62% since 2000 (FAO, 2023). The Americas, particularly the United States and Brazil, lead in pesticide application rates per cultivated area. In Brazil, one of the largest agricultural producers worldwide, pesticides are regulated by Federal Law No. 7,802 of 1989 and Decree No. 4,074 of 2002. Despite these regulations, the country remains one of the largest consumers of these substances, with significant implications for water quality, biodiversity, and public health (LOPES; ALBUQUERQUE, 2018)

Pesticides, however, pose significant risks when mismanaged. Studies indicate that less than 1% of applied pesticides reach target pests, while the remainder disperses into the environment (RAJ; KUMAR; DAMES, 2021). This dispersion occurs through mechanisms such as surface runoff, leaching into groundwater, and atmospheric deposition (BARBIERI et al., 2021). Once in aquatic systems, pesticides affect non-target organisms, causing oxidative stress, genetic mutations, and neurotoxicity (JUNAID et al., 2023).

According to Guillossou et al. (2019), conventional Water Treatment Plants (WTP) were primarily designed to remove suspended particles and pathogenic microorganisms through processes such as coagulation, flocculation, sedimentation, filtration and disinfection, and are therefore not designed to remove pesticides present in surface and/or groundwater. Due to their low molecular weight and presence at trace concentrations, the removal of pesticides in conventional WTPs is limited, necessitating the use of advanced water treatment technologies (DE SOUZA et al., 2020).

Therefore, such compounds also pose a concern for the availability of quality drinking water and, consequently, for human health, since they can disrupt the endocrine, immune, reproductive and neurological systems, in addition to causing oxidative stress, one of the main mechanisms associated with several diseases such as Parkinson's and Alzheimer's (DE SOUZA et al., 2020; SABARWAL; KUMAR; SINGH, 2018). These challenges underscore the need to balance agricultural productivity with environmental conservation. In this context, the limitations of conventional water treatment plants in removing pesticides highlight the importance of investing in advanced technologies, such as membrane separation processes, which have proven to be promising in addressing this issue.

Membrane separation processes have emerged as highly efficient technologies for the treatment of micropollutants, owing to their easy applicability, stability, and low environmental impact, especially when recycled membranes are used (ILYAS et al., 2021). These processes can be applied for various purposes, depending on the characteristics of the membranes, such as pore size and retention efficiency. For instance, microfiltration (MF), with pore sizes between 0.1 and 10 µm, is effective in removing suspended particles and microorganisms, while ultrafiltration (UF), with smaller pores around 0.01 µm, retains macromolecules, viruses, and bacteria. Nanofiltration (NF), with pore sizes ranging from 0.001 to 0.01 µm, efficiently retains divalent salts and medium-sized organic molecules. Reverse osmosis (RO), on the other hand, uses a dense membrane and can remove nearly all types of dissolved solutes, including monovalent ions and heavy metals, making it widely used in water purification and desalination processes, despite requiring high pressures and being more susceptible to fouling. Forward osmosis, another relevant method, operates more economically, leveraging the natural diffusion of solutes to separate substances without the need for high pressures. However, a significant drawback of membranes is fouling, which reduces their contaminant removal efficiency.

To comprehensively assess the advantages and disadvantages of these technologies and support decision-making processes, it is crucial to consider the fate and toxicity of generated by-products, along with energy, economic, and environmental analyses. In this context, membrane separation processes stand out due to their lower energy consumption, as observed in forward osmosis, and their high contaminant retention efficiency in systems like reverse osmosis and nanofiltration, offering promising alternatives to meet environmental and sustainability demands (BROVINI et al., 2023).

According to Krüger (2009), when pollutants are present in the environment, they can cause acute and chronic effects on exposed organisms. Acute effects can be easily observed in ecosystems, as they typically have immediate or short-term impacts with higher exposure intensity. On the other hand, chronic effects are more difficult to assess, as they are detected over the long term with low exposure intensity, interfering with the reproduction and survival of organisms. Furthermore, it is essential to consider the interactions between different pollutants, such as synergism and antagonism. Synergism occurs when the combined effect of two or more substances is greater than the sum of their individual effects, potentially amplifying toxicity. In contrast, antagonism arises when the presence of one substance reduces the effect of another, which may mitigate certain harmful impacts.

Several countries regulate toxicity assays for environmental monitoring, which can also be classified as acute and chronic tests. Acute toxicity tests aim to estimate the concentration of the toxic agent sufficient to produce a measurable response in a test organism or population, usually within 24 to 96 hours. Typically, the response of aquatic organisms is lethality or immobility, and the test results are expressed as LD_{50}, LC_{50}, and EC_{50} (**Table 1**). Even if a chemical substance does not exhibit toxicity in the aforementioned test, it may still produce toxic effects; hence, chronic toxicity tests are also conducted (COSTA et al., 2008).

To evaluate the effects of a toxic agent over a period that spans part or the entirety of the test organism's life cycle, chronic toxicity tests are performed. These assays allow for the assessment of potential toxic effects of chemical substances at sub-lethal concentrations that affect biological functions such as reproduction and growth. The results obtained from these tests are generally expressed as NOEC and LOEC (**Table 1**).

Table 1- Definitions of parameters used in toxicity tests

PARAMETER	DEFINITION	EXPOSURE TIME
LD_{50}	Median Lethal Dose: the dose of a sample that causes 50% mortality of the organisms under the exposure time and test conditions.	24 to 96 h
LC_{50}	Median Lethal Concentration: the concentration of a sample that causes 50% mortality of the organisms under the exposure time and test conditions.	24 to 96 h
EC_{50}	Median Effective Concentration: the concentration of a sample that causes an acute effect (e.g., immobility) in 50% of the organisms under the exposure time and test conditions.	24 or 48 h
NOEC	No Observed Effect Concentration: the highest concentration of a toxic agent that does not cause a statistically significant deleterious effect on organisms under the exposure time and test conditions.	7 days
LOEC	Lowest Observed Effect Concentration: the lowest concentration of a toxic agent that causes a statistically significant deleterious effect on organisms under the exposure time and test conditions.	7 days

Source: Adapted from COSTA et al. (2008).

In recent decades, studies have verified the occurrence of pesticides in surface, groundwater and drinking water at different concentrations. Although it is important to identify the presence of these compounds in the environment, it is also important to assess whether such a concentration of the pollutant represents a risk to the ecosystem in which it is inserted (BROVINI et al., 2023).

An effective method for determining the risk that a given pollutant presents to aquatic organisms is the Environmental Risk Assessment, measured through the risk quotient (RQ). The RQ is calculated through the quotient of the measured concentration (MEC) and the ratio between the toxicity of each pollutant and a correction factor depending on the amount of toxicity data for each pesticide (PNEC), as presented by Equation 1 (US EPA, 2015).

$$\mathrm{RQ} = {}^{\mathrm{MEC}}\!/_{\mathrm{PNEC}} \qquad (1)$$

The Human Health Risk Assessment is widely used to classify the risk that each pollutant presents to human health, and can specify for adults, children or infants. For this purpose, the risk is calculated by the risk quotient (R(H)Q), obtained by the ratio between the measured concentration (MEC) and the drinking water equivalent level (DWEL), as shown in Equation 2.

$$\mathrm{R(H)Q} = {}^{\mathrm{MEC}}\!/_{\mathrm{DWEL}} \qquad (2)$$

The DWEL can be estimated from the tolerable daily intake (TDI) or reference dose (RfD), body mass (BM), contribution of water to exposure (F) and daily water consumption (C), as shown in Equation 3.

$$\mathrm{DWEL} = {}^{(\mathrm{TDI\ ou\ RfD}\ *\ \mathrm{BM} * \mathrm{F})}\!/_{\mathrm{C}} \qquad (3)$$

The risk quotient (RQ) derived from these calculations is then classified according to the levels presented in **Table 2**, which provides a clear framework for assessing the potential risks associated with pesticide exposure.

Table 2 - Risk Quotient Classification

CLASSIFICATION	RQ
HIGH RISK	RQ > 1
MEDIUM RISK	0,1 ≤ RQ ≤ 1
LOW RISK	0,01 ≤ RQ < 0,1
INSIGNIFICANT RISK	RQ < 0,01

Source: EUROPEAN COMMISSION (1996).

Another critical point to be considered is the phenomenon of bioaccumulation, which amplifies the risks of pesticides by allowing these substances to accumulate in the tissues of aquatic organisms, potentially affecting the entire food chain. This process is influenced by factors such as the pesticide's solubility, its octanol-water partition coefficient (Log Kow), and environmental conditions, including temperature, pH, and salinity (SCHÄFER et al., 2015; VOLODYMYR I. LUSHCHAK et al., 2018). Highly hydrophobic pesticides, for instance, have a greater tendency to bioaccumulate in the adipose tissues of aquatic organisms, thereby increasing their potential impact on food chains.

Aquatic organisms can absorb pesticides through respiratory organs, their body surfaces, or the ingestion of food, suspended particles, or contaminated sediments. In this context, the bioaccumulation potential of pesticides in the body tissues of organisms, especially those consumed by humans, cannot be overlooked.

The bioaccumulation potential of a chemical compound can be assessed using various metrics, such as the bioconcentration factor (BCF), bioaccumulation factor (BAF), biota-sediment accumulation factor (BSAF), biomagnification factor (BMF), trophic magnification factor (TMF), and the octanol-water partition coefficient (Kow) (BERNARDO; ALVES; HOMEM, 2022; GIMENO et al., 2024). Kow, expressed as Log Kow, represents the ratio of a compound's concentration between water and octanol at equilibrium and is commonly used as an indicator of hydrophobicity and bioaccumulation potential. When needed, vertebrate animal tests can be performed to directly measure the BCF (GIMENO et al., 2024). From a regulatory perspective, the threshold Log Kow values for classifications between 3 and 5 vary across regions worldwide.

Given the potential risks to the ecosystem and human health, several countries and organizations have enacted legislation to control and monitor the use of pesticides. In 2001, the Stockholm Convention was held in Sweden, where the participating countries discussed the topic and agreed to eliminate or reduce 12 persistent organic pollutants (POPs), 9 of which are used as pesticides (EPA, 2023). **Table 3** shows the aforementioned pesticides and the maximum permitted values for surface waters according to Brazilian and international legislation.

Table 3 - Maximum Permitted Values (µg/L)in different regulations of selected pesticides in the Stockholm Convention

PESTICIDE	CONAMA RESOLUTION 357:2005	EPA FRESHWATER (ACUTE)	EPA FRESHWATER (CHRONIC)
Aldrin	0.005 (Aldrin + Dieldrin)	3.0	-
Chlordane	0.04	2.4	0.0043
Dieldrin	0.005 (Aldrin + Dieldrin)	0.24	0.056
Endrin	0.004	0.086	0.036
Heptachlor	-	0.52	0.0038
Hexachlorobenzene	0.0065	-	-
Mirex	-	-	0.001
Toxaphene	0.01	0.073	0.0002
DDT	0.002	-	-

Since then, institutions such as the European Union, FAO/WHO (Food and Agriculture Organization of the United Nations/World Health Organization), and the EPA (United States Environmental Protection Agency) have established maximum residue limits for pesticides in food and water. Although progress has been made in legislation to balance the benefits and risks of pesticide applications, many of these compounds still require regulation, particularly in developing countries such as Brazil (SOUZA et al., 2023).

Between 2019 and 2022, Brazil implemented policies that significantly relaxed regulations on pesticide use under the justification of "modernization" and increasing the competitiveness of the agricultural sector. These changes resulted in the approval of 2,182 new products, the highest number recorded by any government since 2003. For comparison, between 2003 and 2010, during the two terms of President Luiz Inácio Lula da Silva's administration, approximately 1,360 products were approved. From 2011 to 2014, during President Dilma Vana Rousseff's first term, 1,142 pesticides were registered. During the 2015–2018 period, under the Temer administration, this number rose to 1,506 registrations (SALATI, 2023). The 2,182 registrations during President Jair Bolsonaro's administration represent an approximately 40% increase compared to the previous government and over a 60% increase compared to the average of the previous decade. This growth consolidates Brazil as one of the countries with the highest number of new pesticide registrations in such a short period.

Additionally, about 45% of the products approved between 2019 and 2022 contained active ingredients already banned in other countries, particularly in the European Union, due to their environmental and public health risks (GURGEL; GUEDES; FRIEDRICH, 2021; ROHDEN, 2022). This highlights the expansion of chemical substances in the Brazilian market, many of which have proven harmful effects on human health and the environment.

Among the approved compounds are substances such as chlorpyrifos, atrazine, acephate, mancozeb, and chlorothalonil, all recognized for their severe adverse impacts. Chlorpyrifos, for example, was banned in the European Union in 2020 due to evidence of neurotoxicity, particularly in children, but continues to be widely used in Brazil. Similarly, mancozeb was banned in the EU in 2021 due to its carcinogenic risks, while atrazine has been prohibited since 2004 because of its persistence in the environment and the risk of groundwater contamination. These compounds are widely used in crops of significant economic importance in Brazil, such as soybeans, corn, and sugarcane, contributing to the country's position as one of the world's largest consumers of pesticides (ALMEIDA et al., 2017; ROHDEN, 2022).

The regulatory relaxation was institutionalized primarily through Presidential Decree No. 10,833 of 2021, which amended the 1989 Pesticides Act. This legislation reduced technical requirements and accelerated the deadlines for analyzing and approving new products, limiting in-depth toxicological and environmental assessments. The decree established maximum deadlines of 12 months for evaluating new pesticides and 6 months for those classified as generic, while eliminating the requirement for submitting technical reports on impurities. Furthermore, it transferred to the Ministry of Agriculture the authority to determine which products would receive priority approval, significantly reducing the role of regulatory agencies such as IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) and ANVISA (National Health Surveillance Agency) (GURGEL; GUEDES; FRIEDRICH, 2021; LACERDA, 2023). This process significantly weakened the technical role of these agencies in assessing pesticide impacts, undermining environmental oversight and control. While the government defended these actions as "modernization" to meet the demands of the agricultural sector, experts and researchers warn of the negative consequences, including increased population exposure to residues of potentially toxic substances, the degradation of water quality, and adverse impacts on biodiversity (ALMEIDA et al., 2017; VIPIEVSKI JÚNIOR; VARGAS; BET, 2022). In a global context of tighter regulations and restrictions on pesticide use, Brazil's policies diverge from international trends, raising concerns about environmental sustainability and public health in the medium and long term.

1.1 OBJECTIVES

1.1.1 General objective

Investigate the occurrence of pesticides in surface and groundwater, assess environmental and human health risks and evaluate the efficiency of membrane separation processes in removing these compounds.

1.1.2 Specific objectives

a) Investigate the contamination of surface and groundwater by pesticides on a global scale;
b) Assess the environmental risk of water contamination by pesticides, considering typical occurrence values;
c) Explore the potential of different membrane separation processes currently employed for treating pesticide-contaminated water;
d) Evaluate the potential for mitigating human health risks, considering the capacity of membrane separation processes to remove these contaminants.

1.2 DOCUMENT STRUCTURE

This master's thesis is organized into five chapters. Chapter 1 presents the introduction, objectives, and document structure. Chapter 2 examines the contamination of surface and groundwater by pesticides on a global scale and assesses the environmental risk of water contamination based on typical occurrence values, addressing specific objectives (a) and (b). Chapter 3 addresses the potential of different membrane separation processes currently used for treating pesticide-contaminated water and evaluates their effectiveness in mitigating human health risks by assessing their capacity to remove these contaminants (objectives (c) and (d)). Finally, Chapter 4 provides the final considerations.

CHAPTER 2

2 PESTICIDES IN AQUATIC ENVIRONMENT: OCCURRENCE, ECOLOGICAL IMPLICATIONS AND LEGAL FRAMEWORK

I.F. Farah, C.R. dos Santos, M.C.F. Pinto, C.R. Araújo, M.C.S. Amaral. Pesticides in aquatic environment: occurrence, ecological implications and legal framework. **Journal of Environmental Chemical Engineering** (2024), Article 114072, 10.1016/j.jece.2024.114072.

2.1 INTRODUCTION

Pesticides are agents intended for use in agricultural products' production, storage, and processing sectors, whose purpose is to alter the composition of flora or fauna to preserve them from the harmful actions of living beings considered harmful. With the movement called 'Green Revolution', the intensive use of pesticides began in the 1950s in the United States (LUCAS; KEBREAB, 2024). However, Rachel Carson's 1962 book “Silent Spring” started the debate about the use of pesticides and their effects on non-target fauna and flora and inspired the founding of the EPA in 1970 (SABARWAL; KUMAR; SINGH, 2018). Although their use in agriculture is often considered necessary, the contamination of soil, atmosphere, surface water, and groundwater resulting from indiscriminate, excessive, and improper use of pesticides poses a significant concern for living organisms, including humans (HÜESKER; LEPENIES, 2022).

Since then, the agricultural sector has undergone numerous transformations, with monoculture becoming a prevalent practice to meet the growing global demand for food. Monocultures, which involve the extensive cultivation of a single crop type, offer the advantage of simplifying production; however, they also present a significant drawback. One major issue is that they significantly increase reliance on pesticides (KAUR et al., 2024). This dependency arises from the fact that monocultures reduce biodiversity, creating an ideal environment for pest proliferation (HAAN et al., 2021) As a result, farmers are compelled to use larger quantities of pesticides to control these outbreaks, which, in turn, can lead to the development of pesticide resistance among pests (KAUR et al., 2024)

In this context, to increase yields and safeguard agricultural output, global pesticides use increased between 2000 and 2021 by 62 percent, to 3.5 million tonnes in 2021 (FAO, 2023). The American continent stands out for applying an average of over 1,7 million tonnes of pesticides in agriculture, with the United States and Brazil leading the global use of these compounds per cultivation area in 2021 (FAO, 2023).

The irresponsible use of pesticides can lead to several negative impacts through contamination of soils (HUANG; LI, 2024), surface and underground waters (HOSSEINI et al., 2021; MAC LOUGHLIN; PELUSO; MARINO, 2022), air

(HUANG; LI, 2024) and food (TUDI et al., 2021). According to Raj, Kumar, and Dames (RAJ; KUMAR; DAMES, 2021), only 1% of applied pesticides reach target areas; the remainder interacts with other environmental components, mainly along the edges of agricultural fields, but are also transported to other regions through wind, surface runoff, and infiltration. **Figure 1** presents a diagram of the possible pathways of pesticide dispersion when applied or discarded in the environment. Pesticides can contaminate surface and groundwater through different mechanisms: physical-chemical and biological degradation; sorption-desorption on solid particles; surface runoff; soil leaching; infiltration; absorption by plants; volatilization and atmospheric deposition (BARBIERI et al., 2021). Such contamination is a significant threat to aquatic life, as it can cause multifaceted impacts, including growth and reproduction deficiencies, oxidative stress, genetic enzymatic and histopathological modifications, neurotoxicity, and hepatotoxicity (JUNAID et al., 2023).

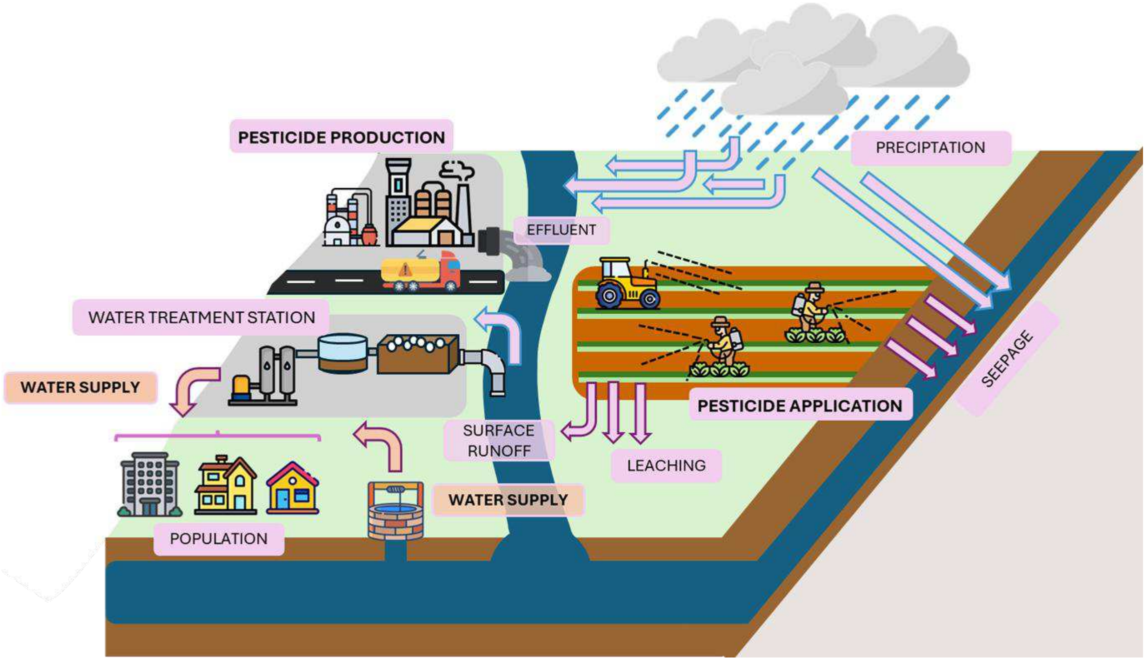


Figure 1 - Possible pathways of pesticides in the environment.

Several pesticides persist in the environment and can bioaccumulate through the food chain. Consequently, these compounds raise concerns regarding the availability of safe drinking water and, by extension, for human health. They have the potential to disrupt the endocrine, immunological, reproductive, and neurological systems and can induce oxidative stress, a key mechanism linked to various diseases such as Parkinson's and Alzheimer's (DE SOUZA et al., 2020; SABARWAL; KUMAR; SINGH, 2018). Thus, the control and monitoring of pesticide use must be continued. In 2001, the Stockholm Convention in Sweden saw participating countries agree to eliminate or reduce 12 persistent organic pollutants (POPs), nine of which are used as pesticides (U.S. ENVIRONMENTAL PROTECTION AGENCY., 2013). These include Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, and DDT. However, more than 20 years later, several of these pesticides, such as Aldrin, Dieldrin, Endrin, Heptachlor, and DDT, are still identified in surface and groundwater.

This topic has been the subject of reviews from different approaches, with an emphasis on impacts on human health and the environment (KAUR et al., 2024; YUE, 2024), toxicity of specific organisms (CUI et al., 2023; NARAYANAN et al., 2024), occurrence and risk of pesticide residues in food (AHMADI; KHAZAEI; MEHRI, 2024; MUNIR et al., 2024; YANG et al., 2024), mitigation strategies (CHAUDHARY, 2024), removal of pesticides present in water (AJIBOYE et al., 2022; BROVINI et al., 2023; BURRATTI et al., 2024; LI et al., 2023; LI; SHI, 2024) However, no reviews were found that specifically address the global distribution of pesticides in surface and groundwater, integrated with toxicity and environmental risk data for each pesticide. This gap in knowledge hinders the identification of the most harmful pesticides and the regions that require urgent attention due to the presence of high-risk pesticides. Furthermore, these discussions could support regulatory agencies in setting legal requirements for pesticide usage and determining maximum permissible concentrations in surface and groundwater, prioritizing those pesticides that present significant risks to the aquatic ecosystem.

That said, this article aims to provide an overview of pesticides' occurrence in surface and groundwater on a global scale, discussing prevalent types of pesticides and how they potentially threaten aquatic ecosystems through data obtained from testing acute and chronic toxicity at different trophic levels and bioaccumulation potential. Furthermore, comparisons of legal limits established by organizations and countries are presented and discussed to assess the need for advances in legislation to maintain the balance between the benefits and risks of pesticide applications.

2.2 METHODOLOGY

A systematic search was carried out for studies published in the last five years (since 2019) of data on the occurrence of pesticides in surface or groundwater in a global context. The search for relevant literature was done through platforms such as Science Direct and Google Scholar, using the keywords “pesticide occurrence”. The critical information extracted from each article included authors, year of publication, country, matrix (surface water or groundwater), identified pesticides, and maximum identified concentration. The number of articles and occurrences of each matrix are presented in **Figure 2.**

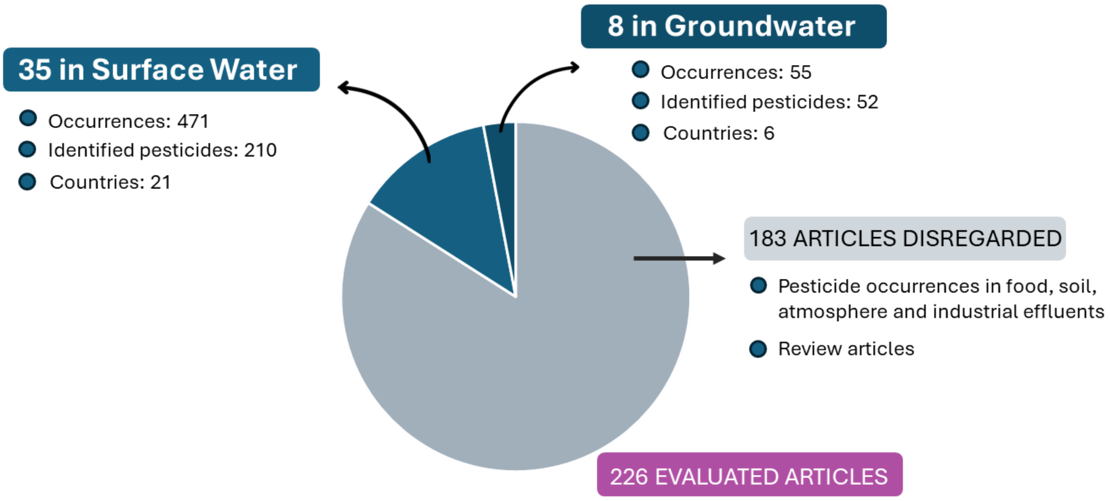


Figure 2 - Quantitative detailing of the systematic review.

The selection of articles targeted specifically on the occurrence of pesticides in surface and groundwater. Articles addressing pesticide occurrences in food, soil, atmosphere, and industrial effluents were excluded, as were review articles. Although the initial poll included 226 articles, only 43 were deemed relevant to the study. Among these, 35 articles focused on pesticides occurrence in surface waters, while 8 articles address pesticides occurrence in groundwater. For surface waters, 471 pesticide occurrences were recorded across 21 countries, with the identification of 210 distinct pesticides. In contrast, groundwater studies documented 55 instances of pesticide detection across 6 countries, identifying 52 different pesticides.

2.3 OCCURRENCE AND TOXICITY OF PESTICIDES IN SURFACE WATER

Pesticides can be categorized in several ways, such as according to their chemical structure, degree of risk to human health, and target (PATHAK et al., 2022). From the specificity of the target organism, pesticides may fall into categories such as insecticides (for insects), herbicides (for weeds), fungicides (for fungi), acaricides (for mites), bactericides (for bacteria), rodenticides (for rodents) and others. Among these categories, herbicides, fungicides, and insecticides have the highest number of compounds (HASSAAN; EL NEMR, 2020), and these are the pesticides explored in the present study.

2.3.1 **Fungicides**

According to literature data, 485 pesticide occurrences were identified in surface water. Of these, 42% of concentrations are related to insecticides, 35% to herbicides, and 23% to fungicides. Fungicides exhibited notable occurrences across Asia (37%), America (37%), and Europe (26%) (**Figure 3**). China reported the highest variety of fungicides, with 20 different types identified. However, such analysis must be carried out cautiously, considering that there are not necessarily more pesticides in these regions; they are probably more studied regions. The highest concentrations recorded for fungicides ranged from 4.0 to 23.93 µg/L, registered for Carbendazim. Carbendazim has been banned by the European Union (EU) due to its high toxicity to aquatic organisms, posing significant risks to algae, invertebrates, and fish. Additionally, it has been classified as a category 1B mutagen and reproductive toxin, with evidence indicating its potential to cause genetic defects, impair fertility, and harm fetal development (BELLISAI et al., 2024). The Galapagos archipelago, Ecuador, recorded the highest concentration of Carbendazim (23.93 µg/L) (RIASCOS-FLORES et al., 2021). Two of the major inhabited islands in Galapagos are Santa Cruz and Isabela. Santa Cruz has agricultural areas across an altitudinal (between 100 and 520 m above sea level), fostering crop diversification (SNELL; STONE; SNELL, 1996). Detection of Carbendazim is likely the result of its use in the high annual production of tomato (77.8 tons), corn (73.02 tons), cucumber (22.82 tons), pepper (17.68 tons), and potato (0.41 tons). Furthermore, pesticide-specific correlation analysis with rainfall was statistically significant positive (0.5 - Spearman's test) (RIASCOS-FLORES et al., 2021).

The second-highest concentration of Carbendazim (13.5 µg/L) was found in Costa Rica, a tropical country with an important agricultural activity (RAMÍREZ-MORALES et al., 2021). The croplands in the country cover a total area of 450 100 ha, representing 8.8 % of the national territory dedicated to agriculture, silviculture and fishing. Moreover, Costa Rica ranks among the top countries for pesticide usage (POLIDORO; MORRA, 2016). The high concentration of Carbendazim in Costa Rica could be attributed to the country's extensive agricultural practices, which include the cultivation of various crops such as banana and pineapple, and the use of pesticides in these agricultural activities.

The third highest concentration of Carbendazim (9.574 µg/L) was found in the Llobregat River basin, Spain, specifically the Llobregat River (surface and groundwater) and the Ter River (QUINTANA; DE LA CAL; BOLEDA, 2019). Llobregat River flows from the north to the south of central Catalonia, finishing at a delta in the Barcelona metropolitan area. The Llobregat River basin is a very industrialized area where tannery industries and vineyard farming are the main spots of pesticide pollution. The final stretch of the Llobregat River is densely populated and highly industrialized (GINEBREDA et al., 2010), influencing the overall water cycle. Ter River flows far from the Barcelona metropolitan area, from the north to the east of Catalonia, and goes through an agricultural area. MEREL et al., (2018) showed that the presence of Carbendazim in the Rhin River area correlates linearly with that of pharmaceuticals, suggesting that the occurrence of Carbendazim in surface water mainly comes from the discharge of treated domestic wastewater, as confirmed by its detection in wastewaters. However, Carbendazim is widely used to control plant diseases in cereals and fruits (GARCÍA-GALÁN et al., 2010).

Other fungicides worth mentioning due to their high concentration include Epoxiconazole, Prochloraz, and Propiconazole. Studies conducted in the

Querne/Weida catchment located in Saxony-Anhalt (central Germany) detected Epoxiconazole with a concentration of 8.2 µg/L (TAUCHNITZ et al., 2020). During the study period, the main crops were winter wheat (36%), silage corn (16%), winter barley and winter oilseed rape (13%), sugar beets (6%) and grain corn (4%). The fungicide Prochloraz was also detected in the same catchment with a 4.0 µg/L concentration. Prochloraz is subject to regulations and monitoring by authorities to ensure its safe and responsible use in Germany. German regulations regarding pesticide usage and maximum residue levels (MRLs) in food products are typically aligned with European Union (EU) standards (CARRASCO CABRERA et al., 2024). The fungicide Propiconazole was found in Tengi River, Malaysia. Near the river is a famous rice granary area (Tanjung Karang in Kuala Selangor), the fourth largest land rice cultivation area in Malaysia. The maximum concentration of propiconazole identified (4.4931 µg/L) in this study exceeded that of previous studies (ELFIKRIE et al., 2020). Propiconazole was found in several samples with a maximum concentration of 0.083 µg/L in Llobregat Rive, Barcelona (QUINTANA; DE LA CAL; BOLEDA, 2019).

Propiconazole stands out for its unique properties-it dissolves easily due to its high-water solubility, rarely volatilizes, undergoes slow degradation, and is unlikely to partition into sediment (BATTAGLIN et al., 2011). Notably, maximum permissible concentrations for surface water, regulated by country regulatory bodies, were identified only for Methomyl in Australia (**Figure 3**).

Toxicity data represented by effect or lethal concentration (E(L)C_{50}) (acute toxicity) and no observed effect concentration (NOEC) (chronic toxicity) for pesticides are presented in **Table S2** and **Table S3** (**APPENDICE A**). The toxicity classification was based on the criteria by PERSOONE et al. (2003): no toxic (NT) when effect > 100, toxic (T) when 10 < effect ≤ 100, very toxic (VT) when 1 < effect ≤ 10, and very high toxicity (HT) when effect ≤ 1. For fungicides, all compounds had acute toxicity, and most were classified as highly toxic (**APPENDICE A - Table S2**). One noticed that the fungicides presented low values of E(L)C_{50} for crustaceans compared to fishes and algae. These results show that these organisms are more sensitive to fungicides and are the best choice for toxicity tests with these compounds.

For example, LEWIS et al. (2016) evaluated the toxicity of the fungicide Quinalphos on the crustacean *Daphnia magna* in terms of lethality in an exposure period of 48 h, and the toxicity to fish for same criterion, with an exposure time of 96 h. The authors observed an EC_{50} of 0.66 µg/L for crustaceans, while for fish, this value was 5 µg/L, approximately eight times less toxic. WANG et al. (2020) evaluated the mode of action of 57 pesticides for *D. magna*. They suggested that, as fungicides kill fungi through inhibition of the nervous and respiratory systems or impair reproductive function, *D. magna* may share target receptors with these organisms to some degree, exhibiting similarity in structure affected by fungicides. Furthermore, the authors affirm that the toxicity of fungicides for *D. magna* is related to the descriptors such as heat of formation, polar surface area, polarity, molecular volume, hydrogen bonding basicity, and Cosmo volume of fungicides, which underlie ligand-receptor interactions between them and biologically active macromolecules in *D. magna.*

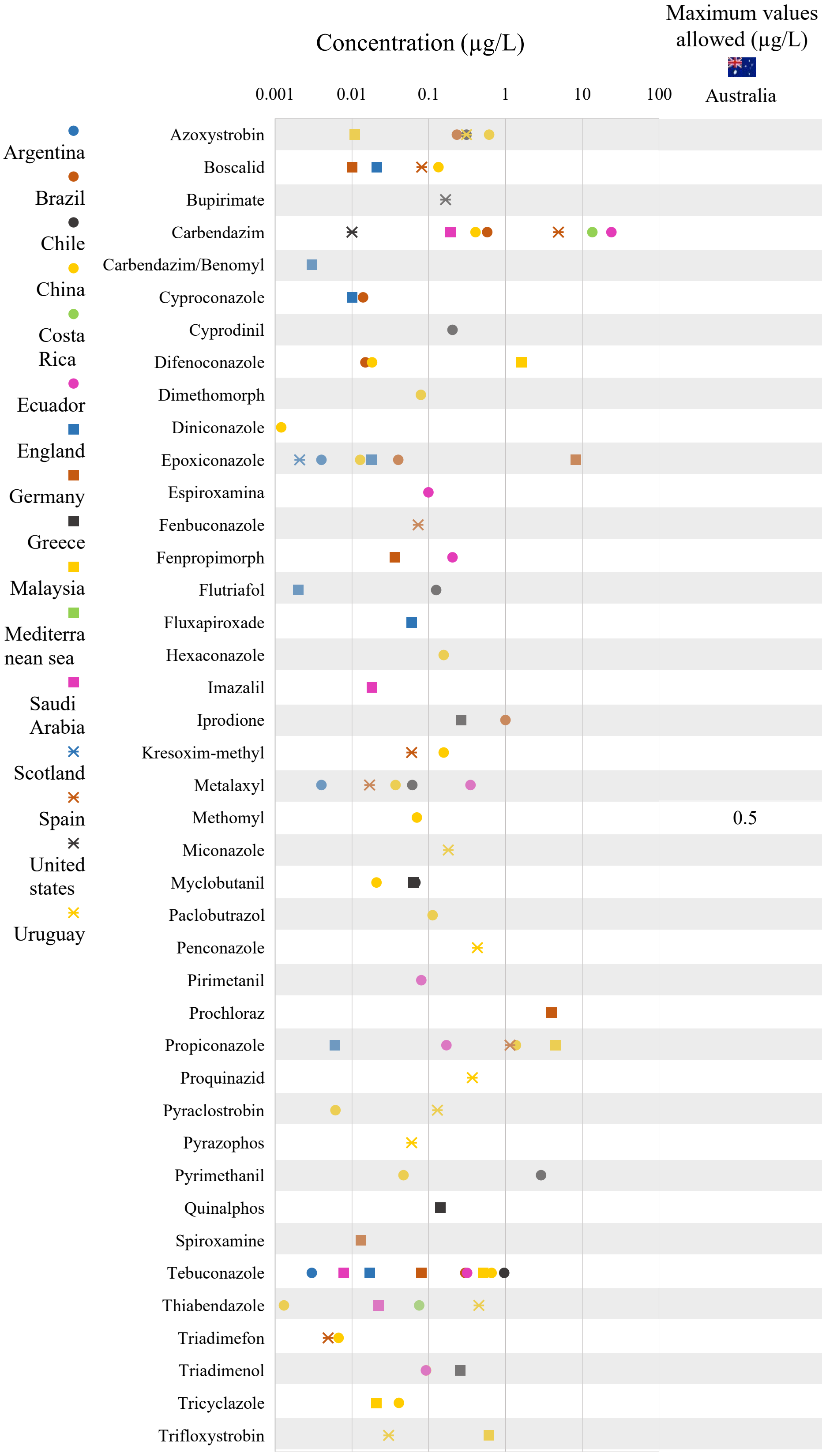


Figure 3 – Average concentrations (µg/L) of fungicides in surface water from several locations.

[1]GUIDELINES FOR FRESH & MARINE WATER QUALITY (DGVs).

Like acute toxicity, all fungicides evaluated for chronic toxicity were toxic (**APPENDICE A - Table S3**). When comparing the same compound for the three trophic levels, crustaceans were more sensitive to fungicides, and unlike acute toxicity, fish had high toxicities regarding chronic effects for many compounds. HUANG et al. (2022) highlight the role of fungicides, especially azole fungicides, as disruptors of the endocrine system in fish, which can cause adverse effects on metabolism, development, behavior, and reproduction of these organisms. In cases where the chronic toxicity of fish was greater than other trophic levels for fungicides, the endpoints evaluated were growth, larvae hatch, embryo development, and reactive oxygen species (ROS) (ECOTOX, 2024).

2.3.2 Herbicides

Herbicides studies indicate that Europe exhibited the highest occurrence frequency, accounting for 49% of the results for this group. America followed this frequency (29%) and Asia (22%). Of the herbicides identified, 39% have a maximum limit in surface waters proposed by some organization or country. Compared with different legislations, 38% of the identified herbicides violated the established limits (**Figure 4**). The highest concentrations were observed for Bentazone (180 µg/L), Propanil (61 µg/L), and Glyphosate (58 µg/L), with the former two being from Spain and the latter from Germany. During the rice-growing season, Bentazone and propanil were found in the Ebro River Delta, Catalonia, in Spain (BARBIERI et al., 2021). This area has rice cultivation for 22,000 ha and an extensive irrigation network where drainage channels have been constructed (BARBIERI et al., 2021). The Glyphosate was detected in the Querne/Weida catchment in Saxony-Anhalt (central Germany). The main crop in this region is winter wheat and silage corn (TAUCHNITZ et al., 2020) There is no legal restriction for Bentazone in surface water. However, in India, propanil is subject to a limit of 7,300 µg/L, while Glyphosate is regulated with maximum limits of 65 µg/L in Brazil and 800 µg/L in Canada.

The herbicides Diflufenican (17.0 µg/L), Metolachlor (14.6 µg/L), and Prometryn (11.6 µg/L) also exhibited notable high reported concentration. The Diflufenican was detected alongside glyphosate. The metolachlor was detected in Laguna de

Rocha and Laguna de Castillos in Uruguay, where both lagoons are characterized by periodically connecting to the ocean (GRIFFERO et al., 2019). Despite being a protected area, an increase in agricultural surface area has been observed in both basins, and the distance between agricultural fields and rivers and lagoon shores is decreasing (RODRÍGUEZ-GALLEGO et al., 2017). Metolachlor is not subject to legal restriction regarding its presence in surface water in Uruguay. However, in other countries on the same continent, such as Canada and Brazil, there is concern regarding the levels of this herbicide. The maximum allowable values in America are set at 7.8 µg/L in Canada (CCME Water-Aquatic Life) and 10 µg/L in Brazil (RESOLUÇÃO CONAMA Nº 357, 2005). The Prometryn was quantified in pond-culture, raft-culture, and rivers in Dalian, Northeast China (ZHANG et al., 2021). Prometryne has been prohibited in China´s aquaculture sector since 2010 due to uncertainty regarding its metabolites in fish and the inability to assess the safety of fish as food (MOA, 2010; VETERINARY SERVICE OF THE MINISTRY OF AGRICULTURE., 2010). However, because of its efficacy for algae and weed control in water, Prometryn continues to be utilized in aquaculture operations and has been found in aquaculture organisms (XIAOPING et al., 2015).

Studies related to herbicides Irgarol have exclusively identified its presence in America (0.01 µg/L) (CALDAS et al., 2018) and Europe (0.275 µg/L) (KÖCK-SCHULMEYER et al., 2021). Irgarol is used in antifouling paints and as an agricultural herbicide (CASTRO; WESTPHAL; FILLMANN, 2011). Studies conducted in South America have detected Irgarol in São Gonçalo Channel which connects the Patos Lagoon with the Mirim Lagoon. In Europe, studies have identified Irgarol in three basins: Adige, Sava, and Evrotas. These findings highlight the global concern over the levels of Irgarol, making it a significant environmental issue that we all need to address.

Besides, among the 75 herbicides for which acute toxicity data were available, approximately 46% were classified as highly toxic, 19% as very toxic, 28% as toxic, and 7% as no toxic (**APPENDICE A - Table S2**). Furthermore, unlike fungicides, several data on the acute toxicity of herbicides were found for species of algae, which appeared to have a greater sensitivity to these compounds than fish and crustaceans. It is crucial to consider that herbicides are formulated to control undesirable plants. Although algae do not belong to the same kingdom as terrestrial plants and are biologically distinct, they share some similar biological characteristics. Consequently, the most sensitive group of aquatic nontarget organisms is expected to be algae (CEDERGREEN & STREIBIG, 2005). Thus, herbicides can promote toxicity to algae through different mechanisms. MA et al. (2006) studied the acute toxicity of 40 herbicides on the green alga *Raphidocelis subcapitata*. They concluded that the descending order of the average acute toxicity to *R. subcapitata* of nine modes of action was: photosynthetic process > cell division > lipid synthesis, acetyl-CoA carboxylase > acetolactate synthase > EPSP synthase, glutamine synthase, hormone synthesis > protoporphyrinogen oxidase. The increasing occurrence of herbicides in the environment, associated with their high toxicity, is worrying since microalgae provide the basis of food chains in the aquatic environment and are fundamental to the functioning of aquatic ecosystems (VALIENTE MORO et al., 2012).

It is essential to highlight that the most toxic compound was the herbicide Irgarol, for algae species. The formulation of this pesticide is intended to prevent algal blooms by effectively blocking a crucial step in the photosystem's electron transport and thus inhibiting photosynthesis in autotrophs. Therefore, Irgarol is highly toxic to algae and aquatic plants (ZHANG et al., 2008). This fact associated with Irgarol's long half-life in an aquatic environment (24 to 200 days) demonstrates its high persistence, making this compound a potential danger to the ecosystem (MOHR et al., 2009).

The only compound that did not show chronic toxicity was the herbicide Tribenuron-methyl for the fish *Oncorhynchus mykiss*, with a NOEC of 560000 µg/L (UNIVERSITY OF HERTFORDSHIRE, 2024) (**APPENDICE A - Table S3**). For herbicides whose chronic toxicity data were found for more than one trophic level, 62.5% of the time, algae had the highest toxicity. At the same time, these values for fish and crustaceans were 30.2% and 22.2%, respectively. Therefore, algae were the organisms most sensitive to herbicides, as well as to acute toxicity. Furthermore, most herbicides were classified as highly toxic for all trophic levels. As with acute toxicity, it is important to highlight the high toxicity of herbicide Irgarol for algae species since the action of this compound is specifically directed towards these organisms.

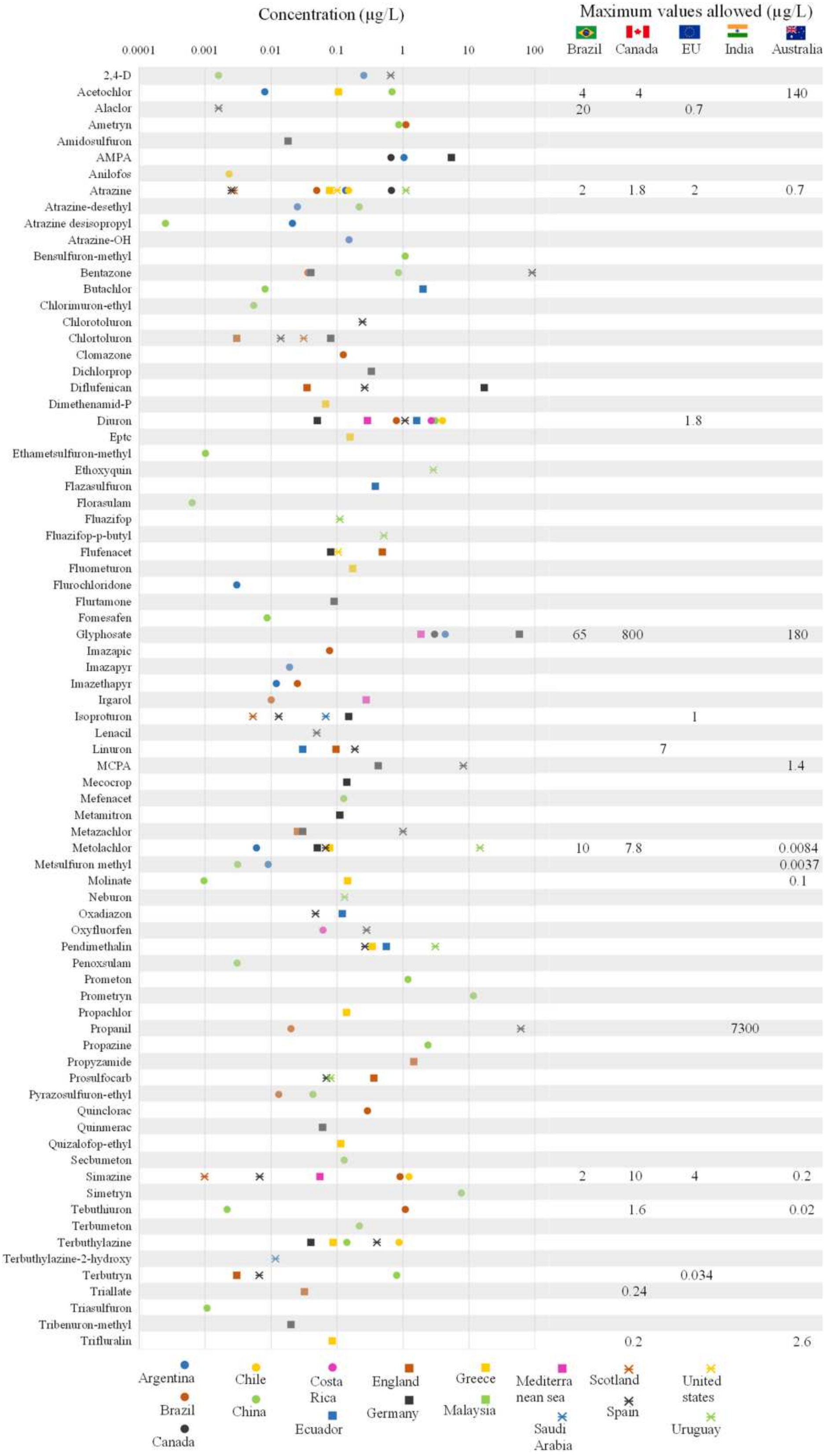


Figure 4 - Average concentrations (µg/L) of herbicides in surface water from several locations. [1]RESOLUÇÃO CONAMA n° 357 (2005); [2]CCME (Water-Aquatic Life); [3]EUR-Lex (2013/39/EU); [4]CWAS (IS: 2296- 1982); [5]GUIDELINES FOR FRESH & MARINE WATER QUALITY (DGVs).

2.3.3 Insecticides

Insecticides showed higher occurrence frequency than other pesticide groups and were identified on four continents: 39% in Asia, 23% in Europe, 20% in the Americas, and 19% in Africa (**Figure 5**). The highest concentrations of insecticides were recorded for endosulfan and DDD. Endosulfan, at 37.56 µg/L, was reported in the Tapti River in Surat Gujarat (HASHMI et al., 2020), a level approximately 3.8 times higher than the allowed limit set by Indian regulations. In Chilika Lake on the east coast of India, DDD reached 23,4 µg/L (NAG et al., 2020). The EPA establishes a maximum concentration of DDD in surface water of 0.011 µg/L. Two potential sources of contamination in the Chilika Lake include pesticide pollution and mixed domestic and industrial wastewater discharge. The proximity of pesticide manufacturing facilities to the studied areas further suggests their potential contribution to the pollutants. Additionally, agricultural activities on nearby land are another potential contributor to the high levels of pesticides detected in the water samples (NAG et al., 2020).

Endosulfan, a highly toxic and hazardous organochlorine pesticide, poses a severe threat to both human and animal health, having caused numerous fatal poisoning incidents (MOSES; PETER, 2010). Despite being banned in most countries, some farmers and industries persist in its use for insect control. A documented case highlights the impact of Endosulfan on male development, where boys in Kasargod, South India, exposed to repeated aerial spraying of Endosulfan, experienced delayed sexual development, including significantly reduced growth of pubic hair, testes, and penis (HASHMI et al., 2020). This correlated with reduced testosterone synthesis and elevated levels of luteinizing hormone (SAIYED, 2004). This study identified Endosulfan as the primary contaminant in the water samples, with concentrations registered during the summer and monsoon seasons.

In studies, Imidacloprid also has high concentrations. The maximum concentration detected was 7,249 µg/L in the Krom River, Berg River, and Hex River in the Western Cape in South Africa (CURCHOD et al., 2020). South Africa is the primary pesticide user in Sub-Saharan Africa (DABROWSKI, 2015; DALVIE; AFRICA; LONDON, 2009), with more than 3,000 pesticide products containing 700 different pesticide compounds legally registered for agricultural use. Nevertheless, there is low knowledge about the occurrence of pesticide mixtures in surface water and potential environmental risks in Africa. A potential increase in pesticide use occurs during changes in climatic conditions (DELCOUR; SPANOGHE; UYTTENDAELE, 2015; ROSENZWEIG et al., 2001), such as droughts or heavy rains (BLOOMFIELD et al., 2006; ROSENZWEIG et al., 2001).

Among the insecticides that had permissible maximum limits established by the respective agency, 73 results of violations were found. Parathion, in China, also showed quantification 60 times lower than the local regulations. Imidacloprid in Canada was quantified 21 times lower than the permissible limit in the country. Chlorpyrifos in Scotland showed a result 20 times lower than the permissible limit in the European Union.

Pesticide residues on the surface can infiltrate the soil and contaminate groundwater bodies (OLIVER; KOOKANA; QUINTANA, 2005). Groundwater pesticide contamination poses a significant threat to aquifer quality globally (ABANYIE et al., 2023). Groundwater serves as the primary drinking water resource for many countries, with some relying on it entirely (e.g., up to 100% in Denmark or Austria, 95% in Hungary, around 90% in Italy, 80% in Switzerland, and around 70% in France and Germany – EurEau, 2021) (BARAN et al., 2022). The UN's Sustainable Development Goals related to water resources, specifically pollution (targets 3.9, 6.3, and 15.1), serve as familiar drivers for progress in pesticide control in groundwater (UNITED NATIONS, 2024).

Pesticide enters the soil through spray drift during foliar treatment and subsequent washing or by release from granules applied directly to the soil. Their mobility is influenced not only by pesticide properties such as solubility or degradation coefficient but also by variables that can change across agricultural fields, such as climatic and hydrological characteristics, or those that vary spatially and temporally, such as crop phenology and climatic factors like temperature, precipitation, evaporation, wind, and solar radiation (PÉREZ-INDOVAL; ROMERO-LÓPEZ, 2024).

Regarding acute toxicity, most insecticides were considered highly toxic (**APPENDICE A - Table S2**), and only Acetamiprid was classified as no toxic, when evaluated about lethal concentration for fish (MALHOTRA et al., 2021). However, no studies were found evaluating the difference between this compound and other insecticides with acute toxicity to fish. Among the compounds evaluated, the highest toxicity values were generally for crustacean and fish species. For example, WESTON et al., (2013) evaluated the acute toxicity of Cyfluthrin to the crustacean *Hyalella azteca* over an exposure time of 96 h and found an LC_{50} of 0.0013 μg/L. One of the main actions of this pesticide is the disruption of the nervous system in fish, binding and prolonging the opening of voltage-dependent ion channels and consequently causing convulsions, paralysis, and death (BRANDER et al., 2009). Similarly, Azinphos-ethyl - one of the most toxic compounds together with Cyfluthrin - has as its primary mechanism of action the inhibition of cholinesterases, a group of enzymes critical to the functioning of the nervous system in fish, thus causing a disturbance in normal functioning of the nervous system (JORDAAN; REINECKE; REINECKE, 2013).

At the same time, an LC_{50} of 0.02 μg/L for Esfenvalerate was observed for the fish *Danio rerio*, in a total exposure time of 4 d. It is essential to highlight the scarcity of algal toxicity data for insecticides compared to other organisms and compared to fungicides and herbicides. Therefore, further investigations are necessary to assess the impacts on these organisms more fully.

Similar to acute toxicity, all compounds had chronic toxicity, and the majority were highly toxic (**APPENDICE A - Table S3**). It is essential to highlight that Acetamiprid, considered no toxic in terms of acute toxicity for fish, was classified as highly toxic for chronic toxicity. For acute toxicity, this compound presented an LC_{50} of 265700 μg/L in 96 h for the fish *Clarias gariepinus* (MALHOTRA et al., 2021). In contrast, for chronic toxicity in an exposure period of 4 d, the NOEC was 170 μg/L for the fish *Danio rerio* when evaluating interleukin-1β, an essential mediator of the inflammatory response in the central nervous system, against trauma and pathological processes (EPA.GOV, 2024). This result emphasizes that acute and chronic tests are complementary since organisms can present different responses at different endpoints and times of exposure (CONNON; GEIST; WERNER, 2012).

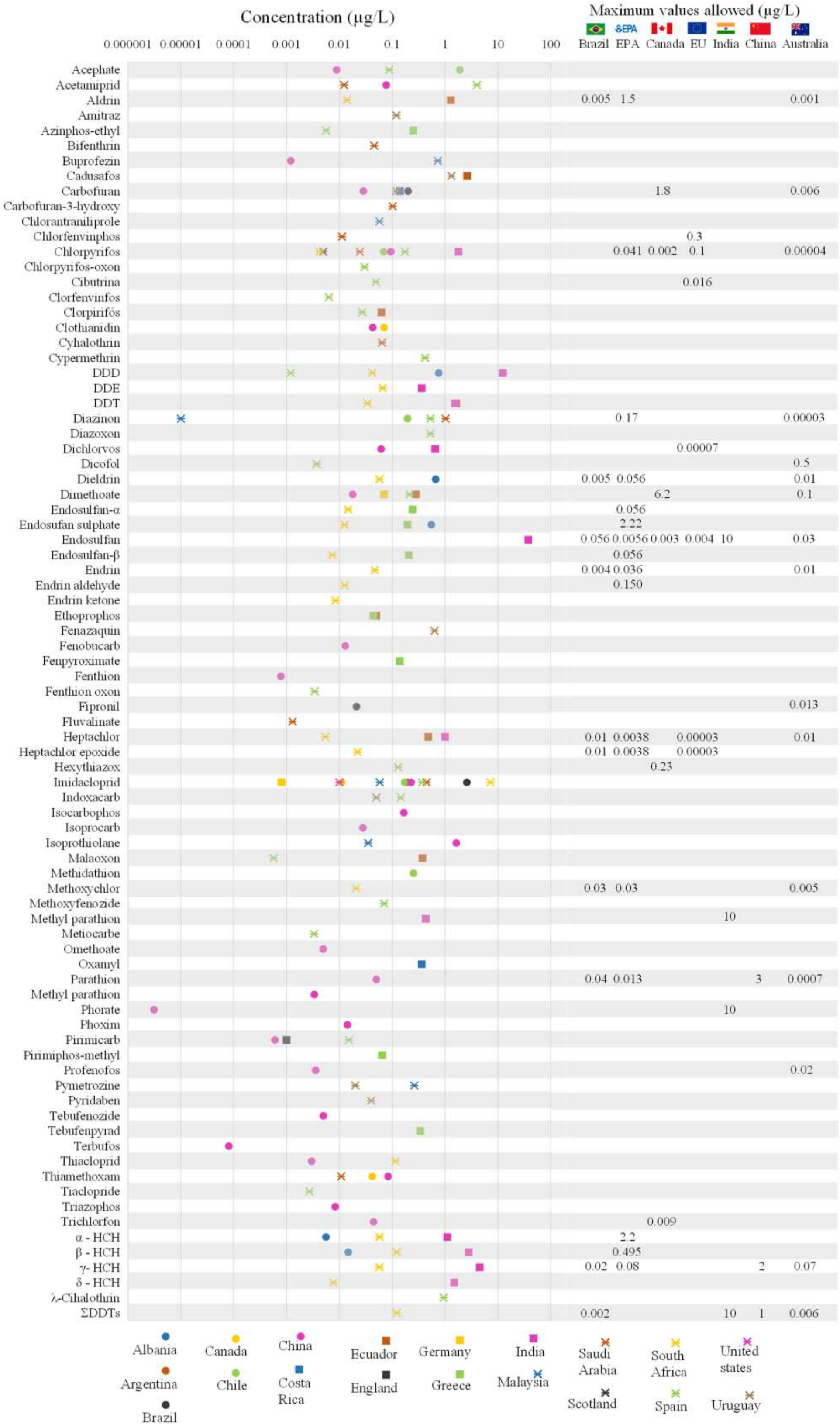


Figure 5 - Average concentrations (µg/L) of insecticide in surface water from several locations. [1] RESOLUÇÃO CONAMA n° 357 (2005); [2]EPA (National Recommended Water Quality Criteria); [3]CCME (Water-Aquatic Life); [4]EUR-Lex (2013/39/EU); [5]CWAS (IS: 2296- 1982); [6]CWR (GB3838-2002); [7]GUIDELINES FOR FRESH & MARINE WATER QUALITY (DGVs).

2.4 OCCURRENCE OF PESTICIDES IN GROUNDWATER

Considering the literature data, 55 data points on pesticide occurrence in groundwater were identified. Of these, 51% of the concentrations are related to insecticides, 27% to herbicides, 22% to fungicides, and none to algicides. The highest frequency of results was for the European continent (67%), followed by Asian countries (31%) and American countries (2%). However, such results must be considered cautiously, as the higher pesticide counts in these regions may reflect more intensive research rather than a greater prevalence of pesticides. Despite the low occurrence frequency observed in American countries, they imported the highest volume of pesticides globally in 2020, totaling 1.1 million tons (FAO, 2022).

Insecticides were most common on the Asian continent (57%), followed by 43% of results on the European continent, in addition to the highest concentrations in groundwater found in India for the HCH series: δ - HCH (2.15 µg/L), γ- HCH (2.10 µg/L), β - HCH (2.01 µg/L) and α - HCH (1.71 µg/L). Fungicides were only identified in European countries (Spain and Italy). Similarly, herbicides were more common in European countries (87%), with Spain having a frequency of occurrence 12 times higher than Italy. Asia and America presented the same frequency, with only one result each, as shown in **Figure 6**. Herbicides exhibited a concentration range between 0.01 and 1.44 µg/L, with the highest concentration observed for atrazine (in China).

It is noteworthy that maximum permissible concentrations for groundwater, regulated by country regulatory bodies, were identified only for the insecticides Carbofuran, Chlorpyrifos, and g-HCH in Brazil and Carbofuran and g-HCH by EPA (**Figure 6**). No violation was observed for any of these pesticides. The database of concentrations is presented in **APPENDICE A - Table S1**.

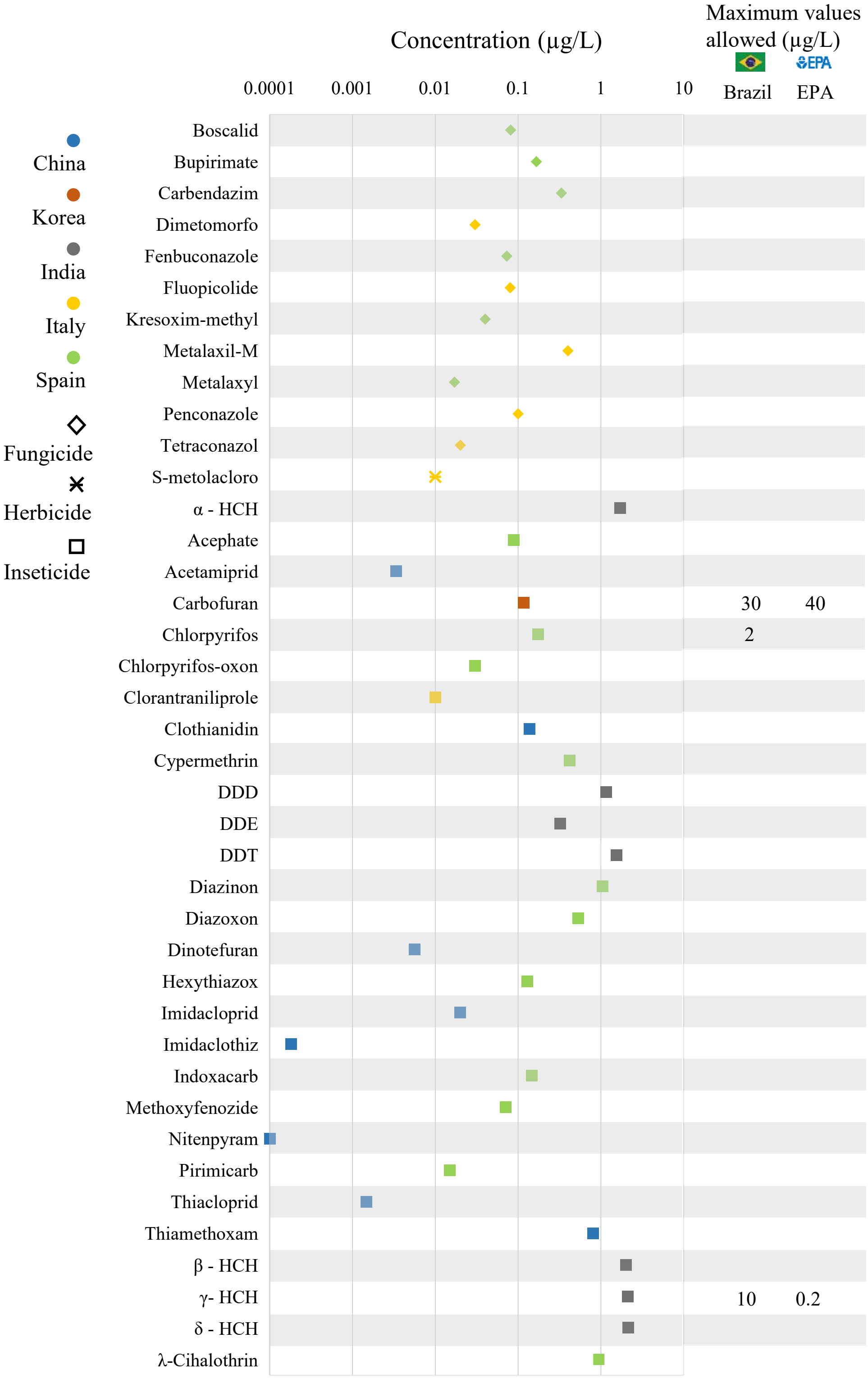


Figure 6 - Average concentrations (µg/L) of fungicide, herbicide, and insecticide in groundwater from several locations.

[1] RESOLUÇÃO CONAMA n° 357 (2005); [2]EPA (National Recommended Water Quality Criteria)

2.5 ENVIRONMENTAL RISK ASSESSMENT

To assess the acute and chronic environmental risks, measured from the risk quotient (RQ), the concentration of each pesticide in surface water was used, as well as the toxicity related to them. Thus, the RQ values were obtained through Equation 1, where MEC is the concentration for each pesticide and PNEC is the predicted no-effect concentration.

$$\mathrm{RQ} = {}^{\mathrm{MEC}}/_{\mathrm{PNEC}} \tag{1}$$

For the PNEC calculation, the acute and chronic effects were divided by a correction factor: 10 for no observed effect concentration (NOEC) from at least three species representing three trophic levels; 50 for NOEC from species representing two trophic levels; 100 for NOEC from only one trophic level; and 1000 for half maximal effective (or lethal) concentration ($E(L)C_{50}$) from each of three trophic levels. PNEC values are presented in **Table S4** (**APPENDICE A**). Thus, the risk of pesticides was classified as high risk (RQ>1), medium risk (0.1>RQ<1), low risk (0.01>RQ<0.1), or negligible risk (RQ<0.01) (EUROPEAN COMMISSION, 1996).

The assessment of acute and chronic environmental risks from pesticides has been separated for surface and groundwater and critically discussed in the following sections. Furthermore, pesticides were separated into fungicide, insecticide, and herbicide classes to facilitate discussion.

2.5.1 Surface Water

For all pesticides classified as high environmental risk, a criticality order was carried out by legislative aspects. Group 1 (critical compounds) corresponds to high-risk pesticides, with no limits or restrictions regarding their use and occurrence in water; group 2 refers to high-risk pesticides that have limits regarding their presence in water; and group 3 corresponds to pesticides with high risk, but which are already banned in the European Union or the United States (**Figure 7** e **Figure 8**). Carbendazim (group 3), for example, was considered a possible human carcinogen by the United States Environmental Protection Agency (EPA) due to its toxic properties and bioaccumulation potential, and was classified as high risk. Although its use in fruits and vegetables is already banned in European Union and United States (FAN et al., 2021), this compound is still widely used due to its effectiveness and low cost of application (XU et al., 2018). Therefore, the indiscriminate use of Carbendazim can lead to contamination of water bodies (MEREL et al., 2018)

Among the 180 pesticides whose environmental risk was measured in surface waters, 110 presented high acute or chronic risks, representing approximately 61% (**Figure 8**). In addition, several compounds presented medium risks. In **Figure 8a** it is possible to notice that 19 fungicides presented high risks, namely, Azoxystrobin, Carbendazim, Cyprodinil, Difenoconazole, Epoxiconazole, Fenpropimorph, Iprodione, Kresoxim-methyl, Methomyl, Myclobutanil, Prochloraz, Propiconazole, Pyraclostrobin, Pyrimethanil, Quinalphos, Spiroxamine, Tebuconazole, Thiabendazole and Trifloxystrobin. The most critical risk scenarios were for the fungicides Carbendazim, Prochloraz, Propiconazole and Pyrimethanil.

Several fungicides were considered critical compounds (group 1), such as Cyprodinil, Difenoconazole, Epoxiconazole, Fenpropimorph, Iprodione, Kresoxim-methyl, Myclobutanil, Prochloraz, Propiconazole, Pyraclostrobin, Pyrimethanil, Quinalphos, Spiroxamine, Tebuconazole, Thiabendazole and Trifloxystrobin. Due to the high environmental risk demonstrated for these compounds, legislative measures and their removal from the aquatic environment are urgent.

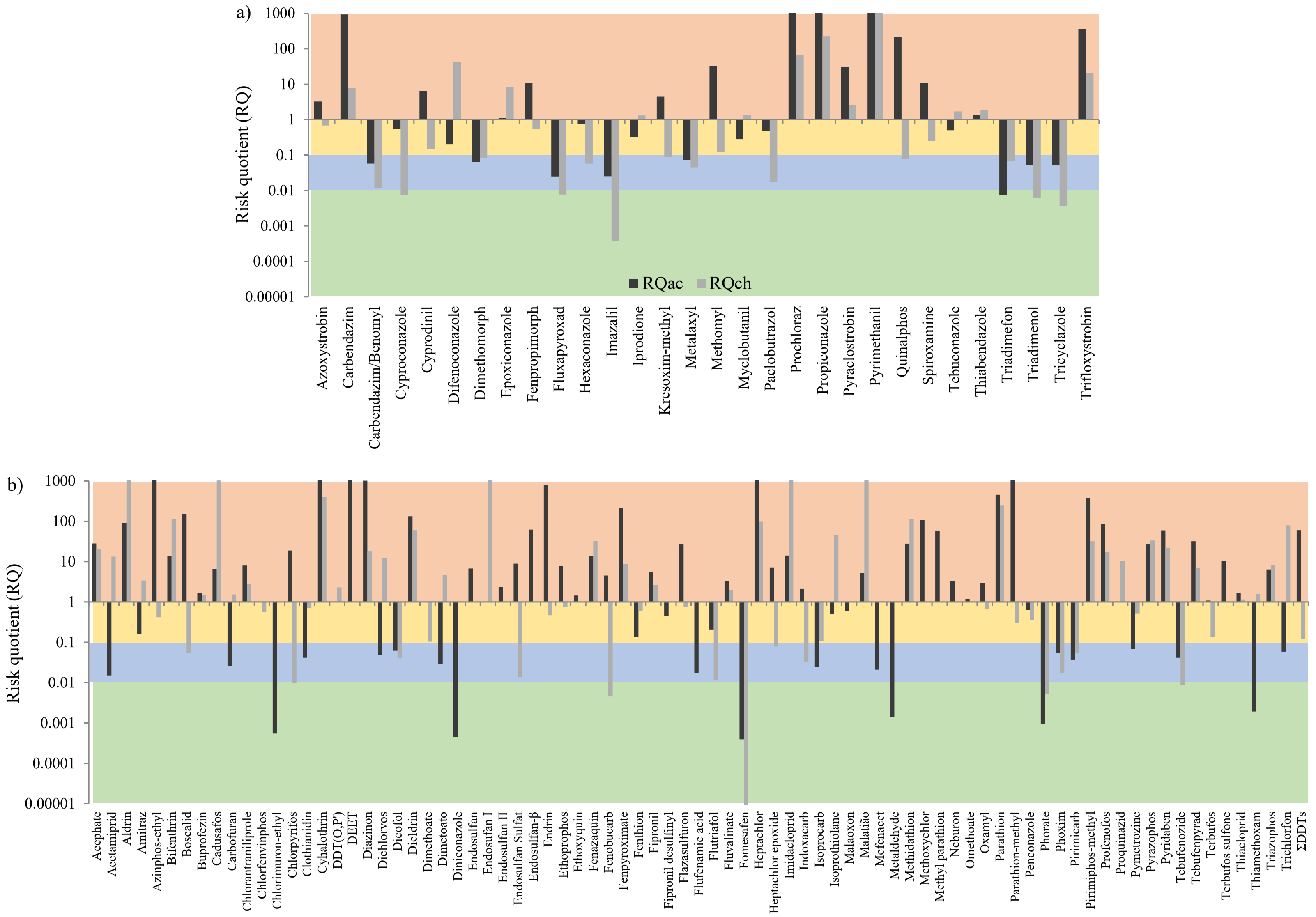
Regarding insecticides, 60 compounds had high risks (**Figure 8b**), which is equivalent to 74%. Also, insecticides generally presented the highest RQ values compared to fungicides and herbicides. The highest acute or chronic RQ values (above 1000) were for Aldrin, Azinphos-ethyl, Cadusafos, Cyhalothrin, DEET, Diazinon, Endosulfan, Heptachlor, Imidacloprid, Malathion and Parathion-methyl. These insecticides were classified in group 3, since they have already been banned in the European Union or USA. However, it is important to highlight that the use of these compounds is still permitted in several other countries. Therefore, they are found in surface waters in several locations, as discussed in Section 2.3, and their removal is essential due to the high environmental risks.

For herbicides, 30 compounds presented high risks (**Figure 8c**), emphasizing Bentazone, Diflufenican, Oxadiazon, Pendimethalin, and Prometryn, that which, in addition to being classified as high acute and chronic environmental risk, were considered critical compounds (group 1). Other herbicides presented high acute and chronic environmental risks; however, they were classified in critical group 2 or 3. For example, Simazine presented a high risk in surface water in Chile, Spain, and Brazil considering the studies explored. OJEMAYE et al., (2020) also assessed the RQ for Simazine in Camps Bay, South Africa, and found high acute risks for algae and crustaceans and high chronic risks for algae and fish. In contrast, LI et al., (2018) assessed the risks of this compound in the Taizi River in China and found risks ranging from low to medium. This shows that the risk of these compounds can vary depending on the location and aquatic organisms evaluated.

In addition, Irgarol (group 3) - one of the compounds with the most critical acute and chronic risks - was recently banned in USA and European Union due to its toxicity to aquatic organisms (U.S. ENVIRONMENTAL PROTECTION AGENCY, 2013). Following the same criteria, Brazil banned the use of Irgarol in 2022 (NORMAM-20/DPC/2022). This compound presented a high risk to São Gonçalo Channel, Brazil (samples collected in 2018) (CALDAS et al., 2018), and Sava River, Croatia (samples collected in 2021) (KÖCK-SCHULMEYER et al., 2021). It is important to highlight the progress in legislation regarding these compounds; however, its remaining concentrations in the aquatic environment can still pose risks to the ecosystem. Therefore, continued investigations regarding its presence in surface water are recommended.

In **Figure 7** it is possible to identify the locations where critical compounds (group 1) were detected. China, a country with limited pesticide-related legislation, was observed to have a high diversity of critical pesticides, with 29 compounds. In contrast, it is possible to observe that even in places with restrictions and regulations on the use of pesticides, such as countries belonging to the European Union, many compounds with high environmental risk are still present in the aquatic environment and require regulation. Among the studies found for North America, only one pesticide was considered critical (group 1) in Canada. However, several pesticides detected in developing countries in South America, such as Brazil, Uruguay, Argentina, Chile, and Ecuador, were classified as critical. These results provide an overview of the compounds that should be prioritized in specific locations due to environmental risk and legislative aspects. Future studies are needed to evaluate the specific locations where these pesticides are present, considering socioeconomic aspects, the primary sources of pesticide release, climatic aspects, and the possibilities of mitigating the presence of these compounds in water bodies.

Figure 7 - Order of criticality regarding environmental risks and legislative aspects for pesticides found in surface waters and groundwater.


a)
Risk quotient (RQ)
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
RQac
RQch
Azoxystrobin
Carbendazim
Carbendazim/Benomyl
Cyproconazole
Cyprodinil
Difenoconazole
Dimethomorph
Epoxiconazole
Fenpropimorph
Fluxapyroxad
Hexaconazole
Imazalil
Iprodione
Kresoxim-methyl
Metalaxyl
Methomyl
Myclobutanil
Paclobutrazol
Prochloraz
Propiconazole
Pyraclostrobin
Pyrimethanil
Quinalphos
Spiroxamine
Tebuconazole
Thiabendazole
Triadimefon
Triadimenol
Tricyclazole
Trifloxystrobin
b)
Risk quotient (RQ)
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
Acephate
Acetamiprid
Aldrin
Amitraz
Azinphos-ethyl
Bifenthrin
Boscalid
Buprofezin
Cadusafos
Carbofuran
Chlorantraniliprole
Chlorfenvinphos
Chlorimuron-ethyl
Chlorpyrifos
Clothianidin
Cyhalothrin
DDT(O,P')
DEET
Diazinon
Dichlorvos
Dicofol
Dieldrin
Dimethoate
Dimetoato
Diniconazole
Endosulfan
Endosulfan I
Endosulfan II
Endosulfan Sulfat
Endosulfan-β
Endrin
Ethoprophos
Ethoxyquin
Fenazaquin
Fenobucarb
Fenpyroximate
Fenthion
Fipronil
Fipronil desulfinyl
Flazasulfuron
Flufenamic acid
Flutriafol
Fluvalinate
Fomesafen
Heptachlor
Heptachlor epoxide
Imidacloprid
Indoxacarb
Isoprocarb
Isoprothiolane
Malaoxon
Malatião
Mefenacet
Metaldehyde
Methidathion
Methoxychlor
Methyl parathion
Neburon
Omethoate
Oxamyl
Parathion
Parathion-methyl
Penconazole
Phorate
Phoxim
Pirimicarb
Pirimiphos-methyl
Profenofos
Proquinazid
Pymetrozine
Pyrazophos
Pyridaben
Tebufenozide
Tebufenpyrad
Terbufos
Terbufos sulfone
Thiacloprid
Thiamethoxam
Triazophos
Trichlorfon
ΣDDTs

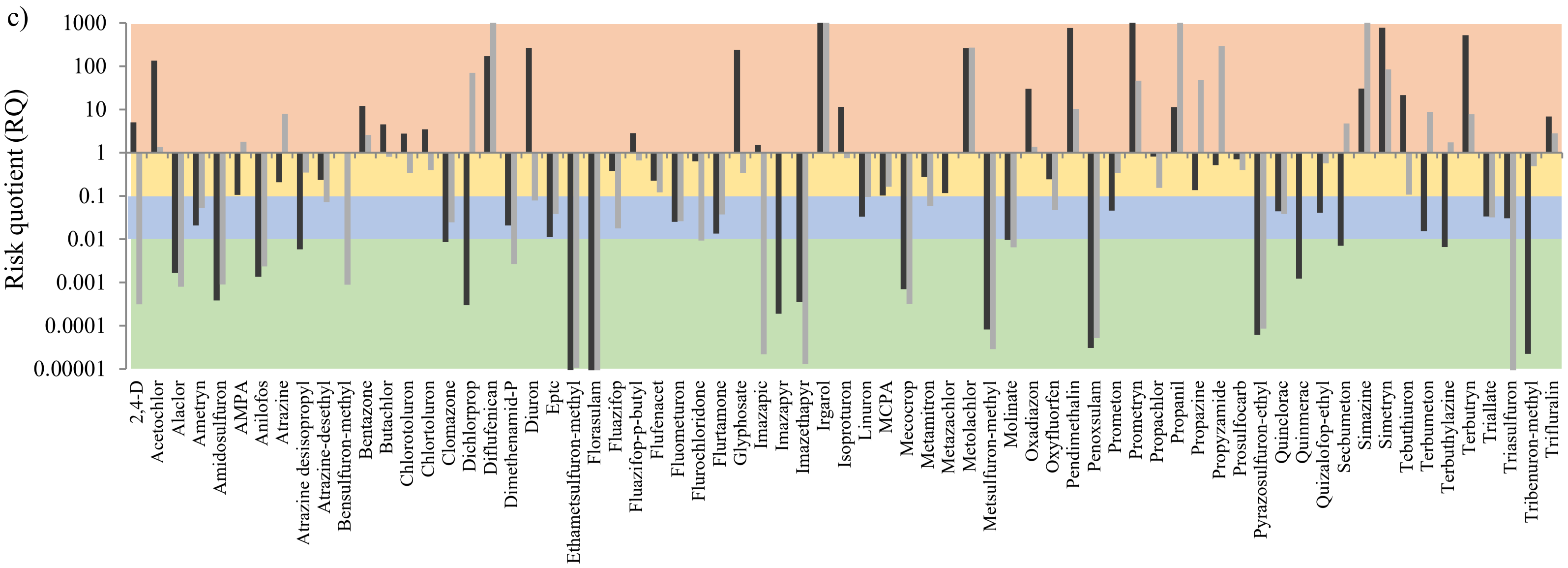


Figure 8 - Environmental acute and chronic risk for a) fungicide, b) insecticide and c) herbicide in surface water. Red area: high risk; Yellow area: medium risk; Blue area: low risk; Green area: negligible risk.

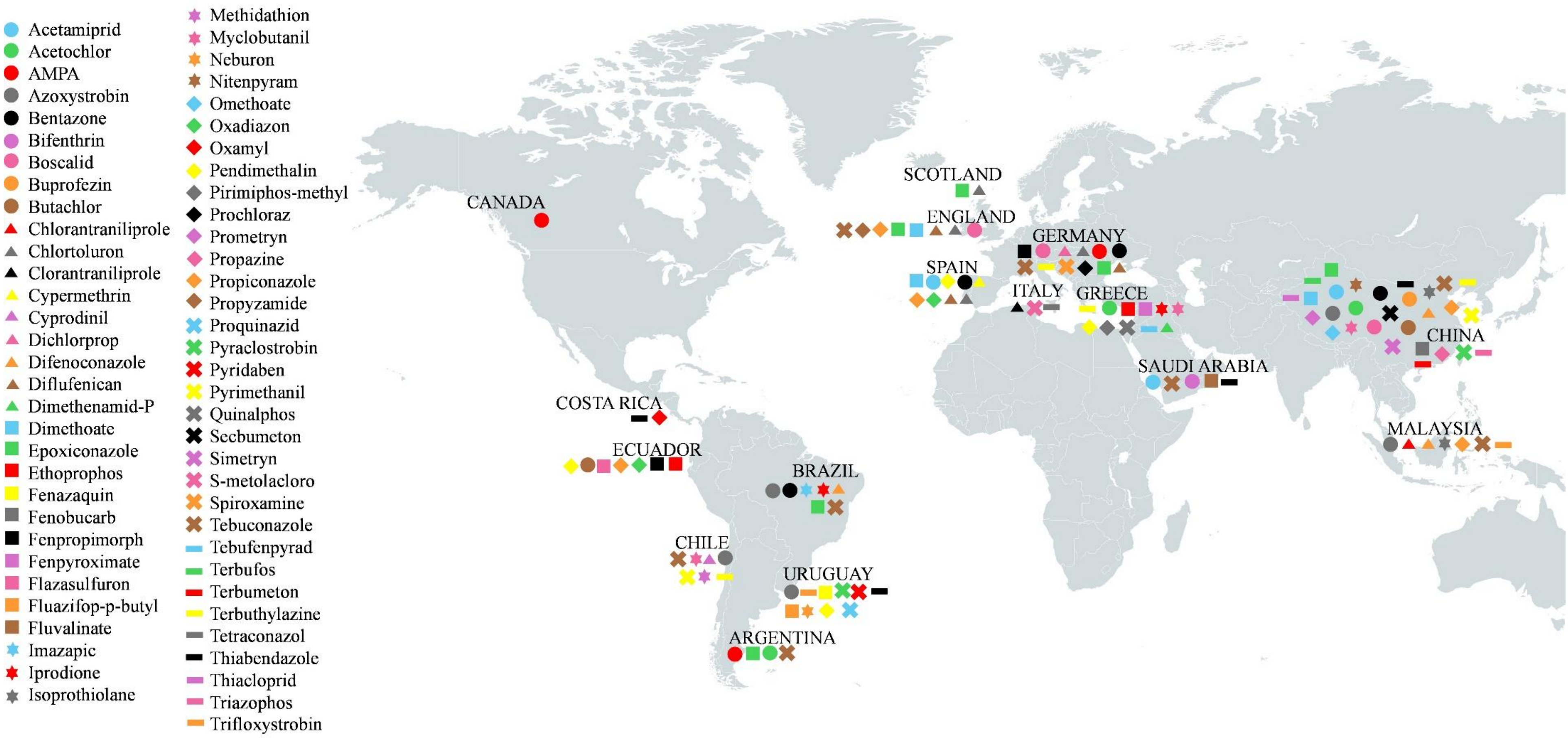


Figure 9 - Occurrence in surface waters or groundwater of compounds identified as priorities about environmental risk and legislative aspects (Group 1).

2.5.2 Groundwater

Insecticides were the category with the most significant number of compounds with high acute environmental risk in groundwater, followed by herbicides and fungicides (**Figure 10)** Among insecticides, those with the highest acute RQs were Diazinon, λ-Cihalothrin, and Diazoxon, while for herbicides and fungicides, they were Pendimethalin and Boscalid, respectively. Regarding chronic risks, the highest RQs were for the insecticides Diazinon, Cypermethrin, Chlorpyrifos, and the herbicide Diflufenican. In contrast, among the fungicides, no compound was classified as high chronic risk, and most had low or negligible risks. Among them, Pendimethalin, Boscalid and Diflufenican are critical compounds (group 1), as they do not have legislation limiting their presence in groundwater.

Some studies were found evaluating the RQ of pesticides in groundwater for specific locations. AFFUM et al., (2018) assessed the environmental risk of pesticides banned by the United States EPA (US EPA), European Union, or EPA of Ghana under the Stockholm and Rotterdam Conventions. The authors also found high chronic risks for Cypermethrin and Chlorpyrifos in groundwater in the Ankobra Basin, Ghana. Similarly, BERNI et al., (2021) showed that Chlorpyrifos had a high ecological risk in groundwater from the Saïss Plain, Morocco, despite being at maximum concentrations below the country's legal limits. In addition, (VERA-CANDIOTI et al., 2021) investigated environmental risks in groundwater from agroecosystems in the Pampas region of Argentina and the results showed high chronic risks for Atrazine.

Compared to surface water, RQ values for groundwater were lower. However, the proportions of high risks for pesticides detected in groundwater were worrisome for herbicides and insecticides, with 77% and 62% of compounds classified as high risks, respectively. Furthermore, several compounds had recurrent high risks concerning surface water, such as Chlorpyrifos, Chlorantraniliprole, Diazinon, Indoxacarb, Carbendazim, Kresoxim-methyl, Chlorotoluron, Diflufenican, Diuron, Metolachlor, Pendimethalin, and Tebuthiuron. This shows that with transport through water and soil, these compounds can reach different layers of the aquatic environment, causing great damage to the ecosystem. Among these compounds, Chlorpyrifos, Diazinon, Indoxacarb, Carbendazim, Kresoxim-methyl, Chlorotoluron, Dinotefuran, and Diuron are compounds already banned by the European Union or USA and were classified as group 3 (**Figure 7**).

The present study found high acute or chronic risks for pesticide concentrations reported for groundwater in China, Spain, Italy, and Brazil. The high environmental risks in these locations are an urgent issue, as groundwater is a vital source of freshwater and plays a crucial role in the global demand for water for drinking, agricultural and industrial purposes (AFFUM et al., 2018). Therefore, protecting groundwater quality is vital to safeguard freshwater reserves that are safe for the aquatic ecosystem and human health.

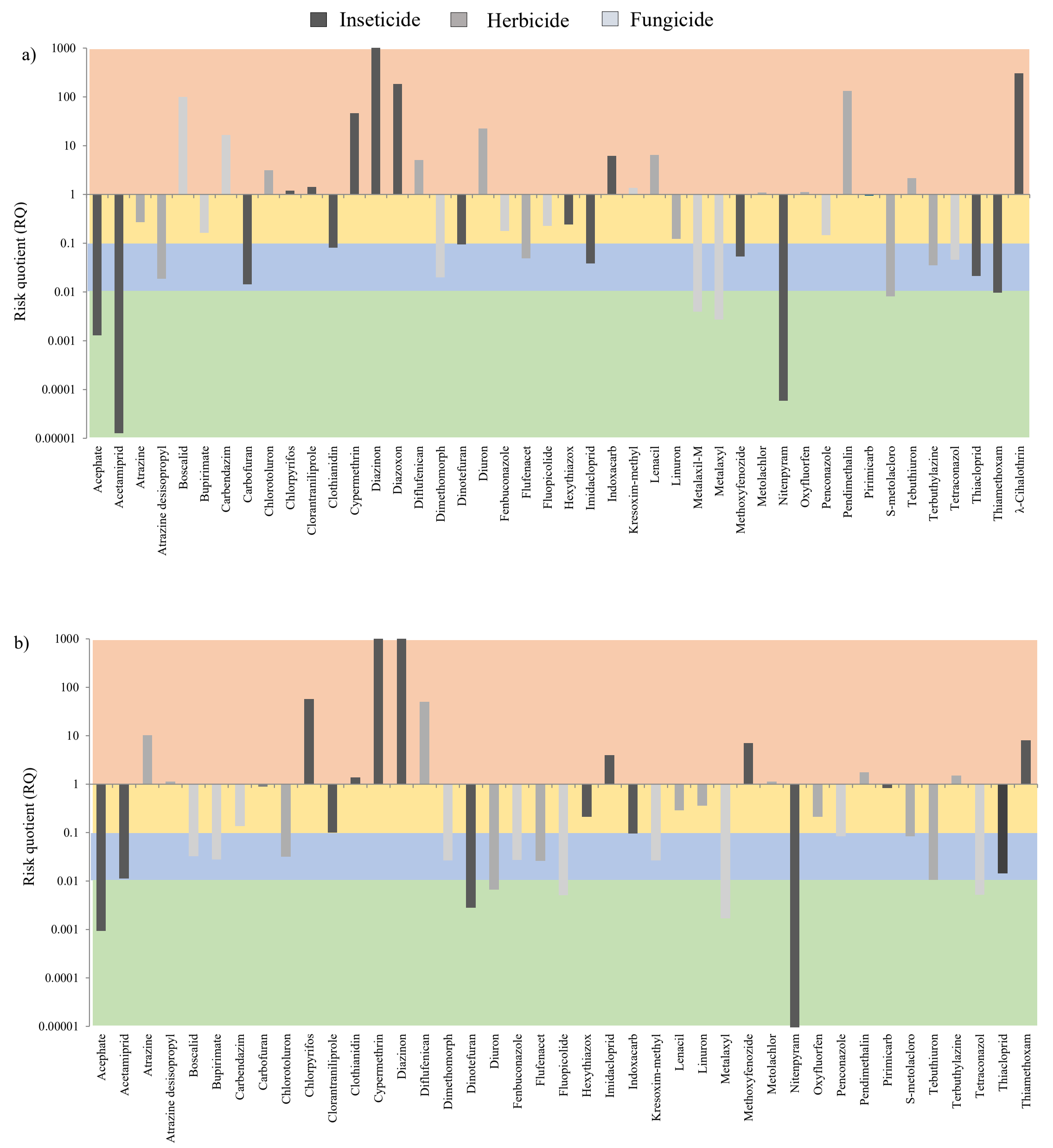


Figure 10 - Environmental a) acute and b) chronic risk for fungicide, insecticide and herbicide in groundwater. Red area: high risk; Yellow area: medium risk; Blue area: low risk; Green area: negligible risk.

2.6 BIOACCUMULATION IN AQUATIC ORGANISMS

Bioaccumulation is the retention or accumulation of a substance over time in an organism (PETERSEN et al., 2019). Bioaccumulation processes in aquatic organisms depend on biological and environmental factors (SCHÄFER et al., 2015). Species, body size, and age of organisms, as well as pH, salinity, temperature, and solubility, potentially influence pesticide absorption (SCHÄFER et al., 2015). The most concerning pesticide bioaccumulation processes include absorption, assimilation, biotransformation, biomagnification, and elimination (VOLODYMYR I. LUSHCHAK et al., 2018). Hydrophobic organic pesticides stand out for their natural tendency to avoid the aqueous phase when introduced into aquatic environments. Consequently, they migrate to non-aqueous media, such as suspended particles, or deposited in biological organisms (Bakanov et al., 2020). Aquatic organisms can absorb pesticides through respiratory organs, body surfaces, or by ingesting food, suspended particles, or contaminated sediments. In this context, the potential for pesticide bioaccumulation in organism tissues, particularly those consumed by humans, cannot be ignored.

According to BERNARDO; ALVES; HOMEM, (2022), the potential for bioaccumulation of a chemical compound can be expressed in different ways such as: bioconcentration factor (BCF); bioaccumulation factor (BAF); sediment-biota accumulation factor (BSAF); biomagnification factor (BMF); trophic magnification factor (TMF); and octanol-water partition coefficient (Kow) (GIMENO et al., 2024). Kow, a crucial parameter in this context, is defined as the ratio of the concentration of a specific compound, at equilibrium, after dissolution in a system formed by two immiscible solvents, water and octanol (Zhu et al., 2022). It is a measure of a compound's hydrophobicity, which is often used as an indicator of its potential bioaccumulation. This is because hydrophobic substances tend to accumulate in organisms due to their affinity for lipids. If necessary, tests with vertebrate animals can be conducted to measure BCF (GIMENO et al., 2024). However, it is important to emphasize that evaluating the potential for bioaccumulation based solely on Log Kow is not applicable to substances known to accumulate through mechanisms other than passive retention driven by hydrophobicity. For instance, some substances may accumulate through active transport across cellular membranes, or by binding to proteins or membrane phospholipids instead of, or in addition to, neutral lipids (SANCHEZ GARCIA et al., 2018). Despite this limitation, many countries have adopted Log Kow as regulatory cut-off values for bioaccumulation screening, as demonstrated in **Figure 5**. The Log Kow limit for classifying substance values varies from region to region, typically falling within the range of 3 and 5.

The pesticides that presented environmental risk (chronic or acute) (**3**) were selected, and their Log Kow values were compared with the global regulatory cut-off values (**Figure 11**).

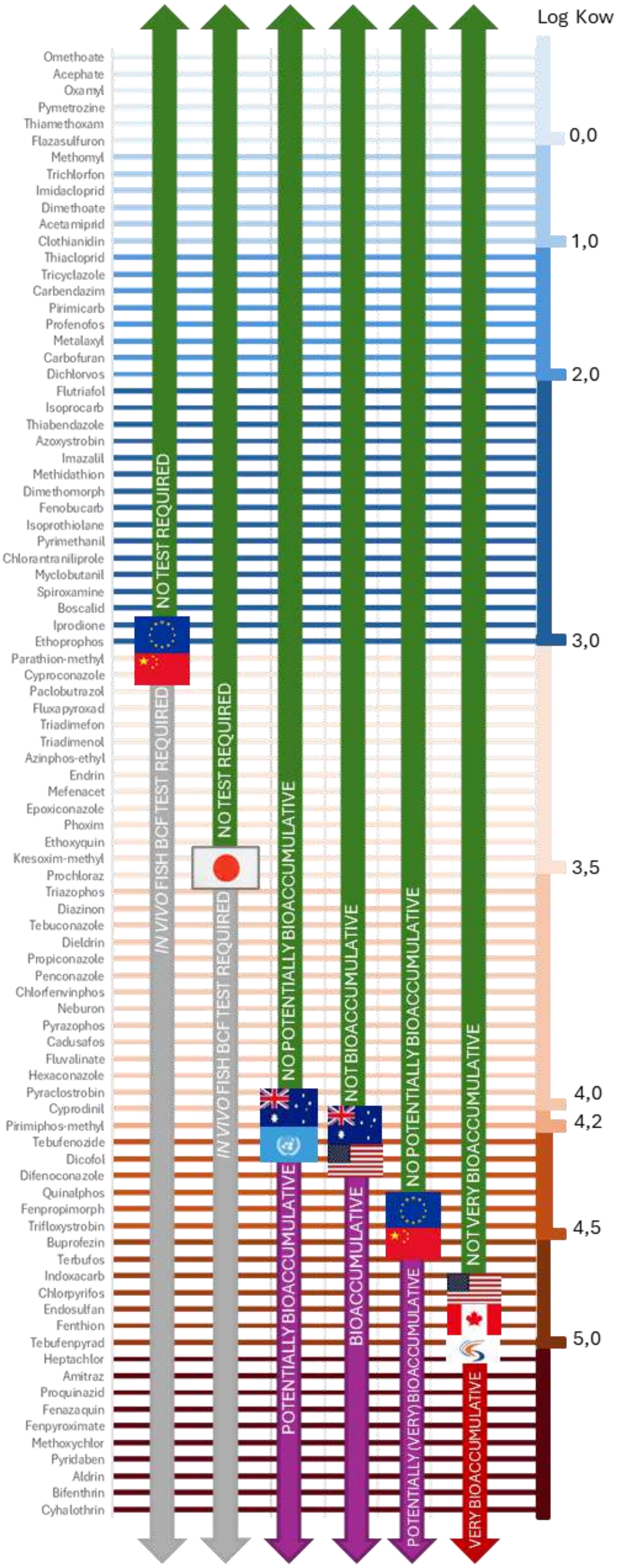


Figure 11- Worldwide regulatory cut-off values for log Kow.

Subtitle: 🇪🇺 European Union – REACH Regulation (EC) No. 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (*Regulation - 1907/2006 - EN - REACH - EUR-Lex*, 2024); Guidance on information requirements and chemical safety assessment, Chapter R.11: PBT Assessment (ECHA, 2017); 🇨🇳 China - Measures for the Environmental Management Registration of New Chemical Substances Order n◦12, (CIRS, 2021); 🇯🇵 Japan - Chemical Substances Control Law (METI, 2024); 🇺🇳. United Nations – Globally Harmonised System of Classification and Labelling of Chemicals, Rev.9 (UNECE, 2021) and; European Union – CLP Regulation (EC) No 1272/2008 of the European Parliament and of the Council on Classification, Labelling and Packaging of substances and mixtures (*Regulation - 1272/2008 - EN - clp regulation - EUR-Lex*, 2024); 🇦🇺 Australia - Australian Industrial Chemicals Introduction Scheme (Industrial Chemicals, 2024); 🇺🇸 USA - Toxic Substances Control Act (TSCA) (O. Us Epa, 2015); 🇨🇦 Canada - Canadian Environmental Protection Act (*CEPA registry - Canada.Ca*, 2024); United Nations - Stockholm Convention: Stockholm Convention on Persistent Organic Pollutants (UN, 2024).

According to GIMENO et al., (2024), Log Kow values of 3 in Europe and China and 3.5 in Japan are overly conservative and lead to unnecessary tests on vertebrate animals. Thus, the authors analyzed a large dataset of chemicals with experimental Log Kow and BCF data available and indicated a Log Kow cutoff value of 4.5. Compounds with Log Kow values below 4.5 have the potential for bioaccumulation, whereas those with Log Kow values above 4.5 are not potentially bioaccumulative.

In this sense, the pesticides Terbufos, Indoxacarb, Chlorpyrifos, Endosulfan, Fenthion, Tebufenpyrad, Heptachlor, Amitraz, Proquinazid, Fenazaquin, Fenpyroximate, Methoxychlor, Pyridaben, Aldrin, Bifenthrin, Cyhalothrin, besides posing a risk to aquatic organisms, have the potential for bioaccumulation. Tebufenpyrad, Heptachlor, Fenazaquin, Fenpyroximate, Pyridaben, Aldrin, Bifenthrin, and Cyhalothrin stand out for their high acute and chronic risks to aquatic organisms.

In the comparison of different classifications, shows that Japanese legislation considers that several pesticides require specific bioaccumulation tests, while in the European Union, UN, China, United States, Australia, and Canada, they are classified as non-bioaccumulative. These differences highlight the importance of standardizing risk assessment methods globally to improve the efficiency of regulatory processes and reduce the redundancy of animal testing.

These discrepancies in classifications and testing requirements demonstrate how pesticide regulation varies globally, directly influencing agricultural practices and environmental safety policies in each country or region. A harmonized approach, based on robust scientific data as presented by GIMENO et al., (2024), can optimize pesticide regulation, minimizing negative environmental impacts and reducing the number of vertebrate animal tests.

2.7 FUTURE PERSPECTIVES

Although there have been advances in legislation to balance the benefits and risks of pesticide applications, this review has identified the urgent need to expand regulations on these compounds. 63 pesticides have been identified in various countries, presenting high environmental risks and still lacking limits or restrictions on their use and presence in water. Furthermore, there is a need to extend regulations to different regions, as 49 pesticides are controlled in one specific region or country but pose high environmental risks in other areas.

Another challenge lies in studies showing that pesticide target organisms are becoming increasingly resistant, necessitating the continuous development of new compounds, which may be even more toxic. Therefore, the importance of developing and utilizing environmentally safer pesticides is emphasized. Green pesticides demonstrate good efficacy in pest control, are safe for application, and do not accumulate in the environment or food chain.

Green pesticides have become a commercially viable option for several reasons. These include the prohibition of many chemical pesticides, the facilitation of biopesticide registration in the United States, Canada, India, Brazil, and China, the growing consumer expectations for pesticide-free products, and the development of pest resistance (Lykogianni, Bempelou, Karamaouna, and Aliferis, 2021). Nevertheless, they still need to be utilized and registered, especially in developing countries. In these countries, due to a lack of awareness, trust, and acceptability, green pesticides are often associated with high costs and inconsistent performance. Hence, there is a need for studies on the occurrence and assessment of ecological risks and human health in developing countries to enhance the appreciation of green pesticides compared to synthetic ones.

Lastly, it is crucial to underscore that water treatment processes must take into account the persistence of these compounds, even with advancements in legislation and usage restrictions. This is because these compounds can still be identified in water sources. Therefore, the adoption of advanced treatment processes is strongly encouraged, as the removal of pesticides in conventional Water Treatment Plants is limited.

2.8 FINAL CONSIDERATIONS

This review has provided relevant contributions regarding the occurrence of pesticides in surface and groundwater in different countries, their toxicity, and environmental risks. With an emphasis on environmental legislation and the classifications of bioaccumulation potential, it was possible to ascertain the criticality of the presence of these compounds in water and how much progress still needs to be made to ensure environmental safety.

A total of 112 pesticides have been identified as posing a significant environmental risk and have been classified by the authors into three distinct groups. Of these, 63 pesticides in Group 1 warrant particular attention due to the lack of restrictions or concentration limits for their use in surface and groundwater across the countries studied. Consequently, it is imperative to prioritize the development and implementation of pesticides that are more environmentally benign. Moreover, advanced water treatment technologies should be prioritized, as conventional processes are inadequate for effectively removing these pesticides.

CHAPTER 3

3 MEMBRANE SEPARATION PROCESSES FOR PESTICIDE REMOVAL FROM WATER: EFFICIENCY, CHALLENGES, AND HEALTH RISK MITIGATION

3.1 INTRODUCTION

The term pesticide refers to any substance or mixture of substances of chemical or biological ingredients intended to repel, destroy, or control any pest or regulate plant growth (HASSAAN; EL NEMR, 2020). Although many authors consider pesticide use necessary due to the increasing demand for food and the expansion of monocultures, it is essential to highlight that its irresponsible use—such as excessive application, lack of proper management practices, or failure to adhere to safety guidelines—poses significant risks to the environment and human health (MUNIR et al., 2024; RANI et al., 2021).

Pesticides can reach humans through multiple routes, posing risks to human health (CHAUDHARY et al., 2024; Figure 12). Direct exposure often happens during pesticide application, particularly among agricultural workers who lack proper protective equipment (EUROPEAN ENVIRIONMENT AGENCY, 2023; TUDI et al., 2022). Indirect exposure occurs when the general population inhales airborne particles, such as pesticide drift during spraying operations (CHAUDHARY et al., 2024; EUROPEAN ENVIRIONMENT AGENCY, 2023), or consumes contaminated food and drinking water containing pesticide residues (DE MEDEIROS; MONTAGNER, 2024; DE OLIVEIRA; AGOSTINETTO; SIEGLOCH, 2023; MUNIR et al., 2024; SUN et al., 2024). Studies have detected significant pesticide levels in vegetables and fruits and in drinking water sources near treated fields (EUROPEAN COMMISSION, 2023; ISCI; GOLGE; KABAK, 2025). After entering the human body, these compounds can interfere with critical biological systems, being linked to hormonal disorders, neurological damage, congenital malformations, cardiovascular disorders, and an increased risk of cancer development (such as prostate cancer, non-Hodgkin’s lymphoma, and leukemia). (AHMAD et al., 2024; TUDI et al., 2022). Research highlights that these contaminants are particularly harmful to the endocrine system, with many pesticides acting as hormonal disruptors, and the nervous system, as evidenced in cases linked to Parkinson's disease (AHMAD et al., 2024; RANI et al., 2021).

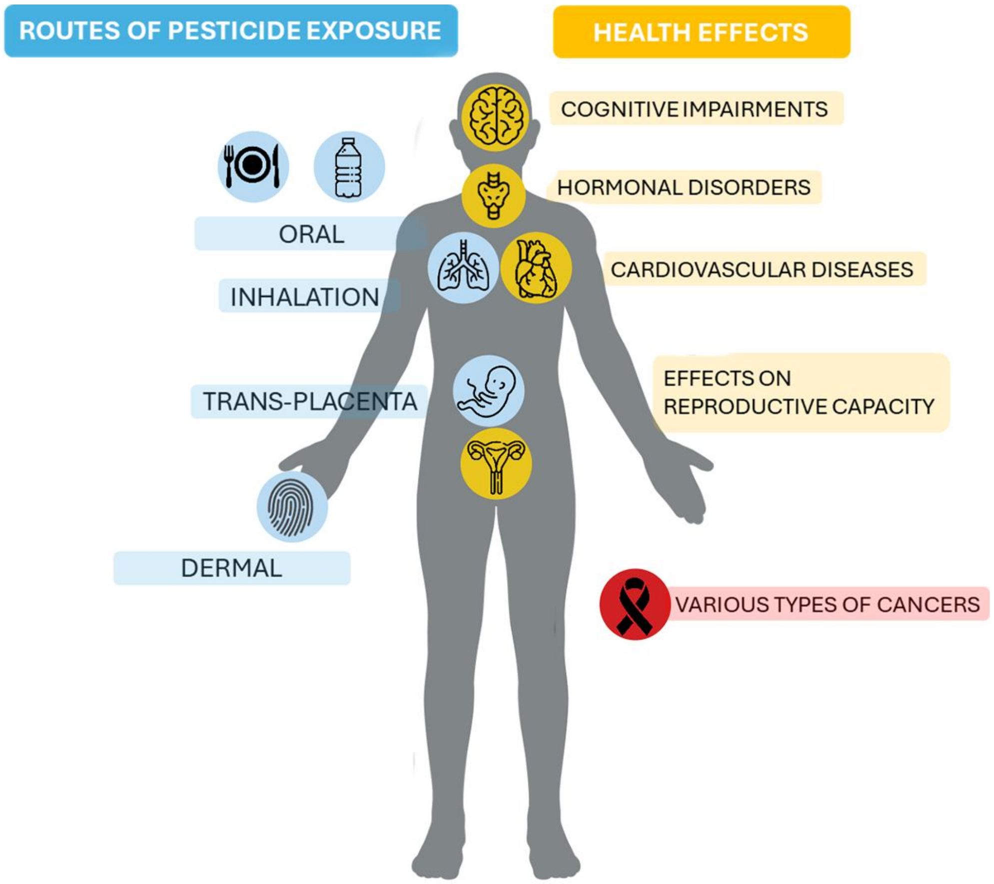
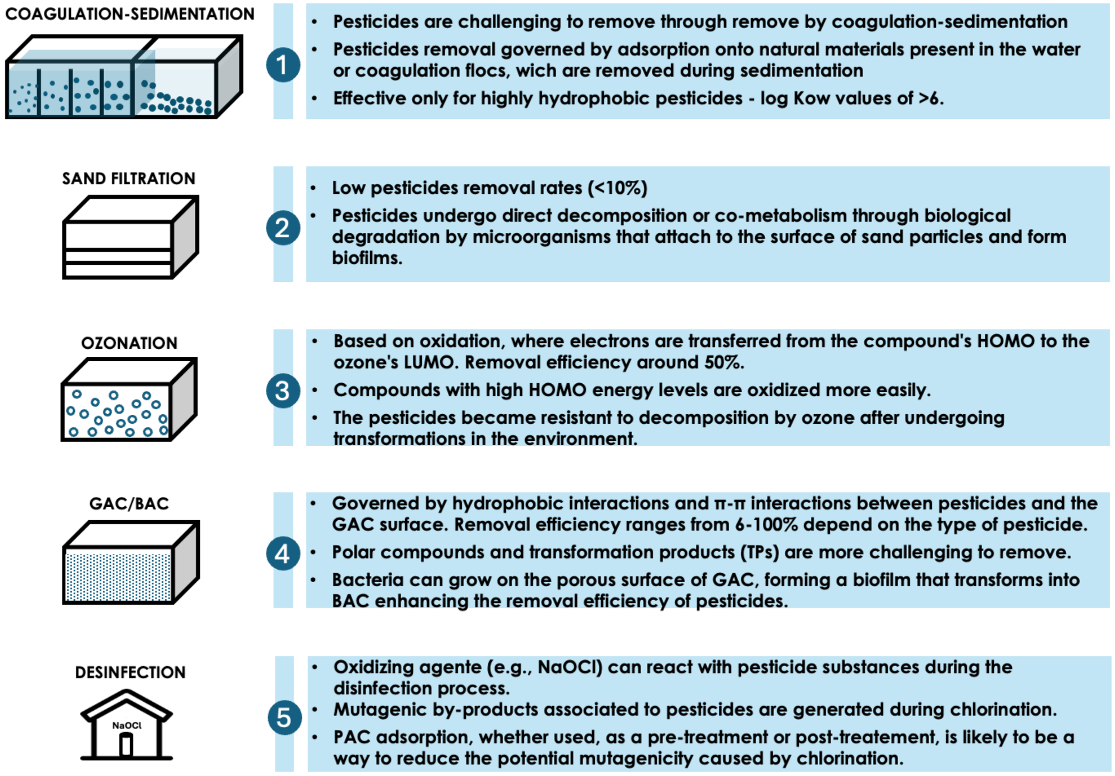


Figure 12 - Pesticide exposure pathways and health impacts related to their exposure.

Many pesticides are frequently detected in surface and groundwater around the world (FARAH et al., 2024)Although these pesticides are typically present in surface and groundwater at trace concentrations of ng/L to µg/L levels, prolonged exposure through various pathways may still pose significant health risks to humans. To safeguard public health, national governments have established guideline levels for pesticides in drinking water. These guidelines vary depending on socio-economic, dietary, geographical, and industrial factors. For example, in the European Union, strict regulations limit pesticide concentrations in drinking water to trace levels, with a maximum of 0.1 µg/L for any single pesticide and 0.5 µg/L for the total sum of pesticides have been considered (EUROPEAN COMMISSION, 2006). While water treatment plants (WTPs) are constructed to ensure access to safe drinking water, research indicates that conventional treatment methods are not particularly effective in removing pesticides from water (BROVINI et al., 2023; MATSUSHITA et al., 2018; TAO et al., 2024). **Figure 13** highlights the key aspects of pesticide removal in conventional drinking water treatment processes.



COAGULATION-SEDIMENTATION

1
- Pesticides are challenging to remove through remove by coagulation-sedimentation
- Pesticides removal governed by adsorption onto natural materials present in the water or coagulation flocs, wich are removed during sedimentation
- Effective only for highly hydrophobic pesticides - log Kow values of >6.

SAND FILTRATION

2
- Low pesticides removal rates (<10%)
- Pesticides undergo direct decomposition or co-metabolism through biological degradation by microorganisms that attach to the surface of sand particles and form biofilms.

OZONATION

3
- Based on oxidation, where electrons are transferred from the compound's HOMO to the ozone's LUMO. Removal efficiency around 50%.
- Compounds with high HOMO energy levels are oxidized more easily.
- The pesticides became resistant to decomposition by ozone after undergoing transformations in the environment.

GAC/BAC

4
- Governed by hydrophobic interactions and π-π interactions between pesticides and the GAC surface. Removal efficiency ranges from 6-100% depend on the type of pesticide.
- Polar compounds and transformation products (TPs) are more challenging to remove.
- Bacteria can grow on the porous surface of GAC, forming a biofilm that transforms into BAC enhancing the removal efficiency of pesticides.

DESINFECTION

5
- Oxidizing agente (e.g., NaOCl) can react with pesticide substances during the disinfection process.
- Mutagenic by-products associated to pesticides are generated during chlorination.
- PAC adsorption, whether used, as a pre-treatment or post-treatement, is likely to be a way to reduce the potential mutagenicity caused by chlorination.

Figure 13 - Removal pesticides for different technologies widely used in drinking water treatment plant. HOMO – highest occupied molecular orbital; LUMO - lowest unoccupied molecular orbital; BAC – biological activated carbon; GAC - granular activated carbon ((BROVINI et al., 2023)

However, it is equally crucial to understand the fate and toxicity of byproducts generated by different approaches, such as oxidation processes and biological treatments, which often lead to complex, not easily biodegradable byproducts (BABU PONNUSAMI et al., 2023). Chlorine, widely used as a disinfectant in the final stage of drinking water treatment, can react with pesticides present in the water, leading to the formation of a wide range of by-products. This reaction significantly increases the water's mutagenicity (TAKANASHI et al., 2013). Since oral ingestion is the most common route of exposure to these contaminants (TUDI et al., 2022) the development of advanced treatment technologies has become essential for effectively removing micropollutants, including pesticides and their transformations products from water supplies (DE MEDEIROS; MONTAGNER, 2024). In this context, membrane separation processes stand out not only in terms of efficiency and low environmental impact, but also due to their reduced generation of complex byproducts and greater operational robustness under varying conditions. These attributes make membrane technologies an especially promising alternative for the treatment of pesticides and other micropollutants (COUTO; LANGE; AMARAL, 2019).

Despite requiring water pre-treatment to prevent fouling that could compromise their efficiency, membrane separation processes have been shown to offer complete removal of persistent pesticides. Additionally, their ability to operate without chemical reagents helps minimize the generation of by-products. In this context, this study investigates the potential of membrane separation processes for the removal of pesticides from water, emphasizing critical and fundamental aspects of the topic. The properties of membranes, including constituent materials and structural characteristics, were evaluated to determine their influence on separation efficiency. The impact of the physicochemical properties of pesticides was examined, as well as the effects of the presence of mixtures of multiple compounds on removal efficiency. Furthermore, operational challenges related to membrane fouling were addressed, and the risks to human health associated with pesticide contamination were assessed, highlighting the role of membrane technologies in mitigating these impacts.

3.2 METHODOLOGY

A systematic search of studies published in the last seven years (since 2017) was conducted to gather data on the efficiency of different membrane separation technologies in removing pesticides from water. Relevant literature was searched through platforms such as Science Direct and Google Scholar, using keywords like "pesticide removal and membrane treatment and drinking water." Data extracted from each study included authors, year of publication, target pesticides, membrane treatment process used, membrane characteristics, removal efficiency, pesticide concentration at the system inlet, and operational data such as pressure, temperature, flow rate, and system scale. The number of articles and occurrences of each matrix are presented in **Figure 14**.

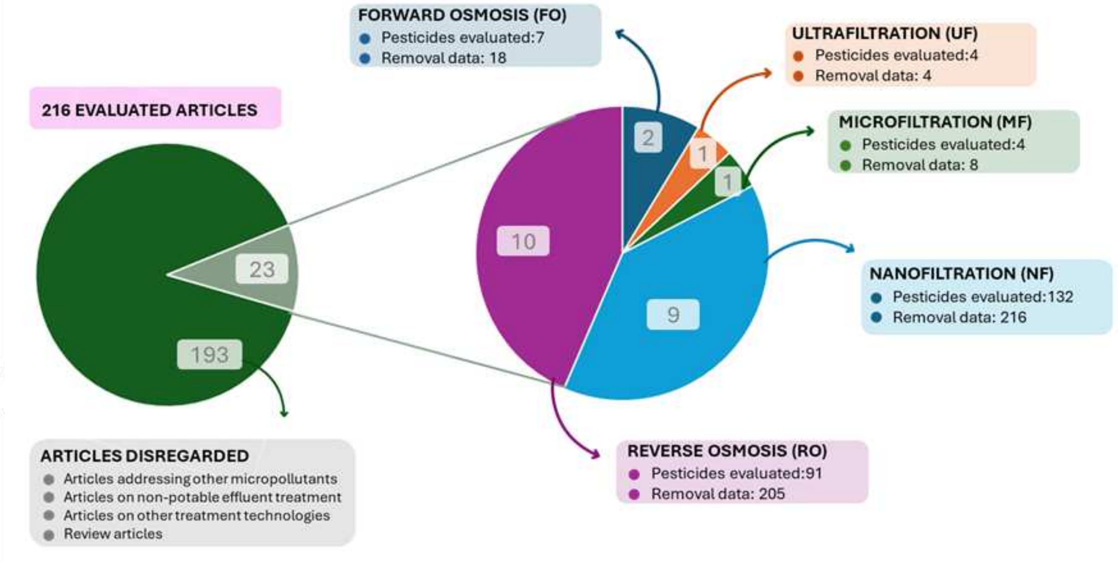


Figure 14 - Quantitative detailing of the systematic review.

The article selection targeted specific studies on pesticide-contaminated water treatment using membrane separation technologies. Articles addressing other micropollutants, non-potable wastewater treatment, or other treatment technologies were excluded, as well as review articles. Although the initial search included 216 articles, only 23 were considered relevant to the study. Among the technologies, nanofiltration (NF) was the most studied, with 132 pesticides evaluated, totalling 216 removal records documented. Reverse osmosis (RO) followed, analysing 91 pesticides and providing 205 removal data records. Forward osmosis (FO) investigated 7 pesticides, resulting in 18 removal records. Microfiltration (MF) and ultrafiltration (UF) showed more modest numbers, evaluating 4 pesticides each, with 8 and 4 removal records, respectively. This analysis highlights the predominance of RO and NF in the literature, emphasizing their efficiency and extensive application in pesticide removal. In contrast, the limited number of studies on MF and UF is likely attributable to their low removal potential for pesticides. Meanwhile, FO remains underexplored, with a smaller volume of available data, pointing to promising opportunities for future research in this area.

In this study, widely used commercial membranes were considered and evaluated to provide technical support for decision-making related to pesticide removal. This approach sought to encompass both a general perspective on the efficiency of separation processes and analyses for specific compounds, contributing to the identification of suitable technologies for different treatment scenarios.

Moreover, the potential for reducing health risks associated with pesticide contamination during water treatment using membrane technologies was specifically evaluated. To achieve this, a widely accepted methodology was employed, focusing on the calculation of the risk quotient for human health (R(H)Q). This parameter quantifies the potential health risk posed by a pollutant and is determined as the ratio of the measured environmental concentration (MEC) to the drinking water equivalent level (DWEL) (COUTO; LANGE; AMARAL, 2019; EUROPEAN COMMISSION, 1996), as shown in **Equation 1**. This method is preferred due to its simplicity and ability to provide a quantitative measure of risk that is directly comparable across different pollutants and exposure scenarios.

$$R(H)Q = {}^{MEC}/_{DWEL} \tag{1}$$

This approach was applied to assess the health risk associated with pesticide concentrations before and after membrane treatment, allowing a direct evaluation of the risk reduction achieved by the technology. The DWEL is derived from critical toxicological reference values, such as the tolerable daily intake (TDI) or reference dose (RfD), and accounts for body mass (BM), water contribution to exposure (F), and daily water consumption (C), as shown in **Equation 2**.

$$DWEL = {}^{(TDI\ or\ RfD)\ x\ BM\ xF}/_{C} \tag{2}$$

This analysis was conducted for different population groups, including adults, children, and infants, with specific values for body mass and daily water consumption as outlined in **Table 4**.

Table 4 - Body Mass and Daily Water Consumption Values

CLASSIFICATION	BODY MASS - BM	DAILY WATER CONSUMPTION – C
ADULT	60 kg	2 L
CHILD	15 kg	1.5 L
INFANT	5 kg	0.75 L

Source: (WORLD HEALTH ORGANIZATION (WHO), 2022)

Some of the evaluated studies enriched the samples with the pesticides under investigation, resulting inlet concentrations significantly higher than those typically observed in environmental matrices such as surface water or groundwater. For instance, the pesticide pirimicarb has been detected in surface waters in China (XU et al., 2020) and England (TAYLOR et al., 2021) at concentrations of 0.0006 μg/L and 0.001 μg/L, respectively. However, studies evaluating the removal potential of this compound, using processes such as nanofiltration (DAGHER et al., 2024) and reverse osmosis (FUJIOKA et al., 2020), apply initial concentrations of 1 μg/L and 5 μg/L, respectively, values that are at least 1,000 times higher than those observed in natural waters. Therefore, for human health risk assessment, only data with concentrations up to 10 times higher than those observed in surface or groundwater in occurrence studies identified in the literature were considered (FARAH et al., 2024). Additionally, to ensure a conservative analysis, in cases where pesticides were evaluated more than once for the same membrane separation process, the lowest recorded removal value was selected. These assumptions were fundamental to ensuring that the presented results were as precautionary and representative of reality as possible. The assessment classified the risk quotient (R(H)Q) into four categories based on the associated health risk, following the European Commission (1996) guidelines: High Risk: $R(H)Q > 1$; Medium Risk: $0.1 \leq R(H)Q \leq 1$; Low Risk: $0.01 \leq R(H)Q < 0.1$; and Insignificant Risk: $R(H)Q < 0.01$ (EUROPEAN COMMISSION, 1996).

By incorporating this analysis, the study provides a robust framework to quantify the reduction in health risks achieved through membrane-based water treatment technologies, highlighting their effectiveness in mitigating pesticide-related health concerns.

3.3 REMOVAL OF PESTICIDES BY MEMBRANE SYSTEMS

Pesticides can be categorized based on various factors, including their chemical structure, risk to human health, and target organisms (PATHAK et al., 2022). Depending on the specificity of the target organism, pesticides may be classified into groups such as insecticides, herbicides, fungicides, acaricides, bactericides, rodenticides, and others. Among these categories, herbicides, fungicides, and insecticides represent the largest number of compounds, which are the focus of this study. The transportation of solute (pesticides) across a porous or dense membrane is influenced by various factors (**Figure 15**). For dense membranes such as NF, RO and FO, the process is governed by the solution-diffusion theory, which is influenced by interactions between solutes and the membrane, including size exclusion, electrostatic repulsion, and adsorption. In porous membranes (MF and UF), the transport occurs through convective flow within the pores. The extent and efficiency of solute transport depend on the interaction between the solute properties and the membrane's structure, affecting both selectivity and permeability.

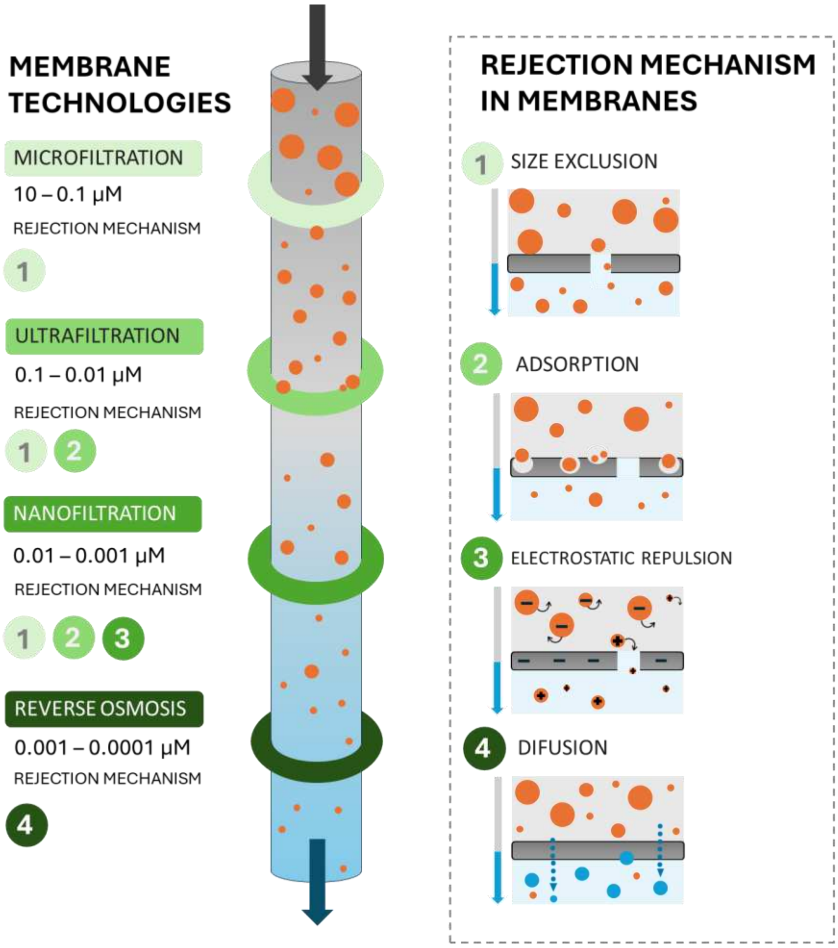


Figure 15 - Membrane separation technologies and their main mechanisms of pesticide rejection

Figure 16 shows the efficiency of MF, UF, NF, RO and FO membrane technologies in removing pesticides (fungicides, insecticides, and herbicides) during drinking water treatment. It is noteworthy that of the 171 pesticides studied, 20% have their use banned in the European or the United States. The fungicide Carbendazim emerged as the most examined due to its extensive agricultural application and stringent regulatory scrutiny, particularly in regions like the European Union where it has been banned due to its persistence and potential risks to human health and aquatic ecosystems (ZHOU et al., 2023). Among insecticides, DDT and Chlorpyrifos were widely studied. Despite being banned in most countries, DDT remains a focal point of research because of its high persistence, bioaccumulative properties, and endocrine-disrupting effects (STOCKHOLM CONVENTION ON PERSISTENT ORGANIC POLLUTANTS, 2024). Chlorpyrifos, which has faced increasing regulatory restrictions due to its neurotoxicity, particularly in children, has also been prohibited in many nations, further emphasizing its significance in water treatment studies (US EPA, 2024). For the herbicides Glyphosate, Atrazine, and Metolachlor stood out. Glyphosate, one of the most widely used herbicides globally, is often studied for its presence in water sources, despite ongoing debates about its health and environmental risks (WORLD HEALTH ORGANIZATION (WHO), 2005). Atrazine, heavily regulated in places like the European Union due to its potential to contaminate groundwater, and Metolachlor, known for its harmful effects on aquatic organisms, also garnered considerable research attention.

a)


Removal (%)
0
10
20
30
40
50
60
70
80
90
100
4,4'-DDE
4,4'-DDT
Acetamiprid
Aldrin
Bifenthrin
Carbaryl
Carbofuran
Carbofuran-3-hydroxy
Chlorantraniliprole
Chlorpyrifos
Cyantraniliprole
Cyromazine
DEET
Diazinon
Dicofol
Dieldrin
Dimethoate
Endosulfan
Ethion
Fenobucarb
Fipronil-sulfide
Flonicamid
Imidacloprid
Isoprocarb
Lindane
Malathion
Methyl parathion
Monocrotofos
op-DDD
op-DDE
op-DDT
Oxydemeton-methyl
Parathion
Permethrin
pp-DDD
pp-DDE
pp-DDT
Pirimicarb
Propoxur
Pymetrozine
Spirotetramat
Tebufenpyrad
Thiamethoxam
Tiacloprid
α-Cypermethrin
α-Endosulfan
β-Endosulfan
β-HCH
γ-HCH
δ-HCH
α-HCH
◆ MF
■ UF
● NF
▶ RO
✚ FO

b)


Removal (%)
0
10
20
30
40
50
60
70
80
90
100
2,6-dichlorobenzamide (BAM)
MCPA
Acetochlor
Alachlor
AMPA
Ametryn
Atrazine
Atrazine-2-hydroxy
Atrazine-desethyl
Atrazine-desethyl-2-hydroxy
Atrazine-desethyl-deisopropyl
Atrazine-desisopropyl
Bentazon
Butachlor
Carbetamide
Chloridazon
Chloridazon-desphenyl
Chloridazon-methyl-desphenyl
Chlorsulfuron
Clethodime
Clopyralid
Cyanazine
Cycloxydime
Desmetryn
Dimethachlor CGA 369873
Dimefuron
Diuron
Ethidimuron
Flazasulfuron
Florasulam
Fluroxypyr
Flurtamone
Glyphosate
Hexazinone
Hydroxyatrazine
Imazamethabenz
Imazamox
Imazapyr
Iodosulfuron-methyl
Ioxynil
Irgarol
Isoproturon
Isoxaben
Lenacil
Mefenacet
Mesosulfuron-methyl
Mesotrione
Metamitron
Metazachlor
Metolachlor
Metolachlor ESA
Metolachlor OXA
Metribuzine
Metsulfuron-methyl
Nicosulfuron
Norflurazon
Paclobutrazol
Paraquat
Pendimethalin
Pethoxamide
Pretilachlor
Prometon
Prometryn
Propazine
Propyzamide
Prosulfuron
Pyroxsulam
Quinmerac
Secbumeton
Simazine
Simazine Hydroxy
Sulcotrione
Sulfosulfuron
Tebuthiuron
Tembotrione
Terbuthylazine
Terbuthylazine-2-hydroxy
Terbuthylazine-desethyl
Terbutryn
Terbumeton-desethyl
Thifensulfuron-methyl
Trinexapac ethyl
◆ MF
■ UF
● NF
▶ RO
✚ FO

c)

Figure 16 - a) Insecticide; b) Herbicide; and c) Fungicide removal efficiency for MF, UF, NF, RO and FO membrane technologies. (**APPENDICE B – Table S2**).

As expected, MF and UF demonstrated limited effectiveness across all pesticide classes, with removal rates generally below 50%. In some cases, certain compounds were not retained at all. This limitation is largely due to the larger pore size of UF membranes, which are more suited for filtering particles and macromolecules but constraint to retain low-molecular-weight pesticides. Conversely, nanofiltration and reverse osmosis membranes have demonstrated high efficiency in the removal of pesticides, as evidenced by the analysed data. Nanofiltration achieved rejection rates exceeding 90% in 66.7% of the analyses, with an average rejection rate of approximately 85%. Reverse osmosis attained these rates in 58.5% of the analyses, presenting an average rejection rate of about 88%. These results underscore the effectiveness of membrane technologies in treating pesticide-contaminated water, positioning reverse osmosis as a robust and reliable option for ensuring the quality of treated water, while nanofiltration offers a high removal rate in a greater proportion of cases.

NF, RO, and FO membranes are generally effective technologies for water treatment, as they exhibit high rejection rates for pesticides. However, for certain compounds, rejection rates reported in the literature vary widely, such as Carbofuran (65.5–100%), 2,6-dichlorobenzamide (30.2–97.1%), Atrazine (45.0–99.9%), Carbendazim (59.6–88.6%), and Tricyclazole (77.2–88.1%). Some pesticides, on the other hand, show lower rejection rates, including Malathion (43.9–69.0%), Methyl parathion (41.7–58.8%), Monocrotophos (31.7–42.1%), Parathion (49.5–62.9%), Chloridazon-desphenyl (35.5%), Ioxynil (83.2%), Propyzamide (62.5%), Dichloran (38.3%), and Diphenylamine (56.1%). These variations indicate that the efficiency of pesticide removal depends on several factors, such as membrane material, pesticide properties (e.g., molecular weight, hydrophobicity, and charge), and operational conditions (e.g., pressure, temperature, and feed water composition).

Although the removal of pesticides by different membrane systems have been extensively reported in literature (BOUSSOUGA; FREY; SCHÄFER, 2021; JACOB et al., 2012; LIPP; SACHER; BALDAUF, 2010; YANGALI-QUINTANILLA et al., 2010; YUN; CHUNG; KWAK, 2018), the comparison of pesticide removal performance among these membrane technologies should be approached with caution, as there are no standardized testing protocols to assess their efficiency against a broader range of pesticide types. Studies are often conducted using different membranes under varying operational conditions. Additionally, some studies focus on limited sets of contaminants, which may not fully represent real-world situations where multiple pesticides coexist simultaneously. Moreover, several authors utilized feeds with pesticide concentrations that are one or more orders of magnitude greater than the concentrations found in real surface waters and effluents (KHAIRKAR et al., 2020; SAMARI; HEYDARI; GHOLAMI, 2024; WANG et al., 2022; ZHANG et al., 2004). One of the reasons for that is the challenging quantification of these organic compounds in low concentrations (NARENDERAN; MEYYANATHAN; BABU, 2020), usually found bellow one microgram per litre (or ppb) (FARAH et al., 2024). The use of high concentrations in the feed can lead to false results since the retention of solutes is lower at higher solute concentrations (MUKHERJEE et al., 2020a; NIKBAKHT FINI; MADSEN; MUFF, 2019). MUKHERJEE et al., (2020) observed that increasing the initial pesticide concentrations in the feed from 20 to 100 μg/L led to a slight increase average rejection (from 83.1 to 84.5 %) own to the fouling caused by pesticide interactions with the membrane (flux declined from 20.1 to 17.9 L/ m^2 h), which can also lead to higher rejection rates for some pesticides.

Therefore, it is important to evaluate the pesticide removal performance of each membrane at conditions as close as possible to the ones encountered at water treatment plants. Nevertheless, besides the complex quantification, low concentrations can lead to higher removals since the pesticides can be partially or totally adsorbed by the membrane. Dagher et al. (2024) studied the performance of two commercial nanofiltration (NF) membranes with molecular weight cut-offs (MWCO) of 400 and 800 Da for removing 164 pesticides and their metabolites, each initially present at a concentration of 1 μg/L. After 48 hours of feed recirculation without applied pressure, the results showed that 68 to 102 pesticides, depending on the membrane model, were completely adsorbed, especially those with log D > 3 methods.

3.4 FACTORS AFFECTING MEMBRANA RETENTION OF PESTICIDES

The retention of micropollutants, such as pesticides, by NF and RO membranes is a combination of several parameters, since it is strongly dependent on the membrane properties (e.g. pore size, surface charge, composition), operating conditions (e.g. permeate flux, pressure, crossflow velocity, pH, feed concentration, water matrix, recovery factor, and temperature) and the physical chemical properties of the pesticides, such as molecular mass, hydrophobicity (expressed as log P, log D, or log K_{OW}), polar surface area, charge, polarizability, and shape (BOUSSOUGA; FREY; SCHÄFER, 2021; DAGHER et al., 2024a; IMBROGNO et al., 2025; JACOB et al., 2012; LIPP; SACHER; BALDAUF, 2010; YANGALI-QUINTANILLA et al., 2010). All these properties will influence on the size exclusion and solution-diffusion separation mechanisms, as well as in the electrostatic interactions, as schematically show in **Table S1 (APPENDICE B)**.

3.4.1 Effect of the membrane properties

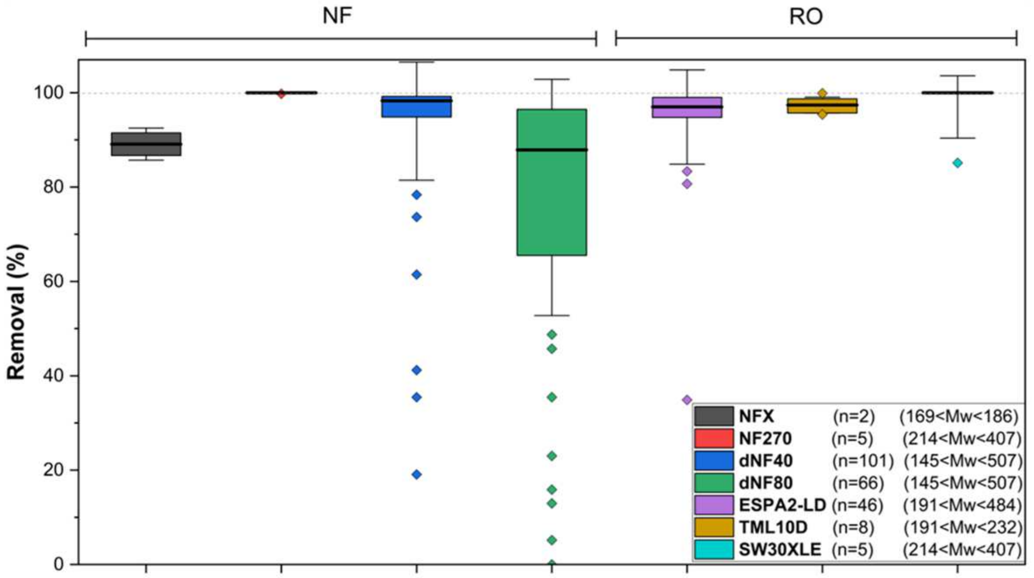
The membrane material plays a crucial role in the pesticide–water–membrane system, significantly influencing rejection performance through physico-chemical interactions. Studies have demonstrated that composite polyamide (PA) membranes surpass cellulose acetate (CA) membranes in rejecting various micropollutants, including pesticides (CAUSSERAND et al., 2005; PLAKAS; KARABELAS, 2012). This superiority is primarily attributed to the lower polarity of PA membranes, which enables better rejection of highly polar pesticides compared to the more polar CA membranes (PLAKAS; KARABELAS, 2012). Comparing PES (Polyethersulfone) and PA, while PA has a slight negative charge, PES is neutral (PATEL; NATH, 2014). In addition, it has been reported that PA is more hydrophobic (contact angle of 52°) than PES (contact angle 73°) (PATEL; NATH, 2014; PLAKAS; KARABELAS, 2012). These facts can explain why PES membranes have lower rejection of non-polar compounds than PA. For example, NF270 (PA) membrane had higher rejections (nearly 100 %) of Aldrin (Mw = 364.9 g/mol, log P = 6.5) and Lindane (Mw = 290.8 g/mol, log P = 3.7)

(SEAH et al., 2024), while for a NF TFC (PES) membrane, rejections were 93.5 and 92.0 %, respectively (ASGARI et al., 2024).

Regarding membrane charge, most of the commercial thin-film composite (TFC) membranes are negatively charged (PLAKAS; KARABELAS, 2012), which minimizes the adsorption of negatively charged pesticides (when feed pH > pKa) and increases their rejection own to the electrostatic repulsion. Fujioka et al. (2020) studied the removal of 158 pesticides by RO (ESPA2 membrane) and observed that the rejection of negatively charged pesticides was higher than the fitted line (rejection *versus* molecular mass) of uncharged pesticides, except for the small pesticide Thidiazuron (Mw = 220.3 g/mol, logP = 1.8, pKa = 8.9), which removal was 43 %. In this way, the presence of charged compounds in the feed can also affect the rejection (PLAKAS; KARABELAS, 2012). For example, the accumulation of natural organic matter (NOM), such as humic substances, contributes for membrane fouling during filtration of surface and ground water, and can increase membrane surface negativity, thus increasing rejection of negatively charged compounds (DEVITT et al., 1998).

Figure 17 shows the pesticides rejections by commercial membranes and the respectively main properties of the membranes. Among NF membranes, NFX and NF 270 have the highest $MgSO_4$ rejection rates, and consequently lowest MWCO values, followed by dNF40, and dNF80 with the highest MWCO. This difference can explain why for pesticides with Mw lower than 200 g/mol, the dNF80 membrane has lower rejections (from 0 to 70 %) than dNF40 (from 20 to 97 %). Moreover, the standard deviation of the rejections obtained with dNF80 membrane are higher than with dNF40 (**Figure 17**) as expected for the lower MWCO of dNF40 membrane. The NFX membrane, with its denser structure, exhibited higher rejection rates than the other NF membranes for compounds within the same molecular weight range. Notably, in studies summarized in **Figure 18**, the NFX membrane was used to remove pesticides with lower molecular weights (<200 Da) compared to those examined in studies using the NF270 membrane, for example. These results underscore the limitations of characterizing global pesticide removal by membranes based solely on the membrane MWCO values, without considering the specific properties of the pesticides. This comparison may be fragile even for comparing pesticides with the same MWCO, since they may share the same molecular mass but differ in conformation and other physical properties. These differences influence molecule–membrane interactions and permeation behaviour.

Regarding RO membranes (ESPA2-LP, SW30XLE, TML10D), all the three reported membranes have very similar NaCl rejections (>99.6 %) and compositions (polyamide-based). Consequentially, all exhibited a high pesticide rejection, with a median of 97.0 % (n=54). The membrane SW30 is slightly less hydrophilic (lower contact angle) and has a more negative zeta potential than ESPA2 and TLM10D membranes, which may explain the higher pesticides retentions reported for this membrane (**Figure 17**), since a great part of pesticides are hydrophobic and, when charged, they have a negative charge.



MEMBRANE	NFX	NF270	dNF40	dNF80	ESPA2 LD	TLM10D	SW30 XLE
SUPPLIER	Synder Filtration	Dupont	NX Filtration	NX Filtration	Hydranautics	Toray	Dupont
SELECTIVE LAYER MATERIAL	PA	Piperazine based PA	Modified PES	Modified PES	Composite PA	Crosslinked aromatic PA	PA
CONTACT ANGLE (°)		53			61.3	58.3	54.9
ZETA POTENTIAL AT pH 7 (mV)		-15.0			-26.0	-27.4	-33.7
MWCO (Da)	150-300	200-400	400	800	-	-	-
$MgSO_4$ REJECTION (%)	99	97	81	76	-	-	-
NaCl REJECTION	40	50	-	-	99.6	99.8	99.8

Figure 17 - Boxplot of the removal of pesticides by commercial membranes and with their respectively properties. PES: polyethersulfone, PA: polyamide, MWCO: molecular weight cut-

off. Membrane properties source: (RAMDANI et al., 2021), (HIDALGO et al., 2023),(DAGHER et al., 2024),(MOHAMMAD et al., 2015),(MUNNI et al., 2024),(KIM; LEE; HONG, 2012),(RHO; CHON; CHO, 2019).

Wide variations of rejection for some pesticide suggests that size exclusion is not the only mechanism governing rejection, which also occurs by solution-diffusion and is affected well as by the electrostatic interactions (CHEN et al., 2004; DAGHER et al., 2024a; FUJIOKA et al., 2020a; RODRÍGUEZ-ALEGRE et al., 2024; SEAH et al., 2024). In this way, the rejection of pesticides is affected by the membrane properties, such as surface charge, roughness, and hydrophobicity. These properties can be modified to improve pesticides rejection as well as the fouling resistance and permeate flux (AN et al., 2023; ISLAM et al., 2023). Therefore, an extensive field of research is being conducted to fabricate new membranes or to modify commercially available membranes. For example, it is known that reducing surface roughness makes the membrane less prone to fouling because solids have less tendency to deposit on smooth surfaces (LEE et al., 2022).

BEN-DAVID et al. (2010) modified NF270 membrane by polarization-assisted graft-polymerization for improving rejection of organic pollutants. The grafting with 3-sulfopropyl methacrylate and 2-hydroxyethyl methacrylate increased Metolachlor retention from ~80 to >95%, owing to the steric and hydrophobic effects, since the added layer had a defect plugging effect. Mehta et al. (MEHTA et al., 2021) developed TFC NF membranes featuring a poly(piperazine-amide) selective layer on a polysulfone substrate through oxidative polymerization of pyrrole. Compared to unmodified TFC membranes, the polypyrrole-enhanced TFC membranes demonstrated improved water flux during Diuron and Isoproturon filtration without compromising rejection performance. The membranes achieved rejection rates of 89.5% for Isoproturon and 78.9% for diuron, with water permeability ranging from 5.34 to 5.49 L/(m^2 h bar). Despite its smaller molecular size, Isoproturon exhibited higher rejection than diuron due to its lower dipole moment, which influences its interaction with the membrane.

HUANG et al. (2021) deposited a polydopamine (PDA) layer on the commercial NF90 membrane. The coated membrane exhibited better rejection for all neutral pesticide compounds compared to pristine NF90, which was explained by the enhanced size-sieving effect and increased surface hydrophilicity caused by the high-density PDA coating. This higher hydrophilicity reduced the adsorption of hydrophobic pesticides and consequentially their diffusion through the membrane. Still, moderately hydrophobic neutral pesticides such as Linuron, Diuron, and Atrazine showed a rejection rate of over 80% due to their molecular weight and size. (HUANG et al., 2021). Khairkar et al. (KHAIRKAR et al., 2020) added a hydrophobic polydimethylsiloxane (PDMS) solution to the organic monomer phase during the interfacial polymerization of polyamide, resulting in the formation of an intercalated network upon curing. The PDMS layer reduced the polarity and surface hydrophilicity of the TFC membranes, thereby enhancing their rejection performance against pesticides such as Acetamiprid, Imidacloprid, and Thiamethoxam. Additionally, the PDMS-coated membranes exhibited enhanced chlorine resistance, making them suitable for wastewater treatment plants where chlorine is commonly used in water treatment systems. However, a notable trade-off was observed between initial water flux and rejection performance due to the increased resistance (KHAIRKAR et al., 2020).

The use of nanomaterials has been widely applied to improve not only membrane performance (XU et al., 2020b; ZHAO et al., 2021) but also providing nanopores or nanochannels that provide extra shortcuts for water transport (EPSZTEIN et al., 2020; YUAN et al., 2019). For instance, mixed matrix membranes (MMMs) incorporate nanomaterials into polymer matrices. Samari et al. (SAMARI; HEYDARI; GHOLAMI, 2024) incorporated green furosemide functionalized CuxP nanoparticles to polyethersulfone (PES), which increased the flux recovery ratio 1.60 times and water flux 2.58 times compared to the bare membrane, while keeping a high retention (98.6%) of diazinon (Mw= 304.4 g/mol). In this way, another possible membrane modification is the addition of inorganic semiconductors that act as photocatalysts to increase the removal and degradation of pesticides. Wang et al. (WANG et al., 2022) fabricated a NF membrane with an ultrathin metal–organic framework (MOF-2) and graphitic carbon nitride (g-C_3N_4) nanosheets alternately arranged to form orderly interlayer nanochannels on porous nylon substrates (pore size of 0.45 μm). The membrane exhibited enhanced removal rates towards Atrazine (98 %), Tetracycline (95 %), Sulfamethazine (89 %), and Sulfamethoxazole (92 %). The removal mechanism is considered to be a combination of pesticide adsorption, photocatalytic degradation, and electrostatic repulsion (WANG et al., 2022). In a similar way, (OSORIO et al., 2025) post-lifespan RO membrane (TFC polyamide) with the addition of TiO_2 nanoparticles and graphene oxide to remove trace organic compounds.

In recent years, the interest for ceramic membranes has been growing, owing to their high chemical, thermal, and mechanical resistances (BORTOT COELHO et al., 2021), which leads to longer lifetimes than polymeric membranes and brings new opportunity to treat heavily contaminated wastewaters, corrosive and high-temperature feeds (BORTOT COELHO et al., 2023). Nevertheless, the availability of ceramic membranes in the nanofiltration rage is still limited and under development. Qin et al. (QIN et al., 2020) developed an yttria-stabilized ZrO_2 NF membrane on α-Al_2O_3 supports with a UF γ-Al_2O_3 interlayer. The developed membrane exhibited a clean water permeability of ca. 4 L/(m^2 h bar) with a MWCO of 800 Da, and Carbofuran (Mw = 221 g/mol) rejection of 85 %, in average.

3.4.2 Effect of pesticides physical chemical properties

As previously discussed, the molecular mass appears as the most direct correlation with the retention (CHEN et al., 2004; DAGHER et al., 2024; FUJIOKA et al., 2020), indicating the importance of size exclusion mechanism (DAGHER et al., 2024a; FUJIOKA et al., 2020). As seen in **Figure 18** e **Figure 19**, in general, the rejection of the pesticides increased with an increase in their molecular mass or a reduction of the membrane MWCO. Dagher et al. (DAGHER et al., 2024) also reported that molar volume could explain the rejection of several pesticides, but molar volume and mass values were highly correlated to each other. Alternatively, Fujioka et al. (FUJIOKA et al., 2020) observed that pesticides rejections by a RO membrane have higher correlation with their minimum projected area (MPA) than with the molecular mass, although these two properties are not totally independent. This was explained by the phenomena that micropollutants with low two-dimensional areas have better mobility within the free volume hole of the membrane structure, resulting in lower rejections (FUJIOKA et al., 2020). For example, the pesticide Ioxynil has a relatively high molecular weight (370.91 g/mol) but exhibits low rejection rates (15.9% for dNF80 and 89.9% for dNF40) compared to other compounds within the same molecular weight range. This behaviour can be attributed to Ioxynil's structural characteristics: it is a small, planar, two-dimensional molecule with a MPA of 0 $Å^2$. Furthermore, Ioxynil does not conform to the typical trend of negatively charged compounds having higher retention rates. This anomaly arises because its substantial molecular weight is primarily due to the presence of two iodine atoms. Nevertheless, in NF and RO, negatively charged compounds have generally higher rejection than neutral compounds, since commonly membrane materials (PES and PA) are negatively charged (DAGHER et al., 2024a; FUJIOKA et al., 2020) in almost all pH range (ABDULKAREM et al., 2020; CHEN et al., 2019). Once there are few data on positively charged pesticides (DAGHER et al., 2024; FUJIOKA et al., 2020; MUKHERJEE et al., 2020), no conclusion can be made about them.

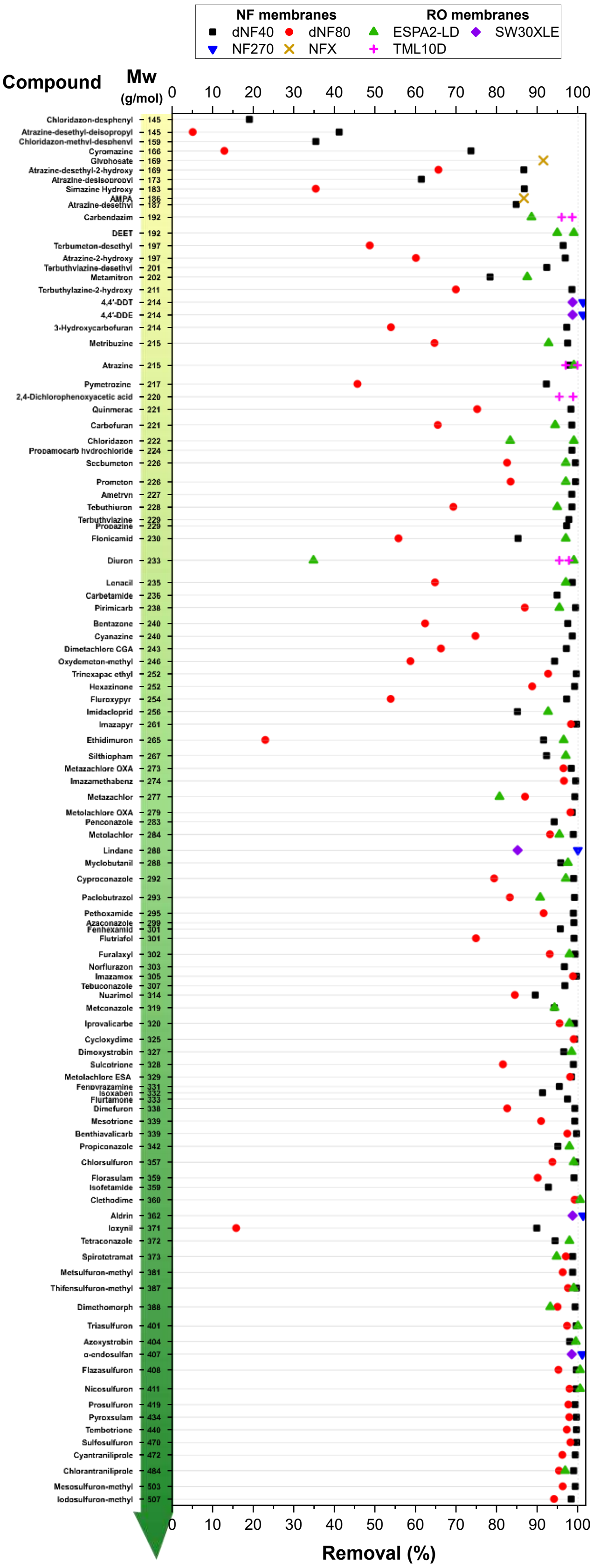


Figure 18 - Pesticides removal by commercial NF and RO membranes in order or molecular mass (**APPENDICE B – Table S1**).

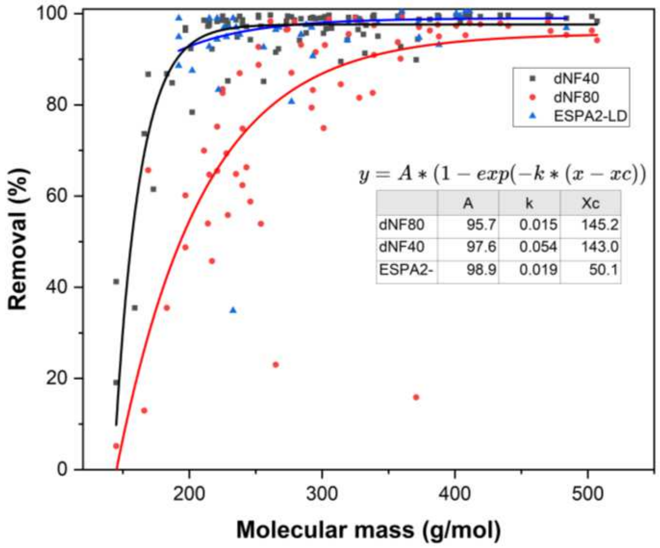


Figure 19 - Effect of the molecular mass on the pesticide removal for commercial NF (dNF80 and dNF40) and RO membranes (ESPA-LD).

Nevertheless, mass, projected area, and charge alone are not enough to explain all the rejection data. The electrostatic interactions and hydrogen bonding also affects the pesticide retention. RO membranes made of aromatic polyamides and have in the amide group some oxygen with a strong partial negative charge, which form hydrogen bonds with the hydrogen of secondary amides of the pesticides. If there is no other negatively charged functional group on the pesticide to repulse the membrane polyamide group, this electrostatic attraction reduces the rejection of secondary amides for PA membranes (FUJIOKA et al., 2020). This explains why Diuron, which is an aromatic pesticide with a relatively high molecular weight of 233 g/mol have low retentions with the RO membrane ESPA2-LD (34 %) and with NF membranes Desal DK (70 %) and NF200 (45 %)(BOUSSAHEL; MONTIEL; BAUDU, 2002). Moreover, Metazachlor (278 g/mol) and Prometon (225 g/mol), pesticides containing amide groups, have lower rejections for polyamide RO membranes than polyester sulfone NF membranes, as seen in **Figure 18.** Diuron and Metolachlor are high risk compounds; Diuron has been banned in the European Union (FARAH et al., 2024) and Metolachlor has been classified carcinogen category 2 by the United States Environmental Protection Agency (ALVAREZ et al., 2023).

Other important factor affecting the rejection of pesticides is the hydrophobicity (or lipophilicity) expressed as water-octanol distribution coefficient (log K_{OW} or log P) for non-ionizable compounds or the distribution coefficient (log D) for ionizable compounds, which is pH dependent. The hydrophilicity of the membranes is commonly measured by the contact angle. For hydrophobic membranes, it has been shown that compounds with log D > 2 were partially or totally adsorbed by NF membranes, while none or low adsorption were observed for pesticides with negative log D values (DAGHER et al., 2024). In the same way, several authors have studied the relationship between pesticide hydrophilicity and rejection (DAGHER et al., 2024a; FUJIOKA et al., 2020a; KISO, 2001; PLAKAS; KARABELAS, 2012). These studies indicate that for hydrophobic membranes, neutral hydrophobic compounds (log D > 2) exhibit higher retention than neutral hydrophilic compounds of similar molecular weight and size (ALBERGAMO et al., 2019; KISO et al., 2000). However, when correlations of the rejection of several pesticides with their physical properties are compared, the molecular mass always appear with greater importance than log D (DAGHER et al., 2024a; FUJIOKA et al., 2020a; KISO, 2001; PLAKAS; KARABELAS, 2012).

Considering the data collected in the present work, no correlation of log D and rejection was found. However, when the pesticides were divided in ranges of molecular mass (**Figure 20**), some trends of log D and rejection can be drawn. For pesticides with molar mass between 100 and 300 Da, lower retentions were observed for compounds with log D around 0, in the range between -1 and 1, while for log D > 2 higher retentions were observed. For molar masses higher than 300 g/mol, no correlation can be identified. Perhaps, the log D can be better used to explain the behaviour of different membranes. For example, Lindane (γ-HCH or γ-Hexachlorocyclohexane), with a molar mass of 291 g/mol, exhibits a lower rejection rate by the SW30XLE membrane (85%) compared to the BW30 membrane (99%), despite SW30XLE having a denser structure. This behaviour can be attributed to Lindane's hydrophobic nature (log D = 2.7), which facilitates its passage through the SW30XLE membrane, which is more hydrophobic (higher contact angle) than the BW30 membrane (SEAH et al., 2024).

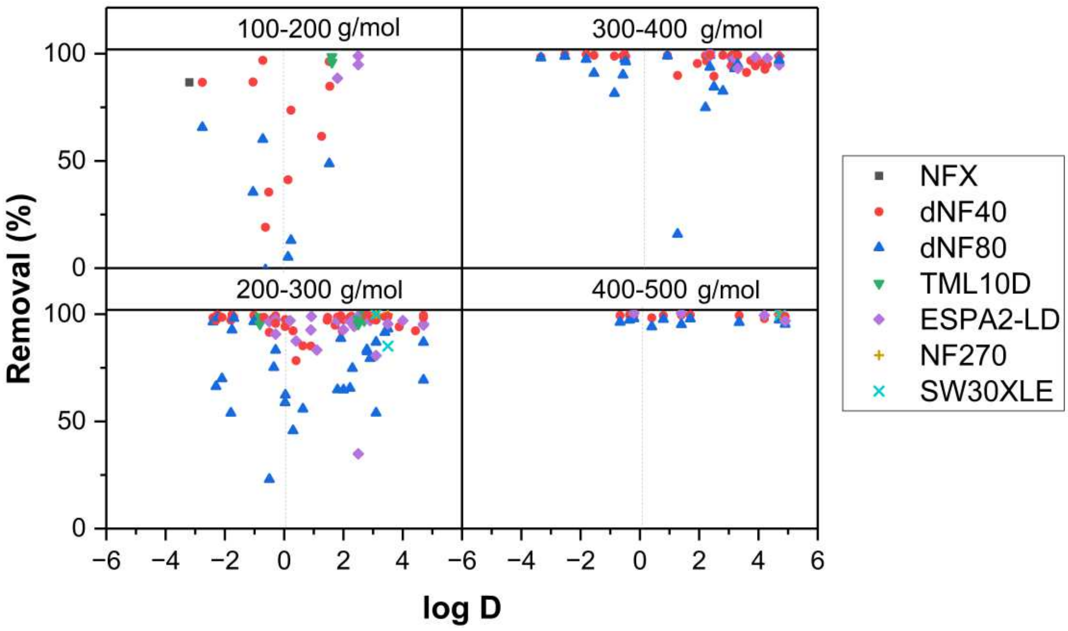


Figure 20 - Effect of the pesticide's distribution coefficient (log D) on the rejection, grouped by pesticide's molecular mass range.

3.4.3 Effect of water matrix/ mixture of pesticides

The water matrix plays a crucial role in affecting both the rejection of pesticides, the water flux, and the fouling behaviour (KABBANI et al., 2021; LEE et al., 2022; PLAKAS et al., 2006; PLAKAS; KARABELAS, 2011; YANGALI-QUINTANILLA et al., 2009; ZHANG et al., 2004; ZHU, 2015). Several studies investigate the rejection of pesticides in distilled water (DAGHER et al., 2024) but the presence of organic compounds and salts can change pesticide-membrane interaction as well as pesticide-solvent interactions (NIKBAKHT FINI; MADSEN; MUFF, 2019; ZHANG et al., 2004), as discussed below. In addition, the use carrying out filtration experiments using each pesticide individually or a mixture of several pesticides (DAGHER et al., 2024a; FUJIOKA et al., 2020a; SEAH et al., 2024) can lead to different retention values. Musbah et al. (MUSBAH et al., 2013) studied the rejection of Desethylatrazine (DEA; MW= 187.2 g mol^{-1}), an Atrazine metabolite, by a NF membrane (FilmTec Corporation/Dow) in distilled water and in distilled water in the presence of other pesticides (atrazine, diuron, and simazine). At 10 bar, the retention of DEA was 78 % with 100 µg/L of DEA in distilled water, but increased to 85.7 % when 100 µg/L DEA and 100 µg/L Simazine were present. Furthermore, when 100 µg/L of each of the four pesticides were in solution, the DEA retention increased up to 94 %. The authors attributed the increase in DEA rejection (up to 44% for all pesticide mixtures and all transmembrane pressures) to the formation of macromolecular complexes which become larger and steric retention effect becomes greater (MUSBAH et al., 2013).

Regarding the presence of ions, different mechanisms were responsible for the changes in rejection, including the pore swelling, salting-out, pore blocking, and competitive ion transmission effects. (KABBANI et al., 2021; LEE et al., 2022). Zhang et al. (ZHANG et al., 2004) observed that the higher rejections of Simazine and Atrazine observed for tap water and river water, compared to distilled water, where caused not only by the NOM presence but by the partial pore blocking caused by ions adsorption on the pores. On the contrary, Zhu et al. (ZHU, 2015) reported that increasing ionic strength from 10 to 20 mM decreased the rejection of pesticides by NF270 membrane, especially Diethyl phthalate (from 75.6 to 33.3 %). The explanation is the pore sweeling (increase in the effective average pore size). The addition of salt (at a constant pH) changes the charge density of the membrane surface by increasing the counter-ions concentration and compacting the electrical double-layer (ESCODA et al., 2010). The higher repulsive forces between counterions inside the pores, makes them larger and reduce pesticides rejection (KABBANI et al., 2021). Nevertheless, this theory implies that zeta potential modulus should decrease with higher salt concentration, but for RO and NF membranes, it was reported that zeta potential increased with ionic strength (MADSEN; SØGAARD, 2014), which is explained by a differential adsorption of cations and anions in the membrane surface (SZYMCZYK; FIEVET; BANDINI, 2010). Another effect observed is the salting-out effect, an increase in the salt concentration partially dehydrates the molecules, which causes the reduction of their hydrodynamic radius and hance can reduce their rejection by the membrane

(ESCODA et al., 2010), which would be hard to distinguish from a pore blocking effect.

3.4.4 Effect of membrane fouling

As discussed, the pesticide retention is a function of several interactions occurring between the pesticides and the membrane, which can be altered either by the feed condition (*e.g.* water matrix, pH, temperature) or by foulants depositing on the membrane surface. Therefore, fouling clearly can influence pesticides rejection. Depending on the pesticide retention and fouling layer properties, two cases can be distinguished. First, if the membrane has higher rejection than the fouling layer, a cake-enhanced concentration polarization, caused by the hindering of back-diffusion by the fouling layer, will result in a greater concentration gradient across the membrane, and hence, a lower pesticide retention (PLAKAS et al., 2006; PLAKAS; KARABELAS, 2011; YANGALI-QUINTANILLA et al., 2009). Second, if the fouling layer rejects the pesticide better than the membrane, the retention of this compound tends to increase with the fouling (PLAKAS; KARABELAS, 2012).

Colloidal fouling in RO caused by silica particles have been reported to decrease pesticides rejection by the cake-enhanced concentration polarization caused by back-diffusion hinderance, which was partially reversed by higher crossflow velocities (NG; ELIMELECH, 2004). Regarding fouling caused by natural organic matter (NOM), pesticides are mostly found in surface water and groundwater (KULIKOVA; PERMINOVA, 2002), which contain considerable amounts of NOM, such as humic and fulvic substances. It has been reported that the presence of NOM increases retention of pesticides (DALTON; BRANT; WIESNER, 2005; GOH et al., 2022; KIM; LEE; HONG, 2012; ZHANG et al., 2004). Two main mechanisms have been proposed to explain this increase: (i) NOM accumulated in the membrane increases its negative charge, which increases the electrostatic repulsion of negatively charged compounds (DEVITT et al., 1998); and (ii) NOM narrows the pores by pore blocking, increasing retention by size exclusion (ZHANG et al., 2004). A third explanation is based on the formation of larger pesticide-NOM complexes, which are rejected by size exclusion (PLAKAS;

KARABELAS, 2009). Nevertheless, as discussed above NOM can lead to cake-enhanced concentration polarization, which reduces the rejection (PLAKAS; KARABELAS, 2011). Plakas & Karabelas (PLAKAS; KARABELAS, 2011) observed that the presence of humic substances did not increase the retention of Atrazine (MW = 215.7 Da) and Prometryn (Mw = 241.4 Da) by NF membranes (NF270, NF90, and XLE), but in the presence of humic substances and Ca^{2+}, a denser fouling layer was formed, increasing the pesticides retention. Yangali-Quintanilla et al. (YANGALI-QUINTANILLA et al., 2009) studied compounds rejection by alginate fouled NF-200 and NF90 membranes. These authors observed that rejections of hydrophobic neutral compounds increased since alginate reduced membrane hydrophobicity, while hydrophilic neutral compounds showed increased rejections own to an enhanced sieving effect.

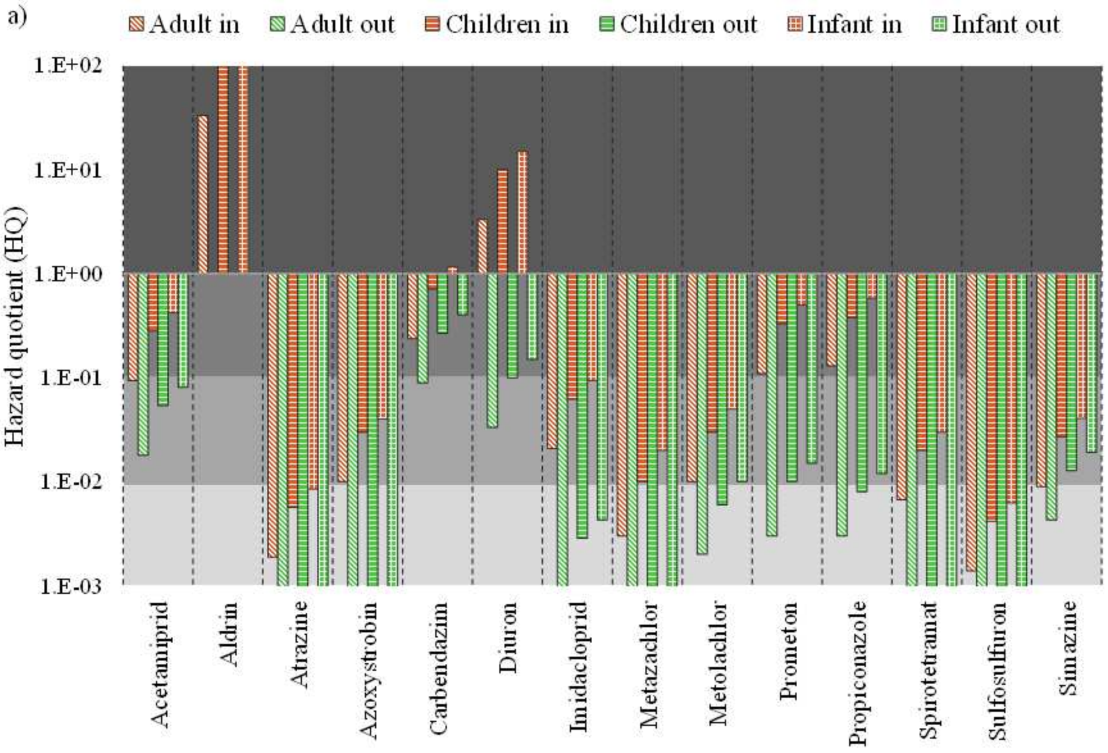
As fouling caused reduction of the membrane permeability, operations of membrane cleaning are periodically carried out to restore the desired permeate flux. Several of these cleaning procedures include the use of high temperatures, acid, bases, and oxidizing agents, such as sodium hypochlorite. These conditions reduce membrane lifetime since they can degrade the selective layer, for example in RO polyamide membranes (COUTINHO DE PAULA; GOMES; AMARAL, 2017). Therefore, the pesticides retention can be lowered if aggressive cleaning conditions were used, or membranes are at the end-of-life state.

3.5 HUMAN HEALTH RISKS

Despite the generally high rejection rates of pesticides by membranes, residual concentrations could be detected in the permeate. Pesticides in surface water and drinking water cause global concern due to the potential risks that these recalcitrant pollutants can pose to human health. Thus, in the present study, the risks to human health - represented by the hazard quotient (HQ) - were measured for water treated by membrane processes at the inlet (in) and outlet (out) of these systems.

RO membranes remove or reduce the health risks to low or negligible for virtually all pesticides (**Figure 21**a). For Aldrin, where the risks were considered high in the RO influent, the membranes were able to eliminate the risks completely since the removal efficiency was 100%, as discussed in Section 3. Regarding Diuron, for which the risks in the influent were also high, the effluent risk ranged from low (adults and children) to medium (infant phase). The same occurred for Carbendazim, which had a high risk in the influent and medium in the RO effluent for the infant phase. On average, the removal of Diuron and Carbendazim by RO were 90.9% and 64% (**Figure 16**).

The same did not occur for NF membranes about Aldrin. For this pesticide, HQ was classified as a high risk to human health for all age groups before and after treatment (**Figure 21b**). This pesticide has already been detected in the aquatic environment at maximum concentrations in the range of 1.55 µg/L – sufficient to cause a high environmental risk – while the legislation of Brazil, EPA, and Australia establish maximum concentrations in surface water equal to 0.005, 1.5 and 0.001 µg/L, respectively (FARAH et al., 2024). However, it is essential to consider that, in studies used to measure the risks discussed here, Aldrin concentrations were 10 µg/L in the NF and RO influent.



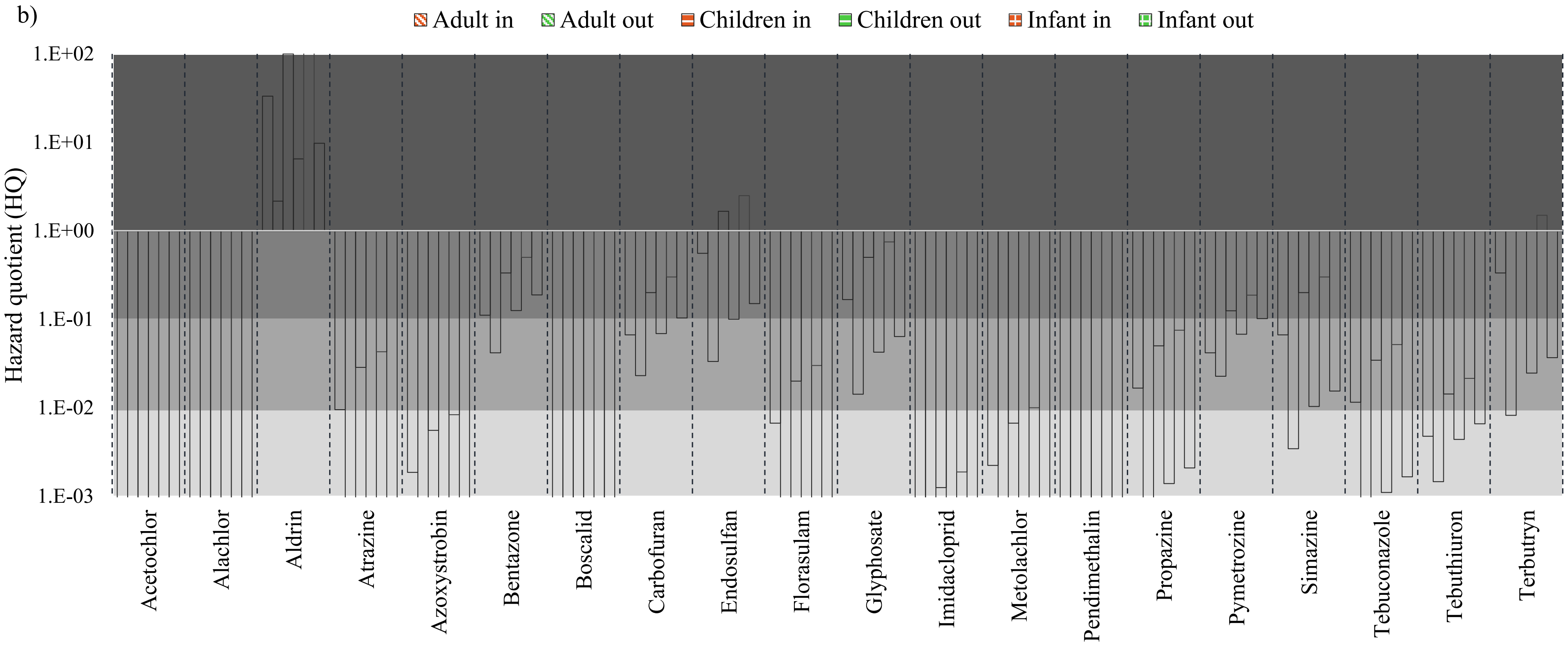
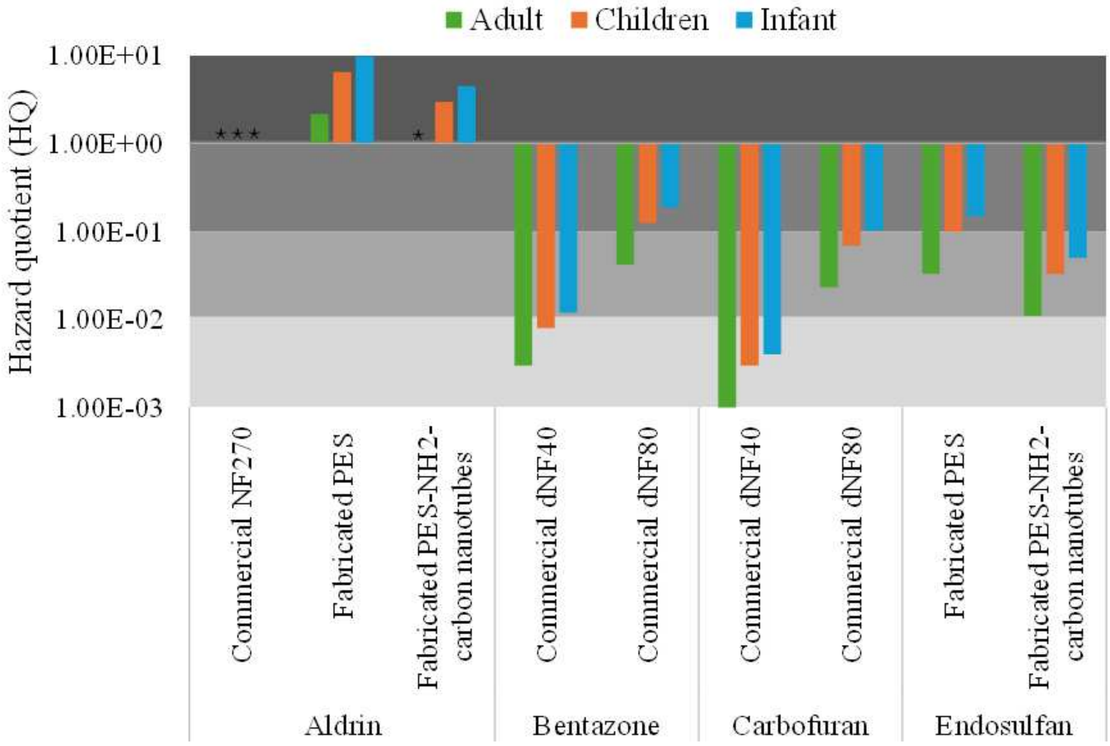


Figure 21 - Human health risk for adult, children, and infant in influent (in) and outlet (out) from (a) RO membranes and (b) NF membranes systems.

In other cases, NF could significantly remove risks to human health in treated water, as observed for Endosulfan and Terbutryn, where the risks were reduced to medium, low, or negligible, depending on the age group. It is also important to note that since most studies were directed at NF, evaluating several pesticides about risk removal by RO was impossible. In addition, for UF, only two pesticides (Carbendazim and Tebuconazole) could be evaluated, with negligible risks before and after treatment by membranes. These findings suggest the need for further studies to comprehensively evaluate the removal of pesticides across different membrane technologies.

In addition, it is important to emphasize that the risks were measured considering the most critical scenario, that is, the lowest removal presented by the membranes. Thus, for pesticides that presented high or medium human health risks after the NF process, the risks were measured for different membranes and, consequently, diverse removal efficiencies and HQ values. For Aldrin, the removals by NF membranes were 93.5% (fabricated PES), 97% (fabricated PES-NH_2-carbon nanotubes), and 100% (commercial NF270). The risk was high using fabricated PES (worst case scenario), and although it remains high, the HQ was reduced when using PES-NH_2-carbon nanotubes. The same occurred for Endosulfan. In contrast, for commercial NF270, the risks of Aldrin were eliminated. For Bentazone and Carbofuran, removals were higher using dNF40 than dNF80 (DAGHER et al., 2024). This is due to the higher size exclusion rejection using the 40 Da MWCF membrane. Thus, the risks considered average evaluating the worst-case scenario (dNF80) were reduced to low or negligible using dNF40. Therefore, it is recommended that the most effective membranes be used for these pesticides so that the risks to human health are reduced.



*HQ=0

Figure 22 - Human health risk after treatment by different types of NF membranes.

To evaluate the membrane systems for risk removal, the most critical concentrations of each pesticide before (sometimes above environmental concentrations) and after treatment were used, as reported in the Methodology section. However, it is known that in many developing countries and regions, direct use of surface water for drinking purposes may occur, mainly by populations on the banks of water bodies (CHIGOR et al., 2012). Therefore, the risks to human health were also measured considering the concentrations already found in surface water (FARAH et al., 2024) for the pesticides evaluated in the RO, NF, and UF systems, as shown in **Figure 23**.

Most pesticides presented a low or negligible risk for all age groups. In general, compounds that presented high risks for raw water treated by membrane processes also presented high risks at environmental concentrations. For example, Aldrin, Diuron, Endosulfan, and Terbutryn - whose maximum concentrations found in surface waters were 1.55 ug/L, 3.95 ug/L, 37.6 ug/L and 1.25 ug/L, respectively (FARAH et al., 2024) - presented high risks to human health prior to treatment by RO and NF. Thus, these compounds were still highly hazardous even at environmental concentrations – generally lower than the concentrations in raw water considered in some studies evaluating membranes. Therefore, Aldrin, Diuron, Endosulfan, and Terbutryn are priority compounds for removal in surface water, especially Aldrin, whose risk was not removed with NF. It is important to highlight that these pesticides are already banned, or there are regulations regarding their concentrations in surface water in the United States and countries of the European Union (FARAH et al., 2024); however, there is an urgent need to extend these restrictions to other locations, especially developing countries.

It is important to highlight that Bentazone poses a high risk to human health in surface water, while for raw water treated by membrane processes, the risk ranges from low to medium. Studies evaluating Bentazone removal by NF have reported concentrations as high as 1 µg/L, while environmental concentrations in surface water vary widely, ranging from 0.04 to 90 µg/L (FARAH et al., 2024). Therefore, it is recommended that the retention of Bentazone by membrane processes be thoroughly evaluated, with a focus on the maximum concentration ever detected in surface water to ensure the safety and quality of treated water.

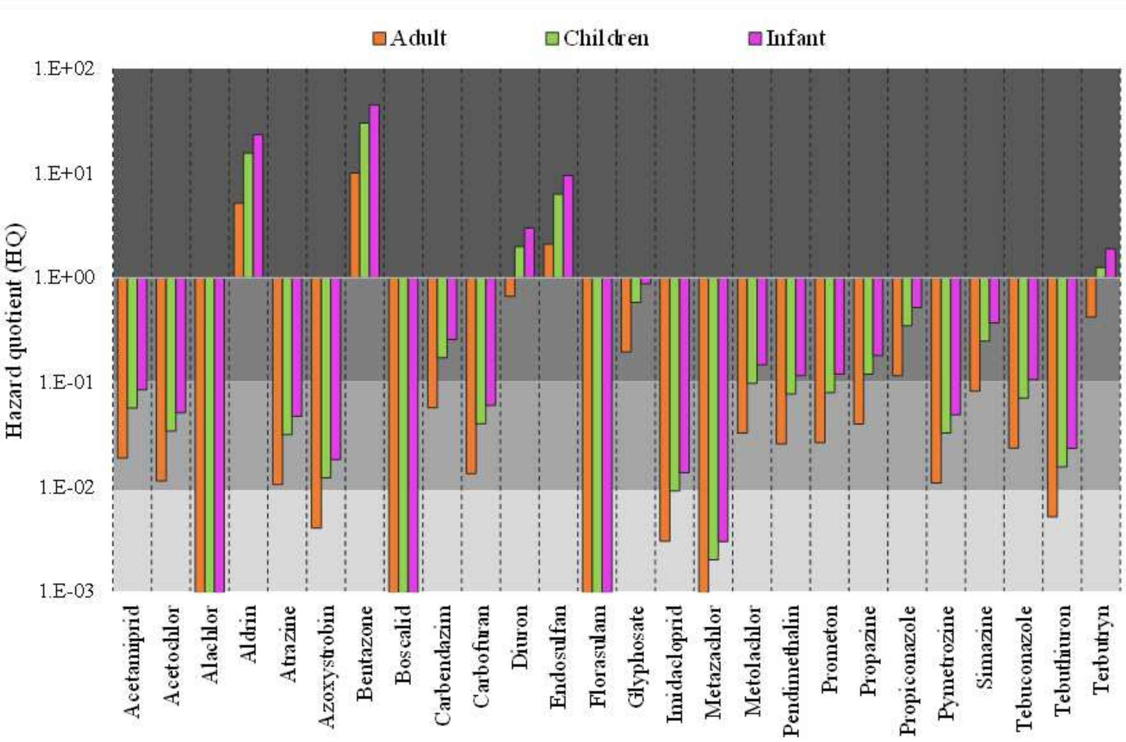


Figure 23 - Human health risk of pesticides in surface water.

3.6 FUTURE PERSPECTIVE

Evaluating the performance of membranes in pesticide removal has proven to be a significant challenge in studies conducted thus far. Despite efforts to standardize study conditions, such as using the same pesticide and membrane model, variability in operational conditions (temperature, pressure, and flow) and modifications to membrane materials hinder direct comparisons between technologies. These limitations are further exacerbated by the diversity of analytical methods and aqueous matrices used in studies, complicating the identification of more efficient solutions. Therefore, harmonizing evaluation protocols emerges as a crucial step to standardize operating conditions, membrane characteristics, and analytical methods. Uniform protocols would enable more reliable comparisons between studies, advancing the understanding of factors that influence membrane performance in real-world scenarios and promoting the development of more effective, safe, and economically viable technologies.

From a public health perspective, risk quotient (R(H)Q) analyses indicate that membranes—particularly those used in reverse osmosis—can significantly mitigate or even eliminate health risks posed by highly toxic or persistent compounds such as Aldrin, Diuron, and Carbendazim. However, the influent concentrations applied in certain studies—often several orders of magnitude higher than those typically detected in natural environments—underscore the importance of designing experiments that incorporate realistic scenarios, including real-world case studies and actual water samples.

Regulatory frameworks also need to evolve to address the complexities associated with pesticides as emerging contaminants. These substances exhibit specific properties, such as high persistence, toxicity, and resistance to conventional treatments, requiring stricter regulatory measures. Updates to water quality guidelines should prioritize pesticides with higher toxicity or persistence or those with lower removal efficiencies due to their physicochemical properties, such as molecular weight, hydrophobicity, charge, and polarizability. These properties also significantly influence the behavior of pesticides in membrane removal processes, especially when considering operational factors such as pH variations, ionic strength, and temperature.

As evidenced in this study, membranes demonstrate significant potential for the efficient removal of pesticides; however, additional studies that reproduce conditions closer to real-world scenarios and consider energy consumption and cost are necessary to refine the understanding and optimization of these processes. This effort will contribute to the development of membranes with greater selectivity and reduced fouling tendencies. Additional research on ceramic membranes, advanced polymer formulations, and hybrid processes (e.g., membranes coupled with adsorbents or photocatalysts) may expand operational capacity and mitigate fouling issues. A hybrid system also offers an effective alternative for addressing the membrane concentrate problem by minimizing both liquid and solid waste generation. This approach reduces the burden on subsequent waste treatment stages, enhancing overall process efficiency. Finally, integrating performance data with cost analyses and life-cycle assessments will facilitate the adoption of more sustainable and economically viable solutions on a large scale.

In conclusion, ensuring that technological advancements are accompanied by collaborations among researchers, industries, and policymakers is indispensable for creating effective, sustainable, and widely accessible solutions. This integrated approach not only facilitates the development and adoption of innovative technologies but also ensures that they meet real-world demands and significantly contribute to environmental protection and human health.

3.7 FINAL CONSIDERATIONS

The findings presented in this study highlight the potential of membrane technology for reducing health and environmental risks associated with pesticides in water sources. Technologies such as nanofiltration (NF) and reverse osmosis (RO) have demonstrated high rejection rates for a variety of pesticides, including those with relatively low molecular weights. However, the performance of these systems is influenced by multiple variables, chiefly the membrane’s constitutive material (e.g., polyamide vs. PES), the molecular weight cut-off (MWCO), hydrophobicity, and surface charge. Differences in membrane surface chemistry and structure—observed in commercial models such as dNF80, dNF40, NF270, NFX, BW30, ESPA2-LD, TML10D, and SW30XLE—emphasize that the choice of a suitable removal system depends on the specific pesticide characteristics and operational requirements, and that no single solution is ideal for every situation.

Fouling remains one of the primary operational challenges. Depending on the characteristics of the fouling layer and the particular pesticide, solid accumulation can either decrease or, in certain scenarios, increase rejection rates. Furthermore, the presence of natural organic matter (NOM) and salts significantly affects both fouling behaviour and overall process performance, thus requiring effective pre-treatment strategies and optimized operating conditions. Frequent cleaning procedures are critical for restoring permeate flux, yet overly aggressive chemical treatments may compromise the selective layer and shorten membrane lifespan, underscoring the need for a careful balance between maintenance and performance preservation.

Therefore, the use of membrane technology constitutes a highly promising strategy for safeguarding human health and the environment in the face of pesticide contamination. Through targeted research, appropriate regulations, and industrial innovations, these technologies are poised to address emerging contaminant challenges effectively, thereby contributing to water security and the development of more resilient water supply systems.

CHAPTER 4

4 FINAL CONSIDERATIONS

Pesticide contamination in surface and groundwater reflects the intensification of agricultural practices in recent decades. With the expansion of monocultures and the increasing use of chemical pesticides, the impacts on aquatic ecosystems have become increasingly evident. This scenario, characterized by the dispersion of pesticides through leaching, surface runoff, and atmospheric deposition, compromises not only water quality but also the health of aquatic organisms and humans.

Environmental risks, particularly for aquatic organisms, include acute and chronic toxic effects such as oxidative stress, genetic mutations, and neurotoxicity. The insufficiency of conventional water treatment processes in removing emerging contaminants is evident. As a result, the quality of water distributed to the population is compromised, especially in the presence of pesticides with high persistence and toxicity.

In this context, membrane separation processes, such as nanofiltration (NF) and reverse osmosis (RO), emerge as promising solutions. These technologies have demonstrated high efficiency in removing pesticides, mitigating environmental and human health risks. However, operational challenges such as fouling require attention to ensure their large-scale viability.

The results of this study highlight that the occurrence of pesticides in water bodies is largely influenced by intensive agricultural activities and the improper management of chemical products. The high concentrations of pesticides in surface and groundwater underscore the urgent need for preventive and corrective strategies to mitigate environmental impacts and protect public health.

It is critical to emphasize and promote strategies aimed at preventing pesticide contamination through the responsible use of these products. This involves more conscientious agricultural practices, such as integrated pest management and the controlled application of pesticides using precision technologies. Moreover, the importance of developing green pesticides should be highlighted, as these have a lower environmental impact and are less toxic to non-target organisms, representing a more sustainable approach to agriculture.

Given the limitations of conventional treatment technologies, it is essential to encourage the development of new functionalized membranes. These membranes should ensure greater robustness and efficiency in the removal of pesticides, including those that are highly persistent and toxic, as well as exhibit greater resistance to fouling. Advances in these technologies will contribute to improving water quality and reducing environmental and human health risks.

The findings of this study also reinforce the urgency of more updated and comprehensive environmental regulations that encourage technological development and the adoption of more sustainable practices. Additionally, it is crucial for future studies to prioritize the standardization of methodologies and cost-benefit evaluations to facilitate the implementation of water treatment technologies in real-world contexts, ensuring greater protection of water resources and public health.

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APPENDICE A - Chapter 2

Table S1- Pesticide occurence

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
Italy	Groundwater	Chlorantraniliprole	0.01	[1]
		Dimethomorph	0.03	
		Fluopicolide	0.08	
		Metalaxil-M	0.4	
		Penconazole	0.1	
		S-metolacloro	0.01	
		Tetraconazole	0.02	
United States	Surface water	Atrazine	0.1	[2]
		Imidaclоprida	0.01	
		Carbendazim	0.01	
Ecuador	Surface water	Aldrin	1.02	[3]
		Cadusafos	3.05	
		Carbendazim	23.93	
		Chlorpyrifos	0.09	
		Ddt(o,p')	0.26	
		Dimethoate	0.28	
		Diuron	1.61	
		Ethoprophos	0.04	
		Phenpropimoph	0.32	
		Flazasulfide	0.38	
		Heptachlor	0.69	
		Linuron	0.03	
		Malathion	0.4	
		Metalaxil	0.45	
		Propiconazole	0.17	
		Aldrin	1.55	
		Cadusafos	4.74	
		DDT(o,p')	2.99	
		Ethoprophos	0.06	
		Phenpropimoph	0.05	
		Heptachlor	0.27	
		Malathion	0.03	
		Metalaxil	0.25	
Spain	Surface water	2,4-d	0.44	[4]
		Bentazone	180	
		Mcpa	8.21	
		Diflufenicane	0.019	
		Propanil	61	
		Methiocarbe	0.0033	
		Molinar	0.048	
		Alachlor	0.0016	
		Metolachlor	0.073	
		Acetamiprida	4	
		Imidaclopride	0.7	
		Tiaclopride	0.0027	
		4.4'-ddd	0.0012	
		Dicofol	0.0037	
		Oxadiazon	0.047	
		Triadimefon	0.0049	
		Azinfos etil	0.0056	
		Clorfenvinfos	0.0063	
		Chlorpyrifos	0.027	
		Diazinon	0.0048	
		Malaoxon	0.00057	
		Fenthion oxon	0.0025	
		Fenthion oxon sulfoxide	0.0032	
		Fenthion sulfoxide	0.0045	
		Chlortoluron	0.014	
		Diuron	0.012	
		Isoproturon	0.013	
		Linuron	0.013	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
		Atrazine	0.0025	
		Cibutrin	0.049	
		Simazina	0.0067	
		Butilazina	0.041	
		Terbutrin	0.0066	
Malaysia	Surface water	Pymetrozine	0.2608	[5]
		Imidacloprid	0.0577	
		Tricyclazole	0.02092	
		Chlorantraniliprole	0.0569	
		Azoxystrobin	0.0109	
		Isoprothiolane	0.0349	
		Tebuconazole	0.5121	
		Propiconazole	4.4931	
		Difenoconazole	1.6203	
		Trifloxystrobin	0.6078	
		Buprofezin	0.7291	
Costa Rica	Surface water	Carbendazim	13.5	[6]
		Carbofuran	0.14	
		Chlorpyrifos	0.094	
		Diuron	2.66	
		Oxamyl	0.36	
		Oxyfluorfen	0.061	
		Andendazole	0.075	
China	Surface water	2,4-d	0.00159	[7]
		Tebuconazole	2.04	
		Azoxystrobin	2.18	
		Propiconazole	2.7	
		Isoprothiolane	3.06	
		Tricyclazole	0.0106	
		Terbutryn	0.352	
China	Surface water	Dichlorvos	0.0615	[8]
		Dimethoate	0.031	
		Isocarbophos	0.145	
		Parathion	0.05	
		Parathion-methyl	0.00336	
		Phoxim	0.0142	
		Triazophos	0.0083	
		Acetamiprid	0.038	
		Imidacloprid	0.438	
		Thiamethoxam	0.0534	
		Methomyl	0.07	
		Azoxystrobin	0.0536	
		Carbendazim	0.508	
		Difenoconazole	0.0108	
		Dimethomorph	0.0946	
		Triadimefon	0.00672	
Brazil	Surface water	Imidacloprid	2,579	[9]
		Carbendazim	1,114	
		Ametrine	1,101	
		Tebuthiuron	1.08	
	Groundwater	Tebuthiuron	0.107	
Spain	Surface water	Carbendazim	9,574	[10]
		Prosulfocarb	0.034	
		2,4-d	0.855	
		Bentazone	0.013	
		Propiconazole	2,216	
		Chlorotoluron	0.228	
		Imidacloprid	0.031	
		Propiconazole	0.082	
		Prosulfocarb	0.104	
		Dimethoate	0.415	
		Simazine	0.456	
		Dimethoate	0.01	
		Diuron	2,127	
		Metazachlor	0.995	
	Groundwater	Carbendazim	0.426	
		Chlorotoluron	0.145	
		Atrazine-desisopropyl	0.068	
		Diuron	0.333	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
South Africa	Surface water	Chlorpyrifos	0.0042	[11]
		Thiacloprid	0.1152	
		Imidacloprid	7,249	
Canada	Surface water	Glyphosate	3	[12]
		Ampa	0.656	
		Clothianidin	0.07	
		Imidacloprid	0.011	
		Thiamethoxam	0.042	
		Atrazine	0.666	
		DEA desethylatrazine	0.192	
China	Surface water	Acephate	0.00883	[13]
		Omethoate	0.00492	
		Dimethoate	0.00779	
		Trichlorfon	0.04433	
		Terbufos sulfone	0.00155	
		Anilofos	0.00378	
		Prophenophos	0.00354	
		Isoprocarb	0.03906	
		Molinate	0.00096	
		Fenobucarb	0.02274	
		Atrazine desisopropyl	0.00025	
		Acetamiprid	0.0666	
		Imidacloprid	0.12171	
		Acetochlor	0.67751	
		Butachlor	0.00809	
		Tebuconazole	0.05004	
		Tebufenozide	0.00496	
		Bentazone	0.85062	
China	Surface water	Bensulfuron-methyl	1.07424381	[14]
		Chlorimuron-ethyl	0.00544179	
		Ethametsulfuron-methyl	0.001006538	
		Metsulfuron methyl	0.003107029	
		Pyrazosulfuron-ethyl	0.04290174	
		Triasulfuron	0.001066702	
		Fouzakn	0.008679957	
		Diuron	3.056049181	
		Tebuthiuron	0.00214414	
		Ametrine	1.677643848	
		Promise	1.186866937	
		Promethrin	11.62459945	
		Secbumeton	0.128043495	
		Simetryn	7.633548842	
		Terbumeton	0.217388474	
		Terbutryn	1.246952739	
		Atrazine-desethyl	0.21588552	
		Propazine	2.38512159	
		Terbuthylazine	0.140515394	
		Mefenacet	0.125956546	
		Florasulam	0.000635344	
		Penoxsulam	0.003053087	
		Metolachlor	0.010087591	
		Anilofos	0.000835091	
		Pyraclostrobin	0.006094188	
		Azoxystrobin	0.00255355	
		Carbendazim	0.10319935	
		Tebuconazole	0.009221065	
		Tricyclazole	0.070945171	
Korea	Groundwater	Carbofuran	0.116	[15]
Brazil	Surface water	Atrazine	0.049	[16]
		Azoxystrobin	0.233	
		Bentazone	0.036	
		Carbendazin	0.042	
		Carbofuran	0.2	
		Cyproconazole	0.014	
		Clomazone	0.124	
		Diuron	0.79	
		Difenoconazole	0.015	
		Epoxiconazole	0.04	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
		Fipronil	0.021	
		Imazapic	0.077	
		Imazethapyr	0.025	
		Iprodione	1	
		Irgarol	0.01	
		Pyrazosulfuron-ethyl	0.013	
		Propanil	0.02	
		Quinclorac	0.288	
		Simazine	0.9	
		Tebuconazole	0.3	
Ecuador	Surface water	Butachlor	2,006	[17]
		Cadusafos	0.081	
		Chlorpyrifos	0.035	
		Fenpropimorphe	0.241	
		Malathion	0.687	
		Oxadiazon	0.12	
		Pirimetan	0.08	
		Spiroxamine	0.099	
		Tebuconazol	0.316	
		Triadimenol	0.092	
Greece	Surface water	Eptc	0.157	[18]
		Molinate	0.144	
		Propachlor	0.139	
		Trifluralin	0.084	
		Atrazine	0.077	
		Terbuthylazine	0.087	
		Dimethenamid-P	0.067	
		Acetochlor	0.105	
		Metolachlor	0.077	
		Pendimethaline	0.34	
		Quizalofop-ethyl	0.114	
		Tebufenpyrad	0.337	
		Fluometuron	0.172	
		Pirimiphos-methyl	0.064	
		Fenpyroximate	0.139	
		Quinalphos	0.142	
		Endosulfan-α	0.241	
		Endosulfan-β	0.205	
		Endosulfan-sulfate	0.194	
		Azinphos-ethyl	0.25	
		Ethoprophos	0.044	
		Triadimenol-A	0.255	
		Iprodione	0.265	
		Myclobytanil	0.063	
China	Surface water	Isoprocarb	0.0166	[19]
		Fenobucarb	0.003	
		Pirimicarb	0.0006	
		Carbofuran	0.0283	
		Andendazole	0.0013	
		Carbendazim	0.6073	
		Metalaxyl	0.0369	
		Imidacloprid	0.1702	
		Acetamiprid	0.0443	
		Boscalid	0.1341	
		Metolachlor	0.1365	
		Thiamethoxam	0.1567	
		Dimethoate	0.0148	
		Isocarbophos	0.1848	
		Diniconazole	0.0012	
		Difenoconazole	0.0259	
		Myclobutanil	0.0209	
		Epoxiconazole	0.0128	
		Triadimenol	0.0922	
		Propiconazole	0.0341	
		Hexaconazole	0.1572	
		Tebuconazole	0.2341	
		Paclobutrazole	0.1125	
		Buprofezin	0.0012	
		Ametrine	0.0384	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
		Azoxystrobin	0.2155	
		Dimethomorph	0.0638	
		Pyrimethanil	0.0469	
		Isoprothiolane	0.2054	
England	Surface water	Boscalid	0.021	[20]
		Carbendazim/benomyl	0.003	
		Chlortoluron	0.003	
		Cyproconazole	0.01	
		Diflufenican	0.035	
		Epoxiconazole	0.018	
		Flufenacet	0.485	
		Flutriafol	0.002	
		Fluxapyroxad	0.06	
		Linuron	0.096	
		Metazachlor	0.025	
		Pirimicarb	0.001	
		Propiconazole	0.006	
		Propyzamide	1,456	
		Prosulfocarb	0.36	
		Quinmerac	0.06	
		Tebuconazole	0.017	
		Terbutryn	0.003	
		Triallate	0.032	
India	Surface water	Endosulfan	37.56	[21]
		Chlorpyrifos	0.86	
		Methyl parathion	0.43	
Spain	Groundwater	Carbendazim	0.238	[22]
		Metalaxyl	0.017	
		Boscalid	0.081	
		Fenbuconazole	0.073	
		Kresoxim-methyl	0.04	
		Bupirimate	0.166	
		Acephate	0.088	
		Pirimicarb	0.015	
		Chlorpyrifos	0.173	
		Chlorpyrifos-oxon	0.03	
		Methoxyfenozide	0.07	
		Cypermethrin	0.42	
		Diazinon	1.049	
		Diazoxon	0.528	
		Indoxacarb	0.145	
		Hexythiazox	0.129	
		Λ-Cihalothrin	0.94	
		Terbuthylazine	0.76	
		Chlorotoluron	0.257	
		Linuron	0.358	
		Lenacil	0.049	
		Flufenacet	0.104	
		Metolachlor	0.061	
		Diflufenican	0.503	
		Pendimethalin	0.526	
		Oxyfluorfen	0.279	
India	Surface water	A - HCH	1.94	[23]
		B - HCH	2.8	
		Γ- HCH	2.97	
		Δ - HCH	2.72	
		P,p ′ – DDT	1.54	
		P,p′ – DDE	1.15	
		P,p′ – DDD	2.02	
	Groundwater	A - HCH	1.71	
		B - HCH	2.01	
		Γ- HCH	2.1	
		Δ - HCH	2.15	
		P,p ′ – DDT	1.54	
		P,p′ – DDE	0.32	
		P,p′ – DDD	1.15	
China	Surface water	Acetamiprid	0.157	[24]
		Clothianidin	0.0476	
		Imidacloprid	0.249	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
		Thiamethoxam	0.0524	
Argentina	Surface water	2,4-d	0.253	[25]
		Acetochlor	0.008	
		Atrazine	0,135)	
		Atz-desethyl	0.025	
		Atz-desisopropyl	0.021	
		Atz-OH	0.1517	
		Flurochloridone	0.003	
		Glyphosate	4.36	
		Ampa	1.03	
		Imazapyr	0.019	
		Imazethapyr	0.012	
		Metolachlor	0.006	
		Metsulfuron-methyl	0.009	
		Imidacloprid	0.19	
		Epoxiconazole	0.004	
		Metalaxyl	0.004	
		Tebuconazole	0.003	
Albania	Surface water	Alpha-HCH	0.00557	[26]
		Beta-HCH	0.0146	
		Dieldrin	0.66087	
		4.4'-ddd	0.75531	
		Endosulfansulfat	0.54692	
Scotland	Surface water	Metaldehyde	0.01049	[27]
		Simazine	0.00098	
		Atrazine	0.00272	
		Isoproturon	0.00531	
		Chlortoluron	0.0311	
		Chlorpyrifos	0.00497	
		Epoxiconazole	0.00209	
India	Surface water	Γ-HCH	6.08	[28]
		A-HCH	0.265	
		Δ-HCH	0.256	
		DDD (op|)	23.4	
		DDE (pp|)	0.062	
		DDE (op|)	0.116	
		Heptachlor	1	
		Chlorpyrifos	2.73	
		Dichlorvos	0.647	
Uruguay	Surface water	Amitraz	0.12	[29]
		Atrazine	1.1	
		Azoxystrobin	0.31	
		Carbofuran	0.12	
		Fenazaquin	0.63	
		Fluazifop-p-butyl	0.51	
		Metolachlor	14.64	
		Neburon	0.13	
		Pendimethalin	3.08	
		Prosulfocarb	0.08	
		Pyraclostrobin	0.13	
		Pyridaben	0.04	
		Cadusafos	1.32	
		Ethoxyquin	2.88	
		Proquinazid	0.37	
		Pymetrozin	0.02	
		Pyrazophos	0.06	
		Andendazole	0.45	
		Fluazifop	0.11	
		Flufenamic acid	5.05	
		Indoxacarb	0.05	
		Miconazole	0.18	
		Penconazole	0.43	
		Trifloxystrobin	0.03	
Saudi Arabia	Surface water	Acetamiprid	0.0122	[30]
		Bifenthrin	0.0453	
		Carbendazim	0.1929	
		Carbofuran-3-hydroxy	0.1021	
		Chlorfenvinphos	0.0112	
		Chlorpyrifos	0.0243	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (µg/L)	SOURCE
		Cyhalothrin	0.0638	
		Diazinon	1,016	
		Fluvalinate	0.0013	
		Imazalil	0.0183	
		Imidacloprid	0.445	
		Isoproturon	0.0674	
		Tebuconazole	0.0078	
		Terbuthylazine-2-hydroxy	0.0116	
		Andendazole	0.0224	
		Thiamethoxan	0.0108	
China	Surface water	Phorate	0.00000308	[31]
		Blessings	0.000777	
		Shattered	0.0000805	
China	Groundwater	Atrazine	1,441	[32]
China	Groundwater	Acetamiprid	0.00338	[33]
		Imidacloprid	0.02	
		Clothianidin	0.137	
		Thiamethoxam	0.807	
		Thiacloprid	0.00146	
		Dinotefuran	0.00564	
		Imidaclothiz	0.00018	
		Nitenpyram	0.0001	
China	Surface water	Imidacloprid	0.154	[34]
		Thiamethoxam	0.0702	
		Clothianidin	0.038	
		Acetamiprid	0.0771	
		Thiacloprid	0.00297	
Chile	Surface water	Diuron	3,952	[35]
		Simazine	1,227	
		Terbuthylazine	0.869	
		Atrazine	0.149	
		Flutriafol	0.125	
		Pyrimethanil	2898	
		Myclobutanil	0.067	
		Cyprodinil	0.204	
		Tebuconazole	0.964	
		Azoxystrobin	0.019	
		Kresoxim-methyl	0.133	
		Metalaxyl	0.061	
		Acephate	1,889	
		Imidacloprid	0.171	
		Methidathion	0.251	
		Diazinon	0.195	
		Chlorpyrifos	0.069	
USA	Surface water	Imidacloprid	0.0968	[36]
Malaysia	Surface water	Diazinon	0.00001	[37]
South Africa	Surface water	Α-HCH	0.0554	[38]
		Β-HCH	0.127	
		Γ-HCH	0.0456	
		Δ-HCH	0.0077	
		Σhchs	0.1944	
		P,p′-DDE	0.0241	
		P,p′-DDD	0.0356	
		P,p′-DDT	0.0248	
		Σddts	0.0835	
		Aldrin	0.0031	
		Dieldrin	0.0519	
		Endrin	0.0463	
		Endosufan sulphate	0.0125	
		Endrin ketone	0.0005	
		Heptachlor	0.0031	
		Heptachlor epoxide	0.0059	
		Methoxychlor	0.0174	
		Endoscove i	0.0183	
		Endosulfan II	0.0077	
		Endrin aldehyde	0.0128	
		Σother ocps	0.0698	
		Σocps	0.2493	

COUNTRY	EVALUATED MATRIX	PESTICIDE	IDENTIFIED CONCENTRATION (μg/L)	SOURCE
		Α-HCH	0.0596	
		Β-HCH	0.115	
		Γ-HCH	0.0689	
		Σhchs	0.212	
		P,*p*′-DDE	0.107	
		P,*p*′-DDD	0.0487	
		P,*p*′-DDT	0.0431	
		Σddts	0.161	
		Aldrin	0.0247	
		Dieldrin	0.062	
		Endrin	0.0468	
		Endrin ketone	0.0162	
		Heptachlor	0.0077	
		Heptachlor epoxide	0.0382	
		Methoxychlor	0.0238	
		Endoscove i	0.0109	
		Endosulfan II	0.007	
		Endrin aldehyde	0.0122	
		Σother ocps	0.0931	
		Σocps	0.2639	
Germany	Surface water	Glyphosate	58	[39]
		Diflufenican	17	
		Epoxiconazole	8.2	
		Ampa	5.4	
		Spiroxamine	0.013	
		Chlortoluron	0.08	
		Amidosulfuron	0.018	
		Bentazone	0.04	
		Dichlorprop	0.33	
		Dimethoate	0.07	
		Diuron	0.05	
		Fenpropimorph	0.036	
		Flufenacet	0.08	
		Flurtamone	0.09	
		Imidacloprid	0.0008	
		Isoproturon	0.15	
		Mcpa	0.42	
		Mecocrop	0.14	
		Metamitron	0.11	
		Metazachlor	0.03	
		Metolachlor	0.05	
		Prochloraz	4	
		Quinmerac	0.06	
		Tebuconazole	0.08	
		Terbuthylazine	0.04	
		Tribenuron-methyl	0.02	
		Boscalid	0.01	
"Mediterranean"	Surface water	Simazine	0.0548	[40]
		Irgarol	0.275	
		Diuron	0.2877	
		Glyphosate	1.87	

Table S2- Acute toxicity - Red area: highly toxic; yellow area: very toxic; blue area: toxic; green area: no toxic.

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY ASSESSMENT CRITERIA	EFFECT (MG/L)	SOURCE
2,4-D	Crustacean	*Ceriodaphnia silvestrii*	48h	EC50	0.169	[41]
Acephate	Crustacean	*Daphnia magna*	48h	EC50	67.2	[42]
Acetamiprid	Fish	*Clarias gariepinus*	96h	LC50	265.7	[43]
Acetochlor	Crustacean	*C. Magister*	96h	LC50	0.005	[44]
Alaclor	Algae	*Scenedesmus quadricauda*	72h	EC50	0.966	[45]
Aldrin	Fish	*Lebistes reticulatus*	96h	LC50	0.017	[46]
Ametryn	Fish	*Danio rerio*	96h	LC50	52.94	[47]
Amidosulfuron	Algae	*Scenedesmus subspicatus*	72h	EC50	47	[48]
Amitraz	Fish	*Oncorhynchus mykiss*	4d	LC50	0.74	[49]
AMPA	bacteria	*Vibrio fischeri*	30min	EC50	50.48	[50]
Anilofos	Fish	*Oncorhynchus mykiss*	96h	LC50	2.8	[51]
Atrazine	Fish	*Oncorhynchus mykiss*	96h	LC50	5.3	[52]
Atrazine desisopropyl	Algae	*Chlorella pyrenoidosa*	3h	EC50	3.6	[58]
Atrazine-desethyl	Algae	*Chlorella fusca*	12d	EC50	0.923	[58]
Azinphos-ethyl	Fish	*Oreochromis niloticus*	48h	LC50	1.00E-06	[53]
Azoxystrobin	Fish	*Sheepshead minnow*	96h	LC50	0.676	[54]
Bensulfuron-methyl	Algae	*Raphidocelis subcapitata*	72h	EC50	0.057	[55]
Bentazone	Fish	*Oreochromis niloticus*	24h	LC50	14.86	[56]
Bifenthrin	Crustacean	*Daphnia magna*	24h	EC50	0.00324	[57]
Boscalid	Crustacean	*Daphnia magna*	48h	EC50	0.00081	[58]
Bupirimate	Fish	*Lepomis macrochirus*	96h	LC50	1	[59]
Buprofezin	Crustacean	*Daphnia magna*	2d	EC50	0.44	[58]
Butachlor	Fish	*Lepomis macrochirus*	96h	LC50	0.44	[60]
Cadusafos	Fish	*Gibelion catla*	4d	LC50	0.72	[58]
Carbendazim	Fish	*Ictalurus punctatus*	96h	LC50	0.0257	[63]
Carbendazim/Benomyl	Algae	*Chlorella pyrenoidosa*	4d	EC50	0.0525	[58]
Carbofuran	bacteria	*Aphanizomenon flos-aquae*	96h	EC50	79,263	[61]
Chlorantraniliprole	Crustacean	*Daphnia magna*	2d	EC50	0.0071	[58]
Chlorfenvinphos	Crustacean	*Daphnia pulex*	3h	LC50	0.011	[58]
Chlorimuron-ethyl	Crustacean	*Daphnia magna*	48h	EC50	10	[62]
Chlorotoluron	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.082	[63]
Chlorpyrifos	Crustacean	*Mysidacea*	48h	LC50	0.145	[64]
Chlortoluron	Algae	*Chlorella fusca*	1d	EC50	0.023	[58]

PESTICIDE	**ORGANISM**	**SPECIE**	**EXPOSURE TIME**	**TOXICITY ASSESSMENT CRITERIA**	**EFFECT (MG/L)**	**SOURCE**
Clomazone	Fish	*Oncorhynchus mykiss*	96h	LC50	14.4	[65]
Clothianidin	Fish	*Clarias gariepinus*	48h	EC50	16,913	[44]
Cyfluthrin	Crustacean	*Hyalella azteca*	96h	LC50	1.30E-06	[66]
Cypermethrin	Fish	*Oreochromis niloticus*	96h	LC50	0.00913	[67]
Cyproconazole	Algae	*Raphidocelis subcapitata*	5d	EC50	0.026	[58]
Cyprodinil	Crustacean	*Daphnia magna*	2d	EC50	0.032	[58]
DDD (op|)	Crustacean	*Daphnia magna*	48h	EC50	0.009	[68]
DDT(O,P')	Crustacean	*Daphnia magna*	48h	EC50	0.005	[69]
DEET	Algae	*Raphidocelis subcapitata*	3d	EC50	0.002	[58]
Deltamethrin	Fish	*Oreochromis niloticus*	96h	LC50	0.00942	[76]
Diazinon	Crustacean	*Daphnia magna*	48h	EC50	0.001	[43]
Diazoxon	Crustacean	*Daphnia magna*	2d	EC50	0.0029	[58]
Dichlorprop	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	1100	[70]
Dichlorvos	Fish	*Oncorhynchus mykiss*	96h	LC50	13.18	[63]
Dicofol	Crustacean	*Opossum shrimp*	96h	LC50	0.06	[63]
Dieldrin	Fish	*Oreochromis niloticus*	4d	LC50	0.00495	[58]
Diflufenican	Fish	*Cyprinus carpio*	96h	LC50	0.099	[71]
Dimethenamid-P	Crustacean	*Daphnia magna*	48h	EC50	3.2	[72]
Dimethoate	Crustacean	*C. Magister*	96h	LC50	0.419	[45]
Dimethomorph	Fish	*Oncorhynchus mykiss*	21d	LC50	1.5	[58]
Dimetoato	Fish	*Lepomis macrochirus*	2d	LC50	9.6	[58]
Diniconazole	Fish	*Danio rerio*	5d	EC50	2.64	[58]
Dinotefuran	Crustacean	*Hyalella azteca*	7d	EC50	0.06	[44]
Diuron	Algae	*Selenastrum capricornutum*	72h	EC50	0.015	[73]
Endosulfan	Fish	*Lebistes reticulatus*	96h	LC50	0.0027	[47]
Endosulfan II	Fish	*Oncorhynchus mykiss*	4d	LC50	0.0033	[58]
Endosulfan Sulfat	Fish	*Oncorhynchus mykiss*	4d	LC50	0.0014	[58]
Endosulfan-β	Fish	*Oncorhynchus mykiss*	4d	LC50	0.0033	[58]
Endrin	Fish	*Oncorhynchus mykiss*	3d	LC50	0.00006	[58]
Epoxiconazole	Fish	*Danio rerio*	4,9d	LC50	7.45	[58]
Eptc	Fish	*Lepomis macrochirus*	96h	LC50	14	[74]
Esfenvalerate	Fish	*Danio rerio*	4d	LC50	0.00002	[58]
Ethametsulfuron-methyl	Crustacean	*Daphnia magna*	48h	EC50	108	[75]
Ethoprophos	Crustacean	*Daphnia ambigua*	4d	LC50	0.00763	[58]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY ASSESSMENT CRITERIA	EFFECT (MG/L)	SOURCE
Ethoxyquin	Crustacean	*Daphnia magna*	2d	EC50	2	[58]
Fenazaquin	Algae	*Fistulifera pelliculosa*	4d	EC50	0.0454	[58]
Fenbuconazole	Algae	*Raphidocelis subcapitata*	5d	EC50	0.41	[58]
Fenhexamid	Algae	*Raphidocelis subcapitata*	3d	EC50	2.68	[58]
Fenobucarb	Crustacean	*Paratya compressa ssp. Improvisa*	4d	LC50	0.00505	[58]
Fenpropathrin	Crustacean	*Daphnia magna*	2d	EC50	0.00053	[58]
Fenpropimorph	Algae	*Chlorella sorokiniana*	1d	EC50	0.03	[58]
Fenpyroximate	Algae	*Desmodesmus subspicatus*	3d	EC50	0.00066	[58]
Fenthion	Crustacean	*Daphnia magna*	48h	EC50	0.0058	[43]
Fenthion sulfoxide	Fish	*Oryzias latipes*	96h	LC50	0.01	[76]
Fenuron	Fish	*Oncorhynchus mykiss*	96h	LC50	204	[77]
Fipronil	Crustacean	*Ceriodaphnia silvestrii*	48h	EC50	0.0039	[1]
Fipronil desulfinyl	Fish	*Oryzias latipes*	4d	LC50	0.0478	[58]
Fipronil sulfide	Crustacean	*Hyalella azteca*	4d	EC50	0.000375	[58]
Fipronil sulfone	Crustacean	*Hyalella azteca*	4d	EC50	0.000155	[58]
Flazasulfuron	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.014	[78]
Flonicamid	Fish	*Cyprinus carpio*	4d	LC50	43	[58]
Florasulam	Crustacean	*Daphnia magna*	48h	EC50	292	[79]
Fluazifop	Fish	*Oreochromis niloticus*	2d	LC50	0.29	[58]
Fluazifop-p-butyl	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.18	[80]
Flufenacet	Fish	*Lepomis macrochirus*	96h	LC50	2.13	[81]
Fluometuron	Crustacean	*Americamysis bahia*	96h	LC50	6.8	[82]
Fluopicolide	Fish	*Oncorhynchus mykiss*	4d	LC50	0.349	[58]
Fluopiram	Fish	*Coleonyx variegatus*	96h	LC50	0.98	[83]
Fluoxastrobina	Crustacean	*Americamysis bahia*	96h	LC50	0.0604	[84]
Flurochloridone	Algae	*Scenedesmus subspicatus*	72h	EC50	0.0047	[85]
Flurtamone	Fish	*Pimephales promelas*	96h	LC50	6.64	[86]
Flutriafol	Algae	*Raphidocelis subcapitata*	4d	EC50	0.6	[58]
Fluvalinate	Crustacean	*Daphnia magna*	2d	EC50	0.0004	[58]
Fluxapyroxad	Fish	*Oncorhynchus mykiss*	4d	LC50	2.4	[58]
Fomesafen	Crustacean	*Americamysis bahia*	96h	LC50	22.1	[87]
Glyphosate	Crustacean	*C. Mestre*	96 horas	LC50	0.242	[45]
Heptachlor	Crustacean	*Orconectes nais*	4d	LC50	0.0005	[58]
Heptachlor epoxide	Fish	*Lepomis macrochirus*	4d	LC50	0.0053	[58]

PESTICIDE	**ORGANISM**	**SPECIE**	**EXPOSURE TIME**	**TOXICITY ASSESSMENT CRITERIA**	**EFFECT (MG/L)**	**SOURCE**
Hexaconazole	Algae	*Microcystis aeruginosa*	4d	EC50	0.204	[58]
Hexythiazox	Fish	*Lepomis macrochirus*	4d	LC50	0.53	[58]
Imazalil	Fish	*Danio rerio*	5d	EC50	0.726	[58]
Imazapic	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.051	[88]
Imazapyr	Fish	*Oncorhynchus mykiss*	96h	LC50	100	[89]
Imazethapyr	Algae	*Raphidocelis subcapitata*	72h	EC50	71	[90]
Imidacloprid	Crustacean	*Clarias gariepinus*	96h	EC50	0.51	[44]
Indoxacarb	Crustacean	*Daphnia magna*	2d	EC50	0.0237	[58]
Iprodione	Fish	*Ictalurus punctatus*	96h	LC50	3.09	[63]
Irgarol	Algae	*Chara vulgaris*	14d	EC50	0.00001175	[58]
Isocarbophos	Crustacean	*Daphnia magna*	48h	EC50	0.014	[91]
Isoprocarb	Fish	*Poecilia reticulata*	2d	LC50	1.6	[58]
Isoprothiolane	Fish	*Oryzias latipes*	2d	LC50	5.9	[58]
Isoproturon	Algae	*Navicula pelliculosa*	72h	EC50	0.013	[92]
Kresoxim-methyl	Algae	*Fistulifera pelliculosa*	5d	EC50	0.0292	[58]
Lenacil	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.0077	[93]
Linuron	Crustacean	*Americamysis bahia*	96h	LC50	2.9	[94]
Malaoxon	Crustacean	*Daphnia magna*	2d	LC50	0.00097	[58]
Malatião	Crustacean	*C. Magister*	96h	LC50	0.133	[45]
Mandipropamida	Fish	*Oncorhynchus mykiss*	96h	LC50	2.9	[95]
MCPA	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	79.8	[96]
Mecocrop	Crustacean	*Daphnia magna*	48h	EC50	200	[97]
Mefenacet	Fish	*Oncorhynchus mykiss*	96h	LC50	6	[98]
Metalaxil-M	Crustacean	*Daphnia magna*	48h	EC50	100	[99]
Metalaxyl	Algae	*Raphidocelis subcapitata*	3d	EC50	6.25	[58]
Metaldehyde	Fish	*Oncorhynchus mykiss*	4d	LC50	7.3	[58]
Metamitron	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.4	[100]
Metazachlor	Fish	*Oncorhynchus mykiss*	96h	LC50	8.5	[101]
Methidathion	Fish	*Lepomis macrochirus*	4d	LC50	0.009	[58]
Methomyl	Crustacean	*Ceriodaphnia reticulata*	2d	EC50	0.00211	[58]
Methoxychlor	Crustacean	*Gammarus pseudolimnaeus*	42d	LC50	0.00022	[58]
Methoxyfenozide	Crustacean	*Americamysis bahia*	4d	LC50	1.3	[58]
Methyl parathion	Crustacean	*Daphnia magna*	48h	EC50	0.0073	[43]
Metolachlor	Algae	*Selenastrum capricornutum*	72h	EC50	0.056	[151]
Metsulfuron-methyl	Fish	*Poecilia reticulata*	96h	LC50	110	[102]
Molinate	Crustacean	*Daphnia magna*	48h	EC50	14.9	[103]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY ASSESSMENT CRITERIA	EFFECT (MG/L)	SOURCE
Myclobutanil	Crustacean	*Americamysis bahia*	4d	LC50	0.24	[58]
Neburon	Algae	*Neochloris sp.*	72h	EC50	0.039	[104]
Nitenpyram	Crustacean	*Lepeophtheirus salmonis*	1d	EC50	1.7	[58]
Omethoate	Crustacean	*Daphnia magna*	26d	LC50	0.0042	[58]
Oxadiazon	Algae	*Scenedesmus subspicatus*	72h	EC50	0.004	[105]
Oxamyl	Algae	*Fistulifera pelliculosa*	5d	EC50	0.12	[58]
Oxyfluorfen	Fish	*Oncorhynchus mykiss*	96h	LC50	0.25	[106]
Paclobutrazol	Crustacean	*Daphnia magna*	2d	EC50	0.24	[58]
Parathion	Crustacean	*Opossum shrimp*	96h	LC50	0.00011	[107]
Parathion-methyl	Crustacean	*Daphnia magna*	1d	LC50	0.00000031	[58]
Penconazole	Crustacean	*Daphnia magna*	18h	EC50	0.682	[58]
Pendimethalin	Algae	*Selenastrum capricornutum*	72h	EC50	0.004	[108]
Penoxsulam	Fish	*Oncorhynchus mykiss*	96h	LC50	100	[109]
Permethrin	Fish	*Anguilla japonica*	2d	LC50	0.75	[58]
Phorate	Fish	*Fundulus similis*	1d	LC50	0.0032	[58]
Phoxim	Fish	*Esox lucius*	96h	LC50	0.263	[116]
Pirimicarb	Crustacean	*Daphnia magna*	2d	EC50	0.016	[58]
Pirimiphos-methyl	Crustacean	*Daphnia magna*	2d	LC50	0.00017	[58]
Prochloraz	Crustacean	*Daphnia magna*	18h	EC50	0.000866	[58]
Profenofos	Crustacean	*Ceriodaphnia dubia*	2d	LC50	0.000041	[58]
Prometon	crustacea	*Daphnia magna*	48h	EC50	25.7	[119]
Prometryn	Algae	*Scenedesmus subspicatus*	72h	EC50	0.002	[120]
Propachlor	Fish	*Oncorhynchus mykiss*	96h	LC50	0.17	[121]
Propamocarb	Crustacean	*Americamysis bahia*	4d	LC50	50.5	[58]
Propanil	Fish	*Oncorhynchus mykiss*	96h	LC50	5.4	[58]
Propazine	Fish	*Oncorhynchus mykiss*	96h	LC50	17.5	[58]
Propiconazole	Crustacean	*Opossum shrimp*	96h	LC50	0.00085	[116]
Propyzamide	Algae	*Raphidocelis subcapitata*	72h	EC50	2.8	[122]
Proquinazid	Crustacean	*Americamysis bahia*	96h	LC50	0.11	[123]
Prosulfocarb	Crustacean	*Daphnia magna*	48h	EC50	0.51	[124]
Pymetrozine	Fish	*Danio rerio*	5d	EC50	3,788	[58]
Pyraclostrobin	Crustacean	*Opossum shrimp*	96h	LC50	0.0041	[116]
Pyrazophos	Crustacean	*Daphnia pulex*	3h	LC50	0.0022	[58]
Pyrazosulfuron-ethyl	Crustacean	*Daphnia magna*	48h	EC50	700	[125]
Pyridaben	Crustacean	*Americamysis bahia*	4d	LC50	0.00067	[58]
Pyrimethanil	Fish	*Sheepshead minnow*	96h	LC50	2,818	[116]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY ASSESSMENT CRITERIA	EFFECT (MG/L)	SOURCE
Quinalphos	Crustacean	*Daphnia magna*	48h	EC50	0.00066	[126]
Quinclorac	Algae	*Scenedesmus acutus*	72h	EC50	6.53	[127]
Quinmerac	Algae	*Chlorella fusca*	72h	EC50	48.5	[128]
Quizalofop-ethyl	Fish	*Lepomis macrochirus*	96h	LC50	2.8	[129]
Secbumeton	Fish	*Oncorhynchus mykiss*	96h	LC50	18	[130]
Simazine	Algae	*Scenedesmus subspicatus*	72h	EC50	0.04	[131]
Simetryn	Algae	*Anabaena flos-aquae*	72h	EC50	0.0098	[132]
S-metolacloro	Fish	*Oncorhynchus mykiss*	96h	LC50	1.23	[133]
Spiroxamine	Algae	*Skeletonema costatum*	4d	EC50	0.00118	[58]
Tebuconazole	Fish	*Rhynchocypris oxycephalus*	96h	LC50	4.07	[44]
Tebufenozide	Algae	*Scenedesmus acutus*	3d	EC50	0.12	[58]
Tebufenpyrad	Crustacean	*Daphnia pulex*	21d	EC50	0.01058	[58]
Tebuthiuron	Algae	*Raphidocelis subcapitata*	72h	EC50	0.05	[134]
Terbufos	Crustacean	*Ceriodaphnia dubia*	4d	EC50	0.000074	[58]
Terbufos sulfone	Crustacean	*Ceriodaphnia dubia*	4d	EC50	0.000148	[58]
Terbumeton	Fish	*Oncorhynchus mykiss*	96h	LC50	14	[135]
Terbuthylazine	Crustacean	*Daphnia magna*	48h	EC50	21.2	[136]
Terbutryn	Algae	*Pseudokirchneriella subcapitata*	72h	EC50	0.0024	[137]
Tetraconazol	Crustacean	*Americamysis bahia*	4d	LC50	0.43	[58]
Thiabendazole	Crustacean	*Americamysis bahia*	4d	LC50	0.34	[58]
Thiacloprid	Crustacean	*Hyalella azteca*	7d	EC50	0.068	[44]
Thiamethoxam	Algae	*Raphidocelis subcapitata*	72h	EC50	81.8	[138]
Triadimefon	Algae	*Raphidocelis subcapitata*	4d	EC50	0.91	[58]
Triadimenol	Algae	*Chlorella fusca var. Vacuolata*	1d	EC50	1.77	[58]
Triallate	Fish	*Oncorhynchus mykiss*	96h	LC50	0.95	[139]
Triasulfuron	Algae	*Raphidocelis subcapitata*	12d	EC50	0.035	[140]
Triazophos	Crustacean	*Daphnia magna*	48h	LC50	0.0013	[141]
Tribenuron-methyl	Crustacean	*Daphnia magna*	48h	EC50	894	[142]
Trichlorfon	Fish	*Salvelinus namaycush*	96h	LC50	0.758	[116]
Tricyclazole	Fish	*Gambusia affinis*	2d	LC50	1.4	[58]
Trifloxystrobin	Crustacean	*Daphnia magna*	2d	EC50	0.0017	[58]
Trifluralin	Algae	*Raphidocelis subcapitata*	72h	EC50	0.0122	[143]
λ-Cyhalothrin	Fish	*Danio rerio*	96h	LC50	0.0031	[44]
ΣDDTs	Crustacean	*Leptocheirus plumulosus*	28d	LC50	0.00269	[146]

Table S3- Chronic Toxicity - Red area: highly toxic; yellow area: very toxic; blue area: toxic; green area: no toxic.

PESTICIDE	**ORGANISM**	**SPECIE**	**EXPOSURE TIME**	**TOXICITY**	**EFFECT (MG/L)**	**SOURCE**
2,4-D	Crustacean	*Ceriodaphnia silvestrii*	8d	NOEC	50	[42]
2,4-D	algae	*Chlorella vulgaris*	4d	NOEC	100	[147]
2,4-D	fish	*Oryzias latipes*	28d	NOEC	27,2	[147]
Acephate	fish	*Pseudaphritis urvillii*	10d	NOEC	4,7	[58]
Acephate	crustacean	*Daphnia magna*	21d	NOEC	43	[43]
Acetamiprid	algae	*Synechocystis sp.*	1d	NOEC	22,26	[58]
Acetamiprid	crustacean	*Gammarus pulex*	2d	NOEC	0,003	[58]
Acetamiprid	fish	*Danio rerio*	4d	NOEC	0,17	[58]
Acetochlor	crustacean	*Daphnia magna*	21d	NOEC	0,022	[147]
Acetochlor	fish	*Oncorhynchus mykiss*	21d	NOEC	0,13	[147]
Acetochlor	1	*Lemna minor*	7d	LOEC	0,005	[148]
Alaclor	fish	*Ictalurus punctatus*	4d	NOEC	0,95	[58]
Alaclor	crustacean	*Ceriodaphnia dubia*	7d	NOEC	12,5	[58]
Alaclor	algae	*Chlorella pyrenoidosa*	4d	NOEC	0,02	[147]
Aldrin	fish	*Danio rerio*	7d	NOEC	1,00E-04	[149]
Ametryn	algae	*Chlamydomonas moewusii*	7d	NOEC	6,82	[58]
Ametryn	crustacean	*Daphnia magna*	21d	LOEC	3,20E-01	[147]
Ametryn	fish	*Pimephales promelas*	35d	NOEC	0,7	[147]
Amidosulfuron	crustacean	*Daphnia magna*	21d	NOEC	1	[147]
Amidosulfuron	fish	*Oncorhynchus mykiss*	21d	NOEC	6,41	[147]
Amitraz	crustacean	*Daphnia magna*	6d	NOEC	0,01	[58]
Amitraz	fish	*Pimephales promelas*	21d	NOEC	0,00353	[147]
AMPA	crustacean	*Daphnia magna*	21d	NOEC	15	[150]
AMPA	fish	*Pimephales promelas*	21d	NOEC	12	[150]
AMPA	Algae	*Nitella microcarpa var. Wrightii*	7d	NOEC	0,03	[58]
Anilofos	algae	*Tolypothrix tenuis*	24d	NOEC	0,16	[58]
Atrazine	algae	*Selenastrum capricornutum*	52d	NOEC	0,0014	[151]
Atrazine	crustacean	*Eurytemora affinis*	56d	NOEC	4,2	[152]
Atrazine	fish	*Cyprinodon variegates*	56d	NOEC	1,9	[152]
Atrazine desisopropyl	algae	*Raphidocelis subcapitata*	3d	NOEC	0,0006	[58]
Atrazine desisopropyl	crustacean	*Procambarus clarkii*	14d	NOEC	0,01	[58]
Atrazine desisopropyl	fish	*Danio rerio*	3d	NOEC	0,1	[58]
Atrazine-desethyl	algae	*Chlamydomonas moewusii*	12d	NOEC	1,25	[58]
Atrazine-desethyl	crustacean	*Hyalella azteca*	42d	NOEC	0,03	[58]
Atrazine-desethyl	fish	*Danio rerio*	2d	NOEC	0,03	[58]
Azinphos-ethyl	algae	*Tetraselmis suecica*	4d	NOEC	1	[153]
Azinphos-ethyl	crustacean	*Penaeus monodon*	4d	LOEC	0,03	[143]
Azoxystrobin	algae	*Cosmarium turpinii*	16d	NOEC	0,032	[58]
Azoxystrobin	fish	*Ctenopharyngodon idella*	2d	NOEC	0,1	[58]
Azoxystrobin	crustacean	*Daphnia magna*	21d	NOEC	0,044	[58]

PESTICIDE	**ORGANISM**	**SPECIE**	**EXPOSURE TIME**	**TOXICITY**	**EFFECT (MG/L)**	**SOURCE**
Bensulfuron-methyl	algae	*Raphidocelis subcapitata*	4d	NOEC	40	[147]
Bensulfuron-methyl	crustacean	*Daphnia magna*	21d	NOEC	12	[147]
Bensulfuron-methyl	fish	*Oncorhynchus mykiss*	21d	NOEC	12	[147]
Bentazone	algae	*Pseudokirchneriella subcapitata*	72h	NOEC	0.7	[154]
Bentazone	crustacean	*Daphnia magna*	21d	NOEC	120	[154]
Bentazone	fish	*Oncorhynchus mykiss*	28d	NOEC	48	[154]
Bifenthrin	fish	*Danio rerio*	6d	NOEC	0,05	[58]
Bifenthrin	crustacean	*Daphnia magna*	21d	LOEC	2,00E-05	[155]
Boscalid	crustacean	*Daphnia magna*	21d	NOEC	1,3	[147]
Boscalid	fish	*Oncorhynchus mykiss*	21d	NOEC	0,125	[147]
Bupirimate	crustacean	*Daphnia magna*	21d	NOEC	0,56	[147]
Bupirimate	fish	*Oncorhynchus mykiss*	21d	NOEC	0,3	[147]
Buprofezin	crustacean	*Daphnia magna*	14d	NOEC	0,025	[58]
Buprofezin	fish	*Clarias gariepinus*	1d	NOEC	0,5	[58]
Butachlor	Algae	*Anabaena oscillarioides*	14d	NOEC	0,1	[58]
Butachlor	crustacean	*Macrobrachium lar*	2d	NOEC	1,5	[58]
Butachlor	fish	*Danio rerio*	30d	NOEC	0,025	[147]
Cadusafos	crustacean	*Daphnia magna*	21d	NOEC	0,00023	[147]
Cadusafos	fish	*Oncorhynchus mykiss*	95d	NOEC	0,0052	[147]
Carbendazim	Algae	*Chlamydomonas sp.*	28d	NOEC	0,1	[58]
Carbendazim	fish	*Clarias gariepinus*	5d	NOEC	0,22	[58]
Carbendazim	crustacean	*Gammarus pulex*	6d	NOEC	0,031	[58]
Carbendazim/Benomyl	crustacean	*Daphnia magna*	21d	NOEC	0,013	[58]
Carbendazim/Benomyl	fish	*Oncorhynchus mykiss*	21d	NOEC	0,026	[58]
Carbofuran	algae	*Scenedesmus obliquus*	4d	NOEC	0,2	[70]
Carbofuran	crustacean	*Ceriodaphnia dubia*	7d	NOEC	0,0013	[156]
Carbofuran	fish	*Carassius auratus*	4d	NOEC	1,5	[157]
Chlorantraniliprole	crustacean	*Daphnia magna*	2d	NOEC	0,00108	[58]
Chlorantraniliprole	fish	*Danio rerio*	1d	NOEC	0,001	[58]
Chlorfenvinphos	Algae	*Chlorella vulgaris*	1h	NOEC	17,98	[58]
Chlorfenvinphos	fish	*Clarias gariepinus*	1d	NOEC	0,001	[58]
Chlorotoluron	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	0,8	[147]
Chlorotoluron	crustacean	*Daphnia magna*	21d	NOEC	11,2	[147]
Chlorotoluron	fish	*Oncorhynchus mykiss*	21d	NOEC	0,4	[147]
Chlorpyrifos	algae	*Brachionus calyciflorus*	4d	NOEC	0,01	[158]
Chlorpyrifos	crustacean	*Daphnia magna*	21d	NOEC	3,00E-05	[43]
Chlorpyrifos	fish	*Fathead minnow*	30d	NOEC	1,29E-03	[159]
Chlortoluron	Algae	*Chlorella pyrenoidosa*	4d	NOEC	0,01	[58]
Chlortoluron	fish	*Danio rerio*	2d	NOEC	2	[58]
Clomazone	algae	*Navicula pelliculosa*	5d	NOEC	0,05	[147]
Clomazone	crustacean	*Daphnia magna*	21d	NOEC	2,2	[147]
Clomazone	fish	*Oncorhynchus mykiss*	21d	NOEC	2,3	[147]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Clothianidin	crustacean	*Orconectes propinquus*	21d	NOEC	0,005	[58]
Clothianidin	fish	*Oncorhynchus nerka*	27d	NOEC	0,114	[58]
Cyfluthrin	Algae	*Scenedesmus acutus*	4d	NOEC	0,03	[58]
Cyfluthrin	crustacean	*Hyalella azteca*	4d	NOEC	0,00017	[75]
Cyfluthrin	fish	*Rainbow trout*	58d	NOEC	1,00E-05	[159]
Cyhalothrin	crustacean	*Gammarus pulex*	3d	NOEC	0,00005	[58]
Cyhalothrin	fish	*Clarias gariepinus*	4d	NOEC	0,000008	[58]
Cypermethrin	Algae	*Chlorella vulgaris*	14d	NOEC	0,00002	[58]
Cypermethrin	crustacean	*Daphnia magna*	21d	NOEC	2E-10	[58]
Cypermethrin	fish	*Oreochromis niloticus*	4d	NOEC	0,004	[76]
Cyproconazole	algae	*Scenedesmus subspicatus*	96h	NOEC	0,021	[147]
Cyproconazole	crustacean	*Daphnia magna*	21d	NOEC	0,019	[58]
Cyproconazole	fish	*Danio rerio*	5d	NOEC	4,377	[58]
Cyprodinil	crustacean	*Gammarus pulex*	2d	NOEC	0,070	[58]
Cyprodinil	fish	*Danio rerio*	4,75d	NOEC	0,743	[58]
DDT(O,P')	fish	*Oncorhynchus mykiss*	21d	NOEC	0,13	[147]
DEET	Algae	*Raphidocelis subcapitata*	3d	NOEC	0,0006	[58]
DEET	crustacean	*Procambarus clarkii*	14d	NOEC	0,0005	[58]
DEET	fish	*Pimephales promelas*	2d	NOEC	0,0006	[58]
Deltamethrin	Algae	*Chlorella vulgaris*	14d	NOEC	0,00002	[58]
Deltamethrin	crustacean	*Daphnia hyalina*	21d	NOEC	0,000005	[58]
Deltamethrin	fish	*Poecilia reticulata*	4d	NOEC	0,02	[161]
Diazinon	algae	*Brachionus calyciflorus*	2d	NOEC	8	[158]
Diazinon	crustacean	*Daphnia magna*	21d	NOEC	0,00056	[43]
Diazinon	fish	*Danio rerio*	4d	NOEC	2	[162]
Dichlorprop	algae	*Scenedesmus acutus var. Acutus*	3d	NOEC	101,08	[58]
Dichlorprop	fish	*Pleuronectes americanus*	1,75h	NOEC	0,000235	[58]
Dichlorvos	fish	*Rainbow trout*	61d	NOEC	0,0052	[159]
Dicofol	crustacean	*Daphnia magna*	21d	NOEC	0,1	[58]
Dicofol	fish	*Pimephales promelas*	296d	NOEC	0,00452	[58]
Dieldrin	crustacean	*Daphnia magna*	21d	NOEC	0,032	[58]
Dieldrin	fish	*Oncorhynchus mykiss*	90d	NOEC	0,00055	[58]
Difenoconazole	crustacean	*Daphnia magna*	21d	NOEC	0,005	[58]
Difenoconazole	fish	*Pimephales promelas*	268d	NOEC	0,0019	[58]
Diflufenican	algae	*Scenedesmus subspicatus*	21d	NOEC	0,0001	[147]
Diflufenican	crustacean	*Daphnia magna*	21d	NOEC	0,052	[147]
Diflufenican	fish	*Oncorhynchus mykiss*	21d	NOEC	0,015	[147]
Dimethenamid-P	crustacean	*Daphnia magna*	21d	NOEC	1,25	[147]
Dimethenamid-P	fish	*Oncorhynchus mykiss*	21d	NOEC	2,5	[147]
Dimethoate	algae	*Pseudokirchneriella subcapitata*	3d	NOEC	0,5066	[170]
Dimethoate	fish	*Oreochromic niloticus*	4d	NOEC	38,1	[76]
Dimethoate	crustacean	*Daphnia magna*	21d	NOEC	0,04	[43]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Dimethomorph	crustacean	*Daphnia magna*	22d	NOEC	0,1	[58]
Dimethomorph	fish	*Oncorhynchus mykiss*	21d	NOEC	0,056	[147]
Dimetoato	Algae	*Chlorella vulgaris*	2h	NOEC	0,23	[58]
Dimetoato	crustacean	*Paratya australiensis*	4d	NOEC	0,01	[58]
Dimetoato	fish	*Cirrhinus mrigala*	10d	NOEC	0,003	[58]
Dinotefuran	crustacean	*Ceriodaphnia dubia*	7d	NOEC	67	[58]
Dinotefuran	fish	*Danio rerio*	14d	NOEC	0,1	[58]
Diuron	algae	*Paramecium caudatum*	1d	NOEC	0,88	[164]
Diuron	crustacean	*Ceriodaphnia silvestrii*	1d	NOEC	0,5	[164]
Diuron	fish	*Danio rerio*	4d	NOEC	2	[162]
Endosulfan	algae	*Brachionus calyciflorus*	3d	NOEC	0,875	[158]
Endosulfan	crustacean	*Gammarus kischineffensis*	2d	NOEC	0,00005	[58]
Endosulfan	fish	*Oncorhynchus mykiss*	28d	NOEC	0,0000001	[58]
Endosulfan Sulfat	crustacean	*Daphnia magna*	4d	NOEC	0,0917	[58]
Endrin	fish	*Gambusia affinis*	1h	NOEC	0,01	[58]
Epoxiconazole	algae	*Gymnodinium mikimotoi*	1d	NOEC	0,01	[58]
Epoxiconazole	crustacean	*Daphnia magna*	21d	NOEC	0,63	[147]
Epoxiconazole	fish	*Gobiocypris rarus*	3d	NOEC	1	[58]
Eptc	algae	*Chlamydomonas eugametos*	3d	NOEC	0,205	[58]
Eptc	crustacean	*Daphnia magna*	21d	NOEC	0,81	[147]
Esfenvalerate	crustacean	*Ceriodaphnia dubia*	2d	NOEC	0,000001	[58]
Esfenvalerate	fish	*Pimephales promelas*	2d	NOEC	0,000001	[58]
Ethametsulfuron-methyl	crustacean	*Daphnia magna*	21d	NOEC	4,7	[147]
Ethametsulfuron-methyl	fish	*Oncorhynchus mykiss*	87d	NOEC	5,4	[147]
Ethoprophos	crustacean	*Daphnia magna*	21d	NOEC	0,0008	[58]
Ethoprophos	fish	*Fathead minnow*	35d	NOEC	0,024	[159]
Ethoxyquin	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	6,1	[147]
Fenazaquin	crustacean	*Daphnia magna*	21d	NOEC	0,0021	[147]
Fenazaquin	fish	*Oncorhynchus mykiss*	21d	NOEC	0,00096	[147]
Fenbuconazole	crustacean	*Daphnia magna*	21d	NOEC	0,078	[58]
Fenbuconazole	fish	*Pimephales promelas*	244d	NOEC	0,027	[58]
Fenhexamid	crustacean	*Daphnia magna*	21d	NOEC	1	[58]
Fenhexamid	fish	*Oncorhynchus mykiss*	96d	NOEC	0,101	[147]
Fenobucarb	fish	*Oreochromis niloticus*	4d	NOEC	0,5	[58]
Fenpropathrin	crustacean	*Daphnia magna*	21d	NOEC	0,00022	[58]
Fenpropathrin	fish	*Pimephales promelas*	260d	NOEC	0,000013	[58]
Fenpropimorph	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	0,058	[147]
Fenpropimorph	fish	*Danio rerio*	2,875d	NOEC	4.765	[58]
Fenpyroximate	algae	*Scenedesmus subspicatus*	4d	NOEC	0,01	[147]
Fenpyroximate	crustacean	*Daphnia magna*	21d	NOEC	0,00016	[147]
Fenpyroximate	fish	*Danio rerio*	20h	NOEC	0,164	[58]
Fenthion	algae	*Tetraselmis suecica*	4d	NOEC	0,5	[153]

PESTICIDE	**ORGANISM**	**SPECIE**	**EXPOSURE TIME**	**TOXICITY**	**EFFECT (MG/L)**	**SOURCE**
Fenthion	crustacean	*Daphnia magna*	21d	NOEC	0,000013	[58]
Fenthion	fish	*Pimephales promelas*	30d	NOEC	0,065	[58]
Fenuron	Algae	*Sargassum polycystum*	42d	NOEC	2.477	[58]
Fenuron	crustacean	*Lepeophtheirus salmonis*	1d	NOEC	1	[58]
Fenuron	fish	*Cyprinus carpio*	7d	NOEC	0,1	[58]
Fipronil	Crustacean	*Ceriodaphnia silvestrii*	8d	NOEC	0,0004	[42]
Fipronil	fish	*Rainbow trout*	90d	NOEC	0,0066	[159]
Flazasulfuron	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	0,005	[147]
Flazasulfuron	crustacean	*Daphnia magna*	21d	NOEC	6,25	[147]
Flazasulfuron	fish	*Oncorhynchus mykiss*	21d	NOEC	5	[147]
Flonicamid	crustacean	*Daphnia magna*	21d	NOEC	3,1	[147]
Flonicamid	fish	*Cyprinus carpio*	22d	NOEC	4,3	[58]
Florasulam	crustacean	*Daphnia magna*	21d	NOEC	38,9	[147]
Florasulam	fish	*Oncorhynchus mykiss*	21d	NOEC	119	[147]
Fluazifop	fish	*Lepomis macrochirus*	4d	NOEC	0,62	[58]
Fluazifop-p-butyl	fish	*Pimephales promelas*	21d	NOEC	0,077	[147]
Flufenacet	Crustacean	*Daphnia magna*	21d	NOEC	3,26	[147]
Flufenacet	fish	*Oncorhynchus mykiss*	21d	NOEC	0,2	[147]
Fluometuron	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	0,0661	[147]
Fluometuron	Crustacean	*Daphnia magna*	21d	NOEC	18	[147]
Fluometuron	fish	*Oncorhynchus mykiss*	21d	NOEC	4,3	[147]
Fluopicolide	crustacean	*Daphnia magna*	21d	NOEC	0,37	[147]
Fluopicolide	fish	*Pimephales promelas*	35d	NOEC	0,155	[147]
Fluopiram	crustacean	*Daphnia magna*	21d	NOEC	1,25	[147]
Fluopiram	fish	*Pimephales promelas*	33d	NOEC	0,135	[147]
Fluoxastrobina	crustacean	*Daphnia magna*	21d	NOEC	0,18	[147]
Fluoxastrobina	fish	*Oncorhynchus mykiss*	21d	NOEC	0,0286	[147]
Flurochloridone	Crustacean	*Daphnia magna*	21d	NOEC	0,83	[147]
Flurochloridone	fish	*Oncorhynchus mykiss*	21d	NOEC	0,016	[147]
Flurtamone	algae	*Navicula pelliculosa*	4d	NOEC	0,024	[147]
Flurtamone	Crustacean	*Daphnia magna*	21d	NOEC	0,071	[147]
Flurtamone	fish	*Oncorhynchus mykiss*	21d	NOEC	0,63	[147]
Flutriafol	crustacean	*Daphnia magna*	21d	NOEC	0,55	[147]
Flutriafol	fish	*Pimephales promelas*	21d	NOEC	4,8	[147]
Fluvalinate	fish	*Pimephales promelas*	30d	NOEC	0,000033	[147]
Fluvalinate	crustacean	*Daphnia magna*	21d	NOEC	0,000037	[58]
Fluxapyroxad	crustacean	*Daphnia magna*	21d	NOEC	0,5	[147]
Fluxapyroxad	fish	*Danio rerio*	1,875d	NOEC	0,39	[58]
Fomesafen	Crustacean	*Daphnia magna*	21d	LOEC	100	[147]
Glyphosate	algae	*Scenedesmus acutus*	4d	NOEC	2	[165]
Glyphosate	crustacean	*Caridina nilotica*	21d	NOEC	2,2	[166]
Glyphosate	fish	*Cyprinus carpio*	4d	NOEC	1,7	[167]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Heptachlor	fish	*Danio rerio*	7d	NOEC	0,001	[149]
Hexaconazole	algae	*Microcystis aeruginosa*	4d	NOEC	0,02	[58]
Hexaconazole	crustacean	*Daphnia magna*	21d	NOEC	0,226	[58]
Hexaconazole	fish	*Danio rerio*	2,875d	NOEC	6,63	[58]
Hexythiazox	crustacean	*Daphnia magna*	21d	NOEC	0,0061	[58]
Hexythiazox	fish	*Oncorhynchus mykiss*	21d	NOEC	0,04	[147]
Imazalil	crustacean	*Procambarus clarkii*	2h	NOEC	0,016	[58]
Imazalil	fish	*Oncorhynchus mykiss*	28d	LOEC	0,043	[147]
Imazapic	crustacean	*Daphnia magna*	21d	NOEC	96	[58]
Imazapic	fish	*Danio rerio*	21d	NOEC	10	[147]
Imazapyr	Crustacean	*Daphnia magna*	21d	NOEC	97,1	[147]
Imazapyr	fish	*Oncorhynchus mykiss*	28d	NOEC	43,1	[147]
Imazethapyr	Crustacean	*Daphnia magna*	21d	NOEC	103	[147]
Imazethapyr	fish	*Pimephales promelas*	21d	NOEC	97	[147]
Imidacloprid	algae	*Planothidium lanceolatum*	24d	NOEC	0,005	[58]
Imidacloprid	crustacean	*Gammarus fossarum*	2d	NOEC	0,00005	[58]
Imidacloprid	fish	*Australoheros facetus*	2d	NOEC	0,001	[58]
Indoxacarb	crustacean	*Daphnia magna*	21d	NOEC	0,075	[58]
Indoxacarb	fish	*Rainbow trout*	32d	NOEC	0,15	[159]
Iprodione	crustacean	*Daphnia magna*	21d	NOEC	0,17	[58]
Iprodione	fish	*Danio rerio*	4d	NOEC	0,038	[58]
Irgarol	algae	*Chara vulgaris*	14d	NOEC	0,0000005	[58]
Irgarol	crustacean	*Daphnia magna*	21d	NOEC	0,56	[58]
Irgarol	fish	*Rainbow trout*	95d	NOEC	0,004	[159]
Isoprocarb	algae	*Scenedesmus acutus var. Acutus*	4d	NOEC	0,1	[58]
Isoprocarb	fish	*Carassius auratus*	5d	NOEC	0,018	[58]
Isoprothiolane	fish	*Cyprinus carpio*	5,04min	NOEC	0,0067	[58]
Isoproturon	algae	*Chlorella pyrenoidosa*	4d	NOEC	0,002	[58]
Isoproturon	Crustacean	*Daphnia magna*	21d	NOEC	0,12	[147]
Isoproturon	fish	*Oncorhynchus mykiss*	21d	NOEC	1	[147]
Kresoxim-methyl	algae	*Chlorella vulgaris*	4d	NOEC	0,015	[58]
Kresoxim-methyl	crustacean	*Daphnia magna*	2d	NOEC	0,2	[58]
Kresoxim-methyl	fish	*Ctenopharyngodon idella*	2d	NOEC	0,01	[58]
Lenacil	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,001687	[58]
Lenacil	Crustacean	*Daphnia magna*	21d	NOEC	0,48	[147]
Lenacil	fish	*Oncorhynchus mykiss*	21d	NOEC	2,3	[147]
Linuron	algae	*Chlamydomonas sp.*	28d	NOEC	0,01	[58]
Linuron	crustacean	*Daphnia magna*	21d	NOEC	0,18	[147]
Linuron	fish	*Rainbow trout*	80d	NOEC	0,042	[159]
Malatião	crustacean	*Gammarus pseudolimnaeus*	30d	NOEC	8,00E-06	[154]
Malatião	fish	*Carassius auratus*	4d	NOEC	2E+00	[169]
Mandipropamida	crustacean	*Daphnia magna*	21d	NOEC	0,87	[147]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Mandipropamida	fish	*Pimephales promelas*	21d	NOEC	0,5	[147]
MCPA	algae	*Raphidocelis subcapitata*	2d	NOEC	0,5	[58]
MCPA	Crustacean	*Daphnia magna*	21d	NOEC	56	[147]
MCPA	fish	*Pimephales promelas*	21d	NOEC	15	[147]
Mecocrop	Crustacean	*Daphnia magna*	21d	NOEC	22	[147]
Mecocrop	fish	*Oncorhynchus mykiss*	21d	NOEC	109	[147]
Metalaxil-M	fish	*Pimephales promelas*	21d	NOEC	9,1	[147]
Metalaxyl	algae	*Raphidocelis subcapitata*	3d	NOEC	0,4	[58]
Metalaxyl	crustacean	*Daphnia magna*	14d	NOEC	0,1	[58]
Metalaxyl	fish	*Pimephales promelas*	30d	NOEC	9,1	[58]
Metamitron	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,0188	[58]
Metamitron	Crustacean	*Daphnia magna*	21d	NOEC	10	[147]
Metamitron	fish	*Oncorhynchus mykiss*	21d	NOEC	7	[147]
Metazachlor	algae	*Prorocentrum minimum*	3d	NOEC	0,01	[58]
Metazachlor	Crustacean	*Daphnia magna*	21d	NOEC	0,1	[147]
Metazachlor	fish	*Oncorhynchus mykiss*	21d	NOEC	2,15	[147]
Methidathion	algae	*Raphidocelis subcapitata*	4d	NOEC	0,5	[58]
Methidathion	Crustacean	*Americamysis bahia*	28d	NOEC	0,000022	[58]
Methidathion	fish	*Aphyocypris chinensis*	3d	NOEC	0,001	[58]
Methomyl	algae	*Nostoc muscorum*	7d	NOEC	100	[58]
Methomyl	Crustacean	*Daphnia magna*	21d	NOEC	0,0004	[58]
Methomyl	fish	*Fathead minnow*	28d	NOEC	0,057	[159]
Methoxychlor	Crustacean	*Cancer magister*	69d	NOEC	0,000005	[58]
Methoxychlor	fish	*Oncorhynchus mykiss*	14d	NOEC	0,0014	[58]
Methoxyfenozide	Crustacean	*Gammarus fossarum*	15d	NOEC	0,0001	[58]
Methoxyfenozide	fish	*Fathead minnow*	31d	NOEC	2,4	[159]
Methyl parathion	algae	*Cryptomonas sp*	7d	NOEC	1,3	[170]
Methyl parathion	fish	*Oreochromis mossambicus*	2d	NOEC	0,09	[58]
Methyl parathion	crustacean	*Daphnia magna*	21d	NOEC	0,0012	[154]
Metolachlor	algae	*Selenastrum capricornutum*	52d	NOEC	0,0027	[151]
Metolachlor	crustacean	*Daphnia magna*	21d	NOEC	0,707	[147]
Metolachlor	fish	*Fathead minnow*	35d	NOEC	0,78	[159]
Metsulfuron-methyl	Crustacean	*Daphnia magna*	21d	NOEC	3,13	[147]
Metsulfuron-methyl	fish	*Salmo gairdneri*	21d	NOEC	68	[147]
Molinate	algae	*Scenedesmus acutus*	4d	NOEC	0,22	[58]
Molinate	crustacean	*Daphnia magna*	21d	NOEC	0,38	[147]
Molinate	fish	*Oncorhynchus mykiss*	73d	NOEC	0,39	[147]
Myclobutanil	algae	*Scenedesmus acutus var. Acutus*	4d	NOEC	5	[58]
Myclobutanil	Crustacean	*Afrochiltonia subtenuis*	56d	NOEC	0,0005	[58]
Myclobutanil	fish	*Danio rerio*	5d	NOEC	0,001	[58]
Nitenpyram	fish	*Gobiocypris rarus*	60d	NOEC	2	[58]
Oxadiazon	algae	*Raphidocelis subcapitata*	3d	NOEC	0,007	[58]

PESTICIDE	**ORGANISM**	**SPECIE**	**EXPOSURE TIME**	**TOXICITY**	**EFFECT (MG/L)**	**SOURCE**
Oxadiazon	crustacean	*Daphnia magna*	21d	NOEC	0,03	[147]
Oxadiazon	fish	*Oncorhynchus mykiss*	21d	NOEC	0,00088	[147]
Oxamyl	crustacean	*Daphnia magna*	21d	NOEC	0,0268	[58]
Oxamyl	fish	*Pimephales promelas*	28d	NOEC	0,5	[58]
Oxyfluorfen	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	2	[147]
Oxyfluorfen	crustacean	*Daphnia magna*	21d	NOEC	0,013	[147]
Oxyfluorfen	fish	*Pimephales promelas*	21d	NOEC	0,038	[147]
Paclobutrazol	crustacean	*Daphnia magna*	21d	NOEC	0,32	[147]
Paclobutrazol	fish	*Danio rerio*	2d	NOEC	10	[58]
Parathion	algae	*Raphidocelis subcapitata*	2d	NOEC	0,35	[58]
Parathion	crustacean	*Daphnia magna*	21d	NOEC	0,000002	[58]
Parathion	fish	*Cyprinodon variegatus*	28d	NOEC	0,00019	[58]
Parathion-methyl	algae	*Tetraselmis suecica*	4d	NOEC	5	[153]
Parathion-methyl	crustacean	*Americamysis bahia*	24d	NOEC	0,00011	[58]
Parathion-methyl	fish	*Cyprinodon variegatus*	38d	NOEC	0,00886	[58]
Penconazole	crustacean	*Daphnia magna*	21d	NOEC	0,06	[147]
Penconazole	fish	*Pimephales promelas*	21d	NOEC	0,36	[147]
Pendimethalin	algae	*Pseudokirchneriella subcapitata*	4d	NOEC	0,003	[147]
Pendimethalin	crustacean	*Daphnia magna*	21d	NOEC	0,0145	[147]
Pendimethalin	fish	*Pimephales promelas*	21d	NOEC	0,006	[147]
Penoxsulam	crustacean	*Daphnia magna*	21d	NOEC	2,95	[147]
Penoxsulam	fish	*Pimephales promelas*	21d	NOEC	10,2	[147]
Permethrin	algae	*Chlorella vulgaris*	14d	NOEC	0,00002	[58]
Permethrin	crustacean	*Daphnia magna*	21d	NOEC	2E-10	[58]
Permethrin	fish	*Salmo salar*	5d	NOEC	0,000015	[58]
Phorate	algae	*Chlorella vulgaris*	1h	NOEC	2,603645	[58]
Phorate	crustacean	*Americamysis bahia*	28d	NOEC	0,0000058	[58]
Phorate	fish	*Rainbow trout*	88d	NOEC	0,0019	[159]
Phoxim	algae	*Microcystis wesenbergii*	6h	NOEC	0,08388	[58]
Pirimicarb	crustacean	*Daphnia magna*	21d	NOEC	0,0009	[58]
Pirimicarb	fish	*Pimephales promelas*	36d	NOEC	4,4	[58]
Pirimiphos-methyl	crustacean	*Daphnia magna*	2d	NOEC	0,0001	[58]
Pirimiphos-methyl	fish	*Oncorhynchus mykiss*	21d	NOEC	0,023	[147]
Prochloraz	fish	*Oryzias latipes*	7d	NOEC	0,003	[58]
Prochloraz	crustacean	*Gammarus pulex*	2d	NOEC	0,1	[58]
Profenofos	crustacean	*Paratya australiensis*	4d	NOEC	0,00001	[58]
Profenofos	fish	*Oreochromis mossambicus*	3d	NOEC	0,03	[58]
Prometon	algae	*Chlorella fusca*	1d	NOEC	0,035	[147]
Prometon	crustacean	*Farfantepenaeus duorarum*	2d	NOEC	1	[58]
Prometon	fish	*Pimephales promelas*	21d	NOEC	0,999	[147]
Prometryn	algae	*Chlamydomonas reinhardtii*	4d	NOEC	0,0025	[147]
Prometryn	crustacean	*Daphnia magna*	21d	NOEC	2	[147]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Prometryn	fish	*Cyprinus carpio*	60d	NOEC	0,08	[147]
Propachlor	crustacean	*Daphnia magna*	21d	NOEC	0,612	[147]
Propachlor	fish	*Pimephales promelas*	30d	NOEC	0,045	[58]
Propamocarb	crustacean	*Daphnia magna*	21d	NOEC	12,3	[58]
Propamocarb	fish	*Pimephales promelas*	32d	NOEC	37,5	[58]
Propanil	algae	*Chlamydomonas moewusii*	4d	NOEC	0,916	[147]
Propanil	crustacean	*Daphnia magna*	21d	NOEC	0,086	[147]
Propanil	fish	*Pimephales promelas*	21d	NOEC	0,0004	[147]
Propazine	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,0065	[58]
Propazine	fish	*Danio rerio*	2d	NOEC	0,03	[58]
Propazine	crustacean	*Procambarus clarkii*	14d	NOEC	0,0005	[58]
Propiconazole	fish	*Oncorhynchus mykiss*	20d	NOEC	0,0002	[58]
Propiconazole	crustacean	*Hyalella azteca*	7d	NOEC	0,014	[58]
Propiconazole	algae	*Scenedesmus acutus var. Acutus*	4d	NOEC	0,05	[58]
Propyzamide	algae	*Raphidocelis subcapitata*	3d	NOEC	0,05	[58]
Propyzamide	crustacean	*Daphnia magna*	21d	NOEC	0,6	[147]
Propyzamide	fish	*Oncorhynchus mykiss*	21d	NOEC	0,94	[147]
Proquinazid	crustacean	*Daphnia magna*	21d	NOEC	0,0018	[147]
Proquinazid	fish	*Oncorhynchus mykiss*	21d	NOEC	0,003	[147]
Prosulfocarb	crustacean	*Daphnia magna*	21d	NOEC	0,045	[147]
Prosulfocarb	fish	*Oncorhynchus mykiss*	21d	NOEC	0,31	[147]
Pymetrozine	crustacean	*Daphnia magna*	21d	NOEC	0,0251	[58]
Pymetrozine	fish	*Oncorhynchus mykiss*	29d	NOEC	11,7	[58]
Pyraclostrobin	algae	*Chlorella vulgaris*	4d	NOEC	0,015	[58]
Pyraclostrobin	crustacean	*Americamysis bahia*	28d	NOEC	0,0005	[58]
Pyraclostrobin	fish	*Rainbow trout*	98d	NOEC	0,00235	[159]
Pyrazophos	crustacean	*Daphnia magna*	21d	NOEC	0,00018	[147]
Pyrazosulfuron-ethyl	fish	*Oreochromis mossambicus*	14d	NOEC	50	[58]
Pyridaben	crustacean	*Daphnia magna*	21d	NOEC	0,00009	[58]
Pyridaben	fish	*Pimephales promelas*	301d	NOEC	0,00028	[58]
Pyrimethanil	fish	*Danio rerio*	4d	NOEC	0,015	[58]
Pyrimethanil	crustacean	*Daphnia pulex*	21d	NOEC	0,015	[58]
Pyrimethanil	algae	*Scenedesmus acutus var. Acutus*	3d	NOEC	12,5	[58]
Quinalphos	algae	*Chlorella vulgaris*	2h	NOEC	0,298	[58]
Quinalphos	fish	*Barbus ticto*	2d	NOEC	0,093	[58]
Quinclorac	crustacean	*Daphnia magna*	21d	NOEC	110	[58]
Quinclorac	fish	*Leporinus obtusidens*	30d	NOEC	0,375	[58]
Quinmerac	crustacean	*Daphnia magna*	21d	NOEC	100	[147]
Quinmerac	fish	*Oncorhynchus mykiss*	21d	NOEC	3,16	[147]
Quizalofop-ethyl	crustacean	*Daphnia magna*	21d	NOEC	0,023	[147]
Quizalofop-ethyl	fish	*Pimephales promelas*	21d	NOEC	0,01	[147]
Secbumeton	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,0027	[58]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Simazine	algae	*Skeletonema marinoi*	9d	NOEC	0,005	[58]
Simazine	crustacean	*Procambarus clarkii*	14d	NOEC	0,01	[58]
Simazine	fish	*Cyprinus carpio*	90d	NOEC	0,00006	[58]
Simetryn	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,0009	[58]
S-metolacloro	algae	*Pseudokirchneriella subcapitata*	72h	NOEC	0,012	[147]
S-metolacloro	crustacean	*Daphnia magna*	21d	NOEC	5,2	[147]
S-metolacloro	fish	*Pimephales promelas*	35d	NOEC	0,78	[147]
Spiroxamine	crustacean	*Daphnia magna*	21d	NOEC	0,034	[58]
Spiroxamine	fish	*Danio rerio*	230d	NOEC	0,0026	[58]
Tebuconazole	algae	*Raphidocelis subcapitata*	3d	NOEC	0,43	[58]
Tebuconazole	crustacean	*Attheyella crassa*	21d	NOEC	0,02	[58]
Tebuconazole	fish	*Rainbow trout*	83d	NOEC	0,012	[159]
Tebufenozide	crustacean	*Daphnia magna*	21d	NOEC	0,029	[58]
Tebufenozide	fish	*Pimephales promelas*	219d	NOEC	0,18	[58]
Tebufenpyrad	fish	*Oncorhynchus mykiss*	21d	NOEC	0,00245	[147]
Tebufenpyrad	crustacean	*Gammarus pulex*	2d	NOEC	0,0025	[58]
Tebuthiuron	algae	*Chlorella sp.*	3d	NOEC	0,1	[58]
Tebuthiuron	crustacean	*Daphnia magna*	21d	NOEC	21,8	[58]
Tebuthiuron	fish	*Pimephales promelas*	21d	NOEC	9,3	[147]
Terbufos	crustacean	*Daphnia magna*	21d	NOEC	0,00003	[58]
Terbufos	fish	*Oncorhynchus mykiss*	95d	NOEC	0,00064	[58]
Terbumeton	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,0025	[58]
Terbuthylazine	algae	*Skeletonema marinoi*	4d	NOEC	0,005	[58]
Terbuthylazine	crustacean	*Daphnia magna*	21d	NOEC	0,019	[147]
Terbuthylazine	fish	*Oncorhynchus mykiss*	21d	NOEC	0,09	[147]
Terbutryn	algae	*Chlorella fusca*	4d	NOEC	0.0016	[147]
Terbutryn	crustacean	*Daphnia magna*	21d	NOEC	1,3	[172]
Terbutryn	fish	*Pimephales promelas*	34d	NOEC	0,84	[172]
Tetraconazol	crustacean	*Daphnia magna*	21d	NOEC	0,19	[58]
Tetraconazol	fish	*Pimephales promelas*	34d	NOEC	0,3	[58]
Thiabendazole	crustacean	*Daphnia magna*	21d	NOEC	0,042	[58]
Thiabendazole	fish	*Oncorhynchus mykiss*	21d	NOEC	0,012	[58]
Thiacloprid	algae	*Chironomus dilutus*	4d	NOEC	0,0016	[147]
Thiacloprid	crustacean	*Gammarus fossarum*	7d	NOEC	0,001	[58]
Thiacloprid	fish	*Danio rerio*	3d	NOEC	0,02	[58]
Thiamethoxam	fish	*Clarias gariepinus*	30d	NOEC	5	[58]
Thiamethoxam	crustacean	*Penaeus monodon*	6d	NOEC	0,00499	[58]
Triadimefon	algae	*Dunaliella tertiolecta*	4d	NOEC	2	[58]
Triadimefon	crustacean	*Daphnia magna*	21d	NOEC	0,025	[58]
Triadimefon	fish	*Gobiocypris rarus*	14d	NOEC	0,001	[58]
Triadimenol	algae	*Dunaliella tertiolecta*	4d	NOEC	2	[58]
Triadimenol	crustacean	*Daphnia magna*	21d	NOEC	0,145	[58]

PESTICIDE	ORGANISM	SPECIE	EXPOSURE TIME	TOXICITY	EFFECT (MG/L)	SOURCE
Triadimenol	fish	*Oryzias latipes*	7d	NOEC	3	[58]
Triallate	algae	*Raphidocelis subcapitata*	4d	NOEC	0,01	[58]
Triallate	fish	*Oncorhynchus mykiss*	21d	NOEC	0,038	[147]
Triallate	crustacean	*Daphnia magna*	21d	NOEC	0,013	[147]
Triasulfuron	crustacean	*Daphnia magna*	21d	NOEC	10	[147]
Triasulfuron	fish	*Oncorhynchus mykiss*	21d	NOEC	36,6	[147]
Triazophos	bacteria	*Microcystis flos-aquae*	4d	NOEC	1	[143]
Triazophos	crustacean	*Daphnia magna*	21d	NOEC	1,00E-05	[143]
Triazophos	fish	*Oncorhynchus mykiss*	21d	NOEC	0,0005	[143]
Tribenuron-methyl	algae	*Chlorella fusca var. Vacuolata*	1d	NOEC	0,0004112	[58]
Tribenuron-methyl	crustacean	*Daphnia magna*	21d	NOEC	120	[147]
Tribenuron-methyl	fish	*Oncorhynchus mykiss*	21d	NOEC	560	[147]
Trichlorfon	algae	*Microcystis wesenbergii*	6h	NOEC	1,0127	[58]
Trichlorfon	crustacean	*Daphnia magna*	21d	NOEC	0,0000056	[58]
Trichlorfon	fish	*Cyprinodon variegatus*	2d	NOEC	1	[58]
Tricyclazole	crustacean	*Daphnia magna*	21d	NOEC	0,96	[147]
Tricyclazole	fish	*Danio rerio*	2d	NOEC	100	[58]
Trifloxystrobin	fish	*Gobiocypris rarus*	5d	NOEC	0,000287	[58]
Trifloxystrobin	crustacean	*Daphnia magna*	21d	NOEC	0,00276	[58]
Trifloxystrobin	algae	*Chlorella vulgaris*	2d	NOEC	0,025	[58]
Trifluralin	algae	*Raphidocelis subcapitata*	3d	NOEC	0,031	[58]
Trifluralin	crustacean	*Daphnia magna*	21d	NOEC	0.051	[147]
Trifluralin	fish	*Fathead minnow*	35d	NOEC	0,0003	[159]
ΣDDTs	crustacean	*Leptocheirus plumulosus*	28d	LOEC	0,134	[146]

Table S4 - Acute and chronic predicted no-effect concentration (PNEC) values used in risk quotient (RQ) calculations.

COMPOUND	ACUTE PNEC	CHRONIC PNEC	COMPOUND	ACUTE PNEC	CHRONIC PNEC
2,4-D	0.000169	2.72	Imidacloprid	0.00051	0.000005
Acephate	0.0672	0.094	Indoxacarb	0.0000237	0.0015
Acetamiprid	0.2657	0.0003	Iprodione	0.00309	0.00076
Acetochlor	0.000005	0.0005	Irgarol	1.175E-08	0.00000005
Alaclor	0.000966	0.002	Isoprocarb	0.0016	0.00036
Aldrin	0.000017	0.000001	Isoprothiolane	0.0059	0.000067
Ametryn	0.05294	0.032	Isoproturon	0.000013	0.0002
Amidosulfuron	0.047	0.02	Kresoxim-methyl	0.0000292	0.0015
Amitraz	0.00074	0.0000353	Lenacil	0.0000077	
AMPA	0.05048	0.003	Linuron	0.0029	0.001
Anilofos	0.0028	0.0016	Malaoxon	0.00000097	
Atrazine	0.0053	0.00014	Malatião	0.000133	0.00000016
Atrazine desisopropyl	0.0036	0.00006	MCPA	0.0798	0.05

COMPOUND	ACUTE PNEC	CHRONIC PNEC	COMPOUND	ACUTE PNEC	CHRONIC PNEC
Atrazine-desethyl	0.000923	0.003	Mecocrop	0.2	0.44
Azinphos-ethyl	0.000000001	0.0006	Mefenacet	0.006	
Azoxystrobin	0.000676	0.0032	Metalaxyl	0.00625	0.01
Bensulfuron-methyl		1.2	Metalaxyl-M	0.1	
Bentazone	0.01486	0.07	Metaldehyde	0.0073	0.00188
Bifenthrin	0.00000324	0.0000004	Metamitron	0.0004	0.001
Boscalid	0.00000081	0.0025	Metazachlor	0.0085	0.0000022
Bupirimate	0.001		Methidathion	0.000009	
Buprofezin	0.00044	0.0005	Methomyl	0.00000211	
Butachlor	0.00044	0.0025	Methoxychlor	0.00000022	0.0002
Cadusafos	0.00072	0.0000046	Methoxyfenozide	0.0013	
Carbendazim	0.0000257	0.0031	Methyl parathion	0.0000073	
Carbendazim/Benomyl	0.0000525	0.00026	Metolachlor	0.000056	0.000054
Carbofuran	0.0079263	0.00013	Metsulfuron-methyl	0.11	0.313
Chlorantraniliprole	0.0000071	0.00002	Molinate	0.0149	0.022
Chlorfenvinphos	0.000011	0.00002	Myclobutanil	0.00024	0.00005
Chlorimuron-ethyl	0.01		Neburon	0.000039	
Chlorotoluron	0.000082	0.008	Nitenpyram	0.0017	
Chlorpyrifos	0.000145	0.000003	Omethoate	0.0000042	
Chlortoluron	0.000023	0.001	Oxadiazon	0.000004	0.000088
Clomazone	0.0144	0.005	Oxamyl	0.00012	0.000536
Clothianidin	0.0016913	0.0001	Oxyfluorfen	0.00025	0.0013
Cyhalothrin	0.00000001	0.00000016	Paclobutrazol	0.00024	0.0064
Cypermethrin	0.00000913		Parathion	0.00000011	0.0000002
Cyproconazole	0.000026	0.0019	Parathion-methyl	3.1E-10	0.000011
Cyprodinil	0.000032	0.0014	Penconazole	0.000682	0.0012
DDT(O,P')		0.0013	Pendimethalin	0.000004	0.0003
DEET	0.000002		Penoxsulam	0.1	0.059
Diazinon	0.000001	0.000056	Phorate	0.0000032	0.00000058
Dichlorprop	1.1	0.0000047	Phoxim	0.000263	0.0008388
Dichlorvos	0.01318	0.000052	Pirimicarb	0.000016	0.000018
Dicofol	0.00006	0.0000904	Pirimiphos-methyl	0.00000017	0.000002
Dieldrin	0.00000495	0.000011	Prochloraz	8.66341E-07	0.00006
Difenoconazole	0.008	0.000038	Profenofos	0.000000041	0.0000002
Diflufenican	0.000099	0.00001	Prometon	0.0257	0.0035
Dimethenamid-P	0.0032	0.025	Prometryn	0.000002	0.00025
Dimethoate	0.000419	0.004	Propachlor	0.00017	0.0009
Dimethomorph	0.0015	0.00112	Propanil	0.0054	0.00004
Dimetoato	0.0096	0.00006	Propazine	0.0175	0.00005
Diniconazole	0.00264		Propiconazole	0.00000085	0.00002
Dinotefuran	0.00006		Propyzamide	0.0028	0.005
Diuron	0.000015	0.05	Proquinazid		0.000036

COMPOUND	ACUTE PNEC	CHRONIC PNEC	COMPOUND	ACUTE PNEC	CHRONIC PNEC
Endosulfan	0.0000027		Prosulfocarb	0.00051	0.0009
Endosufan I		0.00000001	Pymetrozine	0.003788	0.000502
Endosulfan II	0.0000033		Pyraclostrobin	0.0000041	0.00005
Endosufan sulphate	0.0000014	0.000917	Pyrazophos	0.0000022	0.0000018
Endosulfan-β	0.0000033		Pyrazosulfuron-ethyl	0.7	0.5
Endrin	0.00000006	0.0001	Pyridaben	0.00000067	0.0000018
Epoxiconazole	0.00745	0.001	Pyrimethanil	0.002818	0.0015
Eptc	0.014	0.0041	Quinalphos	0.00000066	0.00186
Ethametsulfuron-methyl	0.108	0.094	Quinclorac	0.00653	0.0075
Ethoprophos	0.00000763	0.00008	Quinmerac	0.0485	
Ethoxyquin	0.002		Quizalofop-ethyl	0.0028	0.0002
Fenazaquin	0.0000454	0.0000192	Secbumeton	0.018	0.000027
Fenbuconazole	0.00041		Simazine	0.00004	0.0000006
Fenobucarb	0.00000505	0.005	Simetryn	0.0000098	0.00009
Fenpropimorph	0.00003	0.00058	S-metachlor	0.00123	
Fenpyroximate	0.00000066	0.000016	Spiroxamine	0.00000118	0.000052
Fenthion	0.0000058	0.0000013	Tebuconazole	0.00407	0.0012
Fipronil	0.0000039	0.000008	Tebufenozide	0.00012	0.00058
Fipronil desulfinyl	0.0000478		Tebufenpyrad	0.00001058	0.000049
Flazasulfuron	0.000014	0.0005	Tebuthiuron	0.00005	0.01
Florasulam	0.292	0.778	Terbufos	0.000000074	0.0000006
Fluazifop	0.00029	0.0062	Terbufos sulfone	0.000000148	
Fluazifop-p-butyl	0.00018	0.00077	Terbumeton	0.014	0.000025
Flufenacet	0.00213	0.004	Terbuthylazine	0.0212	0.0005
Flufenamic acid	0.294		Terbutryn	0.0000024	0.00016
Fluometuron	0.0068	0.00661	Tetraconazol	0.00043	
Fluopicolide	0.000349		Thiabendazole	0.00034	0.00024
Flurochloridone	0.0000047	0.00032	Thiacloprid	0.000068	0.0001
Flurtamone	0.00664	0.0024	Thiamethoxam	0.0818	0.0000998
Flutriafol	0.0006	0.011	Triadimefon	0.00091	0.0001
Fluvalinate	0.0000004	0.00000066	Triadimenol	0.00177	0.0145
Fluxapyroxad	0.0024	0.0078	Triallate	0.00095	0.001
Fomesafen	0.0221	1	Triasulfuron	0.000035	0.2
Glyphosate	0.000242	0.17	Triazophos	0.0000013	0.000001
Heptachlor	0.0000005	0.00001	Tribenuron-methyl	0.894	0.00004112
Heptachlor epoxide	0.0000053		Trichlorfon	0.000758	0.00000056
Hexaconazole	0.000204	0.002	Tricyclazole	0.0014	0.0192
Hexythiazox	0.00053		Trifloxystrobin	0.0000017	0.0000287
Imazalil	0.000726	0.00032	Trifluralin	0.0000122	0.00003
Imazapic	0.000051	0.2	ΣDDTs	0.00000269	0.00134
Imazapyr	0.1	0.862	λ-Cihalothrin	0.0000031	
Imazethapyr	0.071	1.94			

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APPENDICE B - Chapter 3

Table S1- Pesticides Physico-Chemical Properties

PESTICIDES	CAS	MONOISOTOPIC MASS (Da)	MOLAR VOLUME(cm^3/mol)	logD (pH=7.4)	STRONGEST ACIDIC pKa	SOURCE
2,4-D	94-75-7	219,9693994	155,655	-0.82 (pH=7)	3,4	[1], [2]
BAM	2008-58-4	190,02	132	1,13	13–14	[1]
MCPA	94-74-6	200,0240218	128,603	-0,81	3,73	[1], [2]
MCPP	93-65-2	214,0396719	167,688	3,1	3,19	[1]
Acetamiprid	135410-20-7	222,67	189,6	1,4	0,7	[1]
Acetochlor	34256-82-1	269,767	237,474	4.14	1,29±0,50	[1]
Alachlor	15972-60-8	269,1182566	240,9	3,09	0,62	[1], [2]
Aldrin	309-00-2	361,875716	228,069	6,5		[1]
Ametryn	834-12-8	227,1205	183,6	1,47	14,63	[3]
AMPA	77521-29-0	186,0640568		-3,2	0,9	[3]
Atrazine	1912-24-9	215,0936	170	2,7	14,48	[3]
Atrazine-2-hydroxy	2163-68-0	197,1277	151,1	-0,72	10,49	[3]
Atrazine-desethyl	6190-65-4	187,0624	136,2	1,54	14,58	[3]
Atrazine-desethyl-2-hydroxy	19988-24-0	169,0964	111,8	-2,76	10,48	[3]
Atrazine-desethyl-deisopropyl	3397-62-4	145,0156	85,6	0,13	15,26	[3]
Atrazine-desisopropyl	1007-28-9	173,0468	119,3	1,26	14,94	[3]
Azaconazole	60207-31-0	299,0228	197,5	2,27	3	[3]
Azoxystrobin	131860-33-8	403,1168	300,1	3,54	0,94	[3]
Benalaxyl	71626-11-4	325,1677936	275,763	3,54	1,52	[1], [2]
Bentazone	25057-89-0	240,0566	178,5	0,04	2,03	[3]
Benthiavalicarb	177406-68-7	339,1053	253,2	-1,81	3,63	[3]
Bifenthrin	82657-04-3	422,1260421	335,619	6,6	-7,1	[1], [2]
Boscalid	188425-85-6	342,0327	250,7	4,69	14,27	[3]
Butachlor	23184-66-9	311,1652068	290,68	4,5	16,6	[3]
Carbaril	63-25-2	201,0789786	166,298	2,36	10,4	[1], [2]
Carbendazim	10605-21-7	191,0695	134,5	1,61	9,7	[3]
Carbetamide	16118-49-3	236,1161	201,2	1,72	13	[3]
Carbofuran	1563-66-2	221,1048	194,4	2,22	14	[3]
Carbofuran-3-hydroxy	16655-82-6	237,1001	194,8	2,42	14,76	[3]
Chlorantraniliprole	500008-45-7	480,9708	290,3	4,26	13,79	[3]
Chloridazon	1698-60-8	221,0355	155,4	0,92	3,38	[3]
Chloridazon-desphenyl	6339-19-1	145,0043	81	-0,63	11,2	[3]
Chloridazon-methyl-desphenyl	17254-80-7	159,0199	102,4	-0,52	0,47±0,20	[3]
Chlorpyrifos	2921-88-2	348,926284	232,172	4,7	-4,2	[1], [2]
Chlorsulfuron	15545-48-9	357,0298	232,9	-0,08	4,26	[3]
Clethodim	99129-21-2	359,1322	304,7	1,12	4,47	[3]

PESTICIDES	CAS	MONOISOTOPIC MASS (Da)	MOLAR VOLUME(cm^3/mol)	logD (pH=7.4)	STRONGEST ACIDIC pKa	SOURCE
Clopyralid	1702-17-6	190,9540837	109,091	-2,63	2,01	[1], [2]
Cyanazine	21725-46-2	240,0889	179,4	2,3	14,44	[3]
Cyantraniliprole	736994-63-1	472,005	293,9	3,35	13,69	[3]
Cycloxydim	101205-02-1	325,1712	267,8	0,93	4,17	[3]
Cyflufenamid	180409-60-3	412,1210186	305,452	4,7	12,08	[1], [2]
Cyproconazole	94361-06-5	291,1138	219,9	2,95	13,32	[3]
Cyromazine	66215-27-8	166,0967	102,4	0,23	14,91	[3]
DEET	134-62-3	191,131014166	191,653	2,18	-0,082	[1], [2]
Desmetryn	1014-69-3	213,1048	180,2	2,7	14,72	[3]
Diazinon	333-41-5	304,1010507	274,189	3,69	2,6	[3]
Dicloran	99-30-9	205,9649828	131,854	2,8	15,44	[1], [2]
Dicofol	115-32-2	367,909603	255,51	4,3	11,03	[1], [2]
Dieldrin	60-57-1	377,870631	217,663	3,7	-4,2	[1], [2]
Difenoconazole	119446-68-3	405,0646968	296,54	4,36	1,07	[1], [2]
Dimefuron	34205-21-5	338,1146	259,5	2,8	12,9	[3]
Dimétachlore CGA 369873	1418095-08-5	243,0565	186,9	-2,3	-0,9	[3]
Dimethoate	60-51-5	228,99962259	175,008	0,75	15,93	[1], [2]
Dimethomorph (E, Z)	110488-70-5	387,1237	315,1	3,31	-1,3	[3]
Dimoxystrobin	149961-52-4	326,1631	297,6	4,2	14,68	[3]
Diphenylamine	122-39-4	169,0891494	143,415	3,41	1,03	[3]
Diuron	330-54-1	232,0169	178,6	2,53	13,18	[3]
Endosulfan	115-29-7	403,816881	226,072	4,75		[1], [2]
Ethidimuron	30043-49-3	264,0351	184,1	-0,01	15,65	[3]
Ethion	563-12-2	384,48	315,148	5,07		[1], [2]
Fenhexamid	126833-17-8	301,0636	225,8	4,17	7,9	[3]
Fenobucarb	3766-81-2	207,1259288	199,298	2,78		[1], [2]
Fenpyrazamine	473798-59-3	331,1354	270,1	1,94	x	[3]
Fipronil-sulfide	120067-83-6	419,9437917	535,751			[1]
Flazasulfuron	104040-78-0	407,0511	262,2	0,29	3,48	[3]
Flonicamid	158062-67-0	229,0463	166,4	0,63	12,56	[3]
Florasulam	145701-23-1	359,03	204,5	-0,57	7,3	[3]
Fluroxypyr	69377-81-7	253,9661	148,2	-1,8	3,21	[3]
Flurtamone	96525-23-4	333,0977	249,2	3,9	11,76	[3]
Flutriafol (isomer)	76674-21-0	301,1027	233,3	2,21	12,55	[3]
Fluxapyroxad	907204-31-3	381,0901	267,9	3,5	14,15	[3]
Furalaxyl	57646-30-7	301,1314	255,6	2,72		[3]
Glyphosate	1071-83-6	169,0140094	98,889	-6,28	5,73	[1], [2]
Hexaconazole	79983-71-4	314,21	243,574	3,9	2,3	[1], [2]
Hexazinone	51235-04-2	252,1586	197,9	1,91	2,2	[3]
Hydroxyatrazine	2163-68-0	197,1276601				[1]
Imazamethabenz	100728-84-5	274,1317	220,2	-1,02	3,71	[3]
Imazamox	114311-32-9	305,1375	231,4	-2,53	2,64	[3]
Imazapyr	81334-34-1	261,1113	193,7	-2,25	2,52	[3]

PESTICIDES	CAS	MONOISOTOPIC MASS (Da)	MOLAR VOLUME(cm^3/mol)	logD (pH=7.4)	STRONGEST ACIDIC pKa	SOURCE
Imidacloprid	138261-41-3	255,0523	160,1	-0,29	14,94	[3]
Iodosulfuron-methyl	144550-36-7	506,9709	280,9	0,4	3,27	[3]
Ioxynil	1689-83-4	370,8304	136,7	1,27	5,61	[3]
Iprovalicarbe	140923-17-7	320,21	307,2	3,29	13,67	[3]
Irgarol 1051	28159-98-0	253,1361	210,9	3,21	14,13	[3]
Isocarbophos	24353-61-5	289,29	226,008	2,7	-1,34±0,70	[1]
isofetamide	875915-78-9	359,1555	318,2	4,22	14,98	[3]
Isoprocarb	2631-40-5	193,1102787	185,808	2.32	4,19	[1]
Isoprothiolane	50512-35-1	290,4	232,32	2.8		[1]
Isoproturon	34123-59-6	206,1419	196,3	2,45	13,79	[3]
Isoxaben	82558-50-7	332,1736	292	3,6	11,35	[3]
Lenacil	2168-08-1	234,1368	188,9	2,56	10,15	[3]
Lindane	58-89-9	287,860066	154,691	3,5		[1], [2]
Malathion	121-75-5	330,0360677	268,585	2,75	-6,8	[1], [2]
Mefenacet	73250-68-7	298,0775989	226,03	3,23	1,53	[1], [2]
Mesosulfuron-methyl	208465-21-8	503,0781	336	-0,67	4,75	[3]
Mesotrione	104206-82-8	339,0413	230,1	-1,55	4	[3]
Metalaxil	57837-19-1	279,33	232,775	1,75	0	[1], [2]
Metamiton	41394-05-2	202,0854	150	0,87		[3]
Metazachlor	67129-08-2	277,0818	232,1	2,28		[3]
Metazachlore OXA	1231244-60-2	273,1113	217,4	-2,4	3,01	[3]
Metconazole	125116-23-6	319,1451	256,7	3,74	13,67	[3]
Metolachlor	87392-12-9	283,1339	257,8	3,22		[3]
Metolachlore ESA	171118-09-5	329,1297	264,9	-3,34		[3]
Metolachlore OXA	152019-73-3	279,1471	241	-1,7	3,21	[3]
Metribuzin	21087-64-9	214,0888	163,5	1,5	12,8	[3]
Metsulfuron-methyl	74223-64-6	381,0743	258,8	-0,48	4,76	[3]
Molinate	2212-67-1	187,1030853	176,199	2,86	-1,22	[1], [2]
Monocrotophos	6923-22-4	223,0609595	192,379	-0,22	13,98	[1], [2]
Myclobutanil	88671-89-0	288,1142	247,9	3,19	2,3	[3]
Napropamide	15299-99-7	271,1572289	229,966	3,3	17,3	[1], [2]
Nicosulfuron	111991-09-4	410,1009	284	-2,31	4,48	[3]
Norflurazon	27314-13-2	303,0386	208,8	2,25		[3]
Nuarimol	63284-71-9	314,0622	232,9	2,5	12,13	[3]
o,p'-DDD	53-19-0	317,953661	243,94	6,12		[1]
o,p-DDE	3424-82-6	315,938011	237,207	7		[1]
o,p-DDT	789-02-6	351,914689	254,326	6,7		[1]
Oxydemeton-methyl	301-12-2	246,0149	187,9	0,03		[3]
p,p'-DDD	72-54-8	320	231,047	6,02		[1], [2]
p,p'-DDE	72-55-9	315,938011	227,143	6,51		[1], [2]
Paclobutrazol	76738-62-0	293,1295	246,7	3,37	14	[3]
Paraquat	4685-14-7	186,1156985	124,167	-4,5		[1], [2]
Parathion	56-38-2	291,0330307	231,167	3,83	-9,7	[1], [2]

PESTICIDES	CAS	MONOISOTOPIC MASS (Da)	MOLAR VOLUME(cm^3/mol)	logD (pH=7.4)	STRONGEST ACIDIC pKa	SOURCE
Parathion-methyl	298-00-0	263,0017306	193,537	3	-9,7	[1], [2]
Penconazole	66246-88-6	283,0643	222,9	3,88	1,51	[3]
Pendimethalin	40487-42-1	281,1375561	240,436	5,4	2,8	[1], [2]
Pentachloroaniline	527-20-8	262,862988	335,398	4,82		[1], [2]
Permethrin	52645-53-1	390,0789499	328,815	6,1	-7,1	[1], [2]
Pethoxamid	106700-29-2	295,1339	271,2	3,4		[3]
Pirimicarb	23103-98-2	238,143	207,8	1,73	4,4	[3]
pp-DDT	50-29-3	354,486	227,244	6,91		[1], [2]
Pretilachlor	81690-06-4	311,847	290,634	4,08	1,41	[1], [2]
Prometon	1610-18-0	225,159	198,8	2,79	14,27	[3]
Prometryn	7287-19-6	241,1361	213,5	3,4	14,46	[3]
Propamocarb hydrochloride	25606-41-1	224,13	196,6	-0,68	9,6	[3]
Propazine	139-40-2	229,1094	178,4	1,45	14,31	[3]
Propiconazole (stereo isomer)	60207-90-1	341,0698	244,9	3,52	1,09	[3]
Propoxur	114-26-1	213,2735	177,322	0,14	14,76	[1], [2]
Propyzamide	23950-58-5	256,128	192,579	3,27	10,38	[1], [2]
Prosulfuron	94125-34-5	419,0875	286,7	0,79	4,81	[1]
Pymetrozine	123312-89-0	217,0964	162,6	0,3	4,06	[1]
Pyroxsulam	422556-08-9	434,062	257,9	1,7	4,88	[3]
Quinmerac	90717-03-6	221,0244	157,5	-0,35	3,32	[3]
Secbumeton	26259-45-0	225,159	198,4	2,8	14,36	[3]
Silthiopham	175217-20-6	267,1113	262,2	4,43	15,21	[3]
Simazine	122-34-9	201,078	153	2,3	14,75	[3]
Simazine Hydroxy	2599-11-3	183,112	135,8	-1,05	10,49	[3]
Spirotetramat	203313-25-1	373,1889	310,8	3,79	11,7	[3]
Sulcotrione	99105-77-8	328,0172	230,2	-0,86	4,47	[3]
Sulfamethazine	57-68-1	278,33	189,922	0.738 (pH= 7.6)	7,5	[1]
Sulfametoxazol	723-46-6	253,28	173,1		1,4; 5,8	[1]
Sulfosulfuron	141776-32-1	470,0678	287	-0,24	5,01	[3]
Tebuconazole	107534-96-3	307,1451	268,1	3,74	13,85	[3]
Tebufenpyrad	119168-77-3	333,9	285,299	4,93	13,32	[1], [2]
Tebuthiuron	34014-18-1	228,1045	192,5	1,74	15,66	[3]
Tembotrione	335104-84-2	440,0308	302,3	-0,35	4,22	[3]
Terbumeton-desethyl	30125-64-5	197,1277	164,4	1,52	14,19	[3]
Terbuthylazine	5915-41-3	229,1094	186	2,99	14,17	[3]
Terbuthylazine-2-hydroxy	66753-07-9	211,1433	171,7	-2,1	9,55	[3]
Terbuthylazine-desethyl	30125-63-4	201,0781	152,4	1,96	14,22	[3]
Terbutryn	886-50-0	241,1361	204,2	1,38	14,31	[3]
Tetraconazole	112281-77-3	371,0215	247,2	3,7	0,8-0,5	[3]
Tetracycline	60-54-8	444,43	617,222		2,92	[1]
Thiacloprid	111988-49-9	252,72	173,096	1,26	1,62	[1], [2]
Thiamethoxam	153719-23-4	291,71	185,803	-0,13	0,4	[1], [2]
Thiamethoxam	153719-23-4	291,71		-0,13	0,4	[1], [2]

PESTICIDES	CAS	MONOISOTOPIC MASS (Da)	MOLAR VOLUME(cm^3/mol)	logD (pH=7.4)	STRONGEST ACIDIC pKa	SOURCE
Thifensulfuron-methyl	79277-27-3	387,0307	248,3	-0,51	5,2	[3]
Triasulfuron	82097-50-5	401,0561	272,8	-0,09	4,73	[3]
Triciclazol	41814-78-2	189,237	135,171	1,4	2,4	[1], [2]
Trinexapac ethyl	95266-40-3	252,0998	185,7	-1,76	4,9	[3]
α-cypermethrin	65731-84-2	416,3	325,234	6,27		[1]
α-endosulfan	959-98-8	406,9	233,198	4,74		[1], [2]
α-HCH	319-84-6	290,83	173,612	3,5		[1], [2]
β-Endosulfan	959-98-8	406,9	233,198	3,83	-5,5	[1], [2]
β-HCH	319-85-7	290,83	173,612	3,8		[1]
δ-HCH	319-86-8	290,81	173,612	3,72		[1]

Table S2- Articles Considered

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Acetamiprid	80,9	RO	Fabricated	Mod	20	[6]
Acetamiprid	78,6	RO	Fabricated	Mod	50	[6]
Acetamiprid	83,7	RO	Fabricated	Mod	100	[6]
Acetochlor	100,0	NF	Commercial	Not available	0,000001	[7]
Alachlor	0,0	NF	Commercial	Not available	0,00136	[7]
Alachlor	91,4	RO	Fabricated	Mod	20	[6]
Alachlor	85,4	RO	Fabricated	Mod	50	[6]
Alachlor	81,7	RO	Fabricated	Mod	100	[6]
Aldrin	100,0	NF	Commercial	NF270	10	[5]
Aldrin	93,5	NF	Fabricated	PES	10	[8]
Aldrin	97,0	NF	Fabricated	Mod	10	[8]
Aldrin	100,0	RO	Fabricated	Mod	10	[5]
Aldrin	100,0	RO	Commercial	SW30XLE	10	[5]
Aldrin	86,4	RO	Fabricated	Mod	20	[6]
Aldrin	87,3	RO	Fabricated	Mod	50	[6]
Aldrin	95,2	RO	Fabricated	Mod	100	[6]
Ametryn	98,5	NF	Commercial	dNF40	1	[9]
AMPA	86,7	NF	Commercial	NFX	50	[10][11]
Atrazine	80,0	FO	Fabricated	Mod	50	[12]
Atrazine	84,0	FO	Fabricated	Mod	50	[12]
Atrazine	74,0	FO	Fabricated	Mod	50	[12]
Atrazine	86,0	FO	Fabricated	Mod	50	[12]
Atrazine	97,9	NF	Commercial	dNF40	1	[9]
Atrazine	95,5	RO	Commercial		0,198	[13]
Atrazine	99,0	RO	Commercial	ESPA2-LD-040	20	[14]
Atrazine	90,1	RO	Fabricated	Mod	20	[6]
Atrazine	93,1	RO	Fabricated	Mod	50	[6]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Atrazine	95,3	RO	Fabricated	Mod	100	[6]
Atrazine-2-hydroxy	96,9	NF	Commercial	dNF40	1	[9]
Atrazine-2-hydroxy	60,1	NF	Commercial	dNF80	1	[9]
Atrazine-desethyl	84,8	NF	Commercial	dNF40	1	[9]
Atrazine-desethyl-2-hydroxy	86,7	NF	Commercial	dNF40	1	[9]
Atrazine-desethyl-2-hydroxy	65,7	NF	Commercial	dNF80	1	[9]
Atrazine-desethyl-deisopropyl	41,2	NF	Commercial	dNF40	1	[9]
Atrazine-desethyl-deisopropyl	5,2	NF	Commercial	dNF80	1	[9]
Atrazine-desisopropyl	61,5	NF	Commercial	dNF40	1	[9]
Azaconazole	99,0	NF	Commercial	dNF40	1	[9]
Azoxystrobin	98,0	NF	Commercial	dNF40	1	[9]
Benalaxyl	0,0	NF	Commercial	Not available	0,000142	[7]
Bentazone	97,5	NF	Commercial	dNF40	1	[9]
Bentazone	62,4	NF	Commercial	dNF80	1	[9]
Benthiavalicarb	99,7	NF	Commercial	dNF40	1	[9]
Benthiavalicarb	97,4	NF	Commercial	dNF80	1	[9]
Bifenthrin	81,4	RO	Fabricated	Mod	20	[6]
Bifenthrin	86,2	RO	Fabricated	Mod	50	[6]
Bifenthrin	94,2	RO	Fabricated	Mod	100	[6]
Boscalid	100,0	NF	Commercial	Not available	0,000005	[7]
Butachlor	100,0	NF	Commercial	Not available	0,00426	[7]
Butachlor	100,0	RO	Fabricated	Mod	20	[6]
Butachlor	100,0	RO	Fabricated	Mod	50	[6]
Butachlor	100,0	RO	Fabricated	Mod	100	[6]
Carbaril	90,0	RO	Fabricated	Mod	20	[6]
Carbaril	80,8	RO	Fabricated	Mod	50	[6]
Carbaril	88,4	RO	Fabricated	Mod	100	[6]
Carbendazim	70,4	RO	Fabricated	Mod	20	[6]
Carbendazim	59,6	RO	Fabricated	Mod	50	[6]
Carbendazim	62,5	RO	Fabricated	Mod	100	[6]
Carbendazim	38,9	UF	Commercial	Not available	0,009	[11]
Carbetamide	94,9	NF	Commercial	dNF40	1	[9]
Carbofuran	99,5	NF	Commercial	Not available	0,00008	[7]
Carbofuran	98,5	NF	Commercial	dNF40	1	[9]
Carbofuran	65,5	NF	Commercial	dNF80	1	[9]
Carbofuran	100,0	RO	Fabricated	Mod	20	[6]
Carbofuran	84,3	RO	Fabricated	Mod	50	[6]
Carbofuran	85,7	RO	Fabricated	Mod	100	[6]
Carbofuran-3-hydroxy	97,3	NF	Commercial	dNF40	1	[9]
Carbofuran-3-hydroxy	54,0	NF	Commercial	dNF80	1	[9]
Chlorantraniliprole	99,0	NF	Commercial	dNF40	1	[9]
Chlorantraniliprole	95,3	NF	Commercial	dNF80	1	[9]
Chloridazon	99,0	RO	Commercial	ESPA2-LD-4040	20	

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Chloridazon-desphenyl	19,1	NF	Commercial	dNF40	1	[9]
Chloridazon-desphenyl	-0,7	NF	Commercial	dNF80	1	[9]
Chloridazon-methyl-desphenyl	35,5	NF	Commercial	dNF40	1	[9]
Chlorpyrifos	100,0	RO	Fabricated	Mod	20	[6]
Chlorpyrifos	84,9	RO	Fabricated	Mod	50	[6]
Chlorpyrifos	76,0	RO	Fabricated	Mod	100	[6]
Chlorsulfuron	99,5	NF	Commercial	dNF40	1	[9]
Chlorsulfuron	93,7	NF	Commercial	dNF80	1	[9]
Clethodime	99,5	NF	Commercial	dNF40	1	[9]
Clethodime	99,2	NF	Commercial	dNF80	1	[9]
Cyanazine	98,6	NF	Commercial	dNF40	1	[9]
Cyanazine	74,8	NF	Commercial	dNF80	1	[9]
Cyantraniliprole	99,4	NF	Commercial	dNF40	1	[9]
Cyantraniliprole	96,2	NF	Commercial	dNF80	1	[9]
Cycloxydime	99,2	NF	Commercial	dNF40	1	[9]
Cycloxydime	99,0	NF	Commercial	dNF80	1	[9]
Cyflufenamid	66,7	NF	Commercial	Not available	0,00845	[7]
Cyproconazole	99,0	NF	Commercial	dNF40	1	[9]
Cyproconazole	79,4	NF	Commercial	dNF80	1	[9]
Cyromazine	73,7	NF	Commercial	dNF40	1	[9]
Cyromazine	13,0	NF	Commercial	dNF80	1	[9]
DEET	99,0	RO	Commercial	ESPA2-LD-4040	20	[14]
Desmetryn	98,1	NF	Commercial	dNF40	1	[9]
Diazinon	76,0	FO	Fabricated	Mod	50	[12]
Diazinon	92,0	FO	Fabricated	Mod	50	[12]
Diazinon	84,0	FO	Fabricated	Mod	50	[12]
Diazinon	86,0	FO	Fabricated	Mod	50	[12]
Dicloran	38,3	NF	Commercial	Not available	0,00564	[7]
Dicofol	83,1	RO	Fabricated	Mod	20	[6]
Dicofol	66,0	RO	Fabricated	Mod	50	[6]
Dicofol	67,5	RO	Fabricated	Mod	100	[6]
Dieldrin	85,2	RO	Fabricated	Mod	20	[6]
Dieldrin	84,1	RO	Fabricated	Mod	50	[6]
Dieldrin	78,4	RO	Fabricated	Mod	100	[6]
Difenoconazole	100,0	RO	Fabricated	Mod	20	[6]
Difenoconazole	100,0	RO	Fabricated	Mod	50	[6]
Difenoconazole	100,0	RO	Fabricated	Mod	100	[6]
Dimefuron	99,3	NF	Commercial	dNF40	1	[9]
Dimefuron	82,6	NF	Commercial	dNF80	1	[9]
Dimétachlore CGA	97,2	NF	Commercial	dNF40	1	[9]
Dimétachlore CGA	66,3	NF	Commercial	dNF80	1	[9]
Dimethoate	67,2	RO	Fabricated	Mod	20	[6]
Dimethoate	75,8	RO	Fabricated	Mod	50	[6]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Dimethoate	78,0	RO	Fabricated	Mod	100	[6]
Dimethomorph (E, Z)	99,3	NF	Commercial	dNF40	1	[9]
Dimethomorph (E, Z)	95,0	NF	Commercial	dNF80	1	[9]
Dimoxystrobin	96,5	NF	Commercial	dNF40	1	[9]
Diphenylamine	56,1	NF	Commercial	Not available	0,01568	[7]
Diuron	82,7	RO	Commercial	Not available	0,226	[13]
Diuron	99,0	RO	Commercial	ESPA2-LD-4040	20	[14]
Endosulfan	94,0	NF	Fabricated	PES	10	[8]
Endosulfan	98,0	NF	Fabricated	Mod	10	[8]
Endosulfan	100,0	RO	Fabricated	Mod	20	[6]
Endosulfan	100,0	RO	Fabricated	Mod	50	[6]
Endosulfan	100,0	RO	Fabricated	Mod	100	[6]
Ethidimuron	91,5	NF	Commercial	dNF40	1	[9]
Ethidimuron	23,0	NF	Commercial	dNF80	1	[9]
Ethion	76,4	RO	Fabricated	Mod	20	[6]
Ethion	97,8	RO	Fabricated	Mod	50	[6]
Ethion	98,7	RO	Fabricated	Mod	100	[6]
Fenhexamid	95,7	NF	Commercial	dNF40	1	[9]
Fenobucarb	95,4	NF	Commercial	Not available	0,000017	[7]
Fenpyrazamine	95,5	NF	Commercial	dNF40	1	[9]
Fipronil-sulfide	85,7	RO	Commercial	Not available	0,014	[13]
Flazasulfuron	99,6	NF	Commercial	dNF40	1	[9]
Flazasulfuron	95,2	NF	Commercial	dNF80	1	[9]
Flonicamid	85,3	NF	Commercial	dNF40	1	[9]
Flonicamid	55,8	NF	Commercial	dNF80	1	[9]
Florasulam	99,1	NF	Commercial	dNF40	1	[9]
Florasulam	90,1	NF	Commercial	dNF80	1	[9]
Fluroxypyr	97,2	NF	Commercial	dNF40	1	[9]
Fluroxypyr	53,9	NF	Commercial	dNF80	1	[9]
Flurtamone	97,5	NF	Commercial	dNF40	1	[9]
Flutriafol (isomer)	99,1	NF	Commercial	dNF40	1	[9]
Flutriafol (isomer)	74,9	NF	Commercial	dNF80	1	[9]
Fluxapyroxad	95,3	NF	Commercial	dNF40	1	[9]
Furalaxyl	99,3	NF	Commercial	dNF40	1	[9]
Furalaxyl	93,1	NF	Commercial	dNF80	1	[9]
Glyphosate	91,5	NF	Commercial	NFX	50	[10]
Hexaconazol	84,2	RO	Fabricated	Mod	20	[6]
Hexaconazol	80,3	RO	Fabricated	Mod	50	[6]
Hexaconazol	73,7	RO	Fabricated	Mod	100	[6]
Hexazinone	99,2	NF	Commercial	dNF40	1	[9]
Hexazinone	88,8	NF	Commercial	dNF80	1	[9]
Hydroxyatrazine	98,5	RO	Commercial	Not available	0,134	[13]
Imazamethabenz	99,5	NF	Commercial	dNF40	1	[9]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Imazamethabenz	96,6	NF	Commercial	dNF80	1	[9]
Imazamox	99,6	NF	Commercial	dNF40	1	[9]
Imazamox	98,8	NF	Commercial	dNF80	1	[9]
Imazapyr	99,7	NF	Commercial	dNF40	1	[9]
Imazapyr	98,3	NF	Commercial	dNF80	1	[9]
Imidacloprid	85,1	NF	Commercial	dNF40	1	[9]
Imidacloprid	74,0	RO	Fabricated	Mod	20	[6]
Imidacloprid	95,4	RO	Fabricated	Mod	50	[6]
Imidacloprid	98,1	RO	Fabricated	Mod	100	[6]
Iodosulfuron-methyl	98,3	NF	Commercial	dNF40	1	[9]
Iodosulfuron-methyl	94,2	NF	Commercial	dNF80	1	[9]
Ioxynil	89,9	NF	Commercial	dNF40	1	[9]
Ioxynil	15,9	NF	Commercial	dNF80	1	[9]
Iprovalicarbe	99,2	NF	Commercial	dNF40	1	[9]
Iprovalicarbe	95,5	NF	Commercial	dNF80	1	[9]
Irgarol 1051	83,2	NF	Commercial	dNF40	1	[9]
Isocarbophos	21,4	UF	Commercial	Not available	0,007	[11]
isofetamide	92,8	NF	Commercial	dNF40	1	[9]
Isoprocarb	99,8	NF	Commercial	Not available	0,000006	[7]
Isoprothiolane	80,9	RO	Fabricated	Mod	20	[6]
Isoprothiolane	88,9	RO	Fabricated	Mod	50	[6]
Isoprothiolane	86,7	RO	Fabricated	Mod	100	[6]
Isoprothiolane	20,0	UF	Commercial	Not available	0,0075	
Isoproturon	87,5	NF	Commercial	dNF40	1	[9]
Isoproturon	85,0	RO	Fabricated	Mod	20	[6]
Isoproturon	86,6	RO	Fabricated	Mod	50	[6]
Isoproturon	90,1	RO	Fabricated	Mod	100	[6]
Isoxaben	91,3	NF	Commercial	dNF40	1	[9]
Lenacil	98,6	NF	Commercial	dNF40	1	[9]
Lenacil	64,8	NF	Commercial	dNF80	1	[9]
Lindane	100,0	NF	Commercial	NF270	296	
Lindane	92,0	NF	Fabricated	PES	10	
Lindane	96,0	NF	Fabricated	Mod	10	
Lindane	99,8	RO	Fabricated	Mod	296	
Lindane	85,1	RO	Commercial	SW30XLE RO	296	
Malathion	43,9	RO	Fabricated	Mod	20	[6]
Malathion	53,6	RO	Fabricated	Mod	50	[6]
Malathion	69,0	RO	Fabricated	Mod	100	[6]
Mefenacet	99,9	NF	Commercial	Not available	0,000002	[7]
Mesosulfuron-methyl	99,4	NF	Commercial	dNF40	1	[9]
Mesosulfuron-methyl	96,3	NF	Commercial	dNF80	1	[9]
Mesotrione	99,3	NF	Commercial	dNF40	1	[9]
Mesotrione	90,9	NF	Commercial	dNF80	1	[9]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Metalaxil	85,0	RO	Fabricated	Mod	20	[6]
Metalaxil	85,4	RO	Fabricated	Mod	50	[6]
Metalaxil	86,6	RO	Fabricated	Mod	100	[6]
Metamiton	78,4	NF	Commercial	dNF40	1	[9]
Metazachlor	99,3	NF	Commercial	dNF40	1	[9]
Metazachlor	87,0	NF	Commercial	dNF80	1	[9]
Metazachlore OXA	98,4	NF	Commercial	dNF40	1	[9]
Metazachlore OXA	96,5	NF	Commercial	dNF80	1	[9]
Metconazole	94,2	NF	Commercial	dNF40	1	[9]
Metolachlor	100,0	NF	Commercial	Not available	0,00926	[7]
Metolachlor	98,9	NF	Commercial	dNF40	1	[9]
Metolachlor	93,2	NF	Commercial	dNF80	1	[9]
Metolachlore ESA	98,4	NF	Commercial	dNF40	1	[9]
Metolachlore ESA	98,1	NF	Commercial	dNF80	1	[9]
Metolachlore OXA	98,6	NF	Commercial	dNF40	1	[9]
Metolachlore OXA	98,2	NF	Commercial	dNF80	1	[9]
Metribuzine	97,5	NF	Commercial	dNF40	1	[9]
Metribuzine	64,7	NF	Commercial	dNF80	1	[9]
Metsulfuron-methyl	98,7	NF	Commercial	dNF40	1	[9]
Metsulfuron-methyl	96,3	NF	Commercial	dNF80	1	[9]
Molinate	0,0	NF	Commercial	Not available	0,000254	[7]
Monocrotophos	31,7	RO	Fabricated	Mod	20	[6]
Monocrotophos	42,1	RO	Fabricated	Mod	50	[6]
Monocrotophos	39,7	RO	Fabricated	Mod	100	[6]
Myclobutanil	95,8	NF	Commercial	dNF40	1	[9]
Napropamide	0,0	NF	Commercial	Not available	0,000298	[7]
Nicosulfuron	99,6	NF	Commercial	dNF40	1	[9]
Nicosulfuron	97,9	NF	Commercial	dNF80	1	[9]
Norflurazon	96,7	NF	Commercial	dNF40	1	[9]
Nuarimol	89,5	NF	Commercial	dNF40	1	[9]
Nuarimol	84,5	NF	Commercial	dNF80	1	[9]
o,p'-DDD	93,9	RO	Fabricated	Mod	20	[6]
o,p'-DDD	94,6	RO	Fabricated	Mod	50	[6]
o,p'-DDD	94,9	RO	Fabricated	Mod	100	[6]
o,p-DDE	94,0	RO	Fabricated	Mod	20	[6]
o,p-DDE	95,2	RO	Fabricated	Mod	50	[6]
o,p-DDE	96,0	RO	Fabricated	Mod	100	[6]
o,p-DDT	90,8	RO	Fabricated	Mod	20	[6]
o,p-DDT	94,9	RO	Fabricated	Mod	50	[6]
o,p-DDT	98,2	RO	Fabricated	Mod	100	[6]
Oxydemeton-methyl	94,3	NF	Commercial	dNF40	1	[9]
Oxydemeton-methyl	58,8	NF	Commercial	dNF80	1	[9]
p,p'-DDD	90,5	RO	Fabricated	Mod	20	[6]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
p,p'-DDD	94,8	RO	Fabricated	Mod	50	[6]
p,p'-DDD	97,1	RO	Fabricated	Mod	100	[6]
p,p'-DDE	95,0	RO	Fabricated	Mod	50	[6]
p,p'-DDE	97,8	RO	Fabricated	Mod	100	[6]
Paclobutrazol	99,2	NF	Commercial	dNF40	1	[9]
Paclobutrazol	83,3	NF	Commercial	dNF80	1	[9]
Parathion	49,5	RO	Fabricated	Mod	20	[6]
Parathion	54,4	RO	Fabricated	Mod	50	[6]
Parathion	62,9	RO	Fabricated	Mod	100	[6]
Parathion-methyl	58,8	RO	Fabricated	Mod	20	[6]
Parathion-methyl	44,2	RO	Fabricated	Mod	50	[6]
Parathion-methyl	41,7	RO	Fabricated	Mod	100	[6]
Penconazole	94,2	NF	Commercial	dNF40	1	[9]
Pendimethalin	98,2	NF	Commercial	Not available	0,000005	[7]
Pentachloroaniline	67,8	NF	Commercial	Not available	0,00102	[7]
Permethrin	86,3	RO	Fabricated	Mod	20	[6]
Permethrin	79,9	RO	Fabricated	Mod	50	[6]
Permethrin	74,2	RO	Fabricated	Mod	100	[6]
Pethoxamide	98,9	NF	Commercial	dNF40	1	[9]
Pethoxamide	91,6	NF	Commercial	dNF80	1	[9]
Pirimicarb	99,4	NF	Commercial	dNF40	1	[9]
Pirimicarb	86,9	NF	Commercial	dNF80	1	[9]
pp-DDE	95,1	RO	Fabricated	Mod	20	[6]
pp-DDT	90,8	RO	Fabricated	Mod	20	[6]
pp-DDT	97,3	RO	Fabricated	Mod	50	[6]
pp-DDT	100,0	RO	Fabricated	Mod	100	[6]
Pretilachlor	99,9	NF	Commercial	Not available/	0,000125	[7]
Prometon	99,4	NF	Commercial	dNF40	1	[9]
Prometon	83,4	NF	Commercial	dNF80	1	[9]
Prometryn	97,7	NF	Commercial	dNF40	1	[9]
Propamocarb hydrochloride	98,6	NF	Commercial	dNF40	1	[9]
Propazine	97,2	NF	Commercial	dNF40	1	[9]
Propiconazole (stereo isomer)	95,1	NF	Commercial	dNF40	1	[9]
Propoxur	99,6	NF	Commercial	Not available	0,000003	[7]
Propyzamide	62,5	NF	Commercial	Not available	0,000003	[7]
Prosulfuron	99,4	NF	Commercial	dNF40	1	[9]
Prosulfuron	97,7	NF	Commercial	dNF80	1	[9]
Pymetrozine	92,3	NF	Commercial	dNF40	1	[9]
Pymetrozine	45,7	NF	Commercial	dNF80	1	[9]
Pyroxsulam	99,6	NF	Commercial	dNF40	1	[9]
Pyroxsulam	97,9	NF	Commercial	dNF80	1	[9]
Quinmerac	98,3	NF	Commercial	dNF40	1	[9]
Quinmerac	75,2	NF	Commercial	dNF80	1	[9]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Secbumeton	99,4	NF	Commercial	dNF40	1	[9]
Secbumeton	82,6	NF	Commercial	dNF80	1	[9]
Silthiopham	92,3	NF	Commercial	dNF40	1	[9]
Simazine	94,9	NF	Commercial	dNF40	1	[9]
Simazine	52,6	RO	Commercial	Not available	0,135	[13]
Simazine Hydroxy	86,8	NF	Commercial	dNF40	1	[9]
Simazine Hydroxy	35,5	NF	Commercial	dNF80	1	[9]
Spirotetramat	98,7	NF	Commercial	dNF40	1	[9]
Spirotetramat	97,0	NF	Commercial	dNF80	1	[9]
Sulcotrione	98,9	NF	Commercial	dNF40	1	[9]
Sulcotrione	81,6	NF	Commercial	dNF80	1	[9]
Sulfosulfuron	99,7	NF	Commercial	dNF40	1	[9]
Sulfosulfuron	98,2	NF	Commercial	dNF80	1	[9]
Tebuconazole	96,8	NF	Commercial	dNF40	1	[9]
Tebuconazole	38,5	UF	Commercial	Not available	0,0065	[11]
Tebufenpyrad	97,0	NF	Commercial	Not available	0,000002	[7]
Tebuthiuron	98,5	NF	Commercial	dNF40	1	[9]
Tebuthiuron	69,3	NF	Commercial	dNF80	1	[9]
Tembotrione	99,6	NF	Commercial	dNF40	1	[9]
Tembotrione	97,3	NF	Commercial	dNF80	1	[9]
Terbumeton-desethyl	96,4	NF	Commercial	dNF40	1	[9]
Terbumeton-desethyl	48,7	NF	Commercial	dNF80	1	[9]
Terbuthylazine	97,8	NF	Commercial	dNF40	1	[9]
Terbuthylazine-2-hydroxy	98,5	NF	Commercial	dNF40	1	[9]
Terbuthylazine-2-hydroxy	70,0	NF	Commercial	dNF80	1	[9]
Terbuthylazine-desethyl	92,4	NF	Commercial	dNF40	1	[9]
Terbutryn	97,5	NF	Commercial	dNF40	1	[9]
Tetraconazol	78,3	RO	Fabricated	Mod	20	[6]
Tetraconazol	76,3	RO	Fabricated	Mod	50	[6]
Tetraconazol	64,3	RO	Fabricated	Mod	100	[6]
Tetraconazole	94,4	NF	Commercial	dNF40	1	[9]
Thiacloprid	74,8	RO	Fabricated	Mod	20	[6]
Thiacloprid	74,3	RO	Fabricated	Mod	50	[6]
Thiacloprid	92,6	RO	Fabricated	Mod	100	[6]
Thifensulfuron-methyl	99,6	NF	Commercial	dNF40	1	[9]
Thifensulfuron-methyl	97,6	NF	Commercial	dNF80	1	[9]
Tiametoxame	61,3	RO	Fabricated	Mod	20	[6]
Tiametoxame	67,9	RO	Fabricated	Mod	50	[6]
Tiametoxame	70,7	RO	Fabricated	Mod	100	[6]
Triasulfuron	99,6	NF	Commercial	dNF40	1	[9]
Triasulfuron	97,4	NF	Commercial	dNF80	1	[9]
Triciclazol	77,9	RO	Fabricated	Mod	20	[6]
Triciclazol	77,2	RO	Fabricated	Mod	50	[6]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Triciclazol	88,1	RO	Fabricated	Mod	100	[6]
Trinexapac ethyl	99,6	NF	Commercial	dNF40	1	[9]
Trinexapac ethyl	92,7	NF	Commercial	dNF80	1	[9]
α-cypermethrin	86,8	RO	Fabricated	Mod	20	[6]
α-cypermethrin	83,9	RO	Fabricated	Mod	50	[6]
α-cypermethrin	82,1	RO	Fabricated	Mod	100	[6]
α-Endosufan	100,0	RO	Fabricated	Mod	20	[6]
α-Endosufan	100,0	RO	Fabricated	Mod	50	[6]
α-Endosufan	100,0	RO	Fabricated	Mod	100	[6]
α-endosulfan	99,8	NF	Commercial	NF270	8	[5]
α-endosulfan	100,0	RO	Fabricated	Mod	8	[5]
α-endosulfan	99,8	RO	Commercial	SW30XLE RO	8	[5]
α-HCH	88,0	RO	Fabricated	Mod	20	[6]
α-HCH	89,6	RO	Fabricated	Mod	50	[6]
α-HCH	90,0	RO	Fabricated	Mod	100	[6]
β-Endosulfan	100,0	RO	Fabricated	Mod	20	[6]
β-Endosulfan	100,0	RO	Fabricated	Mod	50	[6]
β-Endosulfan	100,0	RO	Fabricated	Mod	100	[6]
β-HCH	83,4	RO	Fabricated	Mod	20	[6]
β-HCH	89,0	RO	Fabricated	Mod	50	[6]
β-HCH	98,8	RO	Fabricated	Mod	100	[6]
γ-HCH	100,0	RO	Fabricated	Mod	20	[6]
γ-HCH	100,0	RO	Fabricated	Mod	50	[6]
γ-HCH	99,6	RO	Fabricated	Mod	100	[6]
δ-HCH	85,0	RO	Fabricated	Mod	20	[6]
δ-HCH	84,6	RO	Fabricated	Mod	50	[6]
δ-HCH	94,9	RO	Fabricated	Mod	100	[6]
Thiamethoxam	94,0	RO	Fabricated	Mod	10000	[15]
Acetamiprid	94,0	RO	Fabricated	Mod	10000	[15]
Imidacloprid	93,0	RO	Fabricated	Mod	10000	[15]
Imidacloprid	40,0				2000000	[16]
Imidacloprid	85,0				2000000	[16]
MCPA	97,4	RO	Commercial	BW30	1000	[17]
MCPP	97,6	RO	Commercial	BW30	1000	[17]
MCPA	93,2	RO	Commercial	XLE	1000	[17]
MCPP	93,9	RO	Commercial	XLE	1000	[17]
MCPA	69,1	NF	Commercial	NF99HF	1000	[17]
MCPP	80,7	NF	Commercial	NF99HF	1000	[17]
MCPA	66,3	NF	Commercial	NF270	1000	[17]
MCPP	79,6	NF	Commercial	NF270	1000	[17]
Atrazine	85,0	NF	Commercial	dNF40	3000	[18]
Atrazine	45,0	NF	Commercial	dNF80	3000	[18]
MCPA	95,3	RO	Commercial	BW30	132000	[19]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
MCPA	95,5	RO	Commercial	SW30	132000	[19]
MCPA	71,3	NF	Commercial	NF270	165000	[19]
MCPA	93,2	NF	Commercial	NF90	165000	[19]
Carbofuran	82,0	NF	Fabricated	Mod	40000	[20]
Carbofuran	84,0	NF	Fabricated	Mod	80000	[20]
Carbofuran	85,0	NF	Fabricated	Mod	120000	[20]
Carbofuran	87,0	NF	Fabricated	Mod	160000	[20]
Carbofuran	89,0	NF	Fabricated	Mod	200000	[20]
Paraquat	96,0	PRO	Commercial	CTA-ES	25000	[21]
Glyphosate	96,4	PRO	Commercial	CTA-ES	25000	[22]
Bentazone	96,6	PRO	Commercial	CTA-ES	25000	[21]
Imidacloprid	97,2	PRO	Commercial	CTA-ES	25000	[21]
Clopyralid	96,6	PRO	Commercial	CTA-ES	25000	[21]
Paraquat	97,6	PRO	Commercial	CTA-ES	400000	[21]
Glyphosate	98,0	PRO	Commercial	CTA-ES	400000	[21]
Bentazone	99,2	PRO	Commercial	CTA-ES	400000	[21]
Imidacloprid	99,6	PRO	Commercial	CTA-ES	400000	[21]
Clopyralid	97,6	PRO	Commercial	CTA-ES	400000	[21]
Paraquat	96,4	FO	Commercial	CTA-ES	25000	[21]
Glyphosate	96,8	FO	Commercial	CTA-ES	25000	[21]
Bentazone	97,2	FO	Commercial	CTA-ES	25000	[21]
Imidacloprid	97,8	FO	Commercial	CTA-ES	25000	[21]
Clopyralid	97,4	FO	Commercial	CTA-ES	25000	[21]
Paraquat	98,2	FO	Commercial	CTA-ES	400000	[21]
Glyphosate	98,4	FO	Commercial	CTA-ES	400000	[21]
Bentazone	99,6	FO	Commercial	CTA-ES	400000	[21]
Imidacloprid	99,8	FO	Commercial	CTA-ES	400000	[21]
Clopyralid	98,0	FO	Commercial	CTA-ES	400000	[21]
Atrazine	42,0	MF	Fabricated		5000	[22]
Sulfametoxazol	34,0	MF	Fabricated		5000	[22]
Tetracycline	38,0	MF	Fabricated		5000	[22]
Sulfamethazine	35,0	MF	Fabricated		5000	[22]
Atrazine	97,9	MF	Fabricated		5000	[22]
Sulfametoxazol	91,8	MF	Fabricated		5000	[22]
Tetracycline	95,4	MF	Fabricated		5000	[22]
Sulfamethazine	88,7	MF	Fabricated		5000	[22]
Azoxystrobin	99,5	RO	Commercial	ESPA2-LD	5	[23]
Carbendazim	88,59	RO	Commercial	ESPA2-LD	5	[23]
Carbofuran	94,38	RO	Commercial	ESPA2-LD	5	[23]
Chlorantraniliprole	96,87	RO	Commercial	ESPA2-LD	5	[23]
Chloridazon	83,33	RO	Commercial	ESPA2-LD	5	[23]
Chlorsulfuron	98,98	RO	Commercial	ESPA2-LD	5	[23]
Clethodime	100	RO	Commercial	ESPA2-LD	5	[23]

PESTICIDES	REMOVAL (%)	PROCESS	TIPE	MEMBRANE MODEL	FEED CONCENTRATION (ug/L)	SOURCE
Cyproconazole	97,01	RO	Commercial	ESPA2-LD	5	[23]
DEET	94,91	RO	Commercial	ESPA2-LD	5	[23]
Dimethomorph	93,19	RO	Commercial	ESPA2-LD	5	[23]
Dimoxystrobin	98,45	RO	Commercial	ESPA2-LD	5	[23]
Diuron	34,89	RO	Commercial	ESPA2-LD	5	[23]
Ethidimuron	96,49	RO	Commercial	ESPA2-LD	5	[23]
Flazasulfuron	100	RO	Commercial	ESPA2-LD	5	[23]
Flonicamid	97,01	RO	Commercial	ESPA2-LD	5	[23]
Furalaxyl	97,92	RO	Commercial	ESPA2-LD	5	[23]
Imidacloprid	92,66	RO	Commercial	ESPA2-LD	5	[23]
Iprovalicarbe	97,92	RO	Commercial	ESPA2-LD	5	[23]
Lenacil	97,01	RO	Commercial	ESPA2-LD	5	[23]
Metamitron	87,54	RO	Commercial	ESPA2-LD	5	[23]
Metazachlor	80,69	RO	Commercial	ESPA2-LD	5	[23]
Metconazole	94,24	RO	Commercial	ESPA2-LD	5	[23]
Metolachlor	95,43	RO	Commercial	ESPA2-LD	5	[23]
Metribuzine	92,8	RO	Commercial	ESPA2-LD	5	[23]
Myclobutanil	97,54	RO	Commercial	ESPA2-LD	5	[23]
Nicosulfuron	100	RO	Commercial	ESPA2-LD	5	[23]
Paclobutrazol	90,7	RO	Commercial	ESPA2-LD	5	[23]
Pirimicarb	95,43	RO	Commercial	ESPA2-LD	5	[23]
Prometon	97,01	RO	Commercial	ESPA2-LD	5	[23]
Propiconazole	97,92	RO	Commercial	ESPA2-LD	5	[23]
Secbumeton	97,01	RO	Commercial	ESPA2-LD	5	[23]
Silthiopham	97,01	RO	Commercial	ESPA2-LD	5	[23]
Spirotetramat	94,76	RO	Commercial	ESPA2-LD	5	[23]
Tebuthiuron	94,91	RO	Commercial	ESPA2-LD	5	[23]
Tetraconazole	97,92	RO	Commercial	ESPA2-LD	5	[23]
Thifensulfuron-methyl	98,98	RO	Commercial	ESPA2-LD	5	[23]
Triasulfuron	100	RO	Commercial	ESPA2-LD	5	[23]
Secbumeton	97,01	RO	Commercial	ESPA2-LD	5	[23]
4,4′-DDE	100,0	NF	Commercial	NF270	12	[5]
4,4′-DDE	100,0	RO	Fabricated	Mod	12	[5]
4,4′-DDE	100,0	RO	Commercial	SW30XLE RO	12	[5]
4,4′-DDT	100,0	NF	Commercial	NF270	49	[5]
4,4′-DDT	100,0	RO	Fabricated	Mod	49	[5]
4,4′-DDT	100,0	RO	Commercial	SW30XLE RO	49	[5]
BAM	41,2	RO	Commercial	Not available	1,7	[4]
BAM	97,1	RO	Commercial	BW30	1000	[17]
BAM	92,6	RO	Commercial	XLE	1000	[17]
BAM	32,5	NF	Commercial	NF99HF	1000	[17]
BAM	30,2	NF	Commercial	NF270	1000	[17]

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