Periódico Eletrônico
Fórum Ambiental da Alta Paulista
ISSN 1980-0827 – Volume 18, número 1, 2022

Pesticides, water resources and bioindicators

Juliana Heloisa Pinê Américo-Pinheiro
Ph.D. Lecturer, Civil Engineering Post-Graduation Program, UNESP, Brazil.
juliana.heloisa@unesp.br

Letícia Sales Mercado
M.Sc. Student, Civil Engineering Post-Graduation Program, UNESP, Brazil.
leticia.smercado@hotmail.com

SUMMARY

Pesticides are constantly used to control agricultural and urban pests. However, they can contaminate watercourses and intoxicate aquatic organisms. The ecotoxicological effects of these contaminants can be observed in studies with bioindicators. This article presents a literature review on the main environmental aspects associated with pesticides and their toxicity to aquatic bioindicators. The search for scientific publications was carried out on the platforms Science Direct, Scielo, Virtual University Library and Academic Google. The information found was complemented with aspects related to legislation on pesticides consulted on Government platforms. The occurrence of pesticides in water resources has been recorded in several countries around the world, which shows the constant and inadequate use of these substances. This issue brings to light major challenges that involve the search for preventive and/or recovery measures from possible impacts on the environment, non-target organisms and human beings who are exposed to contamination by pesticides. The use of pesticide contamination bioindicators is essential to identify the effects of these substances on the environment and the sensitivity between species and different aquatic trophic levels. Fish constitute an excellent group of bioindicators, among them the Danio rerio (zebrafish) is the one that stands out in ecotoxicological studies. The most frequently observed ecotoxicological effects in fish include lethality, neurotoxicity, and enzymatic, biochemical, hematological and histological changes. These effects can compromise the survival and health of these vertebrates, interfering with the balance of aquatic environments and possibly impacting human health.

KEYWORDS: Ecotoxicology. Fish. Toxicity.

1 INTRODUCTION

Phytosanitary products, plant protection products, or pesticides are names given to a group of chemical substances used to control agricultural and urban pests (PERES; MOREIRA 2003). The use of these chemical products has become essential for the success of agricultural-production chains aiming at increasing productivity (AMÉRICO et al., 2015).

The use of these products in agriculture has been long described, but it was only with the insecticide dichlorodiphenyltrichloroethane (DDT) that in 1931 their chemical control effectiveness was attested, marking the beginning of the use of such substances in agriculture production (NUNES; RIBEIRO, 1999).

With the Green Revolution in the 1950's, the use of pesticides and fertilizers in agriculture has been intensified together with the emergence of new technologies that allowed productivity expansion in the fields. In that period, not only changes in traditional agricultural practices were observed, but also impacts on the environment and human health (MOREIRA et al., 2002).

According to the latest Pesticides Commercialization Report issued by the Brazilian Institute for the Environment and Natural Resources (*Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais* – IBAMA), the selling of formulated products containing 620,537.98 tons of active (chemical and biochemical) ingredients was recorded in 2019, which represented an increase of 12.97% in the internal sales in relation to 2018 (IBAMA, 2021a).

The increase in consumption and use of pesticides can cause negative changes and impacts on the environment by the contamination of the community of living beings and accumulation of such substances in biotic and abiotic segments of the ecosystems (RIBAS; MATSUMURA, 2009). Among the main environmental compartments impacted by the introduction of pesticides are the aquatic ecosystems, once the occurrence of these contaminants in superficial and underground waters has been recorded in different countries (SILVA et al., 2011; TANG et al., 2013; BECKER et al., 2021; KALANTARY; BARZEGAR; JORFI, 2022).

According to Severo et al. (2020), water bodies close to rural areas are in general severely contaminated by pesticide residues, which can directly affect the equilibrium of aquatic ecosystems. Regarding herbicides, the main effect is observed in aquatic macrophytes, differently from the insecticides, whose more evident effects occur in some fish species.

The adverse effects of pesticides can be lethal or sublethal and can reach aquatic organisms of different trophic levels, such as algae, microcrustaceans, molluscs, and fish species (AMÉRICO et al., 2015). Studies have identified behavioral, biochemical, hematological and histological changes provoked by the exposition of different fish species to pesticides, leading to damages in health and survival of these organisms (NADAN; NIMILA, 2012; AMÉRICO-PINHEIRO et al., 2019; AMÉRICO-PINHEIRO et al., 2020).

When consuming fish, humans are exposed to greater concentrations of these substances than those detected in water (SCHAFER et al., 2011). Evidences show the association of pesticides with increasing cancer risk, for example: stomach cancer, leukemia, and lymphoma (MOSTAFALOU; ABDOLLAHI, 2017). Reports reveal that pesticides can compromise the endocrine system, causing pulmonary discomfort and diabetes in humans (KIM; KABIR; JAHAN, 2017; MOSTAFALOU; ABDOLLAHI, 2017).

Fish and other organisms present in aquatic ecosystems play a useful role as pesticide bioindicators, thanks to their specificity to certain impacts, as countless species are demonstrably sensitive to certain contaminants (WASHINGTON, 1984). Thus, the use of bioindicators to assess environment contamination by pesticides is essential, in order to aid measures of identification of these substances in water, characterization of possible adverse effects to the biota, and proposal of strategies to recover aquatic environments.

2 OBJECTIVE

The objective of this article is to present a bibliographic review on the main environmental aspects associated with pesticides and their toxicity potential to aquatic bioindicators.

3 METHODOLOGY

The search for scientific publications on pesticides and their toxicity potential to bioindicators was carried out using the following research platforms: *Science Direct*, *Scielo*, University Virtual Libraries, and Academic Google. The information found in these platforms was complemented with aspects related to the Brazilian legislation on pesticides collected from Government platforms.

4 DEVELOPMENT

4.1 Pesticide general and environmental aspects

Pesticides are one of the main technologies used in agriculture to protect crops from the harmful action of living organisms that prevent plants from growing. These commercial chemical formulations contain both toxic active ingredients and inert ingredients. The toxic active ingredients are synthetized and carefully selected during a period of 8 to 10 years, under laboratory and field conditions, being toxicity their main characteristic (MACHADO et al., 2013).

In Brazil, discussions exist concerning the adoption of the terms: plant protection products, phytosanitary products, pesticides, and biocides (SPADOTTO et al., 2004). Thus, Law 7802, also known as "Pesticide Law" and dated 1989, defined the term pesticide as:

> a) Products and agents from physical, chemical or biological processes intended for use in production sectors, storage and processing of agriculture products, in pastures, in the protection of native forests and reforestation, and of other ecosystems and also urban, water, and industrial environments, in order to change the composition of flora or fauna, so as to protect them from the damaging actions of living beings considered harmful.
> b) Substances and products used as defoliants, desiccants, growth stimulators and inhibitors (BRAZIL, 1989, p. 1).

The Pesticide Law, as well as other legislations, is regulated by decree and in this case, by Decree 4074 dated 2002. It determines the competences of the agencies in charge of registering such products. These agencies include the Ministry of Agriculture, Livestock and Food Supply (*Ministério da Agricultura, Pecuária e Abastecimento* – MAPA), the Brazilian Health Regulatory Agency (*Agência Nacional de Vigilância Sanitária* – ANVISA), and the Brazilian Institute for the Environment and Renewable Natural Resources (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* – IBAMA) (BRASIL, 2002).

According to Ribas and Matsumura (2009), these chemical substances can be classified as: insecticides (control of insects), fungicides (control of fungi), herbicides (control of weeds), defoliants (control of unwanted foliage), fumigants (control of soil bacteria), rodenticides (control of rodents), and acaricides (control of mites).

The most commercialized pesticide groups are insecticides and herbicides. In 2019, the most commercialized pesticide formulations in Brazil were based on active ingredients such as: glyphosate; 2,4-dichlorophenoxyacetic acid (2,4-D); mancozeb; acephate; atrazine; chlorothalonil; paraquat dichloride; malathion; sulfur, and chlorpyrifos (IBAMA, 2021a).

Regarding insecticides, the groups that stood out in relation to use and toxicity were organochlorine and organophosphorus compounds, carbamates, pyrethroids, and neonicotinoids (FIKES, 1990; SPENCER et al., 2001; TOMIZAWA; CASIDA, 2003; FLORES et al., 2004; AMÉRICO-PINHEIRO et al., 2019; AMÉRICO-PINHEIRO et al., 2020). Regarding herbicides, studies involving glyphosate, 2,4-D, and atrazine are highlighted (SANTOS et al., 2015; CRUZ et al., 2016; RODEA-PALOMARES et al., 2015; HOU et al., 2017; TEIXEIRA et al., 2018). In this context, glyphosate is the most produced and applied active ingredient in the world, being detected in a variety of aquatic ecosystems (MARTINI et al., 2012; FARIA et al., 2021).

Pesticides are used and applied in forests, aquatic environments, urban and industrial areas, agriculture and pastures, according to the recommendation of each product (RIBAS; MATSUMURA, 2009). After the application of a certain pesticide, physical, chemical, and biological processes, such as sorption, transformation, and transport, interfere in its behavior in the environment, besides the interaction of these processes. Meteorological conditions, microorganisms present in the soil, topography, soil management, quantity of water in the surface are also factors that interfere in the flow and destination of pesticides in environmental matrices, such as soil and underground and superficial waters (EMBRAPA, 2021).

Besides the processes that determine the pesticide environmental destination, the structure and properties of these contaminants can influence their displacement and flow in the environment (SPADOTTO et al., 2004). Pesticides not only affect organisms that live in the areas where they are applied, but also domestic animals, people who live nearby, workers, and consumers of food that may contain some kind of residue derived from these compounds (MACHADO et al., 2013).

IBAMA establishes criteria that aid the rational and safe use of pesticides, in order to protect natural resources. Therefore, it is important to know the characteristics and environmental behavior of the pesticide to be registered by means of physical-chemical, toxicological, and ecotoxicological tests. On the basis of such information, pesticides are classified according to their potential for environmental hazards (*potencial de periculosidade ambiental* – PPA) in four classes that vary from I to IV, being Class I the most restrictive from the environmental point of view, as shown in Chart 1 (IBAMA, 2021b).

Chart 1 – Classification of pesticides according to their potential for environmental hazards

Class	Potential for environmental hazards
I	Product extremely hazardous to the environment
II	Product highly hazardous to the environment
III	Product moderately hazardous to the environment
IV	Product slightly hazardous to the environment

Source: Adapted from IBAMA (2001b)

4.2 Pesticides in water resources

The expansion of agricultural areas and the intensification of the use of pesticides in these areas promote the occurrence of pesticide residues in superficial and underground springs that are constantly exposed to these contaminants. These compounds can reach water resources by means of drainage, percolation, superficial and sub-superficial runoff, erosion, drift, and volatilization (SILVA et al., 2009).

Many studies have reported the occurrence of residues of these contaminants in superficial and underground waters around the world, particularly in agricultural areas, thus compromising water quality and damaging the organisms present in these impacted environments (GRÜTZMACHER et al., 2008; MARSALA et al., 2020; BECKER et al., 2021). Chart 2 lists information on pesticides detected in aquatic environmental matrices in different countries of the world.

Chart 2 – Occurrence of pesticides in water resources of several countries

Pesticide	Agronomic class	Environmental matrix	Country	Reference
Atrazine	Herbicide	Superficial water	Brazil and Paraguay	Becker et al. (2021)
			Spain	Rodriguez-Mozaz, Alda, Barceló (2004)
Carbofuran	Insecticide	Superficial water	Brazil	Grützmacher et al. (2008)
		Groundwater	Korea	Lee et al. (2019)
Clomazone	Herbicide	Superficial water	Brazil	Grützmacher et al. (2008)
Chlorpyrifos	Insecticide	Superficial water and water for human consumption	Vietnam	Wan et al. (2021)
Fipronil	Insecticide	Superficial water	Brazil	Grützmacher et al. (2008)
			Vietnam	Wan et al. (2021)
Glyphosate	Herbicide	Superficial water	Brazil	Mattos et al. (2002)
Isoprocarb	Insecticide	Superficial water	China	Chen et al. (2021)
Propiconazole	Fungicide	Superficial water	Malaysia	Elfikrie et al. (2020)
Simazine	Herbicide	Superficial water	China	Chen et al. (2021)
			Japan	Tanabe et al. (2000)
Trimetacarb	Insecticide	Groundwater	Italy	Marsala et al. (2020)

Source: Prepared by the authors.

The study of Martini et al. (2012) carried out in an agricultural area revealed the high potential of transport of herbicide glyphosate and insecticide carbofuran by superficial runoff, representing risk of contamination of superficial waters. Both herbicide glyphosate and insecticide carbofuran are also potential contaminants of groundwater (MARTINI et al., 2012).

Thus, all records of the presence of pesticide residues in water resources are associated with high levels of industrialization, the necessity of increasing food production as population density increases, especially in geographic regions adjacent to the lowest parts of the water courses (ZAGATTO; BERTOLETTI, 2008).

4.3 Ecotoxicology and pesticide bioindicators

Ecotoxicology is a science that investigates the toxic effects of natural and synthetic compounds in living beings, including all aquatic and terrestrial communities and populations, and the interaction of these toxic substances with the environment (TRUHAUT, 1977). The toxicity of a pesticide (active ingredients of a formulation) is based on its capacity to intoxicate certain species or groups of species, causing damage to agricultural crops or harvested products. Nonetheless, these substances can be toxic to non-target organisms (MACHADO et al., 2013).

Ecotoxicological assessment involving chemical substances can be performed via laboratory or field tests, using aquatic and terrestrial species. Regarding aquatic species, algae, microcrustaceans, and fish are the most used organisms (MANSANO; MOREIRA; ROCHA, 2013; CRUZ et al., 2016; AMÉRICO-PINHEIRO et al., 2020; STENSTRÖM; KREUGER; GOEDKOOP, 2021).

The aquatic organisms used in ecotoxicological tests are considered bioindicators of environment contamination by pesticides. According to Arias et al. (2007), the use of bioindicators encompassing different trophic levels allows the identification of the level at which the contaminant interacts with the organisms, and which levels and species are more sensitive to the action of the toxic compound.

The species mostly used as bioindicator in ecotoxicological tests that focus on water quality is *Danio rerio*, a fish popularly known in Brazil as zebrafish. Its characteristics make this fish a safe model for research, as it is a small species easily kept and distributed in aquariums and of high fertility rate (HILL et al., 2005). *D. rerio* is a vertebrate increasingly used in biomedical research, including neurotoxicological studies, as its nervous and neurotransmitter systems are similar to those of humans (HORZMANN; FREEMAN, 2016).

According to Faria et al. (2021), glyphosate concentrations present in many aquatic ecosystems can put fish survival in risk. These authors observed that environmentally relevant glyphosate concentrations lead to neurotoxic effects in *D. rerio*.

Some insecticides, such as carbamates and organophosphorus compounds, are known to block the neuromuscular function of several organisms, that is, they act as anticholinesterase agents (CASIDA; BRYANT, 2017). Cholinesterases represent a group of enzymes responsible for the hydrolysis of carboxylic and choline esters. These enzymes are sensitive to a series of chemical products. Their main and most important function is to act as neurotransmitters (PERES; MOREIRA 2003).

Severo et al. (2020) attested that pesticides can be transported to aquatic environments that are close to rural areas and can cause negative effects, such as the reduction in egg hatch rate and changes in heart rate and in levels of the acetylcholinesterase enzyme (AChE) in fish species, such as *D. rerio*. Both AChE and butyrylcholinesterase (BChE) are enzymes that exist in fish. Theoretically, glyphosate does not act as an anticholinesterase compound, but there are reports on AChE inhibition in fish exposed to it (MOURA et al., 2017; SANCHEZ et al., 2017; TEIXEIRA et al., 2018).

When AChE is blocked, an accumulation of nervous stimuli takes place in the organism, leading to a cholinergic hyperstimulation, which can be lethal (CALDAS, 2000). Cholinesterase inhibition in vertebrates can cause convulsions, unconsciousness and respiratory failure, leading to death. Regarding invertebrates, hyperexcitation occurs, leading to death by exhaustion (ČOLOVIĆ et al., 2013; CASIDA; DURKIN, 2013). For these reasons, AChE and BChE are commonly used as biomarkers in fish, in order to determine their exposition to pesticides.

Besides *D. rerio*, other fish species are used in ecotoxicological tests with pesticides, such as *Hyphessobrycon eques*, *Phallocerus caudimaculatus, Piaractus mesopotamicus* (CRUZ et al., 2015); *Cyprinus carpio* (CLASEN et al., 2018; NUNES et al., 2018); *Oncorhynchus mykiss* (MCCUAIG; MARTYNIUK; MARLATT, 2020), and *Oreochromis niloticus* (AMÉRICO-PINHEIRO et al., 2020). Chart 3 list fish species used in ecotoxicological tests with pesticides and the main effects observed after the exposition to the contaminants.

Chart 3 – Fish species used in ecotoxicological tests with pesticides and observed effects

Pesticide active ingredient	Bioindicator species	Ecotoxicological effects	Reference
Carbosulfan (insecticide)	Rainbow trout *(Oncorhynchus mykiss)*	Sublethal concentrations cause necrosis in liver and kidney	Capkin et al. (2010)
Glyphosate (herbicide)	Hybrid sorubim (*Pseudoplatystoma sp)*	Decrease in antioxidant activities and ascorbic acid levels in fish liver and brain	Sinhorin et al. (2014)
Atrazine (herbicide)	*Pacu (Piaractus mesopotamicus)*	Subchronic effects with changes in the gills, liver and in the acetylcholinestaresis enzyme in the brain	Santos et al. (2015)
Mixing of Cypermethrin and Chlorpyrifos (insecticides)	*Zebrafish (Danio rerio)* and Carp *(Cyprinus carpio)*	Acute effects such as increased ascorbic acid levels and decreased catalase activity	Nunes et al. (2018)
Imidacloprid (Insecticide)	Tilapia *(Oreochromis niloticus)*	Sublethal concentrations modify hematological parameters (white blood cell count, erythrocytes, plasma proteins and thrombocytes)	Américo-Pinheiro et al. (2019)
Carbofuran (insecticide)	Tilapia *(Oreochromis niloticus)*	Sublethal concentrations cause changes in the structure of the gills, necrosis in the liver and kidney	Américo-Pinheiro et al. (2020)

Source: Prepared by the authors.

Despite the relatively few information available on the effects of these contaminants at ecological levels, mainly in sublethal concentrations and their interactions in a continuous, multiple exposure scenario, fish species are promising bioindicators to understand the environmental destination and the dynamics of pesticides in aquatic environments (PÉREZ-PARADA et al., 2018).

5 FINAL CONSIDERATIONS

The occurrence of pesticides in aquatic environmental matrices in several countries highlights the constant and inadequate use of such substances in agricultural and urban areas. This issue brings to light major challenges that involve the search for preventive and/or recovery measures for the possible impacts on the environment, on non-target organisms, and on humans that are exposed to pesticides.

The use of bioindicators to assess contamination by pesticides is essential to identify the effects of these substances in the environment and the sensitivity among the species and the different aquatic trophic levels. Fish species, such as *D. rerio*, constitute an excellent bioindicator group adopted worldwide, particularly in ecotoxicological studies.

The ecotoxicological effects more frequently observed in the studies involving fish species include lethality, neurotoxicity, and enzymatic, biochemical, hematological and histological changes. These effects can compromise the survival and health of these vertebrates, interfering in the equilibrium of the aquatic environments, and possibly impacting human health via consumption of fish and water contaminated by pesticide residues.

REFERENCES

AMÉRICO, J. H. P. et al. O uso de agrotóxicos e os impactos nos ecossistemas aquáticos. **ANAP Brasil**, Tupã, v. 8, n. 3, p. 101-115, 2015. DOI 10.17271/1984324081320151149

AMÉRICO-PINHEIRO et al. Sublethal effects of imidacloprid in hematological parameters of tilapia (*Oreochromis niloticus*). **Water, Air, & Soil Pollution**, v. 230, 193, 2019. DOI 10.1007/s11270-019-4256-0

AMÉRICO-PINHEIRO et al. Histological changes in targeted organs of Nile Tilapia (*Oreochromis niloticus*) exposed to sublethal concentrations of the pesticide carbofuran. **Water, Air, & Soil Pollution**, v. 231, 228, 2020. DOI 10.1007/s11270-020-04628-5

ARIAS, A. R. L. et al. Utilização de bioindicadores na avaliação de impacto e no monitoramento da contaminação de rios e córregos por agrotóxicos. **Ciência & Saúde Coletiva**, v. 12, n. 1, p. 61-72, 2007. DOI 10.1590/S1413-81232007000100011

BECKER, R. W. et al. Pesticides in surface water from Brazil and Paraguay cross-border region: Screening using LC-QTOF MS and correlation with land use and occupation through multivariate analysis. **Microchemical Journal**, v. 168, 106502, 2021. DOI 10.1016/j.microc.2021.106502

BRASIL**. Lei nº 7.802,** de 11 de julho de 1989. Lei dos agrotóxicos. Diário Oficial da União, Brasília, DF. Available on: http://www.planalto.gov.br/ccivil_03/leis/l7802.htm. Access on 25th June, 2021.

BRASIL. **Decreto nº 4.074, de 04 de janeiro de 2002**. **Regulamenta a lei nº 7.802 de 1989**. Available on: http://www.planalto.gov.br/ccivil_03/decreto/2002/d4074.htm. Access on 25th June, 2021.

CALDAS, L. Q. A. **Intoxicações exógenas agudas por carbamatos, organofosforados, compostos bipiridílicos e piretróides**. 1st ed. Niterói: Centro de controle de intoxicações de Niterói, 2000.

CAPKIN, E. et al. Effects of some pesticides on the vital organs of juvenile rainbow trout (*Oncorhynchus mykiss*). **Tissue & Cell** ,v. 42, p. 376–382, 2010.

CASIDA, J. E., BRYANT, R. J. The ABCs of pesticide toxicology: amounts, biology, and chemistry. **Toxicology Research**, v. 6, n.6, p. 755–763, 2017. DOI 10.1039/c7tx00198c

CASIDA, J. E.; DURKIN, K. A. Neuroactive insecticides: targets, selectivity, resistance, and secondary effects. **Annual Reviews**, v. 58, p. 99–117, 2013. DO 10.1146/annurev-ento-120811-153645

CHEN et al. The profiling of elements and pesticides in surface water in Nanjing, China with global comparisons. **Science of The Total Environment**, v. 774, 145749, 2021. DOI 10.1016/j.scitotenv.2021.145749

CLASEN, B. et al. Bioaccumulation and oxidative stress caused by pesticides in *Cyprinus carpio* reared in a rice-fish system. **Science Of The Total Environment**, v. 626, p. 737-743, 2018. DOI 10.1016/j.scitotenv.2018.01.154.

ČOLOVIĆ, M. B. et al. Acetylcholinesterase Inhibitors: Pharmacology and Toxicology. **Current Neuropharmacology**, v. 11, p. 315-335, 2013.

CRUZ, C. et al. Imazapyr herbicide efficacy on floating macrophyte control and ecotoxicology for non-target organisms. **Planta Daninha**, v. 33, n. 1, p. 103-108, 2015.

CRUZ, C. et al. Sensitivity, ecotoxicity and histopathological effects on neotropical fish exposed to glyphosate alone and associated to surfactant. **Journal Environmental Chemistry Ecotoxicology, v.** 8, n. 3, p. 25-33, 2016.

ELFIKRIE, N. et al., Occurrence of pesticides in surface water, pesticides removal efficiency in drinking water treatment plant and potential health risk to consumers in Tengi River Basin, Malaysia. **Science of The Total Environment**, v. 712, 136540, 2020. DOI 10.1016/j.scitotenv.2020.136540

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. **Perdas de agrotóxicos**. Brasília: Embrapa, 2021. Available on: http://www.agencia.cnptia.embrapa.br/gestor/agricultura_e_meio_ambiente/arvore/CONTAG01_39_210200792 14.html. Access on 28th July, 2021.

FARIA, M. et al. Glyphosate targets fish monoaminergic systems leading to oxidative stress and anxiety. **Environment International**, v. 146, p. 106253-106263, 2021. DOI 10.1016/j.envint.2020.106253.

FIKES, J. D. Organophosphorus and carbamate insecticides. **Veterinary Clinics of North America: Small Animal Practice**, v. 20, n. 2, p. 353-367, 1990.

FLORES, A. V. et al. Organoclorados: um problema de saúde pública. **Ambiente & Sociedade**, v. 7, n. 2, p. 111-124, 2004.

GRÜTZMACHER, D. D. et al. Monitoramento de agrotóxicos em dois mananciais hídricos no sul do Brasil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 12, n. 6, p. 632-637, 2008.

HILL, A. et al. Zebrafish as a model vertebrate for Investigating Chemical Toxicity**. Toxicological Sciences,** v. 86, p. 6-19, 2005.

HORZMANN, K. A.; FREEMAN, J. L. Zebrafish get connected: investigating neurotransmission targets and alterations in chemical toxicity. **Toxics**, v. 4, n. 3, p. 19, 2016.

HOU, X. et al. Ascorbic acid induced atrazine degradation. **Journal Hazardous Materials**. v. 327, n. 5, p. 71-78, 2017.

INSTITUTO BRASILEIRO DE MEIO AMBIENTE E DOS RECURSOS NATURAIS (IBAMA). 2021a. **Relatórios de comercialização de agrotóxicos**. Available on: http://www.ibama.gov.br/agrotoxicos/relatorios-de-comercializacao-de-agrotoxicos. Access on 28th July, 2021.

INSTITUTO BRASILEIRO DE MEIO AMBIENTE E DOS RECURSOS NATURAIS (IBAMA). 2021b. **Avaliação do Potencial de Periculosidade Ambiental (PPA) de Agrotóxicos e Afins**. Available on: http://ibama.gov.br/avaliacao-e-destinacao/quimicos-e-biologicos/registro-especial-temporario-de-agrotoxicos-e-afins-ret/182-quimicos-e-biologicos/agrotoxicos/1156-ppa#classificacaoibama. Access on 28th July, 2021.

KALANTARY, R. R.; BARZEGAR, G.; JORFI, S. Monitoring of pesticides in surface water, pesticides removal efficiency in drinking water treatment plant and potential health risk to consumers using Monte Carlo simulation in Behbahan City, Iran. **Chemosphere,** v, 286, e131667, p. 1-12, 2022.

KIM, K. H., KABIR, E., JAHAN, S .A. Exposure to pesticides and the associated human health effects**. Science of The Total Environment**, v. 575, p. 525–535, 2017. DOI 10.1016/j.scitotenv.2016.09.009.

LEE, H-J et al. Occurrence and distribution of pharmaceutical and personal care products, artificial sweeteners, and pesticides in groundwater from an agricultural area in Korea. **Science of The Total Environment**, v. 659, p. 168-176, 2019. DOI 10.1016/j.scitotenv.2018.12.258

MACHADO, A. A. et al. Toxicologia dos agrotóxicos e segurança do trabalho. *In*: Busoli et al. (org.). **Tópicos em Entomologia Agrícola – VI**. 1st ed. Jaboticabal: UNESP, 2013, p. 311-327.

MANSANO, A. S.; MOREIRA, R. A.; ROCHA, O. Toxicidade aguda do agrotóxico carbofuran ao cladócero *Ceriodaphnia silvestrii daday*. **Fórum Ambiental da Alta Paulista**, v.9, n.11, p.91- 103, 2013.

MARSALA, R. Z. et al. First evaluation of pesticides occurrence in groundwater of Tidone Valley, an area with intensive viticulture. **Science of The Total Environment**, v. 736, 139730, 2020. DOI 10.1016/j.scitotenv.2020.139730

MARTINI, L. F. D. et al. Risco de contaminação das águas de superfície e subterrâneas por agrotóxicos recomendados para a cultura do arroz irrigado. **Ciência Rural**, v.42, n.10, p.1715-1721, 2012.

MATTOS, M. L. T. et al. Monitoramento ambiental do glifosato e do seu metabólito (ácido aminometilfosfônico) na água de lavoura de arroz irrigado. **Pesticidas**, v. 12, p. 145-154, 2002.

MCCUAIG, L. M.; MARTYNIUK, C. J.; MARLATT, V. L. Morphometric and proteomic responses of early-life stage rainbow trout (Oncorhynchus mykiss) to the aquatic herbicide diquat dibromide. **Aquatic Toxicology**, v. 222, p. 105446, 2020. DOI 10.1016/j.aquatox.2020.105446.

MOREIRA, J. C. et al. Avaliação integrada do impacto do uso de agrotóxicos sobre a saúde humana em uma comunidade agrícola de Nova Friburgo, RJ. **Ciência e Saúde Coletiva**, v. 7, n. 2, p. 299-311, 2002. DOI 0.1590/S1413-81232002000200010

MOSTAFALOU, S., ABDOLLAHI, M. Pesticides: an update of human exposure and toxicity. **Archives of Toxicology**, v. 91, p. 549–599, 2017.

MOURA, F. R. et al. 2017. Oxidative stress in the hybrid fish jundiara (*Leiarius marmoratus x Pseudoplatystoma reticulatum*) exposed to Roundup Original (R). **Chemosphere,** 185, 445–451, 2017. DOI 10.1016/j.chemosphere.2017.07.030.

NANDAN, S. B.; NIMILA, P. J. Lindane toxicity: histopathological, behavioural and biochemical changes in *Etroplus maculatus* (Bloch, 1795). **Marine Environmental Research**, v. 76, p.63–70, 2012.

NUNES, G. S.; RIBEIRO, M. L**.** Pesticidas: Uso, Legislação e Controle. **Pesticidas**, v. 9, p. 31-44, 1999.

NUNES, M. E. M. et al. Oxidative effects of the acute exposure to a pesticide mixture of cypermethrin and chlorpyrifos on carp and zebrafish – A comparative study. **Comparative Biochemistry And Physiology Part C**: **Toxicology & Pharmacology**, v. 206-207, p. 48-53, 2018. DOI 10.1016/j.cbpc.2018.03.002.

PERES, F.; MOREIRA, J. C. **É veneno ou é remédio? Agrotóxicos, saúde e ambiente.** Rio de Janeiro: Fiocruz, 2003.

PERES-PARADA, A. et al. Recent advances and open questions around pesticide dynamics and effects on freshwater fishes. **Current Opinion in Environmental Science & Health**. v. 4, p. 38-44, 2018. DOI 10.1016/j.coesh.2018.08.004

RIBAS, P. P.; MATSUMURA, A. T. S. A química dos agrotóxicos: impacto sobre a saúde e meio ambiente. **Revista Liberato**, v. 10, n. 14, p. 149-158, 2009.

RODEA-PALOMARES, I. et al. Effect of PFOA/PFOS pre-exposure on the toxicity of the herbicides 2,4-D, Atrazine, Diuron and Paraquat to a model aquatic photosynthetic microorganism. **Chemosphere**, v. 139, p. 65-72, 2015.

RODRIGUEZ-MOZAZ, S.; ALDA, M. J. L.; BARCELÓ, D. Monitoring of estrogens, pesticides and bisphenol A in natural Waters and drinking water treatment plants by solid-phase extraction-liquid chromatography-mass spectrometry. **Journal of Chromatography A**, v. 1045, p. 85-92, 2004.

SÁNCHEZ, J. A. A. et al. Effects of Roundup formulations on biochemical biomarkers and male sperm quality of the livebearing Jenynsia multidentata. **Chemosphere**, v. 177, p. 200-210, 2017.

SANTOS, E. A. et al. Atrazine levels in the Jaboticabal water stream (São Paulo State, Brazil) and its toxicological effects on the pacu fish *Piaractus mesopotamicus.* **Archives Industrial Hygiene and Toxicology.** v. 666, p. 73-82, 2015.

SEVERO, E. S. et al. Ecological risk of pesticide contamination in a Brazilian river located near a rural area: a study of biomarkers using zebrafish embryos. **Ecotoxicology and Environmental Safety**, v. 190, p. 110071-110080, 2020. DOI 10.1016/j.ecoenv.2019.110071.

SILVA, D. R. O. et al. Monitoramento de agrotóxicos em águas superficiais de regiões orizícolas no Sul do Brasil. **Ciência Rural**, v. 39, n. 9, p. 2383-2389, 2009.

SILVA, D. R. O. et al. Ocorrência de agrotóxicos em águas subterrâneas de áreas adjacentes a lavouras de arroz irrigado. **Química Nova**, v. 34, n. 5, p. 748-752, 2011. DOI: 10.1590/S0100-40422011000500004

SINHORIN, V. D. G. et al. Effects of the acute exposition to glyphosate-based herbicide on oxidative stress parameters and antioxidant responses in a hybrid Amazon fish surubim (*Pseudoplatystoma sp*). **Ecotoxicology and Environmental Safety**, v. 106, p. 181-187, 2014. DOI 10.1016/j.ecoenv.2014.04.040

SPADOTTO, C. A. et al. **Monitoramento de risco ambiental de Agrotóxicos: princípios e recomendações**. Documentos 42. Jaguariúna: EMBRAPA:CNPMA, 29p., 2004

SPENCER, C. L. et al**.** Actions of pyrethroid insecticides on sodium currents, action potentials, and contractile rhythm in isolated mammalian ventricular myocytes and perfused hearts. **The Journal of Pharmacology and Experimental Therapeutics,** v. 298, n. 3, p. 1067-1082, 2001.

STENSTRÖM, J. R.; KREUGER, J.; GOEDKOOP, W. Pesticide mixture toxicity to algae in agricultural streams – Field observations and laboratory studies with in situ samples and reconstituted water. **Ecotoxicology and Environmental Safety**. v. 215, 112153, 2021. DOI 10.1016/j.ecoenv.2021.112153

TANABE, A. et al. New monitoring system for ninety pesticides and related compounds in river water by solid-phase extraction with determination by gás chromatography/mass spectrometry. **Journal of AOAC International**, v. 83, n. 1, p. 61-77, 2000. DOI 10.1093/jaoac/83.1.61

TANG, Z. et al. Organochlorine pesticides in the lower reaches of Yangtze River: Occurrence, ecological risk and temporal trends. **Ecotoxicology and Environmental Safety**, v. 87, p. 89-97, 2013.

TEIXEIRA, J. M. et al. Acute toxicity and effects of Roundup Original® on pintado da Amazônia. **Environmental Science and Pollution Research**, v. 25, n. 25, p. 25383-25389, 2018.

TOMIZAWA, M.; CASIDA, J. E. Selective Toxicity of Neonicotinoids Attributable to Specificity of Insect and Mammalian Nicotinic Receptors. **Annual Review of Entomology**, v. 48, p. 339-364, 2003.

TRUHAUT, R. Ecotoxicology: Objectives, Principles and Perspectives. **Ecotoxicology Environmental Safety**, v. 1, n. 2 p. 151-173, 1977.

WAN, Y. et al. Neonicotinoids, fipronil, chlorpyrifos, carbendazim, chlorotriazines, chlorophenoxy herbicides, bentazon, and selected pesticide transformation products in surface water and drinking water from northern Vietnam. **Science of The Total Environment**, v. 750, 141507, 2021. DOI 10.1016/j.scitotenv.2020.141507

WASHINGTON, H. G. Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. **Water Research,** v. 18, p. 653-694, 1984.

ZAGATTO, P. A; BERTOLETTI, E. **Ecotoxicologia aquática:** princípios e aplicações. 2nd ed. São Carlos: Rima, 2008.