Biointerface Research in Applied Chemistry
Platinum Open Access Journal (ISSN: 2069-5837)

Review
Volume 11, Issue 3, 2021, 10131 - 10140
https://doi.org/10.33263/BRIAC113.1013110140

Impact of Pesticide Toxicity in Aquatic Environment

Shefali [1], Rahul Kumar [2], Mahipal Singh Sankhla [3,*], Rajeev Kumar [4], Swaroop S. Sonone [5]

1. Department of Zoology, DPG Degree College, Gurugram, Haryana; shefaligulliya@gmail.com (S);
2. Department of Zoology & Aquaculture, CCS Haryana Agricultural University, Hisar; rahulohila01@gmail.com (R.K.);
3. Department of Forensic Science, School of Basic and Applied Sciences, Galgotias University, Greater Noida; mahipal4n6@gmail.com (M.S.S.);
4. Department of Forensic Science, School of Basic and Applied Sciences, Galgotias University, Greater Noida; rajeev4n6@gmail.com (R.K.);
5. Government Institute of Forensic Science, Aurangabad, Maharashtra; sononeswap4@gmail.com (S.S.S.);

* Correspondence: mahipal4n6@gmail.com;

Received: 18.09.2020; Revised: 7.10.2020; Accepted: 10.10.2020; Published: 12.10.2020

Abstract: The intensified agricultural crop production for growing high yield varieties requires the indiscriminate use of pesticides and fertilizers, which protect the crop from pests, thus helps in improving the quality and quantity of crops. The aquatic environment gets contaminated by the application of pesticides through several routes: runoff, spray drift, and leaching, which pose serious health risks to the aquatic ecosystem as well as to human beings. This exposure can directly affect all levels of biological organization, including primary producers, microorganisms, invertebrates, or fish. Thus, monitoring methods should be adopted for controlling the runoff events in the spraying method, such as suspended matter sampler for particle-associated pesticides that can be used for controlling the number of toxic substances in water bodies.

Keywords: aquatic; environment; toxic; water; pesticides.

1. Introduction

Rapid industrialization and urbanization in the last few decades, with the concomitant growth in population, had taken a toll on the natural resources. Several anthropogenic activities like pollution by toxic substances through pesticides or heavy metals on regional, or global scale results in climate change. Large-scale mortality of living organisms' most important wildlife such as sea mammals and expanding threat to human health, i.e., chronic respiratory diseases, cancer, damage to several major organs like the brain, lungs, kidneys are being witnessed in the recent years as a result anthropogenic perturbations [1]. Of all the anthropogenic sources of pollution, agricultural, industrial, and domestic activities are the major sources responsible for contaminating natural freshwater resources [2]. For example, about 300 billion kilograms of mixtures used in engineering and farming products reach the freshwater frameworks consistently. 10% of the universally open spillover is utilized, producing a surge of wastewater, which streams into groundwater, waterways, lakes, or the seas [3, 4].

With the increase in world population in recent years, there is a pressure on the existing agricultural system, and nowadays, the prime objective of most of the countries is to increase the food production to meet the demands of a growing population which are expected to grow nearly to 10 billion by the year 2050 [5,6]. The process of increasing cop production utilizes the application of higher quantities of agrochemicals such as herbicides, fungicides, nematicides, and fertilizers. These agrochemicals are used for controlling the pest population and increasing the yield for the production of an ample amount of food for the global population, which is estimated at 6.8 billion in 2009, and it reached 7 billion in 2012 [7, 8]. In underdeveloped countries where 1.02 billion people are undernourished, which accounts for 15% and 1.3 billion people live on an inadequate diet, which accounts for 19% thus, there is a need for sufficient sustenance supply. However, freshwater and terrestrial ecosystems are highly polluted by a large number of toxic substances, most importantly by the application of pesticides and fertilizers by the agricultural sector [2], which becomes an important issue globally. Pesticides that are used for the eradication of harmful pests are today flattering an essential part of modern life. Ideally, these should only be toxic to the target organisms [7], but several pieces of evidence from the developing research shows that the industrial chemicals, pesticides, heavy metals, and several other toxic substances interfere with the normal functioning of a large number of species including human beings and aquatic organisms [8-10]. Pesticides are present at higher levels should be removed from drinking water for human safety. There is a need to maintain control on disposal of industrial waste or Agriculture waste in water bodies and to bio-monitor the trace elements in the water and other eatables [11,12].

2. Pesticides

Pesticides are a mixture of substances that are designed to control or slaughter or control the development of pests (undesirable organisms). These pests usually plant pathogens, nematodes, microorganisms, and insects that compete with human food and are responsible for transmitting diseases and destroying crops. Pesticides are usually categorized into biological or synthetic (Fig. 1). The biological pesticides are derived from natural sources, for example, plant extracts (azadirachtin from neem or pyrethrin from chrysanthemum plants), whereas synthetic pesticides are made through the industrial processes. Another category of pesticides are broad-spectrum (used to control a wide range of species) or narrow-spectrum (used to control a small group of species) and they are also categorized depending on the kind of pest they regulate, i.e., insecticides are used for controlling insects, herbicides for weeds and fungicides are used for controlling fungi.

2.1. Insecticides.

Most of the insecticides affect the nervous system at several target sites; they interfere with the membrane transport system of sodium, potassium, calcium, or chloride ions, which inhibits the selective enzymatic activities involved in the chemical transmission at nerve endings [13] (Table 1).

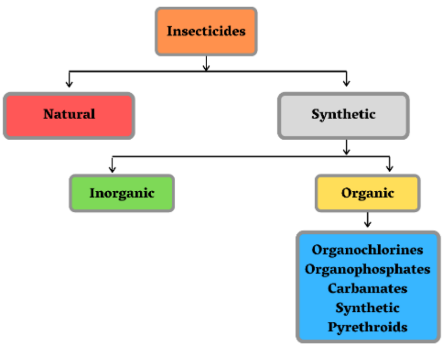

Figure 1. Classification of insecticides.

2.1.1. Organochlorines.

They are a class of insecticides that affect the nervous system as they are chemically unreactive stable compounds, which leads to long-lasting effects. DDT is the most studied pesticide among all insecticides, which inhibits the release of neurotransmitters. Endrine and lindane are other two organochlorine insecticides, in addition to DDT, which affects the nervous system [11].

2.1.2. Organophosphates.

In previous years many countries banned some of the organochlorines (DDT), which were replaced with organophosphorus insecticides like malathion and parathion [14]. This group of insecticides is also neurotoxic, i.e., they inhibit the enzyme acetylcholinesterase (AChE), and the signs and symptoms of intoxication are longer and persistent [15, 16].

2.1.3. Carbamates.

This category of insecticide also inhibits AChE by attaching to the reactive site of the enzyme [10]. It has short and reversible inhibition action of AChE.

2.1.4. Synthetic pyrethroids.

This is the newest category of insecticide, which shows two different acidic portions chrysanthemic or pyrethric acids resulting in type I and type II syndrome [13]. Both of these syndromes affect the sodium channels in the nerve membranes, which is responsible for causing the repetitive neuronal discharge; this mechanism is quite similar to the DDT action. Pyrethroid insecticides have several other sites of action. Some of them include inhibition of Ca^{2+}, Mg^{2+}-ATPase, which results in the interference with calcium removal from nerve endings, causing the release of neurotransmitters in the postsynaptic gap.

2.2. Herbicides.

Herbicides are classified into several categories based on their action. They are produced for killing the harmful plants (weeds) thus. They are associated with affecting various mechanisms that are involved in photosynthesis, respiration, growth, cell and nuclear division, or during the protein or lipid synthesis [13, 17].

2.1.1. Glyphosate.

The most commonly used herbicide for controlling weeds inhibits the single plant enzyme EPSPS (5- enolpyruvoylshikimate 3-phosphate synthase), which is the key enzyme for catalyzing the amino acid biosynthetic pathway, and the inhibition of this enzymes affects the protein synthesis mechanism [18, 19]. In addition to these, herbicides also inhibit many physicochemical and physiological pathways [20, 21]. The ecotoxicologists are highly concerned about the exposure of a non-target aquatic organism to the formulations of glyphosate because of the extensive use of glyphosate in the shallow water ecosystems, and it also possesses high water solubility [22].

2.2.2. Chlorophenoxy herbicides.

This category of herbicides mainly includes 2,4-D (2,4-dichlorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and MCPA (4-chloro-o-toloxyacetic acid), which are known for mimicking the role of growth hormone, i.e., auxin in plants [13, 23, 24] and it is also responsible for several growth abnormalities at higher concentrations which mainly includes leaf or stem curling, inhibition of shoot and root growth [25] which ultimately results in necrosis and plant death.

2.3. Fungicides.

Fungicides are the group of an insecticide which disturb the energy supply in fungi and inhibits spore germination [26]. For example, dithiocarbamates (e.g., maneb and thiram) and the R-S-CCl3 compounds (e.g., captan and dichlofluanid) have multisite action by inhibiting the enzymes which are involved in respiratory processes, whereas another group of fungicides, i.e., the phenylpyrroles, which includes fenpiclonil and iprodione inhibits the spore germination and causes several morphological alterations in the germ tubes of plants which means the elongation of germ-tube is inhibited [27, 28]. In addition to this, fungicides are also identified to constrain the electron transport chain in the respiration process [29].

Table 1. Major classes of pesticides and their mode of action.

Pesticide category	Major classes	Purpose	Mode of action	Examples	References
Insecticides	Organophosphates Carbamates Pyrethroids Organochlorines Neonicotinoids	Kill or repel insects	Neurotoxic, bioaccumulates, and biomagnifies	Malathion, methyl parathion, aldicarb, carbaryl, methomyl	[30]
Herbicides	Phosphonates Chlorphenoxy herbicides Dipuridyl herbicides	Kill weeds or unwanted plants	Neurotoxin to specific stages of insect during development	Glyphosate, 2,4-D, mecoprop, Diquat, Paraquat	[31]
Fungicides	Thiocarbamates Triazoles Strobilurins	Kills mouds and other fungi	Prevent fungal spore formation and stop plant diseases	Metarn sodium fluconazole, myclobutanil, triadimefon	[32]

For agricultural purposes, the pesticide use is enhanced in recent years for increasing the crop yield to meet the needs of the growing human population [33, 34] whereas their use harms the environment and also affects non-targeted organisms along with the targeted pests [26] which are a matter of major concern for decades [35] as it negatively affects several links in the food web. Both the soil and aquatic ecosystem are affected negatively by the pesticide pollution as they move from one ecosystem to another because of their specialized properties such as half-life, solubility, mobility, and degradation (Table 2). The pesticide enters the aquatic ecosystem through runoff, vapourization to the atmosphere, agricultural returns, groundwater intrusions, or by adsorption or through plant uptake [36-38], which adversely affects the health of aquatic organisms. Most of the pesticides in urban and agricultural settings are negatively affecting the deaths of several aquatic organisms, such as birds, fish, and zooplankton [39].

The following given factors are considered to determine the ecological impacts of pesticides in water:

Table 2. Factors affecting pesticide toxicity in aquatic systems.

Factor	Description	References
Toxicity:	Both in the situation of mammals and non-mammals, the toxicity is expressed in the form of Lethal Dose (LD), which is the concentration of the toxic substance (pesticide) responsible for killing the half test organisms in a certain period of time. The lower the value of LD50, the greater will be the toxicity; values of 0-10 are extremely toxic.	[40, 41]
	Using a risk-based assessment, the drinking water and food guidelines are determined. Generally, Risk = Exposure (amount and/or duration) × Toxicity.	[42]
	Toxic response is observed in two forms: **Acute:** death **Chronic:** in this effect, death does not occur during the test period, but certain observable characteristics such as tumors, reproductive failure, and growth inhibition are noticed in the test organism.	[43]
Persistence:	It is measured in the form of half-life, which is the time required for the diffused concentration to decrease by 50%, and its persistence is determined by the degradational processes, whether it be biotic (biodegradation and metabolism) or abiotic (hydrolysis, photolysis, and oxidation) (Calamari and Barg, 1993).	[44]
Degradates:	The process of degradation leads to the formation of degradates, which may have lesser, equal, or greater toxicity when compared to the parent compound, for example, which DDT degrades it results in DDD and DDE.	[45]
Fate (Environmental):	The environmental behavior of the pesticide is mostly affected by the chemical's natural affinity (Calamari and Barg, 1993) for any of the four compartments: solid matter, liquid, gaseous form, and biota.	[46]

3. Pesticides in the Aquatic Ecosystem

To grow high yielding crop varieties farmers, tend to use pesticides to protect the crop from pests as these crops are highly susceptible to the pests and diseases, which may lead to a 40% loss in crop production; thus, these pesticides as used to improve the quality as well as quantity of crop by protecting them from pests [47-51]. Among all the toxic substances that run off into the aquatic ecosystem, pesticides are of major concern as they are known to cause serious threats to the biological organisms, including human beings. Through several different routes such as spillage, industrial effluent, surface runoff, or through pesticide-treated soils, these toxic substances enter into the water sources [52-54]. The toxic effects caused by exposure to these toxic substances can be categorized according to the exposure period, which may be short or long-term, and exposure type, which can be lethal or sub-lethal. The period of short-term exposure does not exceed 96 hours, while long-term exposure is considered to be more than 96 hours (Table 3).

Table 3. Classification of the effect of animals exposed to chemicals [55].

Sr. no	Exposure classification	Classification based on effects	Description
1.	Exposure time	Short-term	≤ 96 h (mortality is measured as endpoint)
2.		Long-term	cellular/molecular/biochemical/physiological level measure as endpoint
3.	Exposure type	Lethal	≥ 96 h (mortality is measured as endpoint)
4.		Sub lethal	cellular/molecular/biochemical/physiological level measure as endpoint

From agricultural fields pesticides generally runoff to reservoirs or drainage systems through rain or by irrigation process [56]. Aquatic organisms are exposed to pesticides primarily by three ways: (i) through the skin: as aquatic organisms are in contact with water thus, through dermal pores, pesticides cause harmful effects, (ii) through breathing: as they respire through gills thus the aquatic organisms directly uptake pesticide through breathing and (iii) orally: aquatic organisms usually get exposed to pesticides by feeding in pesticide-contaminated prey (which is also known as secondary poisoning for example: if fish feeds on pesticide exposed insects then they may get killed if a large amount of toxic compound is consumed by the insects) or by drinking contaminated water.

The aquatic ecosystem consists of various groups of organisms such as invertebrates, plants, microorganisms, fish, or amphibians. Pesticides can affect these organisms directly or indirectly; the direct effect includes physiological changes within an organism [57-59]. For example, the exposure of pesticides to water flea results in their mortality, which can be considered as the direct effect of pesticides, and it may lead to the drastic increase in the biomass of algae because of release from the grazing pressure considered as an indirect effect. Globally, herbicide, mainly glyphosate is used for controlling both the terrestrial and aquatic weeds, and in recent years its use has been tremendously increased, and thus, it is also known to negatively affect the non-target organisms in the aquatic environment [60]. Originally its mode if an action was designed to affect the plants [61] only, but in recent year's several reports have been coming into the picture representing the adverse impact of non-target organisms [17, 62-64], which can be lethal or sub-lethal. The indicators for the exposed organisms at the physical level include a measure of survival, growth, morphological/behavioral changes. The reproductive performance can often be used for the assessment of sub-lethal response, which also includes sexual maturity, time taken to release the first brood, time taken for egg growth, fertility, and modifications in the characteristics of reproduction. In addition to this, several biochemical parameters can also be used to determine the toxicity in exposed animals, which may include disruption in metabolic pathways, steroid metabolism, lipid peroxidation, AChE activity, and activity of cytochrome P450enzymes and levels of blood glucose.

In many studies, two direct measures of growth (body weight and length) have been used for the assessment of sub-lethal effects on arthropods. Simple dry weight is determined by drying organisms, which is sampled at an average temperature of 60º C for 48 hours [65-67]. Fishes interact closely with the physical, biological, and chemical marine ecosystem; thus, they are an important part of the aquatic ecosystem. They are an important food source for other animals such as sea birds and other marine mammals; thus, they are an integral part of the marine food web. Several studies have reported the decline of the fish population to the toxic effect of pesticides [68, 69] as several reports have been mentioned representing the decline in the fish population [12, 70-80].

4. Conclusions

This review paper deals with the effects of rapid growth in the human population on the aquatic ecosystem, which may be noticed in the form of climate change, nutrient enrichment of aquatic bodies, and pollution by the different types of toxic substances, including pesticides in both regional and global scale. These man-made disturbances within the environment are responsible for adversely affecting the normal functioning of living organisms, which includes developmental abnormalities from invertebrates to higher organisms that are mammals. It is being noticed that in past years the use of pesticides is increasing, and it affects non-target organisms at different biological scales.

Funding

This review received no external funding.

Acknowledgments

This review has no acknowledgment.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Shiklomanov, I.A. *World Water Resources: A new Appraisal and Assessment for the 21st Century.* An IHP report, UNESCO, Paris, France, **1998.**
2. Schwarzenbach, R.P.; Escher, B.I.; Fenner, K.; Hofstetter, T.B.; Johnson, C.A.; von Gunten, U.; Wehrli, B. The Challenge of Micropollutants in Aquatic Systems. *Science* **2006**, *313*, 1072-1077, https://doi.org/10.1126/science.1127291.
3. Jurado, A.; Fernandes, M.; Videira, R.; Peixoto, F.; Vicente, J. Herbicides: the face and the reverse of the coin. An in vitro approach to the toxicity of herbicides in non-target organisms. *Herbicides and environment* **2011**, 1-44, https://doi.org/10.5772/12976.
4. Severo, E.S.; Marins, A.T.; Cerezer, C.; Costa, D.; Nunes, M.; Prestes, O.D.; Zanella, R.; Loro, V.L. 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* **2020**, *190*, https://doi.org/10.1016/j.ecoenv.2019.110071.
5. Saravi, S.S.S.; Shokrzadeh, M. Role of pesticides in human life in the modern age: a review. *Pesticides in the Modern World-Risks and Benefits* **2011,** 3-12, https://doi.org/10.5772/18827.
6. Yadav, H.; Kumar, R.; Sankhla, M.S. Residues of Pesticides and Heavy Metals in Crops Resulting in Toxic Effects on Living Organism. *Journal of Seybold Report* **2020,** *15*, 1527-1541, https://doi.org/10.13140/RG.2.2.24806.65609.
7. Population Reference Bureau. 2007 world population data sheet. *Population Reference* **2007.**
8. Vandergragt, M.L.; Warne, M.S.J.; Borschmann, G.; Johns, C.V. Pervasive Pesticide Contamination of Wetlands in the Great Barrier Reef Catchment Area. *Integrated Environmental Assessment and Management* **2020**, *1*, https://doi.org/10.1002/ieam.4298**.**
9. Rosell, G.; Quero, C.; Coll, J.; Guerrero, A. Biorational insecticides in pest management. *Journal of Pesticide Science* **2008**, *33*, 103-121, https://doi.org/10.1584/jpestics.R08-01.
10. Nie, J.; Sun, Y.; Zhou, Y.; Kumar, M.; Usman, M.; Li, J.; Shao, J.; Wang, L.; Tsang, D.C.W. Bioremediation of water containing pesticides by microalgae: Mechanisms, methods, and prospects for future research. *Science of The Total Environment* **2020**, *707*, https://doi.org/10.1016/j.scitotenv.2019.136080.
11. LeBlanc, G.A. Crustacean endocrine toxicology: a review. *Ecotoxicology* **2007**, *16*, 61-81, https://doi.org/10.1007/s10646-006-0115-z.
12. Yadav, H.; Sankhla, M.S.; Kumar, R. Pesticides-induced carcinogenic & neurotoxic effect on human. *Forensic Res Criminol Int J* **2019,** *7*, 243-245, https://doi.org/10.15406/frcij.2019.07.00288.
13. Correia, T.G.; Narcizo, A.M.; Bianchini, A.; Moreira, R.G. Aluminum as an endocrine disruptor in female Nile tilapia (Oreochromis niloticus). *Comparative biochemistry and physiology. Toxicology & pharmacology : CBP* **2010**, *151*, 461-466, https://doi.org/10.1016/j.cbpc.2010.02.002.
14. Singh Sankhla, M.; Kumari, M.; Sharma, K.; Kushwah, R.; Kumar, R. Water Contamination through Pesticide & Their Toxic Effect on Human Health. *International Journal for Research in Applied Science and Engineering Technology* **2018**, *6*, 967-970, https://doi.org/10.22214/ijraset.2018.1146.
15. Ecobichon, D.J. Toxic effects of pesticides in casarett and doull's toxicology. *The Basic Science of Poisons* **1991**.
16. Alencar, B.T.B.; Ribeiro, V.H.V.; Cabral, C.M.; dos Santos, N.M.C.; Ferreira, E.A.; Francino, D.M.T.; Santos, J.B.D.; Silva, D.V.; Souza, M.D.F. Use of macrophytes to reduce the contamination of water resources by pesticides. *Ecological Indicators* **2020**, *109*, https://doi.org/10.1016/j.ecolind.2019.105785.
17. Mondal, S.; Subramaniam, C. Xenobiotic Contamination of Water by Plastics and Pesticides Revealed through Real-Time, Ultrasensitive, and Reliable Surface-Enhanced Raman Scattering. *ACS Sustainable Chemistry & Engineering* **2020**, *8*, 7639-7648, https://doi.org/10.1021/acssuschemeng.0c00902.
18. Wafford, K.A.; Sattelle, D.B.; Gant, D.B.; Eldefrawi, A.T.; Eldefrawi, M.E. Noncompetitive inhibition of GABA receptors in insect and vertebrate CNS by endrin and lindane. *Pesticide Biochemistry and Physiology* **1989**, *33*, 213-219, https://doi.org/10.1016/0048-3575(89)90119-3.
19. Mulla, M.S.; Mian, L.S. Biological and environmental impacts of the insecticides malathion and parathion on non-target biota in aquatic ecosystems. In: Residue reviews. Springer, New York, NY. **1981**; pp. 101-135, https://doi.org/10.1007/978-1-4612-5910-7_5.
20. Belden, J.B.; Lydy, M.J. Impact of atrazine on organophosphate insecticide toxicity. *Environmental Toxicology and Chemistry* **2000**, *19*, 2266-2274, https://doi.org/10.1002/etc.5620190917.

21. Fiorenza, R.; Di Mauro, A.; Cantarella, M.; Iaria, C.; Scalisi, E.M.; Brundo, M.V.; Gulino, A.; Spitaleri, L.; Nicotra, G.; Dattilo, S.; Carroccio, S.C.; Privitera, V.; Impellizzeri, G. Preferential removal of pesticides from water by molecular imprinting on TiO2 photocatalysts. *Chemical Engineering Journal* **2020**, *379*, https://doi.org/10.1016/j.cej.2019.122309.
22. Sikorski, J.A.; Gruys, K.J. Understanding Glyphosate's Molecular Mode of Action with EPSP Synthase: Evidence Favoring an Allosteric Inhibitor Model. *Accounts of Chemical Research* **1997**, *30*, 2-8, https://doi.org/10.1021/ar950122+.
23. Baylis, A.D. Why glyphosate is a global herbicide: strengths, weaknesses and prospects. *Pest Management Science* **2000**, *56*, 299-308, https://doi.org/10.1002/(SICI)1526-4998(200004)56:4%3C299::AID-PS144%3E3.0.CO;2-K.
24. Kanan, S.; Moyet, M.A.; Arthur, R.B.; Patterson, H.H. Recent advances on TiO2-based photocatalysts toward the degradation of pesticides and major organic pollutants from water bodies. *Catalysis Reviews* **2020**, *62*, 1-65, https://doi.org/10.1080/01614940.2019.1613323.
25. Cole, D.J. Mode of action of glyphosate-a literature analysis. *The herbicide glyphosate* **1985,** *48*, 745.
26. Tsui, M.T.K.; Chu, L.M. Aquatic toxicity of glyphosate-based formulations: comparison between different organisms and the effects of environmental factors. *Chemosphere* **2003**, *52*, 1189-1197, https://doi.org/10.1016/S0045-6535(03)00306-0.
27. Grossmann, K. Mode of action of auxin herbicides: a new ending to a long, drawn out story. *Trends in Plant Science* **2000**, *5*, 506-508, https://doi.org/10.1016/S1360-1385(00)01791-X.
28. Briceño, G.; Lamilla, C.; Leiva, B.; Levio, M.; Donoso-Piñol, P.; Schalchli, H.; Gallardo, F.; Diez, M.C. Pesticide-tolerant bacteria isolated from a biopurification system to remove commonly used pesticides to protect water resources. *Plos One* **2020**, *15*, https://doi.org/10.1371/journal.pone.0234865.
29. Leroux, P. Recent Developments in the Mode of Action of Fungicides. *Pesticide Science* **1996**, *47*, 191-197, https://doi.org/10.1002/(SICI)1096-9063(199606)47:2%3C191::AID-PS415%3E3.0.CO;2-I.
30. Leroux, P.; Lanen, C.; Fritz, R. Similarities in the antifungal activities of fenpiclonil, iprodione and tolclofos-methyl against Botrytis cinerea and Fusarium nivale. *Pesticide Science* **1992**, *36*, 255-261, https://doi.org/10.1002/ps.2780360312.
31. Jespers, A.B.K.; De Waard, M.A. Effect of fenpiclonil on phosphorylation of glucose in Fusarium sulphureum. *Pesticide Science* **1995**, *44*, 167-175, https://doi.org/10.1002/ps.2780440210.
32. Martin, H. Pesticide manual. *Pesticide manual* **1968.**
33. USEPA. United States Environmental Protection Agency. http://www.epa.gov/pesticides/about/, **2013**, Accessed July 2013.
34. Ebrahimzadeh, G.; Alimohammadi, M.; Rezaei Kahkha, M.R.; Mahvi, A.H. Contamination level and human non-carcinogenic risk assessment of diazinon pesticide residue in drinking water resources – a case study, IRAN. *International Journal of Environmental Analytical Chemistry* **2020**, 1-12, https://doi.org/10.1080/03067319.2020.1789609.
35. Latijnhouwers, M.; de Wit, P.J.G.M.; Govers, F. Oomycetes and fungi: similar weaponry to attack plants. *Trends in Microbiology* **2003**, *11*, 462-469, https://doi.org/10.1016/j.tim.2003.08.002.
36. Patnaik, L.; Patra, A.K. Haemoatopoietic alterations induced by carbaryl in Clarias batrachus (LINN). *Journal of Applied Sciences and Environmental Management* **2006,** *10*, 5-7, https://doi.org/10.4314/jasem.v10i3.17305.
37. Boran, M.; Altinok, I.; Capkin, E. Acute toxicity of carbaryl, methiocarb, and carbosulfan to the rainbow trout (Oncorhynchus mykiss) and guppy (Poecilia reticulata). *Turkish Journal of Veterinary and Animal Sciences* **2007**, *31*, 39-45.
38. Jabali, Y.; Millet, M.; El-Hoz, M. Spatio-temporal distribution and ecological risk assessment of pesticides in the water resources of Abou Ali River, Northern Lebanon. *Environmental Science and Pollution Research*, **2020,** 1-16. https://doi.org/10.1007/s11356-020-08089-5.
39. Ware, G.W. Effects of pesticides on non-target organisms. In: *Residue reviews.* Springer, New York, NY. **1980**; pp. 173-201, https://doi.org/10.1007/978-1-4612-6107-0_9.
40. Scholz, N.L.; Incardona, J.P.; Baldwin, D.H.; Berejikan, B.A.; Dittman, A.H.; Feist, B.E.; Jordan, C. Evaluating the sublethal impacts of current use pesticides on the environmental health of salmonids in Columbia River Basin. *Bonneville Power Ad-ministration FY 2003 Provincial Project Review* **2003,** 1-41.
41. Maharaj, S. *Modelling the behaviour and fate of priority pesticides in South Africa.* (Doctoral dissertation, University of the Western Cape). **2005.**
42. Khan, M.Z.; Tabassum, R.; Naqvi, S.N.H.; Shah, E.Z.; Ali, F.; Ahmad, I.; Fatima, F.; Khan, M. Effect of Cypermethrin and permethrin on cholinesterase activity and protein contents in Rana tigrina (Amphibia). *Turkish Journal of Zoology* **2003**, *27*, 243-246.
43. USEPA. *Guidelines for Ecological Risk Assessment*. Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum; **1998**.
44. Rubach, M.N.; Baird, D.J.; Van den Brink, P.J. A new method for ranking mode-specific sensitivity of freshwater arthropods to insecticides and its relationship to biological traits. *Environmental Toxicology and Chemistry* **2010**, *29*, 476-487, https://doi.org/10.1002/etc.55.

45. Liess, M.; Schäfer, R.B.; Schriever, C.A. The footprint of pesticide stress in communities—Species traits reveal community effects of toxicants. *Science of The Total Environment* **2008**, *406*, 484-490, https://doi.org/10.1016/j.scitotenv.2008.05.054.
46. Schäfer, R.B.; Caquet, T.; Siimes, K.; Mueller, R.; Lagadic, L.; Liess, M. Effects of pesticides on community structure and ecosystem functions in agricultural streams of three biogeographical regions in Europe. *Science of The Total Environment* **2007**, *382*, 272-285, https://doi.org/10.1016/j.scitotenv.2007.04.040.
47. Fleeger, J.W.; Carman, K.R.; Nisbet, R.M. Indirect effects of contaminants in aquatic ecosystems. *Science of The Total Environment* **2003**, *317*, 207-233, https://doi.org/10.1016/S0048-9697(03)00141-4.
48. Stark, J.D.; Banks, J.E.; Vargas, R. How risky is risk assessment: The role that life history strategies play in susceptibility of species to stress. **2004**, *101*, 732-736, https://doi.org/10.1073/pnas.0304903101.
49. USEPA. *Aquatox 2: Modeling environmental fate and ecological effects in aquatic ecosystems*. Volume 2: Technical documentation. Washington DC; **2004**. (EPA-823-R-04-002).
50. Bagchi, S.; Azad, A.K.; Chowdhury, M.; Uddin, M.; Al-Reza, S.; Rahman, A. Quantitative Analysis of Pesticide Residues in Some Pond Water Samples of Bangladesh. *Asian Journal of Water, Environment and Pollution* **2008**, *6*, 27-30.
51. Dias, L.d.A.; Gebler, L.; Niemeyer, J.C.; Itako, A.T. Destination of pesticide residues on biobeds: State of the art and future perspectives in Latin America. *Chemosphere* **2020**, *248*, https://doi.org/10.1016/j.chemosphere.2020.126038.
52. Ansara-Ross, T.M.; Wepener, V.; van den Brink, P.J.; Ross, M.J. Pesticides in South African fresh waters. *African Journal of Aquatic Science* **2012**, *37*, 1-16, https://doi.org/10.2989/16085914.2012.666336.
53. Uddin, M.A.; Saha, M.; Chowdhuryl; M.A.Z.; Rahman, M.A. Pesticide residues in some selected pond water samples of Meherpur region of Bangladesh. *Journal of the Asiatic Society of Bangladesh, Science* **2013,** *39*, 77-82, https://doi.org/10.3329/jasbs.v39i1.16036.
54. Picó, Y.; Alvarez-Ruiz, R.; Alfarhan, A.H.; El-Sheikh, M.A.; Alshahrani, H.O.; Barceló, D. Pharmaceuticals, pesticides, personal care products and microplastics contamination assessment of Al-Hassa irrigation network (Saudi Arabia) and its shallow lakes. *Science of The Total Environment* **2020**, *701*, https://doi.org/10.1016/j.scitotenv.2019.135021.
55. Peluso, F.; Dubny, S.; Othax, N.; Castelain, J.G. Environmental Risk of Pesticides: Applying the DelAzulPestRisk Model to Freshwaters of an Agricultural Area of Argentina. *Human and Ecological Risk Assessment: An International Journal* **2014**, *20*, 1177-1199, https://doi.org/10.1080/10807039.2014.883800.
56. Best, G. A.; Ruthven, A. D. (Eds.). *Pesticides: Developments, Impacts and Controls*. Elsevier, **1995**
57. Singh, D.B.; Mandal, K. Environmental impact of pesticides belonging to newer chemistry. *Integrated Pest Management* **2013**, 152-190.
58. López-Pacheco, I.Y.; Silva-Núñez, A.; Salinas-Salazar, C.; Arévalo-Gallegos, A.; Lizarazo-Holguin, L.A.; Barceló, D.; Iqbal, H.M.N.; Parra-Saldívar, R. Anthropogenic contaminants of high concern: Existence in water resources and their adverse effects. *Science of The Total Environment* **2019**, *690*, 1068-1088, https://doi.org/10.1016/j.scitotenv.2019.07.052.
59. Acosta-Sánchez, A.; Soto-Garita, C.; Masís-Mora, M.; Cambronero-Heinrichs, J.C.; Rodríguez-Rodríguez, C.E. Impaired pesticide removal and detoxification by biomixtures during the simulated pesticide application cycle of a tropical agricultural system. *Ecotoxicology and Environmental Safety* **2020**, *195*, https://doi.org/10.1016/j.ecoenv.2020.110460.
60. Mensah, P.K.; Palmer, C.G.; Muller, W.J. Lethal and sublethal effects of pesti-cides on aquatic organisms: the case of a freshwater shrimp exposure to Roundup®. *Pesticides: Toxic Aspects, InTech Publica-tions, Rijeka, Croatia* **2014,** 163-185, http://dx.doi.org/10.5772/57166.
61. Larson, S.J. Pesticides in surface waters: Distribution, trends, and governing factors. *CRC Press* **2019,** *3.*
62. Preston, B.L. Indirect Effects in Aquatic Ecotoxicology: Implications for Ecological Risk Assessment. *Environmental Management* **2002**, *29*, 311-323, https://doi.org/10.1007/s00267-001-0023-1.
63. Glusczak, L.; Miron, D.d.S.; Moraes, B.S.; Simões, R.R.; Schetinger, M.R.C.; Morsch, V.M.; Loro, V.L. Acute effects of glyphosate herbicide on metabolic and enzymatic parameters of silver catfish (Rhamdia quelen). *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology* **2007**, *146*, 519-524, https://doi.org/10.1016/j.cbpc.2007.06.004.
64. Khalid, S.; Shahid, M.; Murtaza, B.; Bibi, I.; Natasha; Asif Naeem, M.; Niazi, N.K. A critical review of different factors governing the fate of pesticides in soil under biochar application. *Science of The Total Environment* **2020**, *711*, https://doi.org/10.1016/j.scitotenv.2019.134645.
65. Stenersen, J. *Chemical pesticides mode of action and toxicology*. CRC press. **2004.**
66. Ghanbarlou, H.; Nasernejad, B.; Nikbakht Fini, M.; Simonsen, M.E.; Muff, J. Synthesis of an iron-graphene based particle electrode for pesticide removal in three-dimensional heterogeneous electro-Fenton water treatment system. *Chemical Engineering Journal* **2020**, *395*, https://doi.org/10.1016/j.cej.2020.125025.
67. D'Andrea, M.F.; Letourneau, G.; Rousseau, A.N.; Brodeur, J.C. Sensitivity analysis of the Pesticide in Water Calculator model for applications in the Pampa region of Argentina. *Science of The Total Environment* **2020**, *698*, https://doi.org/10.1016/j.scitotenv.2019.134232.

68. Giesy, J.P.; Dobson, S.; Solomon, K.R. Ecotoxicological risk assessment for Roundup herbicide. *Review of Environmental Contamination and Toxicology* **2004,** *167*, 35-120, https://doi.org/10.1007/978-1-4612-1156-3_2.
69. Salam, M.A.; AbuKhadra, M.R.; Mohamed, A.S. Effective oxidation of methyl parathion pesticide in water over recycled glass based-MCM-41 decorated by green Co3O4 nanoparticles. *Environmental Pollution* **2020**, *259*, https://doi.org/10.1016/j.envpol.2019.113874.
70. El-Shebly, A.; El-Kad, M. Effects of Glyphosate Herbicide on Serum Growth Hormone (GH) Levels and Muscle Protein Content in Nile Tilapia (Oreochromis Niloticus L.). *Research Journal of Fisheries and Hydrobiology* **2008**, *3*, 84-88.
71. OECD (Organisation for Economic Co-operation and Development). *Detailed review paper on aquatic arthropods in life-cycle and two-generation toxicity tests.* An OECD Environment Health and Safety Publications Series on Testing and Assessment, Number 50. Environmental Directorate of Organization for Economic Co-operation and Development, Paris, France, **2005.**
72. Scholz, N.L.; Fleishman, E.; Brown, L.; Werner, I.; Johnson, M.L.; Brooks, M.L.; Mitchelmore, C.L.; Schlenk, D. A Perspective on Modern Pesticides, Pelagic Fish Declines, and Unknown Ecological Resilience in Highly Managed Ecosystems. *BioScience* **2012**, *62*, 428-434, https://doi.org/10.1525/bio.2012.62.4.13.
73. Hamelink, J.L.; Spacie, A. Fish and Chemicals: The Process of Accumulation. *Annual Review of Pharmacology and Toxicology* **1977**, *17*, 167-177, https://doi.org/10.1146/annurev.pa.17.040177.001123.
74. Kumaraguru, A.K.; Beamish, F.W.H. Lethal toxicity of permethrin (NRDC-143) to rainbow trout, salmo gairdneri, in relation to body weight and water temperature. *Water Research* **1981**, *15*, 503-505, https://doi.org/10.1016/0043-1354(81)90061-0.
75. Barry, M.J.; O'Halloran, K.; Logan, D.C.; Ahokas, J.T.; Holdway, D.A. Sublethal effects of esfenvalerate pulse-exposure on spawning and non-spawning Australian crimson-spotted rainbowfish (Melanotaenia fluviatilis). *Archives of Environmental Contamination and Toxicology* **1995**, *28*, 459-463, https://doi.org/10.1007/BF00211628.
76. Steinberg, C.E.W.; Lorenz, R.; Spieser, O.H. Effects of atrazine on swimming behavior of zebrafish, Brachydanio rerio. *Water Research* **1995**, *29*, 981-985, https://doi.org/10.1016/0043-1354(94)00217-U.
77. Moore, A.; Waring, C.P. Sublethal effects of the pesticide Diazinon on olfactory function in mature male Atlantic salmon parr. *Journal of Fish Biology* **1996**, *48*, 758-775, https://doi.org/10.1111/j.1095-8649.1996.tb01470.x.
78. Waring, C.P.; Moore, A. Sublethal effects of a carbamate pesticide on pheromonal mediated endocrine function in mature male Atlantic salmon (Salmo salar L.) parr. *Fish Physiology and Biochemistry* **1997**, *17*, 203-211, https://doi.org/10.1023/A:1007747316943.
79. Csillik, B.; Fazakas, J.; Nemcsók, J.; Knyihár-Csillik, E. Effect of the pesticide Deltamethrin on the Mauthner cells of Lake Balaton fish. *Neurotoxicology* **2000**, *21*, 343-352.
80. Moore, A.; Waring, C.P. The effects of a synthetic pyrethroid pesticide on some aspects of reproduction in Atlantic salmon (Salmo salar L.). *Aquatic Toxicology* **2001**, *52*, 1-12, https://doi.org/10.1016/S0166-445X(00)00133-8.