E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 76.37
(GIF) Impact Factor: 0.549
IJFAS 2025; 13(2): 189-194

www.fisheriesjournal.com
Received: 12-02-2024
Accepted: 15-03-2025

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Pesticide toxicity in some fish species- A review

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DOI: https://www.doi.org/10.22271/fish.2025.v13.i2c.3063

Abstract
Pesticides introduced into aquatic ecosystems can effect on fish health in various ways. Pesticides impair various metabolic and physiological functions within fish organisms the use of pesticides results in lethal toxicity that can lead to mutagenesis, carcinogenesis, haematological alterations, histopathological issues, variations in the endocrine system, and reproductive abnormalities. The introduction of these chemicals into aquatic ecosystems occurs primarily through surface runoff and drainage, resulting in various reproductive issues in fish. These substances can impact the spinal cords of fish, leading to spinal deformities, and cause histopathological changes in the gills, liver, spleen, kidneys, and brain, ultimately reducing fish metabolism. Pesticides into fish bodies leads to various complications in gills, including haemorrhage, clubbed lamellae, damage to gill rakers, and enlargement of gill filaments. Histopathological alterations resulting from pesticide exposure include collapsed, disorganized, and fused lamellae, as well as haemorrhage, necrosis, blood coagulation, and increased mucous secretion]. Pesticides totally effect different organs, causes histological and haematological changes.

Keywords: Pesticides, fishes, insecticides, herbicides. Aquatic ecosystems

Introduction
Pesticides are chemicals commonly employed to manage insects, aquatic weeds, plant diseases, algae, and water snails, etc. The toxicity of these pesticides poses significant risks to fish and various other aquatic organisms.

Pesticides are categorized according to their applications. There are three main categories: Insecticides, utilized for the management of insect populations, (Farid Soliman Sabra; *et al.*, 2015.) [70] Herbicides, aimed at the suppression of weeds (Malik Davendra *et al.*, 2020) [71] fungicides, employed to combat fungal organisms. Insecticides exhibit a higher level of toxicity in comparison to other types of pesticides. (Seyler L, D *et al.*, 1994) [60].

Pesticides introduced into aquatic ecosystems can impact fish populations in various ways. Pesticides impair various metabolic and physiological functions within fish organisms (Ullah S *et al.*, 2014) [68]. The use of pesticides results in lethal toxicity that can lead to mutagenesis, carcinogenesis, haematological alterations, histopathological issues, variations in the endocrine system, and reproductive abnormalities (W. Aktar, *et al.*, 2009) [69], (P.K. Maurya *et al.*, 2016) [46]. The acute toxicity (LC50) of various pesticides, including herbicides, fungicides, and insecticides, results in a change of fish physiology. Pesticides induce behavioral changes, genotoxic effects in fish, histopathological alterations, hematobiochemical changes, and hormonal changes. Agricultural insecticides comprise various chemical groups, including organophosphates, carbamates, organochlorines, pyrethroids, and nicotinoids. (S. Vali *et al.*, 2022) [54], (C.D. Nwani, *et al.*, 2010) [13].

The introduction of these chemicals into aquatic ecosystems occurs primarily through surface runoff and drainage, resulting in various reproductive issues in fish. These substances can impact the spinal cords of fish, leading to spinal deformities, and cause histopathological changes in the gills, liver, spleen, kidneys, and brain, ultimately reducing fish metabolism. (Farid Soliman Sabra *et al.*, 2015) [70].

Biomagnification refers to the buildup of pesticides across various trophic levels within the food chain. The absorption of these pesticides by aquatic plants leads to their consumption by insects, which are subsequently eaten by fish. This results in the accumulation of contaminated pesticides within the bodies of the fish. (Seyler LD *et al.*, 1994) [60].

Fish take these pesticides through their skin and, additionally, through their gills during respiration. Occasionally, these substances also enter fish via the mouth when they consume water or insects that contain pesticide residues. (Kings PD *et al.*, 1980) [30], (Spradley JP; 1985) [62]. The use of pesticides is linked to a variety of health issues, including alterations in fish behaviour, symptoms associated with cancer, gene mutations in fish, physiological malformations, haematological changes, and biochemical abnormalities. (Mukesh Kumar Napit; 2013) [43]. This review elucidates the varying effects of pesticides on different fish species.

Effect of pesticides in different fish species

Oleandrin pesticide causes reduced protein levels in liver tissues, muscle, gills, and intestinal tissue in *Channa punctatus* (Tiwari S *et al.*, 2004) [64]. Common carp, subjected to synthetic pyrethroid for 96 hours, exhibit alterations in swimming behaviour, fish rotate along the horizontal axis (Satya Vardhan K; 2013) [59]. Malathion leads to a decrease in ovarian and oocyte development, as well as the rupture of follicular cells in Ham fish (Satya Vardhan K; 2012) [58]. Carbofuran induces degeneration in follicular walls and vacuolization in ooplasm in catfish when administered. (Chatterjee S *et al.*, 1997) [14]. Treatment of Malathion in catfish leads to cytoplasmic clumping, degeneration of follicular cells, and rupture of the follicular epithelium (Dutta HM *et al.*, 1991) [16]. Diazinon is an organophosphorus compound that leads to an increase in follicular spaces and the adhesion of primary follicles in Bluegill fish (Dutta H M*et al.*, 1991) [16]. Endosulfan exposure led to a decrease in citrate synthesis within the brain, liver, and muscle tissues of catfish (Tripathi GVP, 2004) [66]. Methyl parathion concentrations in catla fish induces opercular movement, irregular swimming patterns, alterations in body colour, and heightened mucous secretion (Ilavazhan RT *et al.*, 2010) [26]. Gills serve as crucial organs for gaseous exchange and maintaining ionic balance, which is essential for osmoregulation. However, the introduction of pesticides into fish bodies leads to various complications in gills, including haemorrhage, clubbed lamellae, damage to gill rakers, and enlargement of gill filaments (B. Velmurugan *et al.*, 2007) [11]. Exposure to pesticides such as deltamethrin results in oedema, necrosis, hyperplasia, and fusion of secondary gill lamellae in *Cyprinus carpio* (common carp) (E.I. Cengiz; 2006) [18]. The application of carbaryl, a pesticide, led to the occurrence of oedema and the fusion of gill lamellae in rainbow trout, *Oncorhynchus mykiss* (H. Boran *et al.*, 2010) [24]. Histopathological changes were noted in Nile tilapia (*Oreochromis niloticus*). Histopathological alterations resulting from pesticide exposure include collapsed, disorganized, and fused lamellae, as well as haemorrhage, necrosis, blood coagulation, and increased mucous secretion (S. Ayoola; 2008) [50]. Diazinon concentrations in rainbow trout leads to epithelial hyperplasia in the gills, tissue oedema, hyperactivation of mucous cells, damage to gill tissue, and dysfunction in osmoregulation (Cengiz EI, *et al.*, 2006) [18]. Deltamethrin induces histopathological alterations in the gills of mosquito fish (Cengiz EI, *et al.*, 2006) [18] as well as in goldfish and yellow perch (Nero VE; 2006) [45]. The treatment of chlorinated hydrocarbons such as Aldrin, Dieldrin, BHC, and DDT in *Cyprinus carpio* results in inflammation of gill lamellae, thickening of gill filaments, fusion of lamellae, and necrosis of gill epithelial cells. The combination of 2, 4-D herbicide and Diazinon administered to silver catfish induces vacuolization, hydropic degeneration, and hepatic necrosis, along with alterations in nuclear morphology and heterochromatin damage in hepatic cells and liver sinusoids. (Gunter V, 2007) [22] (Altinok I, *et al.*, 2007) [8]. Carbaryl and Cyfluthrin therapy in Tilapia nilotica induces enlargement of hepatocytes and elevates the quantity of Kupffer cells (Namita J *et al.*, 2007) [44] (Mata GC *et al.*, 2011) [42]. Treatment with Endosulfan and Diazinon in teleost fish resulted in necrosis and degeneration of renal tubular epithelium, along with a reduction in glomerular filtration (Vinodini, R *et al.*, 2009) [48], (Satyanarayan S *et al.*, 2012) [58]. Treatment with Thiodan and deltamethrin on mosquito fish results in atrophy, necrosis of mucous cells, and lymphocyte accumulation in the lamina propria of the gut. Fish subjected to sublethal concentrations of herbicides such as glyphosate for 2 to 3 days have liver damage and fibrosis (Smith GJ, 1987) [61] (Topal, A.; 2015) [65]. *Channa punctata* is subjected to oleandrin, resulting in reduced protein levels in the gills, blood, intestines, muscle, and liver. Comparable findings were seen in *Cyprinus carpio* when exposed to endosulfan (Tiwari S., *et al.*, 2004) [64]. And protein reduction was also observed in fish *Colisa fasciatus* & Tor putitora when exposed to cypermethrin (Ullah R., *et al.*, 2014) [67]. Thiamethoxan induces a reduction in protein concentration in the liver of *Oreochromis niloticus* (Bose S *et al.*, 2011) [12]. Pesticides also modify enzymatic activity. Enzymes significantly facilitate metabolic pathways in the body; however, pesticide pollution in aquatic habitats disrupts these mechanisms markedly. Cypermethrin was administered to fish for a minimum of 45 days, resulting in a decrease in acetylcholinesterase activity in brain cells (Srivastava P *et al.*, 2016) [63], (Das B.K *et al.*, 2003) [15]. Administration of lambda-cyhalothrin to *Clarias gariepinus*. Shows chromosomal abnormalities, and stunted arms, were detected. In *Channa punctata* treatment with dichlorvos shows formation of additional pieces, attenuation, chromatid degradation, gaps in chromatids, and a centromere (Farid Soliman Sabra; *et al.*, 2015) [70]. Dichlorvos induces modifications in DNA replication, contributing to mutations. Mukesh Kumar Napi (2013) [43] reported that at various impacts of pesticides were seen in different fish species in Bhopal lower lake (M.P). Endosulfan carbonyl induces histological changes in the gill tissues of Catla catla. Chlorpyrifos treatment to *Labeo rohita* induces biochemical alterations in total protein and glycogen levels. Endosulfan with Diazinon induce fluctuations in calcium content within the stomach of Puntius purpureus. Dimethoate induces alterations in the typical behavioral patterns of Puntius punctatus. The administration of Carbofuran to *Cyprinus carpio* results in a reduction in total erythrocyte and leukocyte counts.

The administration of endosulfan to *Heteropneustes fossilis* results in hepatic cellular damage and a reduction in liver glycogen levels. Dimecron treatment in the same fish results in a reduction in haemoglobin and erythrocyte count, as well as diminished O_2-carrying ability. Dimecron treatment inflicts damage to blood vessels in the alimentary canal, liver, kidneys, and gills of *Gambusia affinis*. Elevated quantities of pesticides may adversely affect fish development and reproduction (Rahman MZ *et al.*, 2002) [49]. The fish were subjected to organophosphate (thiodon and Malathion) and organocarbamide (carbaryl) for three weeks, resulting in a reduced feeding and food conversion rate (Avoaja DA, *et al.*, 1997) [9]. With the extension of the exposure duration, a decrease in proteins, lipids, and carbohydrates was noted in

the gills, liver, muscles, and gut of the fish. Exposure of African catfish (*Clarias gariepinus*) to gammalin 20 resulted in respiratory distress, irregular swimming, convulsions, heightened respiratory activity, and loss of balance (Ezemonye L *et al.*, 2010) [19, 31]. Abdel-Maguid (2021) [6] reported that Nile tilapia *(Oreochromis niloticus*) exposed to the pesticide malathion exhibited DNA damage in hepatic cells, along with shrinkage and congestion of blood vessels, as well as vacuolation and degeneration of hepatocytes. Malathion therapy shown deterioration in renal parenchyma and an elevation in melano-macrophage centres. Akter *et al.*, (2020) [7], reported that pesticide exposure affects the physiology and behaviour of fish. Deformation of hepatic cells, alterations in the cell membrane of hepatic cells, vacuolation inside hepatic cells, and changes in Kupffer cells were seen in silver catfish(Rhamdia quelen) owing to 2,4-dichlorophenoxyacetic acid (2,4-D) poisoning (A.K. Mishra *et al.*, 2008) [5]. Hypertrophied liver cells, an increase in Kupffer cell quantity, and the presence of pycnotic and necrotic nuclei were noted in *Gambusia affinis* on exposure to deltamethrin (R. Vinodhini, *et al.*, 2009) [48]. Hypertrophy of the glomerulus and haemorrhages in renal tissue were found in *Clarias gariepinus* as a result of Diazinon intoxication. Inflammation and necrosis were seen in Oncorhynchus mykiss as a result of the same fungicide (H. Boran,*et al.*, 2012) [23]. In *Oreochromis niloticus*, a deformed nucleus was identified in renal cells, along with ovulation in renal tissue owing to exposure to Smithian (S. Sharmin, *et al.*, 2021) [53]. Cellular deterioration, necrosis, and ruptured renal tubules were reported in Mystus tengara as a result of cypermethrin toxicity (S.M. Haque *et al.*, 2017) [56]. Disruption and dysfunction of intestinal cells, reduction of mucus cells, and damage to villi membranes were seen in Gambusia affinis due to the toxicity of Thio dan and deltamethrin (E.I. Cengiz, *et al.*, 2001) [17]. Necrotic epithelial cells, deteriorated mucosal epithelium, and infiltrating lymphocytes in the lamina propria of the gut of *cirrhinus mrigala* were detected as a result of fenvalerate poisoning (M.F.Vajargah, *et al.*, 2017) [39]. Disrupted intestinal villi in grass carp *Ctenopharyngodon idella*, attributable to lindane poisoning (M.F. Vajargah, *et al.*, 2017) [39]. In *Channa punctatus*, the spotted snakehead fish, there was fusion and flattening of the villi owing to chlorpyrifos poisoning. (A. Stalin, *et al.*, 2019) [2]. Diazinon poisoning in fish results in reduced sperm count, the creation of vacuoles in testicular tubules, and inflammation of seminiferous tubules (H.M. Dutta, *et al.*, 2003) [25], (M. Banaee *et al.*, 2009) [33]. In *Puntius punctatus*, carbofuran diminishes the total erythrocyte and leukocyte counts and lowers the haemoglobin level. Aldrin, Dieldrin, BHC, and DDT exhibit bioaccumulation of chlorinated pesticides in the gill tissue, liver, and kidneys of *Cyprinus carpi*o and *Puntius ticto*. Dimecron and Thiodon demonstrate a decrease in food consumption. Dimecron exhibits a reduction in haemoglobin percentage, erythrocyte count, and oxygen-carrying capacity of blood.

Histopathological effects in different fish species.

Trichogaster fasciata fish subjected to Thiamethoxam treatment exhibited necrosis, autolysis, vacuolation, and cellular inflammation in hepatic cells, while the kidneys had irregular renal corpuscles (M. Hasain *et al.*, 2022) [36]. *Mystus cavasius* fish subjected to cypermethrin exhibits oocyte wrinkling in follicles, degeneration of granulosa layers, oocyte degeneration, cytoplasmic clumping in oocytes, deterioration of oocyte walls, increased interfollicular space, and ovarian necrosis (M.H.Uddin, *et al.*, 2022) [40]. *Oreochromis niloticus* develops damage to its gill filament and distributed mucous cells in its gills after being subjected to chlorpyrifos. (M.A. Hossain *et al.*, 2022) [38]. Additionally, it was shown that fish subjected to chlorpyrifos experienced enhanced Kupffer cell hydrophic breakdown, hepatic cell necrosis, and haemorrhages, coagulative necrosis in heart and cardiac muscle disarray were seen (M. Farhan *et al.*, 2021) [35]. After being subjected to lindane, *Ctenopharyngodon idella* fish showed signs of vacuolation, necrosis, (M.F. Vajargah *et al.*, 2017) [39]. Treatment with sumithion for *Oreochromis niloticus*, showed pyknosis in the liver, blood congestion, kidney pyknotic nuclei, vacuolation, and damaged hepatorenal tissues (Sharmin *et al.*, 2021) [53]. Channa punctatus treated to Malathion saw damaged hepatic tissue (S. Bharti *et al.*, 2021) [51]. *Oreochromis niloticus* was administered with carbofuran resulting in hepatic hypertrophy, nuclear displacement, and necrosis in hepatic cells (J.H.P. Americo-pinheiro *et al.*, 2020) [27]. Exposure to cypermethrin in the same fish resulted in gill swelling, fused gill lamellae, expansion of hepatic sinusoids, pyknotic nuclei, and vacuolation in the liver (A. Kenthao, *et al.*, 2020). Exposure to Cypermethrin in *Cyprinus carpio* induces histological alterations in the liver and kidney, as well as apoptosis in the liver (A.F. Khafaga,*et al.*, 2020) [4]. *Oreochromis niloticus* subjected to chlorpyrifos treatment exhibited collapsed, disorganized, and fused gill lamellae, haemorrhage, necrosis, blood congestion, and excessive mucous secretion in the gills, alongside liver necrosis, pyknotic cells, ruptured nuclei, and cirrhosis. Liver hemosiderosis was noted. (A. Subburaj *et al.*, 2020) [3]. Multiple histological liver abnormalities were detected in Catla catla when exposure to Cypermethrin. (R.Sharma *et al.*, 2020) [47]. *Cyprinus carpio* subjected to Sumithion treatment results in hepatopancreatic enlargement, hepatic cell degeneration, increased Bowman's space, and ruptured nephrons (M. Shira *et al.*, 2020) [37]. *Channa punctatus* subjected to chlorpyrifos exhibits necrotic, fused gill lamellae and necrotic hepatocytes (A. Stalin, *et al.*, 2019) [2]. Fasciata subjected to Chlorpyrifos results in cytoplasmic clumping, cytoplasmic retraction, and degeneration of the ovigerous lamellae in the ovary (K. Ahmed *et al.*, 2018) [28]. Irregular swimming, hyperventilation, skin discoloration, and fused lamellae were seen in Sarotherodon melanotheron treated to Lambda cyhalothrin. Swelling of liver cells, necrosis in liver, liver haemorrhage and defective kidney cells were observed *in Barbonymus gonionitus* exposed to sumithion. (M. Al-Emran, *et al.*, 2018) [32]. Vacuolation, necrosis, ruptured kidney tubules, cellular degradation, were observed in *Mystus tengara* which was exposed to cypermethrin. (S.M. Haque *et al.*, 2017) [56]. Haemorrhage, hypotrophy, necrosis, pyknosis, split gills were observed in *Trichogaster fasciata* which was exposed to chlorpyrifos (S.S. Mukti *et al.*, 2018) [57]. Vacuole formation, haemorrhage, degenerated hepatic cells observed in Cyprinus carpio due to exposure to sumithion. (S. Hossain *et al.*, 2016) [52]. Hypertrophy of liver cells, degenerated kidney tubules and renal corpuscle observed in *Barbonymus gonionotus*, due to fish was exposed to Quinalphos (G. M. Mostakim *et al.*, 2015) [21]. Swelled hepatocytes, vacuole formation in cellular cytoplasm of liver cells *in Oncorhynchus mykis* for treatment with diazinon (M. Banaee; 2013) [34] Degenerated seminiferous tubules, atretic oocytes, degenerated phagocytize cells observed in Cyprinus carpio

exposed to Diazinon. (M. Banaee *et al.*, 2009) [33]. Collapsed gill lamellae, fused gill lamellae, oedema and hyperplasia, swelled hepatic cells, dilated sinusoids observed in *Cirrhinus mrigala* which was exposed to Dichlorvos (B. Velmurugan *et al.*, 2007) [11].

Conclusion

Pesticides are good for crop production, insect control, but the pesticides used for agriculture, veterinary. Forestry etc can cause adverse effect on fishes of aquatic bodies because these pesticides can enter in to aquatic ecosystems through surface runoff and cause many problems for organs in fishes. Bioaccumulation of pesticides may cause effect even to human beings those consume fishes. Pesticides can also cause histopathological effects in different fish species. Hence it should be avoided entry of pesticides in to aquatic bodies.

References

1. Kenthao W, Sirisarn P, Jearranaiprepame. Acute toxicity of cypermethrin on *Oreochromis niloticus* fry. Walailak Journal of Science and Technology. 2020;17:708-718.
2. Stalin P, Suganthi S, Mathivani B, Paray BA, Al-Sadoon MK. Impact of chlorpyrifos on behavior and histopathological indices in different tissues of freshwater fish *Channa punctatus* (Bloch). Environmental Science and Pollution Research. 2019;26:17623-17631. https://doi.org/10.1007/s11356-019-05165-3
3. Subburaj P, Jawahar N, Jayakumar A, Srinivasan B, Ahilan M. Effects of acute toxicity of chlorpyrifos (EC 50%) and associated histological alterations in gills, liver and kidney of *Oreochromis mossambicus*. Indian Journal of Animal Research. 2020;1-8.
4. Khafaga AF, Naiel MAE, Dawood MAO, Hany M, Abdel-Latif R. Dietary *Origanum vulgare* essential oil attenuates cypermethrin-induced biochemical changes, oxidative stress, histopathological alterations, apoptosis, and reduces DNA damage in *Cyprinus carpio*. Aquatic Toxicology. 2020;228:105624. https://doi.org/10.1016/j.aquatox.2020.105624
5. Mishra AK, Mohanty B. Acute toxicity impacts of hexavalent chromium on behavior and histopathology of gill, kidney and liver of the freshwater fish, *Channa punctatus* (Bloch). Environmental Toxicology and Pharmacology. 2008;26:136-141. https://doi.org/10.1016/j.etap.2008.02.010
6. Abdel-Maguid WF, Hassan A, Zaki V. Evaluation of the effect of some chemicals used in the Nile tilapia (*Oreochromis niloticus*) culture. Egyptian Journal of Aquatic Biology & Fisheries. 2021;25(3):435-459. www.ejabf.journals.ekb.eg
7. Akter R, Pervin MA, Jahan H, Rakhi SF, Reza AHM, Hossain Z. Toxic effects of an organophosphate pesticide, envoy 50SC on the histopathological, hematological, and brain acetylcholinesterase activities in stinging catfish (*Heteropneustes fossilis*). The Journal of Basic and Applied Zoology. 2020;81(1):1-14. https://doi.org/10.1186/s41936-020-00184-w
8. Altinok I, Capkin E. Histopathology of Rainbow trout exposed to sublethal concentrations of Methiocarb or Endosulfan. Toxicologic Pathology. 2007;35(3):405-410.
9. Avoaja DA, Oti EE. Effect of sublethal concentrations of some pesticides on the growth and survival of the fingerlings of the African catfish-Hereroclarias (Hybrid). Nigerian Journal of Biotechnology. 1997;8(1).
10. Velmurugan M, Selvanayagam M, Cengiz EI, Unlu E. Histopathological changes in the gill and liver tissues of freshwater fish, *Cirrhinus mrigala* exposed to dichlorvos. Brazilian Archives of Biology and Technology. 2009;52:1291-1296. https://doi.org/10.1590/S1516-89132009000500029
11. Velmurugan M, Selvanayagam EI, Cengiz EI, Unlu E. The effects of fenvalerate on different tissues of freshwater fish *Cirrhinus mrigala*. Journal of Environmental Science and Health Part B Pesticides Food Contaminants and Agricultural Wastes. 2007;42:157-163. https://doi.org/10.1080/03601230601123292.
12. Bose S, Nath S, Sahana SS. Toxic impact of thiamethoxam on the growth performance and liver protein concentration of a freshwater fish, *Oreochromis niloticus* (Trewavas). Indian Journal of Fundamental and Applied Life Science. 2011;1:274-280.
13. Nwani CD, Lakra WS, Nagpure NS. Toxicity of the herbicide atrazine: Effects on lipid peroxidation and activities of antioxidant enzymes in the freshwater fish *Channa punctatus* (Bloch). International Journal of Environmental Research and Public Health. 2010;7:3298-3312. https://doi.org/10.3390/ijerph7083298.
14. Chatterjee S, Dutta AB, Ghosh R. The influence of technical grade carbofuran (CF) on the egg maturation process of catfish, *Heteropneustes fossilis* (Bloch). Archives of Environmental Contamination and Toxicology. 1997;23(4):426-430.
15. Das BK, Mukherjee SC. Toxicity of cypermethrin in *Labeo rohita* fingerlings: biochemical, enzymatic and haematological consequences. Comparative Biochemistry and Physiology Part C: Toxicology and Pharmacology. 2003;134(1):109-121.
16. Dutta HM, Nath A, Adhikari S, Roy PK, Singh NK, Munshi SD. Sublethal Malathion induced changes in the ovary of an air-breathing fish, *Heteropneustes fossilis*: a histological study. Hydrobiologia. 1994;294(3):215-218.
17. Cengiz EI, Ünlü E, Balci K. The histopathological effects of thiodan® on the liver and gut of mosquitofish, *Gambusia affinis*. Journal of Environmental Science and Health Part B Pesticides Food Contaminants and Agricultural Wastes. 2001;36:75-85. https://doi.org/10.1081/PFC-100000918.
18. Cengiz EI, Unlu E. Sublethal effects of commercial deltamethrin on the structure of the gill, liver and gut tissues of mosquitofish, *Gambusia affinis*: a microscopic study. Environmental Toxicology and Pharmacology. 2006;21:246-253. https://doi.org/10.1016/j.etap.2005.08.005.
19. Ezemonye L, Ogbomida TE. Histopathological effects of gammalin 20 on African catfish (*Clarias gariepinus*). Applied and Environmental Soil Science. 2010;2010:Article ID138019. https://doi.org/10.1155/2010/138019.
20. Sabra FS, Mehana ESE. Pesticides toxicity in fish with particular reference to insecticides. Asian Journal of Agriculture and Food Sciences. 2013;3(1).
21. Mostakim GM, Zahangir MM, Mishu MM, Rahman MK, Islam MS. Alteration of blood parameters and histoarchitecture of liver and kidney of silver barb after chronic exposure to quinalphos. Journal of Toxicology. 2015;2015:1-8. https://doi.org/10.1155/2015/415984.
22. Gunter V. Monitoring of environmental pollutants such

as pesticides in prawn aquaculture by histological diagnosis. Aquaculture. 2007;67:157-164.
23. Boran H, Capkin E, Altinok I, Terzi E. Assessment of acute toxicity and histopathology of the fungicide captan in rainbow trout. Experimental and Toxicologic Pathology. 2012;64:175-179. https://doi.org/10.1016/j.etp.2010.08.003.
24. Boran H, Altinok I, Capkin E. Histopathological changes induced by maneb and carbaryl on some tissues of rainbow trout, *Oncorhynchus mykiss*. Tissue and Cell. 2010;42:158-164. https://doi.org/10.1016/j.tice.2010.03.004.
25. Dutta HM, Meijer HJM. Sublethal effects of diazinon on the structure of the testis of bluegill, *Lepomis macrochirus*: a microscopic analysis. Environmental Pollution. 2003;125:355-360. https://doi.org/10.1016/S0269-7491(03)00123-4.
26. Ilavazhan RT, Jayaraj SS. Determination of LC50 of the bacterial pathogens, pesticide and heavy metal for fingerlings of freshwater fish *Catla catla*. Global Journal of Environmental Research. 2010;4(2):76-82.
27. Americo-Pinheiro JHP, Machado AA, Aguiar MM, Fernando L, Ferreira R, Torres NH, *et al.* Histological changes in targeted organs of Nile tilapia (*Oreochromis niloticus*) exposed to sublethal concentrations of the pesticide carbofuran. Water Air and Soil Pollution. 2020;231:228. https://doi.org/10.1007/s11270-020-04628-5.
28. Ahmed K, Rashid H, Peeters ETHM, Bosma RH, Van Den Brink PJ. Environmental monitoring and risk assessment of organophosphate pesticides in aquatic ecosystems of north-west Bangladesh. Chemosphere. 2018;206:92-100. https://doi.org/10.1016/j.chemosphere.2018.04.167.
29. Alalibo K, Patricia UA, Ransome DE. Effects of lambda cyhalothrin on the behaviour and histology of gills of *Sarotherodon melanotheron* in brackish water. Scientific African. 2019;6:e00178. https://doi.org/10.1016/j.sciaf.2019.e00178.
30. Kings PD, Kreutzweiser DP. Environmental impact assessment of a semi-operational permethrin application. Forestry Service Report FMP-X-30. Environment Canada, Ottawa. 1980;1-47.
31. Ezemonye L, Ogbomida TE. Histopathological effects of gammalin on African catfish (*Clarias gariepinus*). Applied and Environmental Soil Science. 2010;2010:138019. https://doi.org/10.1155/2010/138019.
32. Al-Emran M, Tanu SF, Rahman MS, Shahjahan M. Effects of sumithion on histopathology of liver and kidney in silver barb, *Barbonymus gonionotus*. Bangladesh Journal of Fisheries. 2018;30:177-185.
33. Banaee M, Mirvaghefi AR, Ahmadi K, Ashori R. The effect of diazinon on histopathological changes of testis and ovaries of common carp (*Cyprinus carpio*). Scientific Journal of Marine Biology. 2009;1:25-35.
34. Banaee M. Physiological dysfunction in fish after insecticides exposure. In: Insecticides - Development of Safer and More Effective Technologies. InTech;2013. p. 103-143. https://doi.org/10.5772/54742.
35. Farhan M, Wajid A, Hussain T, Jabeen F, Ishaque U, Iftikhar M, *et al.* Investigation of oxidative stress enzymes and histological alterations in tilapia exposed to chlorpyrifos. Environmental Science and Pollution Research. 2021;28:13105-13111. https://doi.org/10.1007/s11356-020-11528-y.
36. Hasan M, Uddin H, Islam J, Biswas S, Sumon KA, Prodhan MDH, Rashid H. Histopathological alterations in liver and kidney tissues of banded gourami (*Trichogaster fasciata*) exposed to thiamethoxam. Aquaculture Studies. 2022;23. https://doi.org/10.4194/AQUAST939.
37. Shira M, Chowdhury P, Rahman MS, Haque SM, Shahjahan M. Effects of organophosphate insecticide, sumithion on histopathology of common carp (*Cyprinus carpio*) in the natural pond condition. International Journal of Agricultural Research Innovation and Technology. 2020;10:66-75. https://doi.org/10.3329/ijarit.v10i2.51579.
38. Hossain MA, Sutradhar L, Sarker TR, Saha S, Iqbal MM. Toxic effects of chlorpyrifos on the growth, hematology, and different organs histopathology of Nile tilapia, *Oreochromis niloticus*. Saudi Journal of Biological Sciences. 2022;29:103316. https://doi.org/10.1016/j.sjbs.2022.103316.
39. Vajargah MF, Farsani HG, Gerami MH, Hedayati AS, Nezhad Heydari H. Effects of the prebiotic in reducing histopathological changes and immune response of *Cyprinus carpio* after exposure to abamectin. Iranian Journal of Toxicology. 2017;11:21-26.
40. Uddin MH, Ali MH, Sumon KA, Shahjahan M, Rashid H. Effects of pyrethroid pesticide cypermethrin on the gonad and hemato-biochemical parameters of female gangetic mystus (*Mystus cavasius*). Aquaculture Studies. 2022;22. https://doi.org/10.4194/aquast819.
41. Malik D, Sharma A, Sharma A, Thakur R, Sharma M. A review on impact of water pollution on freshwater fish species and their aquatic environment. In: Advances in Environmental Pollution Management: Wastewater Impacts and Treatment Technologies. 2019;10.
42. Mata GC. Histopathological changes in liver of teleost fish *Catla catla* treated with 1.2% Lindane. Journal of Fish and Agricola. 2011;2(1):17-19.
43. Napit MK. The effect of pesticides on fish fauna of Bhopal lower lake (M.P.). African Journal of Environmental Science and Technology. 2013;7(7):725-727.
44. Namita J, Dharmlata P, Sahu AP. Histopathological changes in liver of *Heteropneustes fossilis* exposed to cypermethrin. Journal of Environmental Biology. 2007;28(1):35-37.
45. Nero VE, Farewell A, Lee LE, Dixon DG. The effects of salinity on naphthenic toxicity to yellow perch: Gill and liver histopathology. Ecotoxicology and Environmental Safety. 2006;65:252-264.
46. Maurya PK, Malik DS. Bioaccumulation of xenobiotics compound of pesticides in riverine system and its control technique: A critical review. Journal of Industrial Pollution Control. 2016;32:580-594.
47. Sharma R, Jindal R. Assessment of cypermethrin induced hepatic toxicity in *Catla catla*: A multiple biomarker approach. Environmental Research. 2020;184:109359. https://doi.org/10.1016/j.envres.2020.109359
48. Vinodhini R, Narayanan M. Heavy metal induced histopathological alterations in selected organs of the *Cyprinus carpio* L. (Common Carp). International Journal of Environmental Research. 2009;3(1):95-100.
49. Rahman MZ, Hossain Z, Mollah MFA, Ahmed GU. Effect of diazinum 60 EC on *Anabas testudineus*, *Channa*

punctatus and *Barbodes gonionotus*. Naga, The ICLARM Quarterly. 2002;25:8-12.
50. Ayoola S. Toxicity of glyphosate herbicide on Nile tilapia (*Oreochromis niloticus*) juvenile. International Journal of Current Microbiology and Applied Sciences. 2008;3:825-834. https://doi.org/10.20546/ijcmas.2019.810.007
51. Bharti S, Rasool F. Analysis of the biochemical and histopathological impact of a mild dose of commercial malathion on *Channa punctatus* (Bloch). Toxicology Reports. 2021;8:443-455. https://doi.org/10.1016/j.toxrep.2021.02.018
52. Hossain S, Miah MI, Islam MS, Shahjahan M. Changes in hepatosomatic index and histoarchitecture of liver in common carp exposed to organophosphate insecticide sumithion. Asian Journal of Medical and Biological Research. 2016;2(2):164-170. https://doi.org/10.3329/ajmbr.v2i2.29006
53. Sharmin S, Islam T, Sadat A, Jannat R, Alam R, Shahjahan M. Sumithion-induced structural erythrocyte alteration and damage to the liver and kidney of Nile tilapia. Environmental Science and Pollution Research. 2021;28:36695-36706. https://doi.org/10.1007/s11356-021-13263-4
54. Vali S, Majidiyan N, Azadikhah D, Varcheh M, Tresnakova N, Faggio C. Effects of diazinon on the survival, blood parameters, gills, and liver of grass carp (*Ctenopharyngodon idella* Valenciennes, 1844;Teleostei: Cyprinidae). Water. 2022;14:1357. https://doi.org/10.3390/w14091357
55. Haque SM, Sarkar CC, Sumon KA. Histopathological alterations in the liver architecture of *Mystus tengara* exposed to sub-lethal concentrations of cypermethrin. Bangladesh Journal of Fisheries. 2018;30:163-168.
56. Haque SM, Sarkar CC, Khatun S, Sumon KA. Toxic effects of agro-pesticide cypermethrin on histological changes of kidney in tengra, *Mystus tengara*. Asian Journal of Medical and Biological Research. 2017;3(4):494-498. https://doi.org/10.3329/ajmbr.v3i4.35340
57. Mukti SS, Ahmed GU, Ahmed ZF, Sumon KA, Fatema MK. Histopathological study of female striped gourami (*Trichogaster fasciata*, Bloch & Schneider, 1801) gill exposed to chlorpyrifos. International Journal of Aquaculture. 2018;8:104-111. https://doi.org/10.5376/ija.2018.08.0014
58. Satyanarayan S, Kotangale AS, Verma S. Histopathological changes due to some chlorinated hydrocarbons pesticides in the tissues of *Cyprinus carpio*. IOSR Journal of Pharmacy. 2012;60-66.
59. Satyavardhan K. A comparative toxicity evaluation and behavioral observations of freshwater fishes to fenvalerate. Middle-East Journal of Scientific Research. 2013;13(2):133-136.
60. Seyler LD, Rutz D, Allen J, Kamrin M. A pesticide information project of the cooperative extension offices of Cornell University. Extoxnet: Extension Toxicology Network. Oregon State University 1994.
61. Smith GJ. Pesticide use and toxicology in relation to wildlife. Organophosphorus and carbamate compounds. USDI Fish and Wildlife Service Resource Publication 170. Washington DC;1987.
62. Spradley JP. Toxicity of pesticides to fish. Arkansas Cooperative Extension Service, Publication MP330. University of Arkansas, Little Rock;1985.
63. Srivastava P, Singh A, Pandey AK. Pesticides toxicity in fishes: biochemical, physiological and genotoxic aspects. Biochemical and Cellular Archives. 2016;16(2):199-218.
64. Tiwari S, Singh A. Toxic and sublethal effects of oleandrin on biochemical parameters of freshwater air-breathing murrel, *Channa punctatus* (Bloch). Indian Journal of Experimental Biology. 2004;42:413-418.
65. Topal A, Atamanalp M, Uçar A, Oruç E, Kocaman EM, Sulukan E, *et al.* Effects of glyphosate on juvenile rainbow trout (*Oncorhynchus mykiss*): Transcriptional and enzymatic analyses of antioxidant defence system, histopathological liver damage and swimming performance. Ecotoxicology and Environmental Safety. 2015;111:206-214.
66. Tripathi GVP. Endosulfan-mediated biochemical changes in the freshwater fish *Clarias batrachus*. Biomedical and Environmental Sciences. 2004;17(1):47-56.
67. Ullah R, Zuberi A, Ullah S, Ullah I, Dawar FU. Cypermethrin induced behavioural and biochemical changes in mahseer, *Tor putitora*. The Journal of Toxicological Sciences. 2014;39:829-836.
68. Ullah S, Zorriehzahra MJ. Ecotoxicology: A review of pesticides induced toxicity in fish. Advances in Animal and Veterinary Sciences. 2014;3(1):40-57. http://doi.org/10.14737/journal.aavs/2015/3.1.40.57
69. Aktar W, Sengupta D, Chowdhury A. Impact of pesticides use in agriculture: their benefits and hazards. Interdisciplinary Toxicology. 2009;2:1-12. https://doi.org/10.2478/v10102-009-0001-7
70. Sabra FS, Kasem AA, Soliman MM, Farid OA. Herbicides induced cytogenetic effects and chromosomal behavior in Allium cepa. Journal of Environmental Biology. 2015;36(2):415-422.
71. Malik D, Jain CK, Yadav KK, Kumar S, Mohan D, Nema AK, *et al.* A review on emerging contaminants: Occurrence, fate, and removal through biological treatment processes. Environmental Technology & Innovation. 2020;17:100503.