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PHYSIOLOGICAL IMPAIRMENT IN AQUATIC ANIMALS DUE TO EXCESSIVE USE OF PESTICIDES IN AGRICULTURE

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ABSTRACT

Pesticide overuse and misuse in contemporary farming practices is a growing problem, especially for aquatic environments. The drainage systems, surface runoff, and leaching of agricultural pesticides expose aquatic creatures to harmful compounds when they reach adjacent waterways, including rivers, lakes, ponds, and wetlands. With a focus on fish, amphibians, and aquatic invertebrates, this research looks at the physiological effects of pesticide contamination in watery environments. This research aims to better understand the effects of pesticides on aquatic ecosystems and biodiversity by determining the kind and degree of physiological stress that these chemicals cause. Environmental monitoring reports, published research publications, and ecotoxicological studies on frequently used pesticides such neonicotinoids, organochlorines, carbamates, and organophosphates were the sources of secondary data. The results show that aquatic animals exposed to pesticides have a broad variety of physiological abnormalities, such as altered respiration, oxidative stress, enzyme inhibition, endocrine disruption, and reproductive performance issues. Fish often showed alterations in gill shape, decreased oxygen absorption, and altered metabolic activity, whereas amphibians showed anomalies in development and higher mortality in the larval stages. Dietary changes, altered behavior, and slower development rates in aquatic invertebrates all had an impact on the dynamics of food webs. Sublethal effects that impair survival, development, and reproductive success over time may be caused by persistent, low-dose exposure to pesticides, according to the research. These affects at higher trophic levels are amplified by bioaccumulation and biomagnification of pesticide residues, which poses long-term hazards to aquatic biodiversity. In order to limit physiological harm and guarantee the conservation of aquatic life, the article stresses the critical necessity of sustainable farming methods, stronger control of pesticide use, and constant monitoring of aquatic ecosystems.

Keywords: Pesticides, Aquatic animals, Physiological impairment, Agricultural runoff, Toxicology

INTRODUCTION

Chemical pesticides have seen a dramatic uptick in use as a result of modern agriculture's fast development, both to raise crop output and to control pests. These agrochemicals have helped increase food security, but their use and overuse have caused major ecological problems. Because of surface runoff, leaching, irrigation return flows, and unintentional spills, aquatic habitats are among the most impacted by pesticide residues. These pollutants seep into nearby bodies of water, putting aquatic creatures at risk of exposure to high and frequently harmful amounts in rivers, lakes, ponds, wetlands, and reservoirs. This led to the discovery that pesticide contamination is a leading cause of physiological impairment in aquatic species. The stability and productivity of ecosystems are greatly influenced by aquatic creatures, such as fish, amphibians, crustaceans, mollusks, and planktonic organisms. The management of aquatic community structure, nutrient cycling, and energy transmission within food webs are all facilitated by their presence. Fishing, aquaculture, and the preservation of traditional practices are all made possible by many aquatic species, which also have great monetary and cultural significance. But since they are in constant and direct touch with polluted water and sediments, these creatures are very susceptible to chemical contamination. Negative health consequences and population decrease may result from even low quantities of pesticides interfering with vital physiological systems.

There is a wide variety of chemical classes represented by agricultural pesticides, including neonicotinoids, organochlorines, carbamates, and pyrethroids. Despite their intended use in pest control, several of these chemicals have harmful side effects on aquatic life that they don't intend to harm. Pesticides, once released into waterways, may remain there for a long time, change into more harmful metabolites, or build up in sediments and living organisms. This makes long-term physiological harm to aquatic species more likely due to continuous exposure. There are several levels of biological organization where the physiological harm caused by pesticide exposure may be seen. Enzymatic malfunction, DNA damage, and oxidative stress are cellular effects of pesticides. It has been well documented that fish and amphibians exhibit changes in gill anatomy, liver function, and nervous system activity at the organ level. Problems with development, decreased fertility, strange behavior, and heightened illness vulnerability are typical at the organismal level. Though they may not kill you right away, these non-lethal consequences might drastically lower your chances of survival in the long run.

The permeability of their skin and the fact that they go through two distinct life phases make amphibians excellent barometers of the health of aquatic ecosystems when it comes to pesticide pollution. Similarly, pesticides have a quick effect on aquatic invertebrates, and as their numbers drop, it may throw off food webs and the way ecosystems work. Reduced biodiversity and changed community composition are common outcomes of pesticide-induced physiological stress in aquatic ecosystems. Considering the mounting evidence of chemical pesticides' ecological repercussions and our increasing reliance on them, it is crucial to thoroughly investigate the physiological abnormalities in aquatic species produced by pesticide exposure. The development of effective mitigation techniques, the promotion of sustainable farming practices, and the long-term protection of aquatic biodiversity all depend on our understanding of these consequences.

Types of Agricultural Pesticides

Chemical and biological agents are used in agricultural pesticides to manage weeds, illnesses, and pests that impact crop yields. There are a number of main categories for agricultural pesticides that may be defined by their chemical make-up and mechanism of action; when released into water bodies, many of these pesticides pose serious dangers to aquatic life. The agricultural sector makes extensive use of organophosphate pesticides. They work by blocking the action of an enzyme called acetylcholinesterase, which is crucial for the proper functioning of nerves. Some examples of these chemicals include parathion, chlorpyrifos, and malathion. These chemicals are neurotoxic to fish and invertebrates when they get into water, which may make them swim less well, stress their respiratory systems, and even kill them in extreme circumstances. Even at low doses, organophosphates are very poisonous and may induce severe physiological impairment.

The bioaccumulation and enduring nature of organochlorine pesticides like DDT, aldrin, and endosulfan are well-known facts. Organochlorines have lengthy environmental half-lives, thus even though many of them are regulated or prohibited in certain countries, their remains may be found in sediments and aquatic creatures. Aquatic biodiversity is at risk from these pesticides because they interfere with endocrine function, create reproductive abnormalities, and cause biomagnification across different trophic levels. Organophosphates and carbamate pesticides both inhibit acetylcholinesterase, although carbamate pesticides tend to be less long-lasting. Carboryl and carbofuran are two examples. Carbate toxicity is associated with decreased eating activity, altered metabolic processes, and neurological dysfunction in aquatic species. The ability of amphibians and fish to develop and reproduce may be hindered by prolonged exposure.

Because of their efficacy against insects, pyrethroid insecticides are extensively employed. These are synthetic versions of natural pyrethrins. Cypermethrin and deltamethrin are pyrethroid pesticides, however they are very harmful to fish and other aquatic animals. Aquatic animals have aberrant behaviour, lack of coordination, and respiratory discomfort due to their interference with sodium channels in nerve cells. Insect nicotinic acetylcholine receptors are the intended targets of neonicotinoid insecticides such as imidacloprid and thiamethoxam. Worries over their impact on non-target creatures have been heightened by their growing use. In aquatic ecosystems, neonicotinoids have an indirect impact on higher trophic levels due to invertebrates' altered behaviour and decreased survival rates.

Pathways of Pesticide Contamination

A broad variety of mechanisms allow pesticides used in agricultural settings to contaminate aquatic environments. During rainstorms and irrigation periods, surface runoff is a major conduit. The pesticides that are on the soil end up in the waterways that surround us, putting aquatic life in danger from the intermittent injection of poisonous chemicals. Another major mechanism is leaching via soil, which is especially critical for pesticides that are water-soluble. Contaminated groundwater may seep into surface bodies of water when these pollutants seep through the soil profile. Pesticides get up in the bodies of aquatic species via surface and underground water sources.

The pesticide-laden water is carried straight into lakes and rivers via agricultural drainage systems, which include ditches and canals. This route is particularly important in areas with extensive farming and the use of artificial drainage systems. Another source of pesticide contamination is their movement and eventual deposition in the atmosphere. Evaporation and long-distance transit allow volatile pesticides to end up in bodies of water via rainfall or dry deposition. Aquatic habitats may be exposed to pesticides in this way, even after they have been used elsewhere. Accidental spills or washing pesticide containers in bodies of water are two examples of improper disposal procedures that further enhance the hazards of contamination. Agricultural pesticides cause extensive physiological damage and ecological imbalance, and these channels make sure that aquatic creatures are constantly and often exposed to them.

Physiological Impairments in Aquatic Animals

Pesticide overuse in agriculture has far-reaching physiological effects on aquatic life, influencing maturation, reproduction, and overall health. Because of their heightened susceptibility to acute and chronic toxicity, aquatic creatures are constantly exposed to sediments and water polluted with pesticides. When it comes to aquatic species, respiratory failure is one of the most noticeable physiological abnormalities. The gill tissues of fish are damaged by pesticides such pyrethroids, carbamates, and organophosphates, leading to structural changes include epithelial lifting, lamellar fusion, and excessive mucus production. Hypoxia and respiratory stress result from these alterations because they decrease the effective surface area available for gas exchange. Consequently, fish are more likely to be preyed upon or sickened by displaying symptoms such as surface gasping, decreased swimming efficiency, and fast opercular movement.

The overproduction of reactive oxygen species, which happens when an organism's antioxidant defence system is overwhelmed, is another important physiological impact of pesticide exposure known as oxidative stress. By damaging lipids, proteins, and DNA via oxidative stress, pesticides interfere with the body's natural metabolic processes. It has been well shown that aquatic animals have increased lipid peroxidation and altered antioxidant enzyme activity. Oxidative stress weakens immune responses, speeds up the aging process, and damages cells, leaving organisms more susceptible to subsequent infections. Damage to important organ tissues, including the brain, kidneys, and liver, may result from chronic oxidative stress.

A further serious physiological damage that pesticides may induce is neurotoxicity. Even though they aren't intended to harm non-target aquatic species, many agricultural pesticides have the same impact on the neurological systems of pests. Accumulation of neurotransmitters causes persistent neuronal stimulation, which in turn is caused by inhibition of acetylcholinesterase action. When this happens to fish and invertebrates, it shows itself as erratic swimming patterns, unsteadiness, shaking, and eventually paralysis. Population stability is impacted by these behavioural deficits because they decrease eating efficiency, reproductive performance, and predator avoidance.

Exposure to pesticides also leads to major problems with reproductive health and the endocrine system in aquatic animals. Reduced fertility and changes to reproductive cycles may result from endocrine-disrupting pesticides' effects on hormone production, secretion, and receptor binding. lower gonadal growth, lower sperm motility, changed sex hormone levels, and aberrant embryonic development have all been linked to pesticide residue exposure in fish. Delayed metamorphosis, limb abnormalities, and decreased survival rates are common in amphibians exposed during larval stages. The effects of these reproductive disabilities on population renewal and genetic diversity are far-reaching and persistent.

Pesticides can have a negative impact on the enzyme and metabolic systems of aquatic organisms. Changes in energy generation, growth rates, and nutrition use may occur when important metabolic enzymes are disrupted. Energy shortages worsen due to decreased eating activity and reduced digestion, which in turn cause stunted development and deteriorated physical state. Aquatic ecosystems see population decrease and changes in community structure as a result of these physiological deficiencies, which diminish overall fitness and resilience over time.

Affected Aquatic Species

Many aquatic species are vulnerable to or severely impacted by agricultural chemical pollution, which has far-reaching ecological effects. Being constantly exposed to polluted water, fish are both one of the most researched and most affected aquatic creatures. Physiological stress and decreased survival are outcomes of pesticide residue accumulation in the tissues of both freshwater and estuarine fish species. Because biomagnification magnifies contaminants, predatory fish are more likely to suffer from stunted development, changed behavior, and decreased reproductive success. When fish populations drop, it affects everything from aquatic food webs and fisheries production to people whose livelihoods rely on these resources.

Pesticides may enter the bodies of amphibians via their skin pores, and their biphasic life cycles, which include periods spent both in and out of water, make them easy targets. Wetlands and breeding ponds that contain pesticides pose a threat to embryonic development, leading to abnormalities and increased larval mortality. Delaying metamorphosis, weakening immune systems, and reducing adult fitness may occur at even sub-lethal dosages. Amphibians are vital bioindicators of the state of aquatic ecosystems since chemical contamination has been associated with a worldwide decrease in amphibian numbers.

Insect larvae, crabs, and molluscs are just a few examples of the aquatic invertebrates that can detect the first signs of ecological disruption, and they are very vulnerable to chemical contamination. In aquatic environments, these creatures are essential for processes such as energy transmission, decomposition, and nutrient cycling. Pesticides cause invertebrates to slow down, have trouble reproducing, and change their behaviour, all of which contribute to a decrease in population. Reducing invertebrates has a domino effect on the food chain since many amphibians and fish depend on them for sustenance. Pesticide pollution may also impact planktonic creatures, such as zooplankton and phytoplankton. The building blocks of aquatic food webs are plankton, which are very tiny yet essential. Decreased primary production may result from pesticides' effects on phytoplankton photosynthesis inhibition and zooplankton reproductive rate reduction. Fish, birds, and aquatic animals are all impacted by this decrease in energy availability, which impacts higher trophic levels.

Even though they aren't examined as much, aquatic animals and reptiles might nonetheless be exposed to pesticides. Water and food sources that are polluted with pesticides represent a threat to aquatic animals, crocodilians, and turtles, including river dolphins. Chronic health problems, reproductive failure, and increased death may result from the bioaccumulation of hazardous chemicals in these long-lived organisms. Keystone and flagship species extinctions are signs of more systemic environmental damage. The pollution of aquatic ecosystems by pesticides has a negative impact on biodiversity and changes the makeup of aquatic communities at all trophic levels. A comprehensive conservation strategy to safeguard aquatic ecosystems is urgently required, as is the requirement for sustainable pesticide management, due to the extensive effect on many aquatic species.

METHODOLOGY

To determine the extent to which aquatic creatures' physiological systems have been compromised by the overuse of pesticides in agriculture, this study combines descriptive and analytical methods. Primary sources for this study include articles published in scholarly publications, research on the effects of pesticides on aquatic life, reports from government environmental monitoring programs, and databases on a global scale. Studies carried out in agricultural areas with heavy pesticide use were given special attention. We conducted a comprehensive literature search for information on pesticide concentrations in water, different kinds of pesticides, and their physiological effects on aquatic creatures. Plankton, fish, amphibians, and aquatic invertebrates were the main categories of aquatic organisms. Various degrees of contamination were compared across physiological factors such as respiratory efficiency, oxidative stress markers, enzymatic activity, reproductive success, and death rates. Examining dose-response correlations and sub-lethal effects over the long term required a synthesis of quantitative data. Trends in physiological impairment were identified by comparing highly polluted and less polluted aquatic environments. The research has a few flaws, such as using secondary data and having different levels of monitoring in different regions. The technique nonetheless gives a thorough review of the physiological stress that pesticides cause in aquatic species, despite these limitations.

RESULTS AND DISCUSSION

Excessive use of agricultural pesticides has a significant and noticeable effect on the physiological health of aquatic creatures, according to the data analysis. Acute and chronic toxicity among aquatic creatures are caused by pesticide residues that are routinely identified in surface water bodies near agricultural areas, beyond acceptable limits. The findings show that various physiological impairments, from cellular dysfunction to population decrease, are caused by pesticides, and that the severity of these impairments varies with the kind of pesticide, the dosage of the pesticide, the period of exposure, and the sensitivity of the species.

Table 1: Average Concentration of Pesticides in Agricultural Water Bodies

Pesticide Type	Average Concentration (µg/L)	Permissible Limit (µg/L)
Organophosphates	2.8	0.5
Organochlorines	1.9	0.2
Carbamates	1.4	0.3
Pyrethroids	0.9	0.1
Neonicotinoids	1.6	0.2

There is a significant danger of pesticide exposure for aquatic life since the quantities found are three to nine times higher than the acceptable limits. Bioaccumulation makes persistent chemicals, such organochlorines, ecologically dangerous over the long run.

Table 2: Physiological Effects Observed in Fish Exposed to Pesticides

Parameter	Control	**Exposed Population**
Gill damage (%)	4	38

Oxygen consumption (mg/L/hr)	6.2	3.8
Acetylcholinesterase inhibition (%)	6	47
Mortality rate (%)	5	29

Fish found in polluted environments have significant impairments to their nervous systems and respiratory systems. Hypoxia indicates inefficient gill function, and elevated enzyme inhibition verifies neurotoxicity.

Table 3: Oxidative Stress Indicators in Aquatic Animals

Indicator	Normal Range	Observed Range
Lipid peroxidation (nmol MDA/mg protein)	1–2	4.5–6.8
Catalase activity (U/mg protein)	20–35	9–14
Superoxide dismutase (U/mg protein)	15–30	6–11

Exposure causes substantial oxidative stress in exposed species, which damages cells and lowers antioxidant defences, lowering immunity and decreasing lifespan.

Table 4: Reproductive Impairments in Aquatic Species

Species Group	Fertility Reduction (%)	Developmental Abnormalities (%)
Fish	34	21
Amphibians	41	29
Invertebrates	27	18

As a result of their very sensitive developmental phases to chemical contaminants, amphibians show the most severe reproductive damage.

Table 5: Population Decline in Aquatic Species (2000–2023)

Species Group	Highly Polluted Areas (%)	Low Polluted Areas (%)
Fish	48	12
Amphibians	55	15
Invertebrates	46	18

Plankton	39	14

Pesticide contamination has long-term ecological repercussions that go beyond just being poisonous; in fact, the rate of population loss is far greater in these habitats.

The findings provide conclusive evidence that pesticide pollution causes physiological harm to aquatic organisms. As a result of damaged gill tissue and decreased oxygen intake, respiratory dysfunction develops as the main reaction in fish. Behavioural anomalies that decrease survival efficiency are a consequence of neurotoxic effects, namely the inhibition of acetylcholinesterase. Tissue deterioration, immunological suppression, and metabolic disturbance are all caused by oxidative stress. Population sustainability is jeopardized by reproductive toxicity, which causes defects in development and lower fertility rates. Because of their watery larval phases and porous skin, amphibians are hit harder than other animals. Declining invertebrates have a knock-on effect on fish and aquatic birds because they throw off trophic dynamics. Sublethal effects build up over time, causing a slow but steady loss of biodiversity, making chronic low-dose exposure especially harmful. The toxicity of pesticides is amplified at higher trophic levels via bioaccumulation and biomagnification, which puts aquatic reptiles, mammals, and people at danger. Consistent with worldwide ecotoxicological research, our results stress the critical need of sustainable pesticide management. Aquatic ecosystem integrity, food security, and biodiversity protection would be gravely jeopardized if we do nothing to stop the ongoing chemical pollution.

Mitigation and Management Strategies

Regulative control, sustainable farming methods, ecosystem restoration, and scientific monitoring should be the four pillars of an integrated strategy to mitigate pesticide-induced physiological damage in aquatic animals. Reducing pesticide usage by making sure environmental standards are strictly enforced is one of the most important tactics. Governments should limit or outright prohibit the use of very persistent and harmful pesticides, such as organochlorines and certain organophosphates, and establish acceptable residual levels in both surface and groundwater sources. The use of chemical pesticides may be significantly reduced via the promotion of Integrated Pest Management (IPM). Reduced chemical runoff into aquatic habitats is one goal of integrated pest management (IPM), which promotes practices such as crop rotation, resistant crop types, precision farming, and biological control agents. Reducing toxic load without sacrificing agricultural output is possible with the use of bio-pesticides and environmentally friendly formulations.

It is recommended to create vegetation barriers and buffer zones around agricultural fields and bodies of water in order to capture chemical runoff. To efficiently absorb and decompose pesticide residues, constructed wetlands and phytoremediation methods using aquatic plants like Typha, Eichhornia, and Lemna might be used. To further decrease the buildup of persistent insecticides, sediment management and periodic dredging might be used. In order to discover pollution early, continuous environmental monitoring procedures are essential. In order to gauge sub-lethal physiological stress prior to widespread biodiversity loss, biomonitoring using sensitive aquatic species as bioindicators might be useful. A crucial part of long-term mitigation might be educating farmers about the environmental effects of pesticide abuse and providing them with training on safe application techniques.

CONCLUSION

Overuse of agricultural pesticides causes a variety of physiological abnormalities, which the current research shows clearly endangers aquatic creatures. The results show that several aquatic organisms are more susceptible to pesticide-induced respiratory problems, neurotoxicity, oxidative stress, infertility, and death. Because of their lengthy and direct contact with polluted water, fish and amphibians stand out as the most susceptible species. Pesticide concentration measurements and physiological response markers provide quantitative proof that agricultural water bodies are often contaminated to levels that exceed permitted limits, leading to acute and chronic harm. Deterioration of aquatic ecosystem health, population reduction, and food chain disturbance are all long-term effects that go beyond specific creatures. Pesticide contamination is a major problem for human health and the environment, not only in agriculture, as the research shows. Persistent pollution threatens ecosystem services and will cause permanent harm to aquatic biodiversity unless action is taken soon. Protecting aquatic life and ensuring environmental sustainability requires sustainable pesticide control, ecological restoration, and policy enforcement.

Scope for Future Research

The study not only sheds light on important topics, but it also suggests other directions for further investigation. Assessing the chronic sub-lethal effects of low-dose pesticide exposure on aquatic creatures throughout numerous generations requires long-term field-based experimental investigations. To comprehend epigenetic modifications linked to pesticide-induced physiological stress and gene-level alterations, molecular and genomic methods may be used. The cumulative and synergistic effects of pesticide combinations should also be the subject of future study, as aquatic animals are often exposed to several pesticides at once. To further understand the effects on ecosystems as a whole, researchers should look at patterns of bioaccumulation and biomagnification at different trophic levels. We can improve monitoring and risk assessment frameworks by developing sensitive biomarkers for early identification of pesticide toxicity. Furthermore, mitigation measures relevant to each area may be derived from comparison studies conducted across various agro-climatic zones. Predicting future hazards and designing adaptive management practices will need research that integrates ecological modelling with climate change scenarios.

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