



IMPACT OF PESTICIDES ON FISH HEALTH AND FISHERIES SUSTAINABILITY

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ABSTRACT

This research explored the effect of pesticide contamination on fish health and sustainability of fisheries in the freshwater ecosystems that are vulnerable to intensive agricultural practices. The results showed that the pesticide residues are extremely higher in water and fish tissues in contaminated sites, which are indicators that agricultural runoff is a significant source of aquatic pollution. Exposure to these contaminants showed significant behavioral abnormalities, decreased growth performance, enzyme inhibition, elevated oxidative stress, severe tissue damage and a significant inhibition of reproductive and developmental parameters. These changes are posing a threat to fish survival, population stability and biodiversity leading to the compromising of the sustainability of capture fisheries and aquaculture systems. This paper emphasizes the dire necessity of sustainable pesticide management mechanisms, improved regulatory systems, and frequent surveillance of the water bodies to safeguard the health of the fish and guarantee sustainability of fisheries in the long term.

Keywords: *Pesticides, Fish health, Aquatic ecosystems, Bioaccumulation, Fisheries sustainability*

1. INTRODUCTION

Modern agriculture that has resulted in the use of pesticides in large numbers has also led to high crop yields and food security but has also become a significant environmental issue as a result of the unintended side effects on the aquatic environments. The agricultural runoff, spray drift, leaching, industrial release, and poor disposal of pesticides find their way into freshwater, marine environment being especially susceptible to rivers, lakes, reservoirs, wetlands, and coastal waters. Among the non-target organisms that are most impacted is fish as they are also the most sensitive bioindicators of water quality and are part of the aquatic food webs. This is because of the continued or unintentional exposure to pesticide residues which have a devastating impact on the health of fish, the fish population and the ultimate sustainability of fisheries.

Organophosphates, carbamates, organochlorines, pyrethroids and more recently, neonicotinoids are some of the pesticides known to have both acute and chronic toxic effects on fish. In acute cases, the effects include the immediate death, abnormal swimming, loss of balance, respiratory distress, and impaired feeding, whereas in chronic cases with sub-lethal doses, the effects include long-term physiological and biochemical changes. These are enzyme inhibition, oxidative stress, destruction of critical organs like gills, liver, and kidneys, endocrine, impaired reproduction, development defects in larvae, and immunosuppression. Health deformities decrease the growth rates, survival, and reproductive success hence causing progressive declines in fish population despite lack of apparent mass mortality events.

In addition to the health of individual fish, the issue of pesticide contamination has far reaching effects on the sustainability of fisheries. Sustainability in fisheries is based on healthy stocks of fish, balanced ecosystems as well as the capacity of the aquatic systems to regenerate themselves. This may alter aquatic food chains by interfering with plankton, benthic organisms and invertebrates which are primary food sources to fish through pesticides. The accumulation of the persistent pesticides in the tissues of fish and biomagnification of the same at the trophic levels not only pose serious risks to the top predators, but also raises serious health concerns in respect of fish consumption by human beings. The reduced numbers of fish (or their disappearance), a change in species composition and biodiversity loss has direct negative

impacts on the productivity of capture fisheries and aquaculture (especially in areas where communities depend on fisheries as a source of livelihoods, nutrition and economic stability).

These risks are further deployed in developing countries where the regulatory frameworks, monitoring frameworks and awareness on the usage of pesticides are usually minimal. Fisheries especially inland, ponds and reservoirs found close to agricultural field are most prone to contamination, hence small-scale and artisanal fisheries are very susceptible. The economic impacts of losses of fish caused by pesticides are decreased yields of catches, higher cost of production in fish farming caused by diseases and malformation, and deterioration of water resources in the long run.

The importance of the research on the effects of pesticides on the health of fish and the sustainability of fisheries is thus of great significance to such matters as environmental sustainability, food security, and socio-economic welfare. The proper evaluation of the toxicity, the route of exposure, and environmental impact of the pesticides is necessary in coming up with effective management schemes, enhancing safer pest management practices, strengthening the regulatory policies, and supporting the integration of agriculture and aquaculture. This is not only an effort of conserving aquatic biodiversity but also makes fisheries resources viable in the long term to serve the current and future generations.

2. LITERATURE REVIEW

Abbas et al. (2022) assessed the impacts of new natural nano-pesticides on the health of fish and water physico-chemical conditions. Their experiment evaluated the effect of these other pesticide formulations on fish physiological functions and the entire water quality. The results showed that some nano-pesticides were relatively less toxic to fish health and at the same time, their water quality parameters were tolerable, implying their possible application to replace the currently used chemical pesticides, which are not considered safe. Nonetheless, the authors noted that controlling dosage, and monitoring of their ecological effects over a long period of time is necessary.

Ali et al. (2020) studied the human health and environmental impact of pesticide residues, their persistence, distribution and accumulation in various compartments of the environment. Their publication emphasized that agricultural runoffs and poor application methods of pesticides usually find their way into water bodies and aquatic life as a result of contaminant residues of

pesticides. The article indicated that long-term exposure to low levels of pesticides residues might lead to bioaccumulation and biomagnification, which are harmful to the aquatic life and human consumers. The authors emphasized the need to study residue analysis, risk assessment, and remediation plans in order to mitigate the environmental risks of pesticides.

Ali et al. (2020) examined the effects of pesticides on the fauna of fish, outlining the significant risks, issues, and potential solutions to them. Their comparison indicated that exposure to pesticides had an adverse impact on the behavior, growth, reproduction and survival of fish, and thereby correlated to the reduction in fish diversity and fish population biomass. The paper also addressed other issues like insecurity due to non-enforcement of regulations and poor awareness by farmers. The authors offered the methods of bioremediation, sustainable agriculture, and a more rigid adherence to the methods of policies as the potential solutions to reduce the harm caused by pesticides to aquatic life and fisheries assets.

3. RESEARCH METHODOLOGY

The research was descriptive and analytical combined with field sampling with laboratory analysis of the effects of pesticides on the health and sustainability of fisheries. Statistical analysis of seasonal data was conducted and all the processes were ethical in nature.

3.1. Research Design

The current research paper adheres to the descriptive and analytical research design to conduct the systematic investigation on the effects of pesticides on fish health, and the fisheries sustainability. The study combines both field observations and laboratory based experimental studies to get ecological and toxicological information. A mixed-method is applied, which is a combination of quantitative data, connected with pesticide residues, fish health indicators, and fisheries yield with qualitative data gathered through the surveys of stakeholders. This holistic design allows a holistic evaluation of the biological impacts and the sustainability impacts.

3.2. Study Area

The research is conducted in the chosen freshwater aquatic environment like rivers, ponds, reservoirs and aquaculture farms in the agriculturally intensive areas. These areas are selected because they are very susceptible to pesticide pollution by surface run-offs, leaching and irrigation returns flows. There are also control sites that have little agricultural impact that will

also serve to give comparative baseline data. The study areas used are the ones that guarantee the representation of the real-world situations where fisheries are coexisting with the agricultural activities.

3.3. Selection of Fish Species

The fish species to be used in the study are chosen according to ecological significance, commercial significance and sensitivity to environmental pollutants. Wild and cultivated species that are consumed by the local people are included to represent the situation of realistic exposure. Trophic level and habitat preference has also been taken into account in the selection to have an understanding of the responses to pesticide contamination differentially. In this manner, the results can be directly transferred to fisheries management and food safety issues.

3.4. Sampling Procedure

The sampling is done at the seasons to represent changes in the pesticide use practices and the environment. The standard sampling procedures are followed in obtaining water samples in various sites in each study site. Sampling on fish is done through conventional fishing nets and traps, which cause little stress and harm to fish. All samples are well labeled, stored and transported to the laboratory in controlled conditions to be analyzed further.

3.5. Assessment of Pesticide Residues

Pesticide residues found in water and fish tissues are analyzed in laboratory. Gills, liver and muscle tissues are fish organs that are studied as a result of their varying functions in breathing, purification and human eating. Pesticides that are commonly used are identified and quantified using standard techniques of analysis such as chromatographic methods. This test is used to determine the level of contamination and bioaccumulation among aquatic organisms.

3.6. Evaluation of Fish Health Parameters

- **Behavioral Observations**

The toxicity of pesticides is observed through the behavioural reactions of fish. They can be seen in terms of behavioral changes with regard to swimming, feeding, frequency of surfacing, and loss of balance. The abnormal behavior patterns are also recorded and compared in the

contaminated sites and control sites to determine reaction to stress associated with exposure to the pesticides.

- **Physiological and Biochemical Parameters**

The physiological health is considered through evaluation of the growth performance, condition factor, and survival rates. The biochemical studies are aimed at the enzyme activity, the markers of oxidative stress, and the metabolic changes which indicate sub-lethal toxicity of pesticides. These parameters can give understanding of the internal physiological disturbances which are not easily observed but have a strong impact on fish fitness.

- **Histopathological Analysis**

Histopathological analyses of the key organs, gills, liver, kidneys are performed to determine the cellular and tissue-level injury. The samples of tissues are stained with routine histology and under a microscope. The effects of pesticides on the structure are recorded to prove the toxic effects of pesticides by structural changes like lifting epithelial, necrosis, inflammatory changes, and cell degeneration.

3.7. Reproductive and Developmental Studies

The level of reproductive health is evaluated by examining the gonadal development, gonadosomatic index, fecundity and spawning success. Moreover, the viability of eggs, the hatching rate of eggs, and the survival rate of larvae are also studied to understand the impact of the exposure to pesticides on the early stages of life. These parameters are pivotal in comprehending sustainability of the population in the long-term and the ability to recruit.

3.8. Fisheries Sustainability Assessment

Sustainability of fisheries is assessed by examining the structure of fish population, diversification of species and harvest per unit effort. Fisheries aspects such as abundance of fish, species composition, and yield trends are studied with respect to the levels of pesticide contamination. The socio-economic surveys are done to fishermen and aquaculture farmers to collect data on the variation in the fish availability, level of income, cost of production and

level of perceived environmental risks. This compound evaluation connects the ecological degradation to livelihood and economic effects.

3.9. Data Analysis

All the data obtained are logically structured and evaluated with the help of the necessary statistical applications. Pesticide concentration and fish health parameters are summarized with the help of descriptive statistics, whereas inferential statistics are utilized to conduct tests to reveal significant differences between contaminated and control sites. Correlations and comparative studies are done to determine the relationship between pesticide exposure, fish health degradation and productivity of fisheries.

3.10. Ethical Considerations

There are ethical principles to the conduct of research involving aquatic organisms that are observed during the researchers. There is minimal harm and stress when handling the fish and sampling. Relevant authorities are given the necessary permission, and the study complies with environmental and animal welfare policies.

4. RESULTS AND DISCUSSION

The findings strongly suggest that pesticide pollution has a tremendous influence on the health of fish at various levels. High pesticides concentration in water and fish's tissues were linked to the development of serious behavioral defects, physiological and biochemical stress, widespread tissue-damage, and reproductive malfunction. Together, these negative impacts suggest that the survival of fish, their stability in population and the sustainability of fisheries in pesticides-affected aquatic environments will be put at risk.

4.1. Pesticide Residues in Water and Fish Tissues

Table 1. Mean pesticide residue levels in water and fish tissues (mg/L or mg/kg)

Sample Type	Control Sites	Contaminated Sites
Water	0.01 ± 0.003	0.18 ± 0.04
Fish gills	0.05 ± 0.01	0.42 ± 0.08

Fish liver	0.09 ± 0.02	0.76 ± 0.12
Fish muscle	0.02 ± 0.004	0.21 ± 0.05

Agricultural runoff is a significant source of aquatic pollution as the high levels of pesticides present in the polluted areas attest. The accumulation in the liver tissues is higher, leading to the indication of the organs in the process of detoxification, and the contamination of the gills, which means that the organ is exposed to direct absorption through the water. Despite relatively less accumulation in muscle tissue, its contamination is essential because it is directly related to human consumption. Their findings are consistent with the previous literature that indicated bioaccumulation and biomagnification of pesticides in water food webs.

4.2. Behavioural Responses of Fish

Table 2 and Figure 1 indicate that fish in pesticide-contaminated sites had a lot of abnormalities in behavior compared to their counterparts in the control sites. Such behaviors as erratic swimming, decreased feeding, shallow breathing, and loss of balance were significantly higher in polluted environments.

Table 2: Frequency of observed behavioral abnormalities

Behavior	Control Sites	Contaminated Sites
Erratic swimming	6	48
Reduced feeding	9	52
Surface breathing	4	41
Loss of balance	2	36

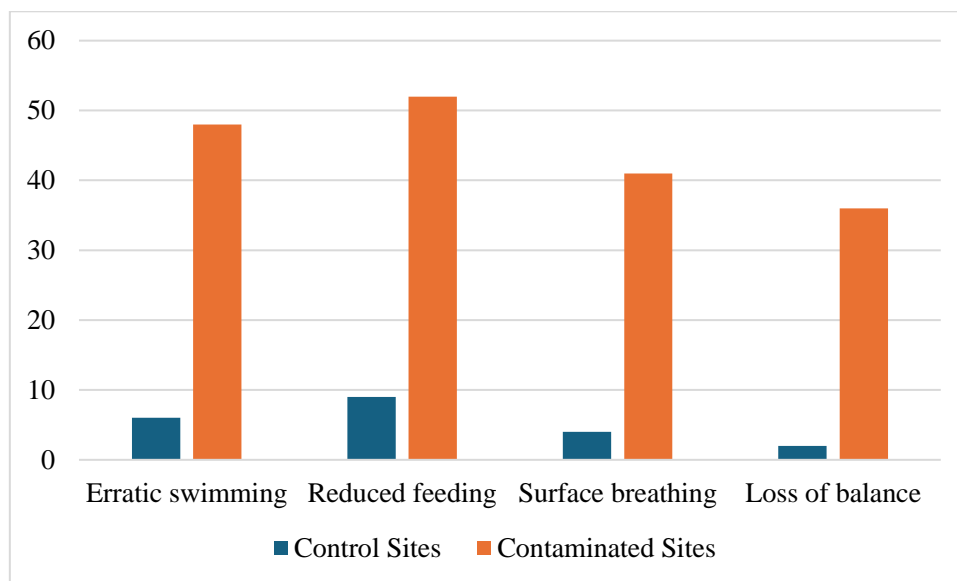


Figure 1: Graphical Representation of Frequency of observed behavioral abnormalities

The fact that there is a higher incidence of abnormal behaviors speaks of stress and neurotoxic consequences of being exposed to pesticides. These behavioral alterations at the very young age can minimize fish survival, and growth which in the end will have an impact on fish populations and the sustainability of fisheries.

4.3. Physiological and Biochemical Alterations

Table 3 shows the physiological and biochemical reaction of fish in control and pesticide-polluted areas. The fish at the contaminated sites exhibited a significant decrease in the growth rate, condition factor and acetylcholinesterase (AChE) activity, whereas the lipid peroxidation levels were significantly elevated than those of control fish.

Table 3: Physiological and biochemical parameters of fish

Parameter	Control Sites	Contaminated Sites
Growth rate (g/month)	12.6 ± 1.4	7.3 ± 1.1
Condition factor	1.48 ± 0.09	0.96 ± 0.07
AChE activity (µmol/min/mg)	8.2 ± 0.6	3.1 ± 0.5
Lipid peroxidation (nmol MDA/mg)	1.2 ± 0.2	4.6 ± 0.8

The reduction in growth and condition factor shows ill physiological health when exposed to pesticides. Decreased AChE activity indicates neurotoxic effects and increased lipid peroxidation indicates increased oxidative stress and damage of cells. Combining these alterations attests to the fact that pesticide contamination generates important sub-lethal stress on fish that has adverse impacts on their health and survival chances.

4.4. Histopathological Changes

Table 4 and Figure 2 are the prevalence of the histopathological lesion of fish organs in control sites and pesticides-contaminated sites. The prevalence of tissue lesions was significantly higher in fish in polluted locations with liver necrosis being the most common (71 per cent), gill lesions (62 per cent) and kidney destruction (58 per cent) being the predominant lesions compared to the control sites.

Table 4. Prevalence of histopathological lesions (%)

Organ	Control Sites	Contaminated Sites
Gill damage	8	62
Liver necrosis	5	71
Kidney degeneration	6	58

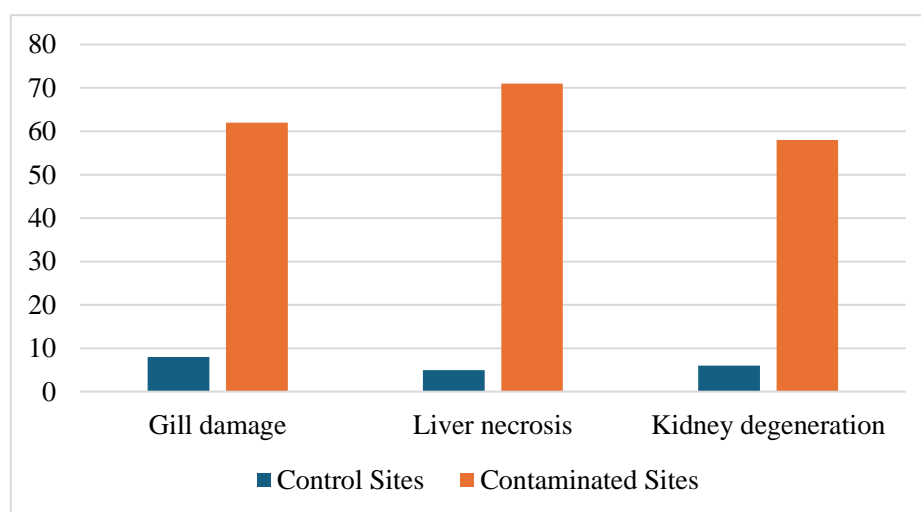


Figure 2: Graphical Representation of Prevalence of histopathological lesions

The fact that organ damage is observed in high rates in contaminated sites shows that the toxic effects of being exposed to pesticides are severe and at the tissue level. Gill injuries may interfere with the respiration process, liver necrosis affects liver detoxification and metabolic processes, and kidney destruction influences osmoregulation. Such structural malfunctions decrease fish survival and resilience rate with a long-term outcome of jeopardizing fish population stability and fisheries sustainability.

4.5. Reproductive and Developmental Impacts

Table 5 presents an evident decrease in reproductive and developmental parameters of fish in pesticide contaminated sites in comparison to control sites. The fish which experienced contaminated environment had low values of gonadosomatic index, less fecundity and a sharp decline in the survival rates of larvae.

Table 5. Reproductive parameters of fish

Parameter	Control Sites	Contaminated Sites
Gonadosomatic index (%)	7.8 ± 0.6	4.1 ± 0.5
Fecundity (eggs/female)	12,400 ± 950	6,800 ± 720
Larval survival (%)	78	41

The gonadal development, egg production, and larval survival declined are all indicative of the negative impact of the pesticide exposure on the reproductive performance and the development of early life stages. These impairments may inhibit effective recruiting and population renewal, which is a very grave omen to the sustainability of fish populations and fisheries in the long run.

5. CONCLUSION

The research findings conclude that pesticide contaminants have severe sub-lethal and chronic toxicity in fish, which are manifested at many biological levels, including behavior and physiology, tissue integrity, as well as reproduction. High levels of pesticides in water and fish tissues cause oxidative stress, enzyme suppression, organ toxicity, and low reproductive success, which ultimately result in the depleting fish stocks and lowering fisheries productivity.

These effects are devastating ecological and socio-economic issues especially to communities that rely on fisheries as a source of food and livelihood. Thus, to reduce the risks associated with pesticides, encourage the use of more environmental friendly pest control methods, and combine sustainable practices in agriculture and fisheries management, it is necessary to implement more rigid pesticide regulations, introduce more environment-safe means of pest control, and combine all these with more sustainable ways of managing aquatic ecosystems and fisheries resources.

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