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IMPACT OF AGRICULTURE PESTICIDE ON AQUATIC ECOSYSTEMS WITH SPECIAL REFERENCE TO FISH HEALTH AND BIODIVERSITY

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ABSTRACT

The current study investigates the impact of agricultural pesticides on aquatic ecosystems with special reference to fish health and biodiversity in freshwater ponds of North Bihar, India. The study was conducted from August 2023 to May 2024, covering monsoon, winter, and summer seasons. Selected ponds were categorise into control, chlorpyrifos-exposed, malathion-exposed, and combined pesticide-treated groups to evaluate comparative effects. The results significantly revealed deterioration in quality of water parameters, reduced dissolved oxygen, turbidity increase, ammonia level and hardness and alkalinity in pesticide exposed ponds. These stressful environmental conditions were created by physiological changes for aquatic organisms. Fish population analysis showed decline in pesticide-treated ponds, with the highest mortality observed under chlorpyrifos and combined pesticide exposure. Growth performance studies indicated reduced length–weight relationship in exposed fish, suggesting metabolic disturbances. Behavioural abnormalities such as swimming, surface gulping, and reduced feeding were also observed, indicating sub-lethal toxic stress. Seasonal variation played a critical role, with maximum adverse effects recorded during summer due to higher temperature and enhanced toxicity. The 96-hour acute toxicity bioassay demonstrated that chlorpyrifos exhibited the highest toxicity, reaching LC_{50} during summer, while malathion showed moderate toxicity. Combined pesticide exposure resulted in comparatively lower mortality, suggesting possible antagonistic interaction. The study highlights that pesticide contamination significantly affects fish health, survival, and aquatic biodiversity, emphasizing the need for sustainable pesticide management practices to protect aquatic ecosystems.

KEYWORDS: Agricultural pesticides, Aquatic ecosystem, Fish health, Biodiversity, Chlorpyrifos, Malathion, Water quality, Acute toxicity, LC_{50}, Seasonal variation

In aquatic ecosystem pesticides enter through multiple pathways, including agricultural runoff, spray drift, and leaching during rainfall or irrigation events (Schäfer *et al.*, 2011; Anderson *et al.*, 2021). Once pesticides introduced in water bodies, these toxic substances can affect various component of aquatic environment, including water, sediment and biota (Habib *et al.*, 2024). In aquatic environment the presence of pesticide residue has raised serious environment concerns due to their toxic effect on non-target organism (Farag *et al.*, 2021).

Pesticides chemical contamination can affect organism at different tropic level and disrupt ecological processes that are highly sensitive to aquatic ecosystem (Schäfer *et al.*, 2011). The flow of energy within food chains is often disturbed when pesticides impact one or more trophic levels, leading to ecological imbalance (Ali *et al.*, 2011). Long-term exposure to pesticides has been associated with biodiversity loss and the endangerment of various aquatic species, including fish, amphibians, and other organisms (Ali *et al.*, 2011).

Fish are particularly vulnerable to pesticide exposure due to their constant interaction with the aquatic environment. Ingestion of pesticides in fish bodies through gills, skin, and ingestion, leading to toxicological effects on various physiological systems (Hinton *et al.*, 2001). These toxicants can cause oxidative stress by generating reactive oxygen species, which damage cellular structures and impair normal physiological functions (Lushchak, 2011). In addition, pesticides can induce changes in hematological parameters, metabolism, and biochemical composition, making fish more susceptible to diseases (Burch *et al.*, 2025).

Sources and Pathways of Pesticides into Aquatic Ecosystems

In agriculture pesticides are widely used to control pests and enhance crop productivity, however, a significant proportion of these chemicals does not reach the target organisms and instead enters the surrounding environment. The major sources of pesticide contamination in aquatic ecosystems include agricultural fields, industrial discharge, sewage effluents, and atmospheric deposition. Intensive agricultural practices, especially in regions where water bodies are located near farmlands, contribute significantly to pesticide pollution. Improper application, excessive use, and lack of

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awareness among farmers further aggravate the contamination of aquatic systems.

Pesticides enter aquatic ecosystems through multiple pathways. Surface runoff is the primary route, where rainfall or irrigation water carries pesticide residues from agricultural lands into nearby ponds, rivers, and wetlands. This process is particularly intensified during heavy rains and flooding, which facilitate the transport of contaminants over long distances and into distant aquatic bodies.

Apart from these, pesticides can also enter aquatic environments through direct application, aerial spraying, and atmospheric deposition followed by precipitation. Industrial effluents and sewage discharge further introduce pesticide residues into water bodies, increasing the level of contamination. In agriculture soil erosion contribute to the transport of pesticide bound particle into aquatic systems.

Classification of Common Agricultural Pesticides

The Pesticides term covers a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, and plant growth regulators. These chemicals are widely used in agriculture for controlling pests and improving crop productivity.

Further classification of pesticides is based on their chemical groups, which differ in their persistence and toxicity to aquatic organisms. Organochlorines, organophosphates, carbamates, pyrethroids, and neonicotinoids are the major classes commonly used in agriculture.

Organochlorine pesticides such as DDT and endosulfan are highly persistent in the environment and exhibit very high toxicity to fish. Organophosphates like chlorpyrifos and malathion show moderate persistence but high toxicity. Carbamates (e.g., carbaryl) exhibit low to moderate persistence and moderate toxicity. Pyrethroids such as cypermethrin are less persistent but highly toxic to aquatic organisms, especially fish. Neonicotinoids like imidacloprid are moderately persistent and show moderate toxicity.

Different classes of pesticides vary significantly in their environmental behaviour and toxic effects. Pyrethroids and organochlorines are particularly harmful to fish even at very low concentrations, whereas organophosphates and carbamates exert moderate to high toxicity depending on exposure duration.

MATERIALS AND METHODS

The present study was conducted in selected freshwater ponds located in North Bihar, India, a region characterized by intensive agricultural activities and extensive use of chemical pesticides. These ponds are directly influenced by agricultural runoff, irrigation overflow, and rainfall-mediated transport of pesticides from surrounding fields. The study was carried out over a period from August 2023 to May 2024, covering monsoon, winter, and summer seasons to evaluate seasonal variation in pesticide impact on aquatic ecosystems.

A total of 12 ponds are selected and these 12 ponds are divided into 4 sub ponds: control, chlorpyrifos, malathion and mixed pesticide. These pesticides come into water through ground water (0.10 mg/L). In each pond, 40 fishes are taken. Fish death rate (mortality) changes according to survival and season. Fish length and weight are measured, and these values help to find out the growth and health report. For checking the water quality, the following parameters are measured: Temperature, pH, Oxygen, Turbidity, Ammonia, Nitrate, Hardness and Alkalinity. Also, colour and odour are checked. The control ponds have clean water, while the pesticide ponds have odour and turbid water.

The percentage mortality and survival were calculated using the following formulae:

$$\text{Mortality (\%)} = \frac{\text{Number of dead fish}}{\text{Total number of fish}} \times 100$$

$$\text{Survival (\%)} = \frac{\text{Number of live fish}}{\text{Total number of fish}} \times 100$$

Physicochemical characteristics of pond water were analysed seasonally to determine environmental changes associated with pesticide contamination. These parameters were used to evaluate water quality and its influence on fish health. All analyses were performed in accordance with standard procedures prescribed by the American Public Health Association (APHA) to ensure accuracy and reproducibility of results. These parameters were selected due to their fundamental role in determining aquatic habitat quality, nutrient status, and physiological functioning of fish. Variations in dissolved oxygen and ammonia directly affect respiratory efficiency and metabolic stress in fish, while changes in turbidity, hardness, and alkalinity influence light penetration, buffering capacity, and overall water stability.

In addition to laboratory analysis, visual observations of water quality were recorded, including colour, transparency, odour, and surface characteristics. Changes such as increased turbidity, reduced clarity, and presence of odour were considered indicators of pesticide pollution and environmental degradation. Control ponds consistently exhibited clear water with good transparency and no detectable odour, indicating relatively stable and unpolluted conditions. In contrast, ponds exposed to insecticides and pesticides showed noticeable deterioration in visual water quality, characterized by increased turbidity, reduced clarity, and the presence of chemical or pungent odours. These changes were more pronounced during periods of intensive pesticide application and were often accompanied by surface films and suspended particulate matter. The visual deterioration of water quality laboratory findings and served as an effective preliminary indicator of pesticide-induced stress on the aquatic environment.

Fish behaviour was monitored as an early indicator of sub-lethal toxicity. Abnormal behaviours such as erratic swimming, surface gulping, reduced feeding, and lethargy were recorded more frequently in pesticide-affected ponds. These behavioural responses were associated with physiological stress, neurological disturbance, and deteriorating water quality conditions. Seasonal variation was analysed to understand its influence on pesticide toxicity and ecological impact. Summer season showed maximum adverse effects, including higher mortality and poor water quality, while monsoon and winter showed relatively moderate impacts. All data were compiled and expressed as mean ± standard deviation, and comparative analysis was performed between control and pesticide-exposed ponds to assess the ecological impact of agricultural pesticides on fish health and aquatic biodiversity. To complement field observations, an acute toxicity bioassay was conducted under controlled laboratory conditions. Fish were acclimatized and exposed to different concentrations of pesticides, and mortality was recorded over a 96-hour period. Behavioural responses were also noted during the experiment. The LC_{50} values were determined based on observed mortality, providing baseline toxicity.

RESULTS

Fish Population Structure and Survival

The analysis of fish population revealed a clear distinction between control and pesticide-exposed ponds. Control ponds (P1, P2, P3) showed very low mortality (2.5–5%) and clean, odour-free water, indicating good water quality. In contrast, chlorpyrifos-treated ponds (P4, P5, P6) showed high mortality, increasing from 35% in monsoon to 50% in summer, along with turbid water and chemical odour. Malathion-treated ponds (P7, P8, P9) also showed high mortality (32.5–47.5%), reduced growth, and poor water quality. Interestingly, combined pesticide ponds (P10, P11, P12) showed comparatively lower mortality (22.5–30%), suggesting an interaction effect, although water quality remained degraded. Overall, pesticide exposure increases fish mortality and deteriorates water quality, with the highest impact observed in summer, while control ponds remain stable. (Figure 1.1)

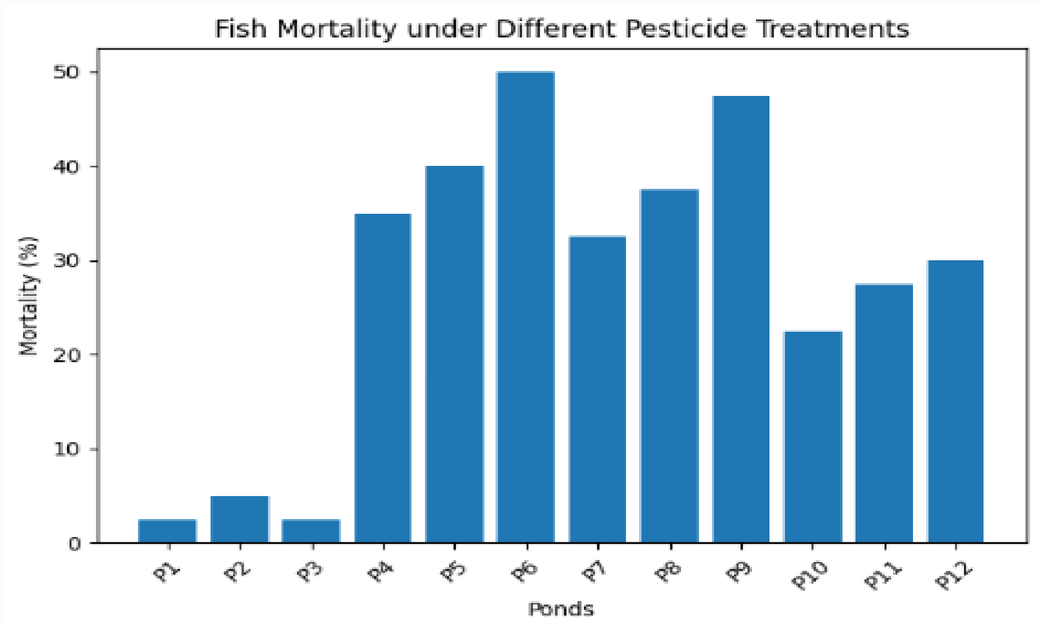

Figure 1.1: FishMortality under Different Pesticide Treatments. The bar chart represents mortality (%) of fish across different experimental ponds (P1–P12). Control ponds (P1–P3) show very low mortality, while pesticide-treated ponds (P4–P9) exhibit significantly higher mortality, with the highest observed in P6 (50%). Combined pesticide treatment (P10–P12) shows moderate mortality compared to individual treatments

Seasonal Variation in Fish Mortality and Growth Performance (Length–Weight Relationship)

The analysis of fish population revealed a clear distinction between control and pesticide-exposed ponds. The control ponds (P1, P2 and P3) show very low fish death rate (2.5–5%). Fish are almost safe and the water is clean and odour-free. Chlorpyrifos pond is the most dangerous pesticide. In monsoon, fish death rate is 35%, in winter 40%, and in summer more than 50%. The water is turbid and has a chemical smell. Malathion pond is harmful but less harmful than chlorpyrifos. In monsoon, fish death rate is 32.5%, in winter 37.5%, and in summer 47.5%. Fish growth decreases and water quality is bad. In mixed pesticide ponds, monsoon shows 22.5%, winter 27.5%, and summer 30%. The death rate decreases compared to single pesticide treatment. (Figure 1.2)

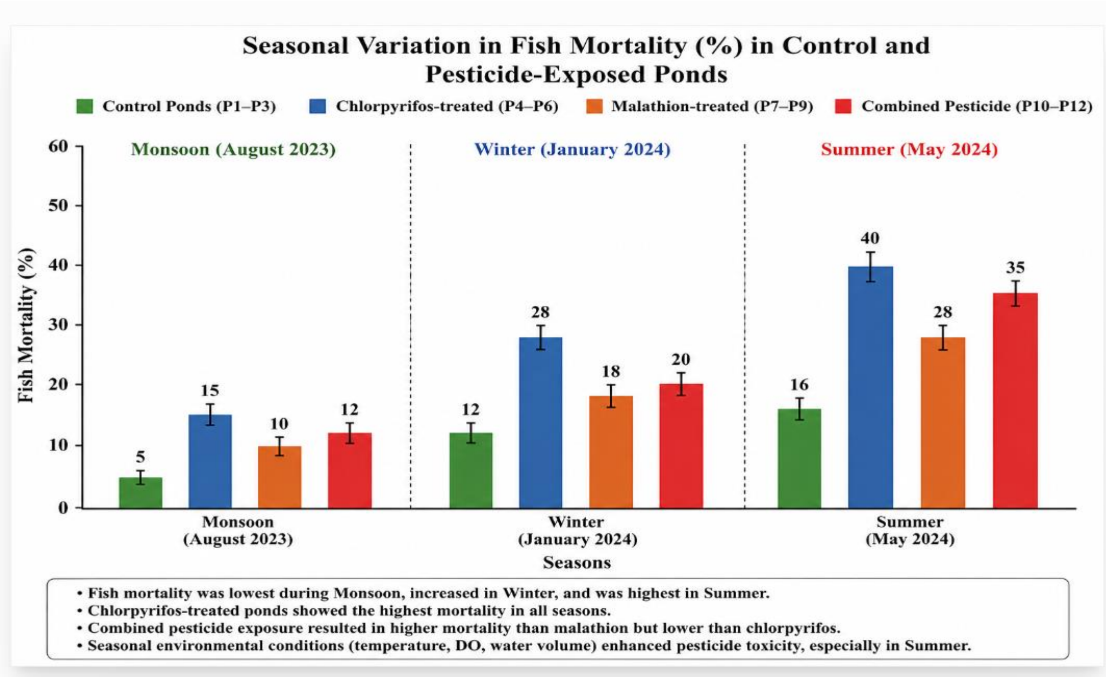

Figure 1.2: Seasonal variation in fish mortality (%) in control and pesticide-exposed ponds during monsoon (August 2023), winter (January 2024), and summer (May 2024). The figure compares mortality in control ponds, Chlorpyrifos-treated, Malathion-treated, and combined pesticide-treated ponds. Results show that fish mortality was lowest during monsoon, increased in winter, and reached maximum levels in summer. Among treatments, Chlorpyrifos exhibited the highest toxicity, followed by combined exposure and Malathion, while control ponds showed minimal mortality. The observed seasonal increase in mortality may be attributed to higher temperature, reduced dissolved oxygen, and increased concentration of toxicants during summer.

VISUAL WATER QUALITY ASSESSMENT AND PHYSICOCHEMICAL CHARACTERISTICS OF WATER

Seasonal Variation In Water Quality Parameter

The assessment of pond water across monsoon, winter, and summer seasons revealed significant seasonal fluctuations in physicochemical parameters such as dissolved oxygen (DO), turbidity, ammonia, total hardness, and alkalinity. These variations were influenced by climatic factors including rainfall, temperature, evaporation, and biological activity.

- **Monsoon season** showed dilution effects due to rainfall but increased turbidity from runoff.
- **Winter season** exhibited stable conditions with lower temperatures and higher dissolved oxygen.
- **Summer season** was characterized by high temperature, evaporation, and concentration of dissolved substances.

Overall, seasonal changes played a crucial role in determining water quality and ecosystem stability.

Dissolved Oxygen (DO) and Its Impact on Fish Health

Dissolved oxygen levels were consistently highest in control ponds across all seasons, indicating better water quality.

- **Monsoon:** Control (9.536 mg/L) vs pesticide-treated ponds (4.868–6.273 mg/L)
- **Winter:** Control (9.271 mg/L) vs treated (4.881–5.249 mg/L)
- **Summer:** Control (10.496 mg/L) vs treated (4.496–5.862 mg/L)

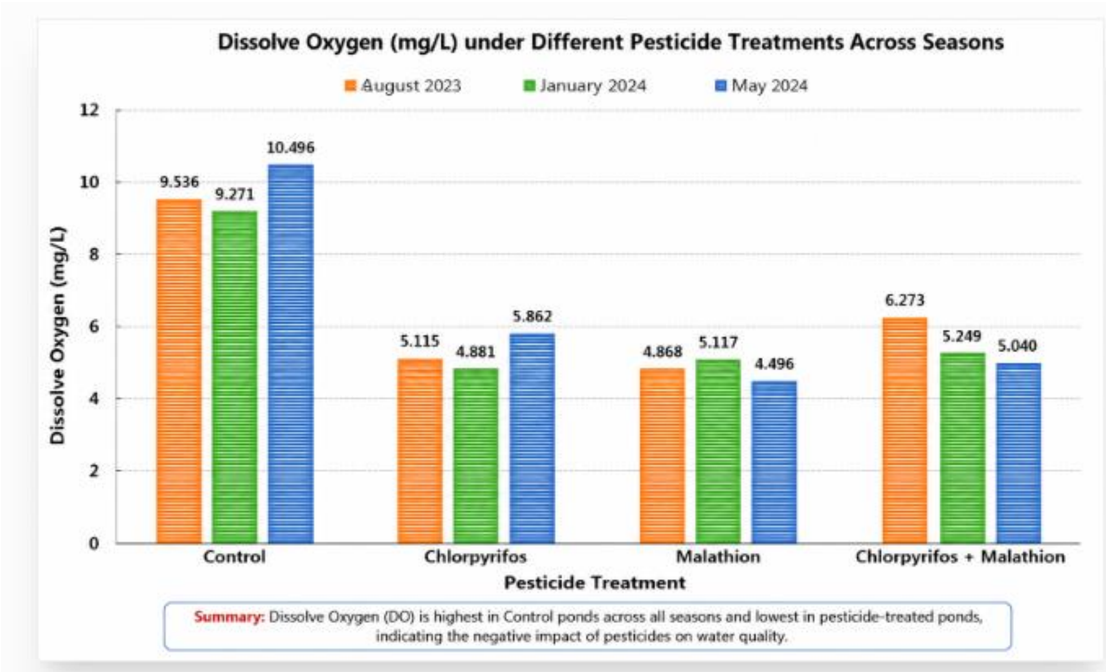

Figure 1.3: Bar Chart Showing Dissolved Oxygen (mg/L) Levels in Control and Pesticide-Treated Ponds during Summer Season, winter season and monsoon season.

Pesticide-treated ponds showed significantly reduced DO levels, especially under chlorpyrifos exposure. Lower oxygen availability can cause physiological stress, reduced metabolism, and increased mortality in fish, thereby negatively affecting fish health and biodiversity. (Figure 1.3)

Turbidity and Its Ecological Significance

Turbidity showed a clear increase in pesticide-treated ponds, particularly under combined pesticide exposure. (Figure 1.4)

- **Monsoon:** Highest in combined treatment (33.573 NTU)
- **Winter:** Increased turbidity in treated ponds (22.718–27.649 NTU)
- **Summer:** Maximum in combined treatment (27.931 NTU)

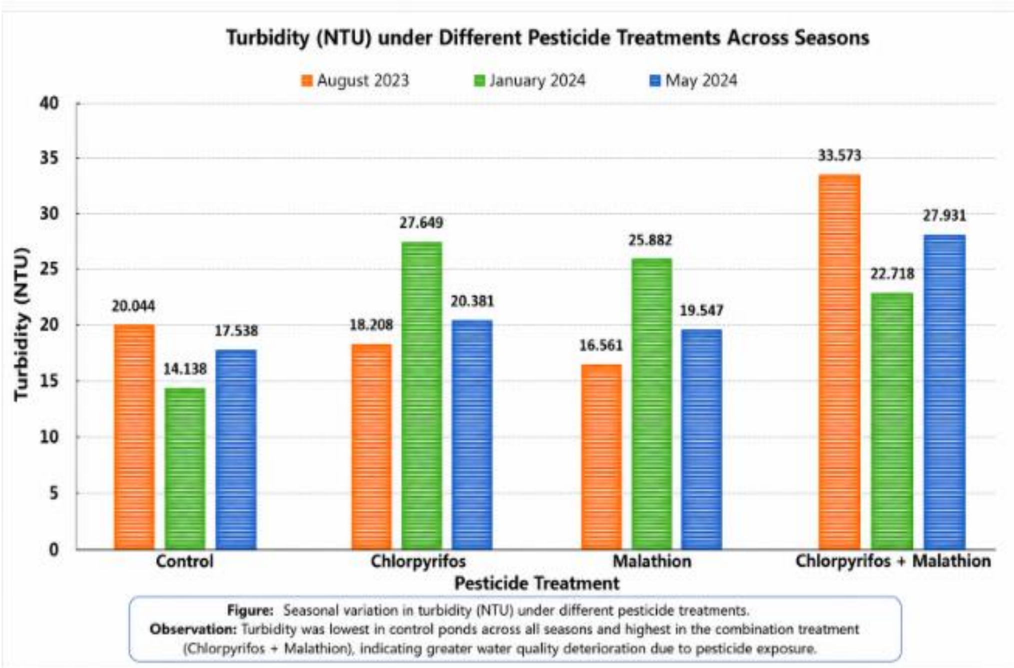

Figure 1.4: Bar Chart Showing Turbidity (NTU) in Control and Pesticide-Treated Ponds during Summer Season, winter season and monsoon season.

Higher turbidity reduces light penetration, affecting photosynthesis and primary productivity. This leads to reduced food availability for aquatic organisms, there by impacting fish growth.

Ammonia Concentration and Toxic Effects

Ammonia levels were lowest in control ponds and significantly elevated in pesticide-treated ponds.

- **Monsoon:** Control (0.181 mg/L) vs combined (1.449 mg/L)
- **Winter:** Control (0.052 mg/L) vs combined (0.467 mg/L)
- **Summer:** Control (0.067 mg/L) vs combined (0.543 mg/L)

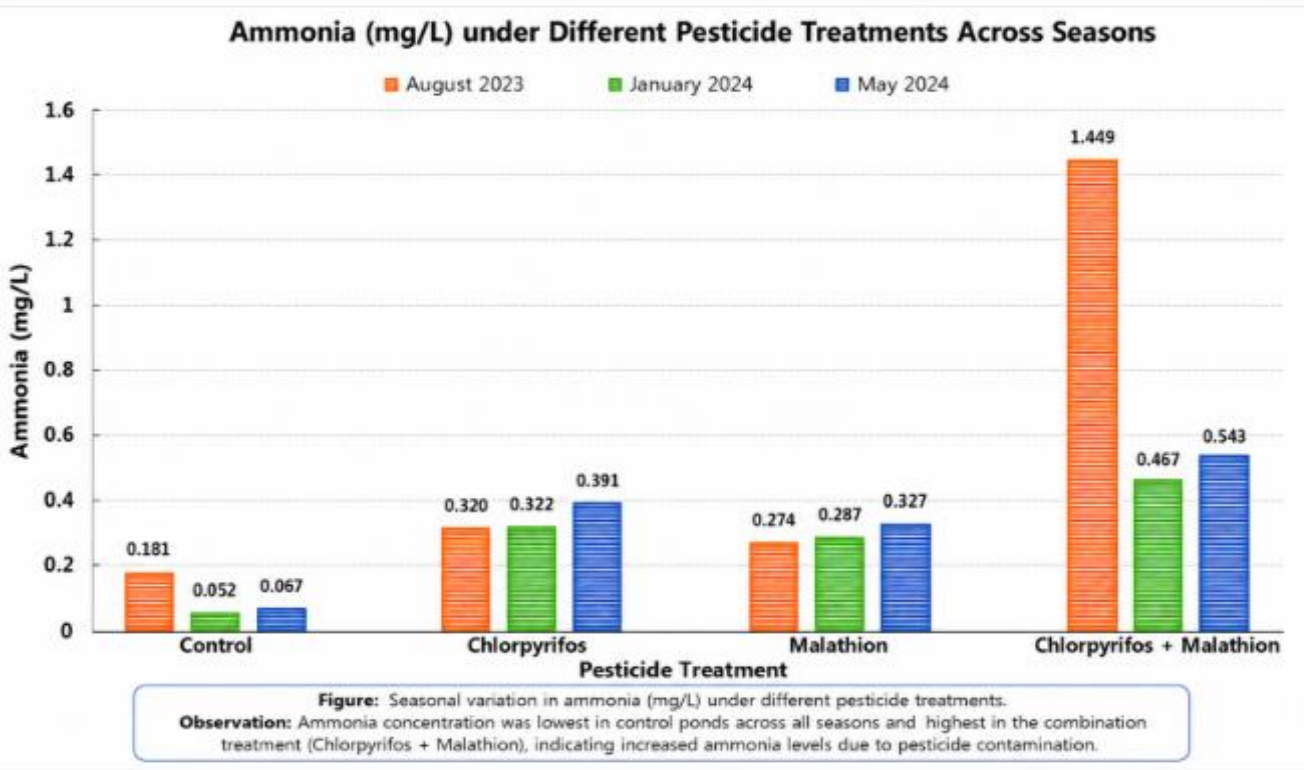

Figure 1.5: Bar Chart Showing Ammonia Concentration (mg/L) in Control and Pesticide-Treated Ponds during Summer Season, winter season and monsoon season.

Elevated ammonia concentrations are toxic to fish and can cause gill damage, reduced growth, and increased mortality. The highest toxicity was observed under combined pesticide treatment, indicating synergistic harmful effects. (Figure 1.5)

Total Hardness and Water Quality

Total hardness varied seasonally and increased in pesticide-treated ponds during monsoon and winter.

- **Monsoon:** Control (114.13 mg/L) vs combined (185.02 mg/L)
- **Winter:** Control (122.15 mg/L) vs treated (158.81–184.88 mg/L)
- **Summer:** Naturally high in control (201.81 mg/L), with mixed pesticide effects

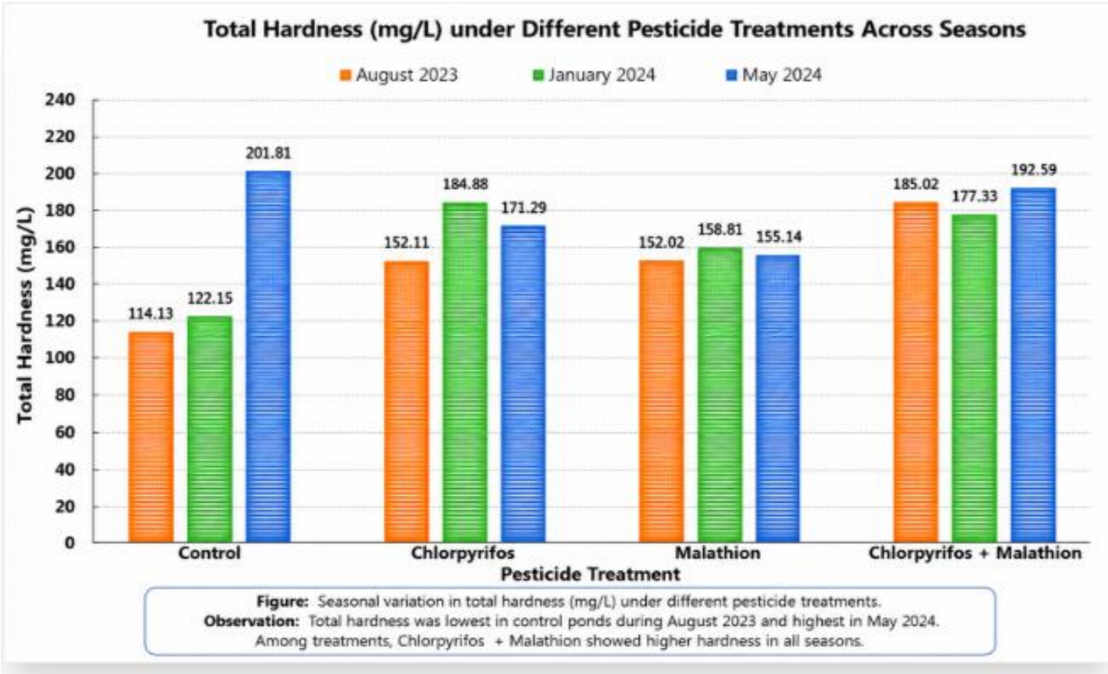

Figure 1.6: Bar Chart Showing Total Hardness (mg/L as $CaCO_3$) in Control and Pesticide-Treated Ponds during Summer Season, winter season and monsoon season.

Increased hardness reflects higher dissolved salts, which may alter osmoregulation in fish and affect aquatic biodiversity. (Figure 1.6)

Total Alkalinity and Buffering Capacity

This bar chart shows that the alkalinity of pond increases due to the excess use of pesticide. During monsoon (August 2023), the control pond P1 shows normal alkalinity (93 mg/L). The ponds in which pesticide are used (P4, P7) show increased alkalinity (132 mg/L), and mixed pesticide (P10) shows the highest alkalinity (164 mg/L). The above detail shows that the use of pesticide increases the alkalinity due to increase of bicarbonate and carbonate in water.

During winter (January 2024), the control pond P2 shows high alkalinity, while chlorpyrifos shows the highest alkalinity (181 mg/L), mixed shows (162 mg/L), and malathion shows (145 mg/L). In winter, pesticide accumulation increases and it shows high alkalinity.

In summer (May 2024), the control pond P3 shows low alkalinity (93 mg/L), while chlorpyrifos P6 shows high alkalinity (155 mg/L), malathion P9 shows (132 mg/L), and mixed shows the highest alkalinity (174 mg/L). In summer, the water quantity is low and more evaporation happens. Due to this, chemical concentration increases, and because of this alkalinity increases. (Figure 1.7)

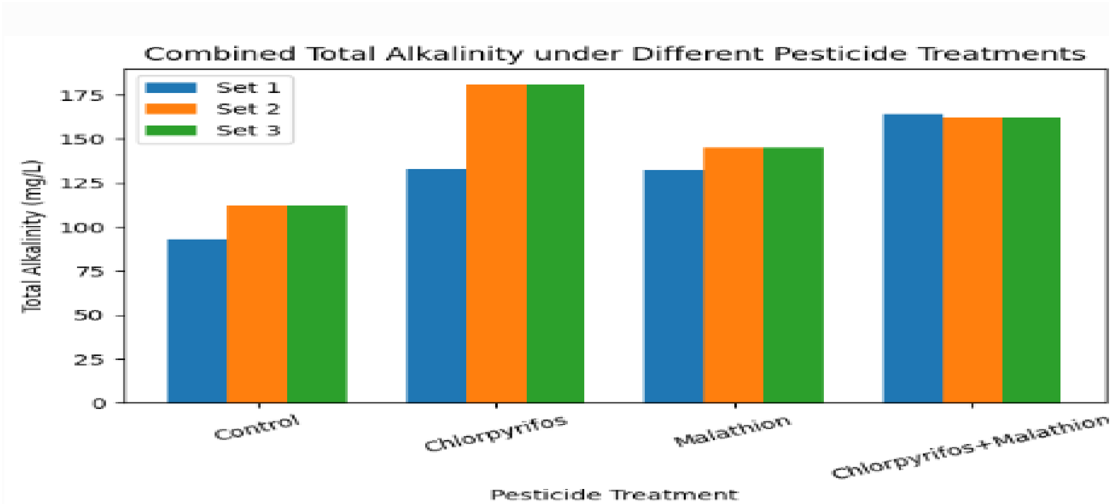

Figure 1.7: Total Alkalinity (mg/L as $CaCO_3$) in Control and Pesticide-Treated Ponds during Winter Season, summer season and monsoon season.

Overall Impact on Fish Health and Biodiversity

The combined analysis of physicochemical parameters indicates that pesticide exposure:

- Reduces dissolved oxygen levels
- Increases turbidity and ammonia concentration
- Alters hardness and alkalinity

These changes create stressful environmental conditions for fish, leading to:

- Reduced growth and biomass
- Physiological stress
- Increased susceptibility to mortality
- Decline in aquatic biodiversity

chlorpyrifos showed the most severe negative impact**,** while combined pesticide treatments exhibited amplified adverse effects on water quality and aquatic life.

Behavioural Responses in Fish

Fish in pesticide-exposed ponds exhibited abnormal behavioural patterns, including erratic swimming, surface gulping, reduced feeding activity, and lethargy. These behavioural changes were more pronounced in ponds exposed to organophosphate pesticides and were indicative of sub-lethal toxic stress affecting neurological and physiological functions.

ACUTE TOXICITY BIOASSAY

A 96 h assay was conducted to evaluate the effect of pesticides on fish. The 4-day results show that chlorpyrifos pesticide in monsoon shows 35% fish death, in winter 40%, and in summer 50% fish death is observed. Approximately half of the fish population died, which shows that chlorpyrifos is the most toxic pesticide. Malathion shows less toxic effect than chlorpyrifos. In monsoon and winter, the death of fish is less, but in summer 47.5% death is observed, which is almost LC50.Mixed pesticides were used and gave a surprising result. In monsoon it shows 22.5%, in winter it shows 27.5%, and in summer it shows 30%. The mixed pesticides show better results and the death of fish decreases. This is called antagonistic effect (in this effect both pesticides decrease the effect of each other). (Figure 1.8)

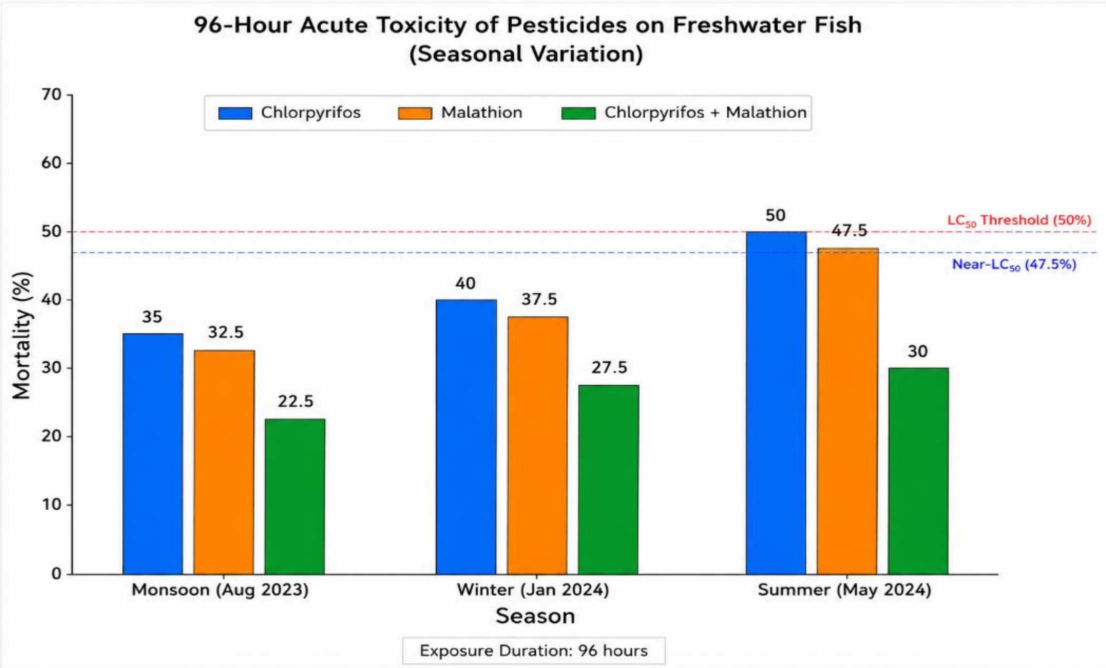

Figure 1.8: Bioassay LC_{50} Response of Fish Based on 96-Hour Mortality Data

DISCUSSION

The present study clearly demonstrates that agricultural pesticide contamination significantly affects aquatic ecosystems, particularly fish health and biodiversity. Pesticides are harmful for both fish as well as water. They affect fish health, growth, and biodiversity. In control ponds, the fish are normal and safe, whereas in pesticide ponds fishes die and mortality increases. Mixed pesticides also show negative effects. Thus, pesticides affect the survival of fish. Seasonal effects of pesticides are also observed. In monsoon, the quantity of water is more and dilution increases, which shows better results. In winter, fish growth is slow due to pesticide stress. In summer, the water quantity is low, which affects the oxygen level of water, and maximum death is observed in the summer season. In pesticide ponds, the weight of fish is less, showing that pesticides affect both weight and length. The water quality of pesticide-treated ponds is also affected: oxygen level decreases, turbidity increases, ammonia increases (causing toxicity), and hardness and alkalinity increase. Behavioural changes observed in fish, such as erratic swimming, surface gulping, reduced feeding, and lethargy, serve as early indicators of toxic stress. These responses suggest neurological and physiological disturbances caused by pesticide. Chlorpyrifos exhibited the highest toxicity, reaching LC_{50} during summer, while malathion showed moderate toxicity. Interestingly, the combined pesticide treatment resulted in comparatively lower mortality, suggesting possible antagonistic interaction between the two chemicals. However, despite lower mortality, combined exposure still negatively affected fish health and water quality parameters.

CONCLUSION

The present study clearly demonstrates that agricultural pesticides have a significant negative impact on aquatic ecosystems, particularly on fish health and biodiversity. Pesticide contamination led to deterioration of water quality, as evidenced by reduced dissolved oxygen, increased turbidity, and elevated ammonia levels. These changes created unfavourable environmental conditions, resulting in physiological stress and increased mortality in fish. Fish population analysis indicated a substantial decline in pesticide exposed ponds, shows high toxicity than mixed pesticide and malathion. Growth performance was affected, as reflected by reducing length-weight relationship, indicating metabolic disturbance under pesticide stress. Behavioural abnormalities confirmed that sub lethal toxicity. Acute toxicity bioassay results confirmed that pesticide toxicity is influenced by both chemical nature and environmental conditions. In influencing pesticide toxicity, a crucial role is played by seasonal variation. Summer season exhibited most severe impact due to high temperature, low dissolve oxygen, and high concentration of toxicants, maximum fish mortality. The continuous pesticide release in aquatic system that disturb the ecological balance, reduce fish survival and leads to biodiversity loss. Therefore, there is an urgent need for controlled pesticide use, proper management practices**,** and increased awareness to minimize environmental contamination and ensure sustainable aquatic ecosystem health.

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