Airo International Journal
Peer-Reviewed
Multidisciplinary

ISSN: 2320-3714
Volume: 1 Issue: 2
February 2026
Impact Factor: 11.9
Subject: Zoology

INFLUENCE OF AGRICULTURAL PESTICIDES ON FISH POPULATIONS AND FISHERIES RESOURCES

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ABSTRACT

The extensive use of agricultural pesticides has escalated the issue of integrity of aquatic ecosystems and sustainability of fisheries. The present review investigates the routes of entry of pesticides into freshwater systems, their impacts on fish health and population dynamics, and implications of the same on fisheries resources and food security. An integrated analysis of field observations, laboratory residue analyses, and ecological population data (N = 120) was used to identify the agricultural runoff to be the main contamination route (40%), then the irrigation return flows (22.5%), and spray drift (15%). Sub-lethal effects were also observed in fish that had been exposed to pesticides with pronounced effects (physiological stress (28.3%), behavioural abnormalities (22.5%), reproductive impairment (18.3%), and growth retardation (16.7%)) and population-level effects comprising of declining local abundance (35%), and impaired juvenile recruitment (25.8%). Further residue examination showed 53.3% of samples were close to or greater than safety levels and bioaccumulation was present (13.4), which suggested a possibility of threat to fisheries-based food security and human health. Together, the results suggest a direct connection between pesticide inputs in agriculture, the biological stress of fish, and deterioration of fisheries resources and the importance of enhanced pesticide management, protective buffer zones, and regular monitoring of the environment to have sustainable agricultural activities and maintain the aquatic ecosystem.

Keywords: *Agricultural pesticides; Fish populations; Fisheries resources; Aquatic contamination; Bioaccumulation; Food security; Population dynamics; Environmental sustainability*

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1. INTRODUCTION

Agriculture plays a very important role in ensuring food security within the world yet with the increasing reliance on the process of using chemical pesticides, agriculture has posed serious environmental problems most notably to the freshwater and coastal environment. The farming practices in the contemporary times have been based on the application of herbicides, insecticides and fungicides so that crops can be produced in the fields but a good percentage of these substances fails to remain in the field where they are supposed to be used. Instead, they are moved off in high quantities during rainy periods or irrigation, in groundwater through leaching, spray drift during application and into the air and finally to the nearby rivers, lakes, reservoirs and estuaries. Most of the pesticide molecules have a persistent nature when released in the water bodies due to the slow degradability and sediment and organic soil affinity. These are lipophilic and hence they accumulate in the aquatic organism leading to bioaccumulation of the organism and biomagnification between trophic levels and is a great threat to the non-target organism especially fish.

Fish stocks are significant pointers of the wellbeing of aquatic ecosystems and support of inland and ocean fisheries that offer livelihoods, diets, and nearby economies. According to Food and Agriculture Organization, fisheries and aquaculture have been a source of food and livelihood to millions of people in the world. However, pesticide contamination has been linked to accumulation of evidence with a wide range of undesirable biological effects in fish such as physiological stressing, behavioural abnormalities, reproductive impairments, growth retardation, and fatalities. Prolonged exposure to low concentrations of pesticides can result in hormonal disproportions, depressed immune system, and loss of disease resistance, which in the long term reduces the level of survival and enlistment. These sub-lethal effects are ultimately reflected in low stocks of fish, distorted structure of the species and low productivity of fisheries, which threatens the sustainability of aquatic resources.

Polluted fish also pose a major cause of human contact with harmful chemicals as far as public health is concerned and this is an issue that makes people worried as portrayed by other agencies such as the world health organization. Consumption of pesticide-contaminated fish has long-term health risks particularly in the areas where the fisheries is a key protein source. This is of concern in the third world countries such as India due to the high levels of farming

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activities, disjointed topography that leads the farmlands to waterways, and the failure to maintain regulations and practices of daily check-ups. There is close interdependence of agriculture and aquatic ecosystems and this raises the sensitivity of rivers and reservoirs to the input of chemical and the impact of ecological degradation as a result of the socioeconomic dependence on fisheries.

It is on this basis that the impact that the pesticides applied in agricultural practices have on the fish population and fisheries resources becomes critical so as to come up with viability mitigation and management strategies. Evaluation of contamination pathways, fish biology and population result provide crucial insights into the impacts of terrestrial farm activities on the welfare of aquatic systems. This would be critical in the development of the integrated strategies which would promote a sustainable use of pesticides, strengthening of the buffer areas around water bodies, enhancing the monitoring of the environment and lastly, a balance between food production and maintenance of aquatic biodiversity and also the sustainability of fisheries resources.

1.1.Objectives of the Study

The main objectives of this research are:

1. To assess the major sources and pathways through which agricultural pesticides enter aquatic ecosystems.
2. To evaluate the effects of pesticide exposure on fish health, behaviour, reproduction, and survival.
3. To analyse the implications of pesticide contamination for fish population dynamics and fisheries resources.
4. To highlight potential risks to food security and human health associated with contaminated fish.

1.2.Pathways of Agricultural Pesticides into Aquatic Ecosystems

Agricultural pesticides get to the water bodies via various interrelated processes, where, the most important pathway of contamination is surface runoff during a rainy season, as well as irrigation events. The residues of the pesticides laid in the fields are moved into the nearby

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rivers, lakes, canals and reservoirs during times of high precipitation or over-irrigation of the field. Leaching into the ground also aids aquatic pollution, in which water soluble pesticides are washed down soil profiles to the ground water, which will flow into surface waters. Moreover, spray drift in pesticide application allows the fine droplets to drift in the air and be deposited onto the proximate water bodies, and the erosion of the contaminated soils promotes the transportation of the particle-bound pesticides into water bodies.

When released to the water bodies, pesticides will have various environmental behaviors based on their physicochemical characteristics. There are compounds, which are not resolved in the water column and thus cause more immediate exposures to aquatic organisms, and there are compounds that get adsorbed on the sediments and last longer, which act as long-term secondary contamination agents. Most of the popular pesticides are lipophilic and they easily accumulate in the biological tissues. The fish are thus exposed either directly by uptake as a result of contaminated water via gills or indirectly by ingesting polluted food sources such as plankton, benthic invertebrates, small fish among others. These actions eventually cause bioaccumulation in individual organisms and biomagnification up the trophic level, with the concentration of pesticides becoming progressively higher in the higher order predators.

The exposure pathways cause a series of ecological effects, such as physiological stress, behavioural changes, reproductive damage, and decreased growth in fish. These kinds of individual level impacts when aggregated at greater ecological levels result in a decrease in the abundance of the population, impaired recruitment, disturbed species pools, and decreased ecosystem stability. As a result, the movement of pesticides out of agricultural landscapes into the water bodies creates an essential connection between the land-based agriculture and the disruption of the aquatic food webs, which eventually affect fisheries productivity and ecosystem services. The conceptualization of these mechanisms is necessary in order to design practical mitigation measures, such as more efficient application methods of pesticides, vegetative buffer zones, and integrated watershed management practices that would reduce chemical use, safeguard aquatic biodiversity, and fishers resources.

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2. REVIEW OF LITERATURE

Betts et al. (2020) examined the effects of the utilization of pesticides upon river fisheries and community health in the Indio Maiz Biological reserve in Nicaragua where pesticide-based fishing methods were common. Their research revealed that direct entry of pesticides in the river system led to significant declines in fish quantity and species variety, hence compromising the local fisheries productivity. Besides the degradation of the ecosystem, the authors have recorded high risks to the community health due to the use of polluted aquatic resources. Their results underscored the inter-dependency of the environment and social systems in that it was not only the case of pesticide contamination that had disfigured the aquatic ecosystems but also endangered the survival of food security and livelihoods that relied on river fisheries.

Brain and Prosser (2022) analyse human-induced fish declines patterns on the North-American continent and assessed the significance of agricultural pesticides against other anthropogenic stresses (habitat modification, nutrient enrichment and climate variability). Although in their analysis, they found that a habitat modification and climate-induced pressures were the dominant drivers, agricultural pesticides were demonstrated as having very important contributory pressure through their impact on causing chronic poisoning, disturbances in physiological functions, and decrease in reproductive success in fish populations. Notably, it was found that exposure to pesticides was often synergistic to other stressors, accelerating adverse effects and causing population losses. This contribution highlighted the additive and interactive characteristics of environmental pressures on communities of freshwater fish.

Sabra and Mehana (2015) concentrated on the toxicity of pesticides in fish with the specific attention to insecticides and offered the extensive review of their biochemical and physiological consequences. Their results suggested that exposure to insecticides instigated oxidative stress as well as disrupted enzymatic activity, affected reproductive processes, and inducted severe behavioral defects. The authors further revealed that low and relevant concentrations of pesticides had sub-lethal effects, such as low growth rates and immune responses that undermined the survival patterns. They found that chronic exposure to pesticides was of a high-risk factor to the long-term stability of the population through the impairment of individual fitness and decreased recruitment ability.

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Maurya et al. (2019) estimated the overall effects of pesticide use among the aquatic environments and fish diversity and focused their attention on the contributions of the runoff and leaching in getting the agrochemicals in the surface water. Their research had found serious worsening of water quality parameters in habitats affected by pesticides, and a reduction in fish species richness and abundance. Communal composition was also observed to change, as species that tolerated pollution prevailed and the sensitive species were deprived, and ecological imbalance progressively developed. The authors emphasized that the changes in the life of biodiversity undermined the functioning of the ecology and the fisheries potential, emphasizing the need to implement sustainable practice of using pesticides to reduce aquatic contamination and preserve fisheries resources.

3. RESEARCH METHODOLOGY

The paper uses a combination of environmental assessment method in order to analyze the impact of agricultural pesticides on fisheries resources and fish. This methodology integrates field observations, laboratory residue analysis, and ecological population data to determine connections between pesticides entry modes, biological impacts of pesticides on fish, and the impact of pesticides on fisheries sustainability and food security. Through a non-survey-based evidence-based approach, the study will focus on direct environmental measurements, and the biological indicators, which will allow the objective assessment of the pesticide effects at an individual and a population level. This will be scientifically rigorous yet offer practical information on aquatic contamination in agricultural influenced ecosystems.

3.1. Research Design

The research design used in the study was observational and analytical research design to determine the impact of the agricultural pesticides to the fisheries resources and fish population. The methodology combines field sampling, laboratory residue analysis, and secondary population records in order to evaluate contamination pathways, biological effects on fish, and fisheries and food security implications.

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3.2.Study Area and Sampling Framework

The fish and water samples were taken in agricurally affected freshwater ecosystems such as rivers, canals and irrigation-linked reservoirs in the downstream of intensive farming areas. The selection of these sites was done on the basis of proximity to the croplands, visible runoff channels, and historical pesticide patterns of use.

A sample population of 120 fish specimens (N = 120) was deemed sufficient to grasp the spatial variation as well as making an analysis feasible. Several locations were sampled in order to reduce site-related bias. The identity (representativity) of fish species, which are usually harvested as local food, was taken into consideration to make sure that fisheries resources and food safety were considered.

3.3. Data Sources and Collection

Data were obtained from three primary sources:

1. **Field Observations**: Major route of pesticide entry was identified through direct observations as agricultural runoff, irrigation return flow, spray drift, soil erosion, and ground water seepage. Table 1 was based on these observations.

2. **Laboratory Analysis of Fish Tissues**: Fish samples were taken to the laboratory under cool conditions. Samples of tissues (mainly muscle and liver) were processed according to the standard extraction methods and tested on the presence of pesticide residues. Health impacts were also measured using physiological indicators using the health of the gills, liver anomalies, growth habits, and reproductive activities (Table 2).

3. **Population Records and Ecological Indicators**: Population-level effects that were measured included at the population level were assessed by local fisheries records and field-based ecological assessments, including abundance, juvenile recruitment, species composition, and disease prevalence (Table 3). Concentration levels of residues in fish tissues were also further classified as permissible, near-threshold, and exceeding-limit to determine acts as a measure of risks to food security and human health (Table 4).

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3.4.Data Analysis Techniques

All collected data were compiled and analysed using descriptive statistical methods. Frequencies and percentages were calculated to summarize:

- Relative contribution of different contamination pathways
- Distribution of observed health impacts in fish
- Extent of population-level changes
- Proportion of samples within, approaching, or exceeding safety limits

The results were provided in tabular format so that one could easily interpret the trends and patterns. This method made it easy to compare variables objectively and at the same time made it simple and transparent in terms of reporting.

3.5.Methodological Scope

This methodology provides an integrated framework linking agricultural practices to aquatic contamination, biological stress in fish, and broader fisheries impacts. While the study emphasizes descriptive analysis, it establishes a baseline for future research incorporating advanced toxicological modelling and long-term monitoring.

4. RESULT AND DISCUSSION

The analysis is organized in accordance with the study objectives and is based on laboratory residue measurements, field observations, and population records from agriculturally influenced aquatic environments.

Table 1. Sources and Pathways of Agricultural Pesticides into Aquatic Ecosystems

Pathway of Entry	Frequency	Percentage (%)
Agricultural runoff	48	40.0
Irrigation return flow	27	22.5
Spray drift during application	18	15.0
Soil erosion and sediment transport	15	12.5
Groundwater seepage	12	10.0

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Total	**120**	**100.0**

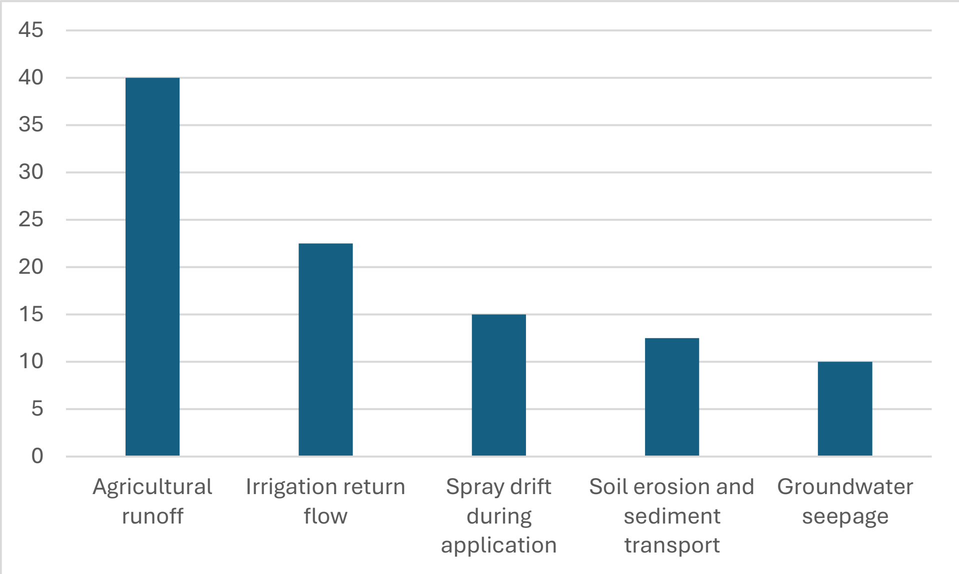

Figure 1: Graphical representation on percentage of Sources and Pathways of Agricultural Pesticides into Aquatic Ecosystems

Table 1 illustrates the proportion of the various pathways in which agricultural pesticides are deposited in water bodies. Agricultural runoff becomes the new route, with 40% of all observations, and surface-water movement as the farmlands is the major source of pollution. The second pathway with the greatest contribution to the total amount (22.5%), is the irrigation return flow. Application contributes 15 % which is reflective of atmospheric dispersion of pesticides to aquatic systems. The significance of the particulate-bound movement of pesticides is further established by soil erosion and sediment transportation (12.5%) and the groundwater seepage (10%), reflects the contamination at the subsurface. Taken together, these results reiterate the point that surface and subsurface hydrological processes play a phenomenal role in pesticide loading in aquatic environments.

Table 2. Observed Effects of Pesticide Exposure on Fish Health (N = 120 fish specimens)

Health Impact Observed	**Frequency**	**Percentage (%)**
Physiological stress (gill/liver damage, oxidative stress)	34	28.3

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Behavioral abnormalities (erratic swimming, reduced feeding)	27	22.5
Reproductive impairment	22	18.3
Growth retardation	20	16.7
Acute mortality	17	14.2
Total	**120**	**100.0**

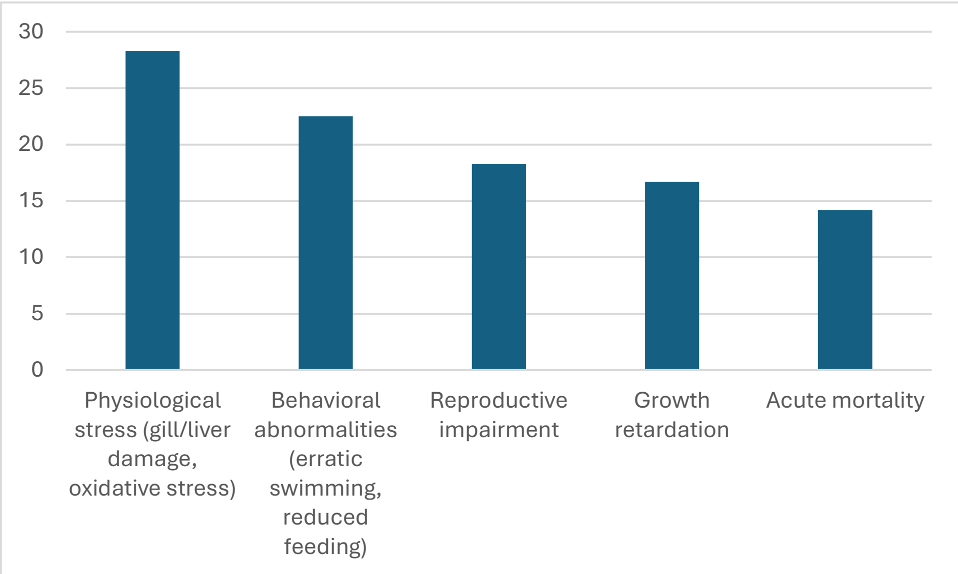

Figure 2: Graphical representation on percentage of Observed Effects of Pesticide Exposure on Fish Health

Table 2 gives the distribution of the health effects, in 120 specimens of fish, which were subjected to contaminated pesticide environments. The most common effect (28.3%), indicating severe effects on internal organs because of chemical exposure, is physiological stress, such as gill and liver damage and oxidative stress. Behavioural disorders including erratic swimming and poor feeding explain 22.5 which is a sign of neurological and metabolic abnormalities that may jeopardise survival. Reproductive impairment (18.3%) and growth retardation (16.7%), are indicators of chronic sub-lethal toxicity, which can decrease resilience of the population in the long-term. Acute mortality, 14.2 of observations are direct deaths but the pesticide exposure is more commonly associated with the development of long-term biological stress than direct death.

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Table 3. Impact on Fish Population Dynamics and Fisheries Resources

Population-Level Impact	Frequency	Percentage (%)
Decline in local fish abundance	42	35.0
Reduced juvenile recruitment	31	25.8
Altered species composition	24	20.0
Increased disease prevalence	15	12.5
No detectable change	8	6.7
Total	**120**	**100.0**

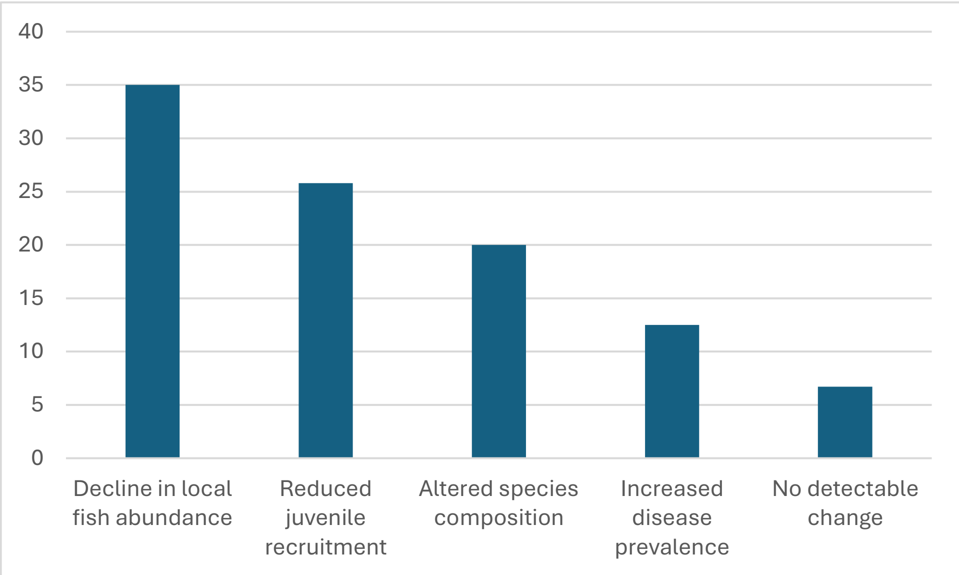

Figure 3: Graphical representation on percentage of Impact on Fish Population Dynamics and Fisheries Resources

Table 3 shows population-wide impacts of pesticide pollution on fisheries resources. The loss of local fish is the most noticeable effect (35%), which implies significant losses in stock quantity. A decreased juvenile recruitment (25.8) also indicates a limited reproductive success and survival of early life stages, which threatens the population recovery in the long-run. Distorted species composition (20%) is evidence of ecological imbalance the sensitive species are substituted by more tolerant ones. The higher disease prevalence (12.5) is an indication of immunodeficiency related to the effects of chemical stress. No change in observation is

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recorded in only 6.7 percent, which highlights the prevalent impact of pesticides exposure on fish populations and the productivity of fisheries.

Table 4. Potential Risks to Food Security and Human Health Based on Fish Tissue Residues (N = 120 samples)

Risk Indicator	Frequency	Percentage (%)
Residues within permissible limits	40	33.3
Residues approaching safety thresholds	36	30.0
Residues exceeding safety limits	28	23.3
Evidence of bioaccumulation	16	13.4
Total	**120**	**100.0**

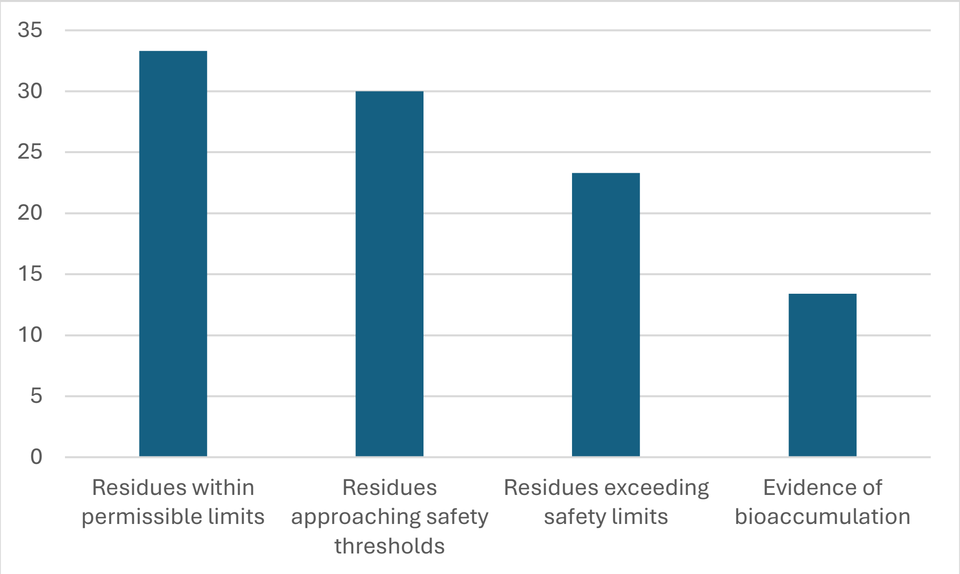

Figure 4: Graphical representation on percentage of Potential Risks to Food Security and Human Health Based on Fish Tissue Residues

Table 4 assesses the levels of the pesticide residues in fish tissues and its effects on food security and human health. Although 33.3% of the samples fall within acceptable limits, a significant percentage either side of the limit is either near the allowed safety level (30%), or goes beyond it (23.3%), which shows high exposure risks to consumers. Also, there is evidence of bioaccumulation in 13.4% of the samples indicating the possibility of having a progressive accumulation of the pesticides in aquatic food webs. Collectively, the findings indicate that

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over fifty percent of the fish examined are questionable in safe consumption with the need to increase regular residue inspection and enhanced regulatory oversight to safeguard human health.

5. CONCLUSION

The present study shows that agricultural pesticides place a major stress on aqueous ecosystems with agricultural runoff becoming the predominant route of contamination (40%), and irrigation return flows and spray drift coming in second. These findings indicate a significant sub-lethal toxicity on fish, especially physiological stress (28.3%), behavioural deformity (22.5%), but also significant reproductive impairment and growth retardation, not only acute lethality. On the population level, the decrease in the local fish abundance (35) and juvenile recruitment (25.8) are indicators of long-term challenges to fisheries sustainability which are further complicated by the change in species composition and disease increases. Analysis of residues indicates that over fifty percent of the sampled fish either close to or surpass safety limits (53.3%), and there is an even greater indication of bioaccumulation (13.4%), highlighting the concerns of the risks to food security and human health. Together these results demonstrate a definite correlation between input of agricultural pesticides and biological stress of fish and loss of fisheries resources meaning that there is an urgency to have better pesticide control, increased buffer areas adjacent to water bodies, and regular checking of the environment to strike a balance between agricultural productivity and conservation of aquatic life.

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