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Research Article

The Effects Of Pollution On Aquatic Life In Freshwater Ecosystems

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Abstract
Aqueous systems that serve essential biodiversity needs and ecological services face growing danger from agricultural-related contamination. Pesticides function as a major pollution source which endangers aquatic wildlife populations while harming ecosystem health. This review investigates macroinvertebrates as indicators of freshwater ecosystem condition particularly in detecting pesticide water contamination. Due to their sensitivity to contaminants macroinvertebrates deliver important information about short-term and long-term environmental changes that help determine ecosystem degradation. The effectiveness of macroinvertebrates in monitoring faces obstacles from their species-specific reactions and their changing population patterns. Studies have proven that pesticide contamination results in population reduction of macroinvertebrates which propagates through food chains to harm fish and amphibians and consequently harms entire ecological systems. When pesticides act along with other environmental pressures from climate change and reduced habitats they create dense cumulative impacts on ecosystems. The existing biological monitoring systems remain useful but show problems because scientists follow different procedures and the regions lack unified monitoring procedures. Standards and better monitoring procedures are required including molecular analysis solutions with remote sensing and expanded chemical analysis. Research initiatives should concentrate on identifying combined pollution effects between multiple contaminants while establishing combined biological chemical and physical monitoring methods. The sustainability of freshwater ecosystems depends on both full environmental monitoring data and stronger pesticide controls to create effective management solutions which must be implemented.

Keywords: Macroinvertebrates, pesticide pollution, freshwater ecosystems, biological monitoring, aquatic biodiversity

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1. Introduction

The planet depends heavily on freshwater ecosystems because these include rivers lakes and wetlands with streams. The humus and the necessary ecosystem services of water purification are provided together with nutrient cycling and carbon sequestration by these ecosystems (Rodríguez et al., 2024). Cancer plagues different forms of life from microscopic organisms to fish and amphibians who provide important ecosystem benefits and habitat. The 3% composition of fresh water ecosystems in the Earth's water resources makes them acutely susceptible to environmental degradation especially through pollution (Zamora-Barrios et al., 2023). Many species depend on freshwater habitats for their survival while human beings rely on these ecosystems as a fundamental resource base for drinking water as well as agricultural and industrial sectors and recreational activities. The systems face increasing pressure from human activities while pollution represents their most critical threat. The water quality deteriorates because of pollution which simultaneously disrupts ecosystem functions thus causing biodiversity decline and essential service alterations (Rodríguez et al., 2024). Freshwater ecosystems experience entry of pollutants through different pathways which include industrial waste and agricultural runoff and sewage.

Water bodies accumulate chemical pollutants together with heavy metals and pesticides which create severe risks for aquatic organisms and damage ecosystem health (Schindler et al., 2008). The accumulation of pollutants throughout time causes ecosystem imbalance which produces detrimental impacts on organisms inhabiting these areas (Tudi et al., 2021). Freshwater ecosystems function as final receivers of numerous contaminants thus they demonstrate the total pollution load that impacts their capability to sustain wildlife populations and human communities.

Multiple pollutants that originate from farming operations industrial factories and municipal water treatment facilities cause freshwater environmental contamination. Freshwater systems contain primarily chemical pollutants that consist of pesticides and herbicides and heavy metals as well as excessive nitrogen and phosphorus (Zakari-Jiya et al., 2022). Various pathways including water runoff, atmospheric fallout and direct wastewater releases allow pollutants to enter waters which damage the health of aquatic ecosystems and water quality impairment occurs. The rising concern over pesticide pollution has become a major environmental issue in the recent times. Agricultural pest control uses extensive pesticides which exhibit toxicity to non-target organisms that include aquatic species (Edwards et al., 2024). Water systems receive these chemicals through runoff that causes harm to aquatic organisms including fish and amphibians as well as macroinvertebrates. Pesticides disrupt biological processes which affect growth and reproduction and feeding behaviour thus causing biodiversity loss and ecosystem deterioration (Tiwari & Pal, 2022). Contamination of freshwater habitat by pesticides remains a concern for scientists due to the resilience of these chemicals in the environment. Pesticides linger in the environment for extended periods of time before they become concentrated in sediments and biotic organisms so as to cause lasting ecological damage (Pastorino et al., 2023). Freshwater ecosystems are continuing to lose their resistance against environmental hazards due to the fact that the pollutants are building up in time (Schindler et al., 2008).

Biological monitoring is one of the crucial methodologies to determine the condition of freshwater ecosystem especially in pollution study by the professionals. Bioindicators are used to help measure environmental conditions by evaluation of active biological organisms that identify pollution-related alterations. Bioindicators provide integrated information about long-term pollutant accumulation over time which is superior to the information that can be gathered from traditional chemical analysis (Masese et al., 2022). Fish and macroinvertebrates combined with plants are used as bioindicators because they are highly sensitive to changes in water quality. Biological reactions to pesticides provide data concerning the well-being of the whole ecosystem (Rodriguez et al., 2024). Biological monitoring provides very useful data on the changes in water quality that cannot be readily identified using chemical test procedures. The alteration of macroinvertebrates populations or diversity is identified as the presence of contaminants to sound an alarm about the decline in water quality (Pastorino et al., 2023). Bioindicators form a significant part of a freshwater monitoring program that is meant to determine the quality of water and control pollution as outlined by Ruhl and Sanders (2024). Their high sensitivity to effects of contaminants and the long exposure period of aquatic organisms make them necessary to give instant measurements of the health of the ecosystem and the impact of the contaminants. The macroinvertebrates group of bioindicators is distinguished in the biological monitoring sphere by its distribution in freshwater systems and the occurrence of various susceptibilities to environmental contaminants such as pesticides (Masese et al., 2022). The food web depends on these animals being insects and mollusks and crustaceans since they feed fish and birds at the apex levels. Various pollutants cause various reactions among these organisms therefore rendering them important pointers to identify the long term effects of contamination. Macroinvertebrates are of great help in biological monitoring owing to a number of advantages. Macroinvertebrates are a cheap and readily available method of assessment to the scientist since they are easy to collect and identify (Stalter & Lonard, 2024). These creatures remain exposed to pollutants over the long term that enables them to build chemical elements in their bodies such that scientists can examine the pollutants levels in their ecosystems (Rodríguez et al., 2024). The sensitivity of macroinvertebrates reaches various pollutants including pesticides so they act as effective indicators of chemical contamination in freshwater systems (Zamora-Barrios et al., 2023). Microorganisms serve as crucial components of the ecosystem because they affect biological processes related to nutrient cycling and sediment stabilization and habitation functioning. The population changes in macroinvertebrates enable researchers to monitor ecosystem health in addition to assessing pollution management strategy success (Schindler et al., 2008).

This review aims at reviewing the contemporary biological assessment techniques that target macroinvertebrates in the assessment of the health of freshwater ecosystems in pesticide-contaminated systems. The key objectives of this review are the following ones:

The review focuses on the current methods of biological monitoring by explaining the evaluation of ecosystem freshwater by using macroinvertebrate bioindicators.

The analysis assesses the pesticide pollution through analyzing the association between pesticide contamination and the importance of macroinvertebrates to keep freshwater ecosystems healthy. The review lays particular stress on pesticide toxicity in conjunction with their long-term impact on the biodiversity.

The review will demonstrate existing research gaps and future direction plan by emphasizing biological monitoring partnership with chemical assessments. The paper identifies research opportunities which include enhancing monitoring tools and studying the combined toxic effects of multiple contaminants.

2. Literature Review

The contamination from pesticides stands as a primary factor leading to freshwater ecosystem degradation especially within regions where agriculture takes place intensively. Multiple research investigations have studied pesticide residue effects on aquatic life over extended periods to demonstrate their widespread distribution in aquatic environments. Anzalone et al. (2022) conducted research to measure pesticide concentrations in Sacramento River watershed juvenile Chinook salmon and their prey species. Research results showed substantial pesticide contamination throughout both riverine and floodplain areas which threatens juvenile fish and other organisms that inhabit these habitats. The research highlights the requirement of studying pesticide contamination in freshwater ecosystems by analysing both riverine and floodplain habitats.

The environmental dangers from pesticides become worse as the use of emerging contaminants including pharmaceuticals and personal care products and microplastics intensifies (Parker & Keller, 2021). The tool Organ Fate developed by Parker and Keller (2021) enables users to model urban and agricultural watershed systems so they can assess risk to ecology despite limited availability of data. The study proved that pollutant combinations result in substantial ecological damage thus requiring better monitoring of multiple contaminants in freshwater ecosystems.

The impacts of water pollutants have grown worse because of climate change effects on freshwater environments. Research indicates that water temperature increases make pesticides and other chemicals more toxic to aquatic organisms which are already facing environmental stress. The research by Liu et al. (2022) demonstrated that ammonia toxicity strengthened at higher environmental complexity levels which affected macroinvertebrates in ecosystems with temperature fluctuations. Research data indicates climate change together with ammonia pollution produces more severe negative impacts on freshwater biodiversity.

The research of De Souza et al. (2023) analyzed through meta-analysis how climate change and pesticide exposure influence each other. Research showed that the simultaneous effects of pesticides together with temperature increases produced major negative impacts on freshwater organisms with macroinvertebrates suffering most from reduced survival rates during warmer conditions. Freshwater ecosystem health evaluation must consider the effects of both climate change and chemical pollution because they are mutually influencing each other. The research conducted by Ahmed et al. (2022) shows how climate change creates wider environmental problems which makes freshwater ecosystems more susceptible to pollution. Water purification alongside nutrient cycling and carbon sequestration functions are key ecosystem services which freshwater ecosystems provide. The vital ecosystem services are endangered because freshwater biodiversity is continually decreasing. Scientific research proves that the biodiversity is reduced in these ecosystems, resulting in the degradation of essential services. The Negra River region of Patagonia showed major biodiversity decline due to agricultural pollution combined with pesticide contamination that impaired water quality according to Arias et al. (2021). The biodiversity loss disrupts natural ecosystem capabilities in the provision of important services such as water supplies and agricultural foundations. Paredes del Puerto et al. (2021) examined fish communities in Argentine urbanized streams and determined that the water quality degradation associated with urban runoff affected fish community structures. Freshwater ecosystem function is jeopardized by this directional shift in species populations because fish maintain marine balance through their control of algae development while building food web structures.

Macroinvertebrates function as bioindicators because they react strongly to environmental changes thus scientists widely utilize them to evaluate freshwater ecosystem water quality. Scientific research indicates that tracking macroinvertebrate population shifts reveals extended chemical pollution patterns which helps evaluate the ecological conditions of an environment. Gholizadeh (2021) has studied floods in northern Iran that were responsible for macroinvertebrates to exhibit major changes in composition due to pesticide exposure during these events. The analysis confirms why populations of macroinvertebrates need to be monitored because they are the first to indicate the presence of stressors affecting the health of the environment. Macaulay et al. (2021) conducted experimental research to understand the nature of the effects of exposure to the imidacloprid pesticide on macroinvertebrate populations living in stream environments. The authors demonstrated by their study that short periods of exposure to pesticides caused significant community reorganization that resulted in population declines or species extinction of affected species. The research proves that macroinvertebrates have high sensitivity to pesticides which makes them valuable detectors of environmental pollutions. Traditional sources of freshwater pollution are increasing and additional contaminants such as medicines and personal hygiene products and small pieces of plastic continue to increase in number. Water contamination by these substances creates substantial worry regarding their permanent ecological effects on freshwater environments. Zakari-Jiya et al. (2022) executed a systematic review which demonstrated substantial pharmaceutical and personal care product pollution of Nigerian surface water ecosystems. The survey reveals that there is a requirement to expand current monitoring systems by adding emerging pollutants alongside conventional pollutants including pesticides. Giles and Hamilton (2024) explained that freshwater ecosystems require attention to microplastics as a critical factor. The researchers maintained that microplastics found everywhere in aquatic habitats now have the potential to intensify chemical pollutant effects such as pesticides. Research needs to expand regarding the unknown chemical-microplastic interactions so scientists can determine their combined destructive effects on aquatic life. Intercognized management methods in freshwater ecosystems represent a mandatory approach due to the intricate relationships between pollutants and climate change-induced effects and biodiversity loss. Scientific experts demand monitoring platforms which track chemical toxins while simultaneously monitoring ecological components like ecological diversity and ecosystem usefulness. Miserendino et al. (2022) explained that Patagonia's freshwater and wetland ecosystems require a complete monitoring system to assess land-use changes combined with agricultural practices and climate change effects. Integrated assessments provide better protection of freshwater biodiversity and enable more effective management strategies according to their argument.

3. Research Methodology

The review article uses three main research methods to examine pollution effects on aquatic wildlife in freshwater ecosystems through an analysis of pesticide pollution studies and biological monitoring with macroinvertebrates and aquatic biodiversity impact assessments. The review framework performs an intensive review of the existing literature and defines gaps of information in the literature as well as in the context of defining the future research directions.

3.1 Literature Search Strategy

An intensive research study was conducted to gather the literature on the impacts of pollution particularly pesticide contamination of freshwater systems and aquatic organisms. The study that was done was intended to collect various studies that would lead to a holistic view of the topic. The study was conducted in Sarayan River Located in Sitapur in sate of Uttar Pradesh . The chosen databases provided a wide access to research papers related to the topic of the study. The search strategy also included various search terms and keywords that are relevant and enabled the search of the most significant studies. The study involved such phrases as freshwater ecosystems and pesticide pollution and aquatic biodiversity and bioindicators and macroinvertebrates and pollutant effects and biological monitoring and aquatic wildlife and ecosystem health. The wide choice of key words helped the search to retrieve a wide scope of research that studied several aspects of pollution that impact aquatic ecosystems.

Research articles that were included in this review were required to fulfil certain criteria in terms of relevance and rigor of the methods. The studies incorporated in this review had to focus on freshwater environments that comprise rivers lakes streams are the primary study areas. The study necessitated the investigation of the effects of pollution on the aquatic life as well as the health condition of these ecosystems when the emphasis was laid on pesticide and chemical contamination pollution. One of the key points in the sense that macroinvertebrates are the basic parameters in the pollution monitoring was the use of macroinvertebrates as bioindicators. The literature used in the research was collected form a study done at Sirayan river in Uttar Pradesh and accepted reports of authoritative sources that fell between 10 and 15 years old to make sure that the material was relevant and up to date to the freshwater ecosystem challenges.

The review eliminated studies that examined either marine environments, or failed to address freshwater contamination and studies that lacked empirical data on aquatic organisms. A limitation criterion adopted by this review maintained their study focus to the impacts of pollution in freshwater and organisms that inhabit this environment. The approach that was developed allowed the researchers to create an in-depth foundation on the investigation of pesticide contamination , Direct disposal of the domestic waste in river and also the Result of Religious activities during the Ganpati Pooja impacts and pollution effects on aquatic animals in freshwater environments.

3.2 Study Selection and Data Extraction

The critical analysis of the chosen studies offered the necessary information concerning the impact of pesticide contamination in aquatic environments. The following aspects were the subject of data extraction: Researchers analysed what pollutants they investigated (pesticide residues e.g., imidacloprid, atrazine and heavy metals as well as excess nutrients e.g., nitrogen, phosphorus and emerging contaminants (e.g., pharmaceuticals, microplastics). The team recorded data on the various study designs that comprised field research and laboratory work and modelling techniques. The review concentrated on studies that tracked the pollution based on biological techniques particularly use of macroinvertebrates to measure pollution. The study sites were recorded to test the impact of pesticide contamination on freshwater ecosystems in various areas. Researchers identified the studied species which included macroinvertebrates for their ability to function as bioindicators that detect pollution effects. Special attention was paid to research that explained how particular macroinvertebrate communities could be used to monitor water quality.

3.3 Synthesis and Analysis of Findings

The extracted data of the relevant studies was reviewed by the research team to achieve the goals of the review article. The impacts of pesticides on aquatic wildlife were reviewed by investigating the impacts of pesticides on fish amphibians and macroinvertebrates. The synthesis discussed the biological disturbances of reproduction and feeding and growth caused by pesticides that lead to depletion of biodiversity and degradation of ecosystems. Macroinvertebrates are a primary factor that was evaluated in the review as bioindicators to assess pollution. The research reviewed scientific studies that measured macroinvertebrate population densities and community diversity and species composition relative to pollutant concentration levels particularly pesticide exposure. The analysis paid specific attention to macroinvertebrate-dependent biological monitoring because they exhibit sensitivity to pollution and are involved in ecosystem elemental cycles while keeping sediments stable.

The review looked at research regarding the effects of pesticide contamination when combined with other pollution such as heavy metals pharmaceuticals or microplastics. The effects of pollutants on the freshwater ecosystems in combination with the potential of destruction on the environment were investigated in this review. The review examined climate change's effects on the toxicity of pollutants by considering warming temperatures and pesticide exposure. Researchers were able to research how climate change increases the toxicity of pesticides and chemicals in aquatic organisms through their studies.

3.4 Evaluation of Biological Monitoring Techniques

This review attempt to evaluate both the performance and difficulties regarding the biological monitoring approaches that are utilized to evaluate the health of freshwater ecosystem in polluted environments. This review explored several important areas in the relationship between biological assessment and freshwater health monitoring in areas with pollution. The review discussed the use of macroinvertebrates as bioindicators as a pesticide contamination investigation tool in great detail. Scientists assessed macroinvertebrate response to various levels of pollution as well as vulnerability levels of target species and contamination reporting capacity for long-term changes in water quality. The function of the biological monitoring program which deploy macroinvertebrates as bioindicators through assessments of their design and implementation were evaluated. The analysis was done on the advantages and disadvantages of these programs in order to enable one detect the changes in the environment that may not be detected by chemical analysis. The review compared various indices that decode macroinvertebrate data such as EPT index and biotic index and pollution tolerance index. Analysis focused on evaluating research efforts that designed or implemented these indices to determine how well they perform in environmental evaluation and pollution management procedures.

3.5 Identification of Research Gaps and Future Directions

Among the purposes of this assessment, one was to determine areas of the research that are lacking and provide recommendations on how to advance what we already know about the impacts of freshwater ecosystem contamination. The next two research directions have to be explored: The study should have high-level monitoring systems that unite biological chemical and ecological testing procedures to measure various effects of pollutants. Research requirement: To carry out long term tracking studies on the impact of pesticide pollution on aquatic ecosystem by researching on the change with time in the presence of various environmental conditions.

Research on the coexistence of emerging pollutants with the traditional contaminants like pesticides should be increased because of the fact that the contaminants are likely to share the aquatic environments leading to probable magnification of the damage. Further research on climate change should be done to calculate how the environment is changing and affecting the sustainability of freshwater ecosystems and the escalation of the risk of the pollutants. Predictions of future health of freshwater ecosystems need studies that analyze combinations of rising temperatures and different precipitation levels and exposure to pollutants. Further studies should consider macroinvertebrates as bioindicators in disturbed habitats since such ecosystems have unique pollution issues.

3.6 Limitations of the Review

This review strives to deliver an extensive review of pesticide pollution effects on aquatic wildlife yet faces certain restrictions: The current literature contains sufficient data about pollution effects from multiple contaminants together especially for recent contamination sources like Industrial waste, Sewage waste and waste from Domestic and Religious activities . The majority of research focuses on Sarayan River for freshwater pollution despite the need for global representation. Methodological approaches used in the reviewed studies varied between field sampling and laboratory experiments and modelling studies thus affecting the ability to compare results. The present review gives a comprehensive view of freshwater pollution research while emphasizing bioindication through macroinvertebrates although it has certain data collection constraints.

4. Results

Biological monitoring proves highly effective for pollution assessment in freshwater ecosystems because macroinvertebrates function as bioindicators according to all reviewed studies. Macroinvertebrates function as early pollution detection agents because they respond strongly to environmental changes along with pollutants causing scientists to monitor aquatic ecosystem health effectively. The combination of three different monitoring tools enables complete knowledge about pollution levels by providing species diversity information and population size assessments along with community composition analysis. These monitoring tools face problems that reduce their capability to achieve optimal results. The reaction levels of macroinvertebrate species differ based on pollutant type while monitoring methods commonly lack standardized procedures. The strength of resistance in different species towards particular pollutants creates obstacles for developing standardized evaluation methods across environmental regions. Evidence from reviewed studies proves that macroinvertebrates effectively identify long-term water quality alterations by revealing extensive damage from pesticides and other pollutants in freshwater systems.

The data in Table 1 presents pollutant-induced effects on macroinvertebrates through diverse species decline and mixed mortality trends while showing reproductive limitations. The data analysis reveals pesticides as the most severe pollutant because they cause severe damage to biodiversity and ecosystem health.

Table 1: Impact of Different Pollutants on Macroinvertebrate Diversity and Mortality

Pollutant Type	Impact on Diversity (High = 0, Low = 10)	Mortality Rate (%)	Reproductive Impact (%)
Pesticides	7	30	50
Heavy Metals	9	60	75
Nutrients	6	20	35
Pharmaceuticals	5	15	40
Microplastics	8	25	60

Biological monitoring programs succeed at evaluating how different contaminants interact with each other through time. The position of macroinvertebrates in the food web enables them to detect water quality changes from short-term and long-term contamination exposure which makes them essential for pollution monitoring.

Figure 1.1: Effect of Direct disposal of Domestic waste into the Sirayan river

Macroinvertebrates as Bioindicators Pesticide sensitivity levels in macroinvertebrates show differences between species because some species demonstrate higher vulnerability to these chemicals. Ephemeroptera Plecoptera and Trichoptera (EPT taxa) demonstrate high sensitivity to pesticide contamination. Scientists observe the disappearance of EPT taxa species when these organisms encounter pesticides including organophosphates, herbicides and insecticides. Research through case studies demonstrates that pesticides imidacloprid and atrazine generate substantial toxicity effects on macroinvertebrate populations which results in immediate population death and long-term reproductive damage.

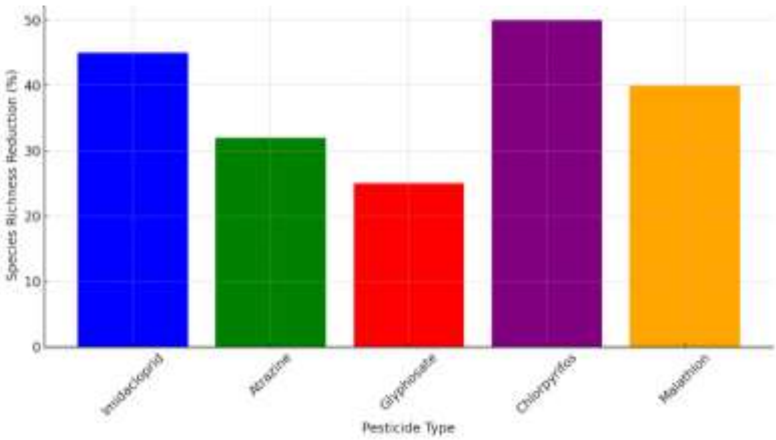

Figure 1: Impact of Different Pesticides on Macroinvertebrate Species Richness

The chart in Figure 1 demonstrates how pesticide types including imidacloprid and atrazine decrease aquatic invertebrate biodiversity. The research findings show that species diversity decreases dramatically when exposed to minimal pesticide concentrations.

Table 2 demonstrates the particular population effects that various pesticide products cause to macroinvertebrates by showing reductions in species diversity together with population numbers and reproductive failure rates. The table demonstrates how widespread and severe pesticide effects include the three common pesticides imidacloprid, chlorpyrifos and glyphosate..

Table 2: Impact of Pesticides on Macroinvertebrate Populations

Pesticide Type	Species Richness Reduction (%)	Abundance Reduction (%)	Reproductive Impact (%)
Imidacloprid	45	60	55
Atrazine	32	45	40
Glyphosate	25	38	30
Chlorpyrifos	50	70	65
Malathion	40	55	50

Multiple research studies show that macroinvertebrates work effectively as biological indicators for monitoring purposes especially when pesticides are abundant in water bodies. The combined population distribution of macroinvertebrates allows scientists to detect water quality changes when pollution-tolerant species grow while sensitive species decrease in numbers. Investigative research has achieved vital progress in identifying main pollutants with a specific focus on pesticides while shaping water quality management approaches.

4.3 Pesticide Pollution and Its Impact on Aquatic Wildlife

Pesticide pollution results in severe toxic effects toward macroinvertebrates by causing immediate death and disrupting reproduction while also changing their behaviour patterns. Research demonstrates how exposure to organophosphates combined with imidacloprid and glyphosate causes both population mortality rates to decrease and growth rates to slow down in macroinvertebrate communities. Pesticides create reproductive problems which result in lasting population reductions.

Figure 2 demonstrates how different pesticides affect macroinvertebrate reproduction by causing substantial declines in reproductive success particularly in cases involving imidacloprid and atrazine and additional widely used pesticides.

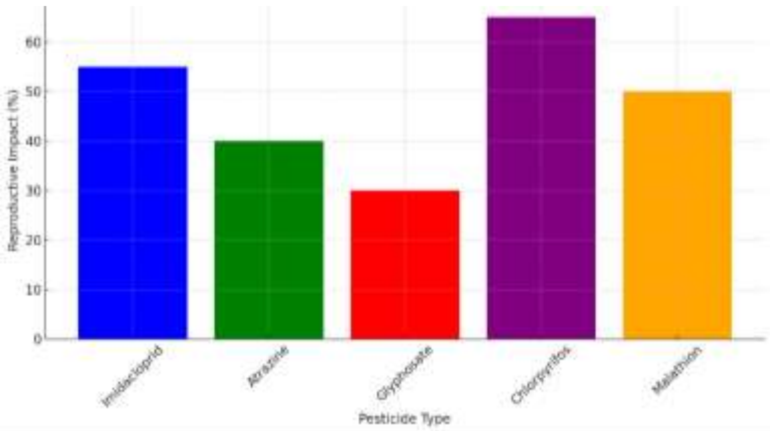

Figure 2: Reproductive Impact of Pesticides on Macroinvertebrates

Pesticide contamination causes macroinvertebrate population declines which trigger a sequence of negative impacts through the entire freshwater food web structure. The ecosystem suffers disruption because macroinvertebrates provide essential food to fish and amphibians. Ecosystem functions perform poorly due to decreased predator numbers when critical organisms are scarce from pesticide exposure.

Table 3 demonstrates the process through which pesticide contamination causes disruptions in freshwater food webs. The document shows how pesticide contamination results in decreased numbers of primary consumers (macroinvertebrates) and secondary consumers (fish) through direct and indirect impacts on trophic levels.

Table 3: Toxic Effects of Pesticides on Freshwater Food Webs

Pesticide Type	Impact on Primary Consumers	Impact on Secondary Consumers	Impact on Tertiary Consumers
Imidacloprid	Mortality, reduced reproduction	Reduced food availability, population decline	Disrupted predator-prey relationships
Atrazine	Reduced species richness	Reduced survival rates in fish	Impaired hunting behavior
Glyphosate	Reduced abundance and diversity	Loss of prey	Reduced predator population
Chlorpyrifos	High mortality rates	Fish population decline	Disruption of trophic interactions
Malathion	Reduced growth and survival	Reduced reproductive success	Weakened food web

The reviewed studies provide compelling evidence which demonstrates that pesticide contamination leads to reduced aquatic biodiversity. Pesticide usage in agricultural areas leads to the greatest biodiversity reductions specifically within proximity to rivers streams and wetlands. Fisheries service's degrade because pesticide pollution causes biodiversity reduction in freshwater ecosystems. Pesticide pollution remains a critical environmental danger that harms freshwater ecosystems to a substantial extent. The examined research demonstrates that pesticides cause harm to macroinvertebrates while disrupting the entire aquatic food web which results in multiple ecological effects. A comprehensive approach mixing macroinvertebrate assessments with chemical analysis gives ecosystems important instruments to handle pesticide-related environmental damage.

5. Discussion

Aquatic ecosystems use macroinvertebrates as effective natural indicators of water quality condition because these organisms demonstrate strong sensitivity to water quality changes and maintain critical roles in food chain networks. The aquatic ecosystem health can be measured through the analysis of insects and molluscs and crustaceans that occupy different positions in the trophic chain. The wide variety of species from different sensitivity levels enables researchers to obtain detailed information about environmental stressors. Some macroinvertebrate species demonstrate high chemical contaminant sensitivity to pesticides yet others display tolerance to these pollutants. Macroinvertebrates exhibit sensitive reactions to environmental conditions thus showing signs of pollution before damage to ecosystems or pollution becomes observable. Using macroinvertebrates for pollution monitoring requires managers to overcome multiple implementation difficulties. The main challenge in pollution monitoring arises from different species exhibiting unique reactions to pollutants. Some species experience quick population drop and reproductive problem responses to pollution but other species present delayed or less noticeable responses to pollution. Such species-specific responses to pollutants preclude scientists from using general conclusions about the effects of pollution on all macroinvertebrate species in an ecosystem. Temporal variations present an additional difficulty in the monitoring of programs. Natural variations in macroinvertebrates populations occur throughout time due to seasonal fluctuations and life cycle patterns and environmental conditions thus making it difficult to interpret monitoring data properly. Proper planning of monitoring systems along with long data collection helps to identify real pollution effects from natural ecosystem waves. This valuable ecosystem health is grounded on various and abundant macroinvertebrate communities regardless of environmental challenges. The presence of a healthy ecosystem is typically indicated by a mature macroinvertebrate community with a diverse species assemblage since these animals facilitate such key ecosystem functions as nutrient cycling and sediment protection and primary producer control. Macroinvertebrate indicators can be used to track water quality and trends in biodiversity since the indicators capture both decreased diversity and a shift of species towards pollution-tolerant forms.

The pollution of pesticides poses a great threat to freshwater ecosystems and their wildlife. The cumulative effects of pesticides develop vast damage that promotes declines in the population of organisms and reorganisation of the community along with the disintegration of ecological processes. The pesticides that are used in agriculture are absorbed by fresh water systems and are released into the systems by surface runoffs and atmospheric cascades and open water discharges. The waters cause the pesticides to settle in the sediments where they pollute the aquatic organisms and the entire ecosystem. The most evident loss of macroinvertebrates sensitive to chemical pollutants is caused by pesticides pollution. The food web is affected negatively in several ways since macroinvertebrates are the main food source of fish not to mention amphibians and birds. The reduction of the macroinvertebrates leads to the decline of fish population that brings further instability to the food web structure. The exposure to pesticides that has been long term has also led to loss of biodiversity in the sense that the vulnerable species either reduce or completely disappear in their habitats. Studies that have been carried out on exposure to pesticides reveal in-depth evidence on the influence of these chemicals on the structure of different species in definite geographical locations. A change in aquatic species composition occurs in agricultural regions which heavily employ pesticides within their intensive farming operations. Waterways polluted by contaminants have lost their sensitive species including mayflies and stoneflies yet more resistant species have increased in numbers. The species compositions that cause this change bring about a loss of biodiversity in addition to ecological function changes such as water purification and nutrient cycling. The cumulative effects of pesticide contamination are likely to aggravate with other environmental stress factors that comprise of climate change and habitat demolition. The hostile conditions that pesticides cause to aquatic organism are aggravated by the effects of climate change that alters temperatures and water levels and precipitation patterns. Urbanization causes the loss of habitats with the subsequent loss of forests and increased agricultural activities that decrease the health of the ecosystems since it restricts their capacity to withstand pesticide pollution. The interaction of the environmental stressors has negative effects that are interactive thus increasing the toxicity of pesticides and decreasing the ability of the ecosystem to recover after events of disturbance.

Macroinvertebrate-based laboratory procedures are useful tools that assist scientists to analyze the status of aquatic ecosystems. These evaluation techniques show the ability of identifying water quality changes both in the long and in the short run. Macroinvertebrates are also effective pointers in the evaluation of water quality considering that they combine the exposure to pollutants over a long duration of time as they harbor contaminants in their body tissues respectively. The existence of a large variety of different kinds of macroinvertebrates and their quantity is an evidence of the health of an ecosystem along with the level of pollution of the ecosystem. The current monitoring practices are subject to various restrictions. The major impediment in biological monitoring is due to lack of universal protocols and procedures. Different regions use contrasting monitoring techniques that create barriers to obtaining meaningful global conclusions from comparison of results. Different monitoring approaches fail to develop effective policy recommendations because their results depend on methods used and species selection and environmental conditions at sampling times. The evaluation of individual pollutants primarily investigates pesticides as a standalone while neglecting their interaction with other stresses in the system. The management of freshwater ecosystems needs full knowledge concerning the interaction between chemical pollutants and nutrients and emerging contaminants due to the interaction of these stressors. The existing approaches to monitoring are not sufficient to detect whole toxin interaction effects that leads to inappropriate evaluation of ecological health. The dynamic temporal distribution pattern and location-dependent location of macroinvertebrates determine the closure of water quality. The interpretation of monitoring results becomes complex with seasonal change in distributions of species and community and extensive differences in pollution among habitats. Scientists must come up with comprehensive programs with the data of pollutants and data of species and ecosystem interactions based on several monitoring sources to overcome known monitoring problems.

The determination of the impacts of pollution on freshwater ecosystems needs better biological monitoring systems that should be devised as soon as possible. The potential breakthrough in this area of development is possible new technologies like the molecular techniques and remote sensing. DNA barcoding-based molecular tools, environmental DNA (eDNA) analysis enhance monitoring initiatives by enabling the detection of those species that are difficult to identify and the identification of pollutants at extremely low concentrations. Remote sensing technologies open the prospects of collecting valuable information in the form of satellite imagery and drone monitoring that make it possible to track the quality of the habitat and land use and water quality on a large scale at regional and global levels. There should be more research to learn how several pollutants interplay with one another and with other environmental stressors like climate change. The presence of pesticides in freshwater systems remains uncommon because it accompanies the presence of several contaminants such as the heavy metals and pharmaceuticals and nutrients. The study to establish the relations between pollution and species and the functional change of the ecosystems following contamination will be the force in the evolution of the improved methods of contamination management. Bio, chemical and physical data analysis should be integrated by a detailed monitoring system. A combined monitoring scheme incorporating data on water quality and quantity of pollutant and species health outcomes will be useful in coming up with comprehensive ecosystem health data to inform prudent decisions. The combination of these monitoring systems introduces increased compatibility of the data in the region so that the global organizations can protect the aquatic ecosystem against the impact of pollution.

6. Conclusion

The assessment demonstrates that macroinvertebrates may serve as important pollution indicators of freshwater systems. Macroinvertebrates are sensitive to pesticides and can respond to the pollution in both short term and long term environmental changes. The high pollution of religious activities , Domestic waste is affecting population of aquatic wildlife by reducing biodiversity and other factors such as species distribution and disruption of key ecosystem processes. The interaction of exposure to pesticides , Construction and Sewage waste leads to further problems of freshwater ecosystems that are compounded by stressors like climate change. The protection of freshwater ecosystems with good pollution management requires that the environmental policy employ biological methods of monitoring. Macroinvertebrate bioindicator schemes and waste management Schemes such as Namami Ganga need to be integrated in the environmental regulations to measure levels of pollution along with the ecosystem health assessment. The enforcement agencies should tighten the regulation of pesticides since this will ensure that the health of fresh water resources is preserved as well as protecting aquatic wild life. The main focus of the policy makers who must have such assessments in order to make a decision regarding the use of pesticides and control of pollution such as fine must be impose on the people for direct disposal of waste into the river, Construction work should not be done near the river and monitored by the government should be based on long-term ecological assessment that requires the use of both chemical and biological data. The mandate of maintaining freshwater ecosystems does not only entail an ongoing study and monitoring process to overcome the rising environmental stressors, but also the pollution threats. The advantages of biological monitoring in broader conservation programs are due to the superior potential of restoration of aquatic ecosystem which is provided. The combination of better means of monitoring and better regulatory measures will enable protection of important ecosystems hence ensuring their sustainability over time to the advantage of future generations.

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