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Effective Pest Management and Biodiversity Conservation in Bangladesh

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ABSTRACT

In Bangladesh, rich agro-biodiversity is increasingly threatened by unsustainable pest management practices, environmental degradation, pest resistance, decline of beneficial species, and contamination of food and water. This study evaluates prevailing pest management strategies, their ecological and economic impacts, and opportunities to develop biodiversity- and eco-friendly pest control systems. A cross-sectional mixed-methods approach was applied across five agroecological zones, involving surveys of 500 smallholder farmers, 30 key informant interviews, ecological field assessments, and laboratory analysis of pesticide residues in soil, water, and vegetables. Quantitative data were analyzed descriptively and inferentially, while biodiversity indices measured species richness; qualitative data were thematically analyzed to explore knowledge, institutional barriers, and perceptions. Results show that 87% of farmers rely solely on chemical pesticides, often applying high doses based on visual inspection rather than integrated thresholds. Pesticide residues were detected in 85% of vegetable and 80% of soil samples, with 28% exceeding national maximum residue limits. Ecological assessments revealed lower populations of pollinators and beneficial predators in high pesticide-use areas compared to fields managed under IPM or ecological agriculture. Only 13% of farmers received IPM training, and under 11% practiced it actively. Economic analysis indicated that IPM fields achieved similar yields but lower input costs, generating higher net income. Biodiversity was notably higher in diversified farms with hedgerows, polycultures, and ecological buffer zones.

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ABSTRAK

Template ini merupakan format panduan untuk Di Bangladesh, keanekaragaman hayati pertanian yang kaya semakin terancam oleh praktik pengelolaan hama yang tidak berkelanjutan, degradasi lingkungan, resistensi hama, penurunan spesies bermanfaat, dan kontaminasi makanan dan air. Studi ini mengevaluasi strategi pengelolaan hama yang berlaku, dampak ekologis dan ekonominya, serta peluang untuk mengembangkan sistem pengendalian hama yang ramah keanekaragaman hayati dan lingkungan. Pendekatan metode campuran lintas sektoral diterapkan di lima zona agroekologi, yang melibatkan survei terhadap 500 petani kecil, 30 wawancara informan kunci, penilaian lapangan ekologis, dan analisis laboratorium residu pestisida dalam tanah, air, dan sayuran. Data kuantitatif dianalisis secara deskriptif dan inferensial, sedangkan indeks keanekaragaman hayati mengukur kekayaan spesies; data kualitatif dianalisis secara tematik untuk mengeksplorasi pengetahuan, hambatan kelembagaan, dan persepsi. Hasil menunjukkan bahwa 87% petani hanya bergantung pada pestisida kimia, seringkali menerapkan dosis tinggi berdasarkan inspeksi visual daripada ambang batas terintegrasi. Residu pestisida terdeteksi pada 85% sampel sayuran dan 80% sampel tanah, dengan 28% melebihi batas residu maksimum nasional. Penilaian ekologis mengungkapkan populasi penyerbuk dan predator bermanfaat yang lebih rendah di daerah dengan penggunaan pestisida tinggi dibandingkan dengan lahan yang dikelola dengan IPM atau pertanian ekologis. Hanya 13% petani yang menerima pelatihan IPM, dan kurang dari 11% yang mempraktikkannya secara aktif. Analisis ekonomi menunjukkan bahwa lahan IPM mencapai hasil panen yang serupa tetapi biaya input yang lebih rendah, menghasilkan pendapatan bersih yang lebih tinggi. Keanekaragaman hayati secara signifikan lebih tinggi di lahan pertanian yang terdiversifikasi dengan pagar tanaman, polikultur, dan zona penyangga ekologis.

INTRODUCTION

Preserving biodiversity is an increasing concern in agriculture-based countries, where the frequent use of synthetic fertilizers and pesticides poses serious ecological risks. Despite awareness of these impacts, many farmers continue to rely, often reluctantly, on chemical inputs in an effort to increase crop yields. In Bangladesh, with its fertile deltaic plains and favorable agro-climatic conditions, agriculture plays a central role in ensuring national food security, providing rural employment, and contributing significantly to the country's GDP. Despite rapid industrialization and urbanization, agriculture still accounts for around 12.7% of GDP and employs about 40% of the labor force (Bangladesh Bureau of Statistics (BBS), 2023). The major crops include rice, jute, wheat, vegetables, potatoes, and various fruits. However, the intensification of agricultural practices to meet growing food demands has been paralleled by a substantial increase in the use of chemical inputs, particularly synthetic pesticides. From the early 1990s to 2020, pesticide use in Bangladesh increased almost fivefold, with a corresponding rise in chemical dependency among smallholder farmers (Thakur & Sharma, 2024).

The heavy reliance on synthetic pesticides has led to a series of agronomic, environmental, and public health concerns. Pests are becoming increasingly resistant to chemical control, leading to pest resurgence and a "pesticide treadmill," where more potent chemicals are applied more frequently (Siam *et al*., 2024). Furthermore, many pesticides used in Bangladesh especially by smallholder

farmers do not meet international safety standards, and their application often lacks appropriate protective measures (Nasrin & Jahan, 2021). Studies have reported pesticide residues above the Maximum Residue Limits (MRLs) in vegetables, fruits, and even staple cereals in local markets (Bello-Bravo *et al*., 2023).

Non-target species such as beneficial insects (e.g., pollinators, parasitoids), amphibians, birds, and aquatic organisms suffer significantly from pesticide exposure, which ultimately disturbs the ecological balance of agro-ecosystems (Jha *et al*., 2025). Moreover, chemical runoff and leaching contaminate surrounding water bodies and soil, adversely affecting both biodiversity and ecosystem services (Hossain *et al*., 2020). Chronic pesticide exposure among agricultural workers and rural communities has been associated with respiratory problems, neurological disorders, reproductive issues, and in some cases, cancers (He *et al*., 2023).

Collectively, non-compliance in agricultural pest management has severely impacted the country, causing irreversible ecological changes that affect the entire biomass.

The rich biodiversity of Bangladesh includes more than 1,600 vertebrate species and over 5,000 species of angiosperm plants (Center for Integrated Pest Management (CIPM), 2020). The country's diverse ecological zones such as the Sundarbans mangrove forest, Chittagong Hill Tracts, backswamp (wetlands that contain rainwater), and coastal estuaries support numerous endemic and threatened specieks. Biodiversity in all these ecosystems is increasingly under threat due to habitat loss, pollution, and agricultural expansion (Khondker *et al*., 2023). Agrochemical pollution and land-use changes have been identified as the primary drivers behind the declining populations of pollinators, amphibians, and aquatic biodiversity in rural landscapes (Ryalls *et al*., 2024).

Agroecosystems, if managed sustainably, can contribute to both productivity and biodiversity conservation. However, monoculture cropping systems, habitat fragmentation, and the eradication of vegetative cover for pest suppression purposes continue to reduce ecosystem complexity and resilience (Shammi *et al*., 2020). There is a critical need to restore landscape heterogeneity and incorporate ecological principles into agricultural practices to ensure long-term sustainability.

Bangladesh, though geographically small, harbors a rich array of biological diversity due to its diverse ecosystems ranging from the world's largest mangrove forest (the Sundarbans) and floodplain wetlands (haors and baors, local names that are used interchangeably for the backswamps that contain rain or flood water) to hill forests and coastal estuaries. These ecosystems provide critical habitats for over 1,600 vertebrate species and more than 5,000 plant species, many of which are endemic and under severe threat (Khondker *et al*., 2023). As mentioned earlier, most threats stem from unsustainable and non-scientific agricultural practices, with

excessive pesticide use being a primary concern.

Integrated Pest Management (IPM) offers a comprehensive and ecologically sound approach to managing pest populations. IPM involves the integration of multiple strategies biological control, cultural techniques, physical and mechanical controls, and cautious chemical use to keep pest populations below economic thresholds while minimizing risks to the environment and human health (IPCC, 2022).

Bangladesh introduced IPM practices in the 1990s through government and NGO programs, including Farmer Field Schools (FFSs) and donor-supported projects (e.g., DANIDA, FAO, USAID). These initiatives aimed to build farmers' capacity to make informed decisions based on agro-ecological principles (Center for Integrated Pest Management (CIPM), 2020). Despite early successes, large-scale adoption has been slow. Barriers include limited farmer knowledge, poor access to biological control agents (e.g., Trichogramma, Beauveria bassiana), inadequate extension services, and insufficient policy enforcement (Shahidullah *et al*., 2023).

A recent trend in pest management research emphasizes conservation biological control and ecological engineering. These involve enhancing on-farm biodiversity such as planting flowering strips, using hedgerows, or maintaining non-crop habitats to support natural enemies of pests (Shahidullah *et al*., 2015). Such agroecological approaches not only improve pest regulation but also enhance soil health, water conservation, and climate resilience, making them ideal for the context of smallholder-dominated agriculture in Bangladesh.

The growing pressure to increase agricultural productivity has driven widespread use of chemical fertilizers and pesticides in Bangladesh, often without proper guidance or regulation. Monoculture farming, habitat fragmentation, over-irrigation, and the elimination of hedgerows and natural vegetation have further exacerbated biodiversity loss in agricultural landscapes (Piris, 2024). Pesticide overuse directly impacts non-target species such as pollinators, natural predators of pests, soil organisms, birds, and aquatic fauna, thereby weakening the ecosystem services essential for sustainable crop production (Piris, 2024).

One of the most notable consequences is the decline in pollinator populations, including native bees and butterflies, which are critical for fruit, vegetable, and oilseed crops. The loss of these services can result in decreased crop yields, increased dependence on artificial inputs, and overall ecological imbalance (Hossain *et al*., 2020). Moreover, pesticide contamination in water bodies has been linked to reduced fish stocks, amphibian deformities, and loss of aquatic biodiversity in rural and peri-urban zones (Nasrin & Jahan, 2021).

The degradation of biodiversity not only undermines ecological stability but also poses significant economic threats. Many rural households in Bangladesh depend directly on natural resources for their livelihoods, such as fishing, forestry, livestock rearing, and small-scale agriculture. The collapse of biodiversity-based livelihood systems increases rural

poverty, food insecurity, and socio-economic vulnerability, particularly among smallholder farmers and marginalized communities (Augustiny *et al*., 2025).

Additionally, the growing cost of managing resistant pests has become an economic burden. As natural pest regulation services decline due to biodiversity loss, farmers are forced to apply more frequent and stronger doses of pesticides, increasing input costs while potentially reducing net farm income. This "pesticide treadmill" leads to diminishing returns, especially for resource-poor farmers (Gamage *et al*., 2023). In some cases, entire crops have been lost due to secondary pest outbreaks triggered by pesticide misuse, resulting in substantial economic losses for farming communities (IPCC, 2022).

Moreover, biodiversity degradation can disrupt ecotourism, cultural values, and traditional knowledge systems, further eroding community resilience. Ecosystem degradation also weakens the natural buffers against climate change impacts such as floods, droughts, and salinity intrusion—threats that are already disproportionately affecting agriculture in coastal and flood-prone regions of Bangladesh (Alam *et al*., 2023).

Given the intertwined nature of ecological health and economic well-being, conserving biodiversity is not only an environmental imperative but also a critical component of sustainable rural development. Integrated Pest Management (IPM), agroecological farming, conservation agriculture, and the restoration of on-farm biodiversity offer pathways to mitigate biodiversity loss while enhancing agricultural productivity and economic resilience. These approaches can reduce pesticide dependency, enhance natural pest regulation, lower input costs, and contribute to long-term food and livelihood security (Layek *et al*., 2023).

Despite the recognized benefits of IPM and biodiversity-based pest management, existing policies in Bangladesh still favor input-intensive agriculture. Subsidies and market incentives are largely aligned with chemical inputs rather than ecological alternatives (Mazed *et al*., 2022). Furthermore, environmental regulations on pesticide registration, usage, and monitoring are not adequately enforced, and awareness among stakeholders including retailers and consumers remains low.

The institutional capacity for field-level IPM implementation, biodiversity monitoring, and research on ecological pest dynamics remains weak. There is a shortage of trained entomologists, field pathologists, and extension workers skilled in promoting alternative pest management technologies (Alam *et al*., 2023). Moreover, limited collaboration between agricultural and environmental departments restricts integrated action for biodiversity conservation.

In this situation, there is an urgent need to systematically assess the effectiveness of current pest management strategies, their ecological consequences, and the potential for mainstreaming biodiversity friendly alternatives in the agricultural sector of Bangladesh. This study aims to bridge the knowledge and policy gaps by exploring the

links between pest control practices, biodiversity conservation, and sustainable agriculture. It will evaluate ecological, institutional, and socio-economic factors that influence pest management decisions, with a view to developing context-specific recommendations for a more sustainable and resilient agricultural future in Bangladesh. However, without effective policies, institutional capacity, and awareness among farmers and stakeholders, the threats to biodiversity and rural economies will continue to intensify. A holistic, evidence-based, and participatory approach is essential to reverse the trend of biodiversity decline and to foster sustainable agriculture that is economically viable and ecologically resilient. This study aims to evaluate prevailing pest management strategies in Bangladesh, assess their ecological and economic impacts especially on non-target biodiversity and explore opportunities for ecologically sustainable, biodiversity-friendly pest management systems.

METHOD

This study employed a mixed-method, cross-sectional design combining quantitative and qualitative data collection techniques to assess pest management practices, their ecological impacts, and implications for biodiversity conservation across agricultural zones in Bangladesh.

The research integrated field-based ecological assessments, farmer surveys, stakeholder interviews, and laboratory-based pesticide residue analysis, allowing for triangulation and a comprehensive understanding of the socio-ecological dynamics involved in pest control and biodiversity loss.

The study was conducted in five agro-ecological zones (AEZs) in Bangladesh to capture ecological and cropping system diversity as stated below:

- AEZ 11: High Ganges River Floodplain (e.g., Rajshahi, Kushtia)
- AEZ 13: Ganges Tidal Floodplain (e.g., Khulna, Bagerhat)
- AEZ 20: Eastern Surma-Kushiyara Floodplain (e.g., Sylhet)
- AEZ 9: Old Brahmaputra Floodplain (e.g., Mymensingh)
- AEZ 1: Madhupur Tract (e.g., Tangail)

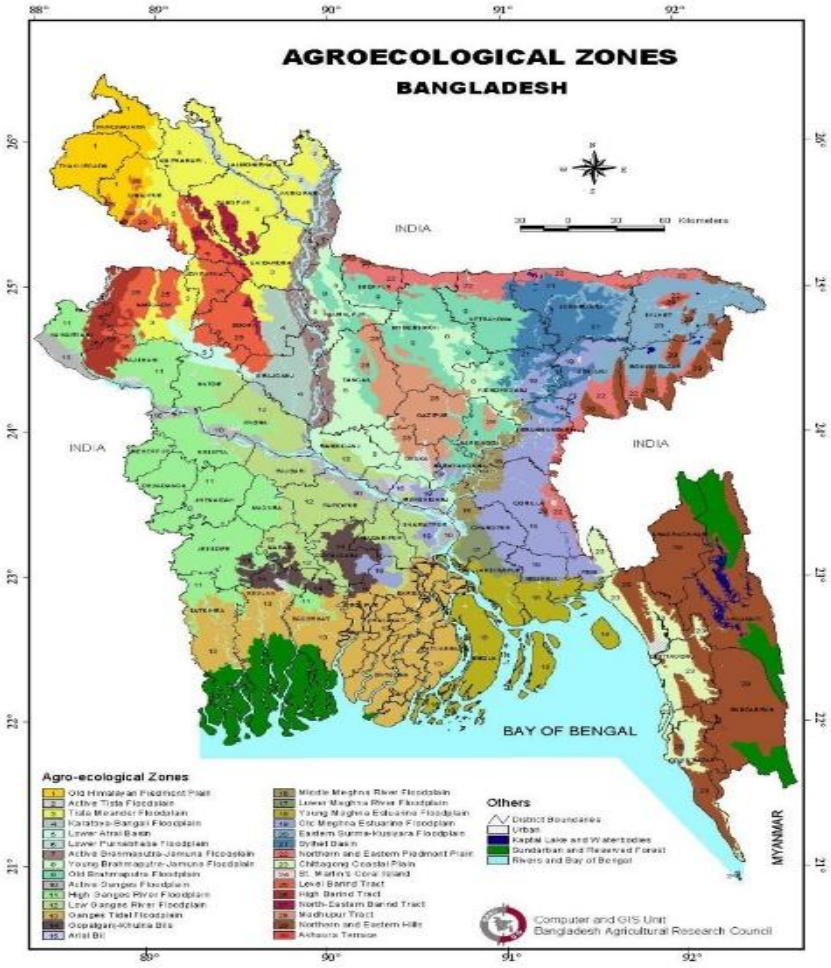


Figure 1. Map of Bangladesh and study area

Selections are clustered based on high level of pesticide use areas, diversity in cropping patterns, proximity to ecologically sensitive areas (e.g., wetlands, forests).

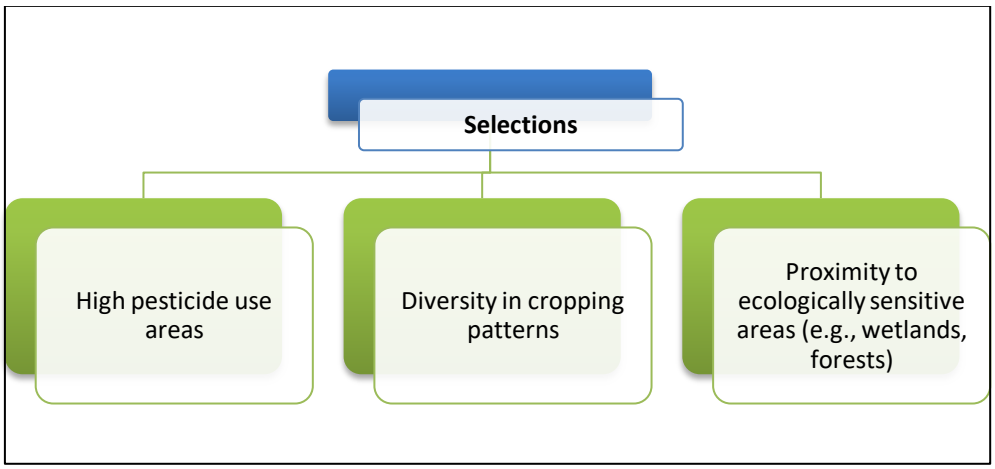


Figure 2. Selective area and scale

Sampling framework for quantitative component consisted of target respondents (Smallholder farmers practicing vegetable, rice, and fruit cultivation), sampling method (Multistage stratified random sampling), sample size (Approximately 500 farmers (100 from each AEZ), determined using Cochran's formula with a 95% confidence level and 5% margin of error).

Sampling framework for qualitative component consisted of Key Informant Interviews (KIIs) With extension workers, local pesticide dealers, IPM specialists, and policymakers (approx. 25–30 interviews), Focus Group Discussions (FGDs) with farmer groups, women farmers, and community-based organizations (2 FGDs per site, total 10), and Biodiversity Observations (Transect walks and habitat assessments with field ecologists in selected fields (minimum 2 locations per site)).

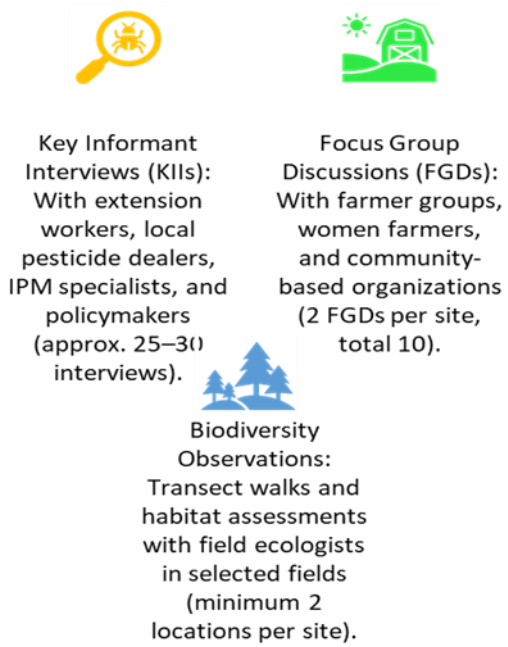


Figure 3. Qualitative component of the study

A pre-tested, structured questionnaire will capture demographic information, cropping patterns, pest control methods (chemical/biological/mechanical), frequency, quantity, and types of pesticides used, farmers' knowledge and perceptions on biodiversity and IPM, sosts and economic returns.

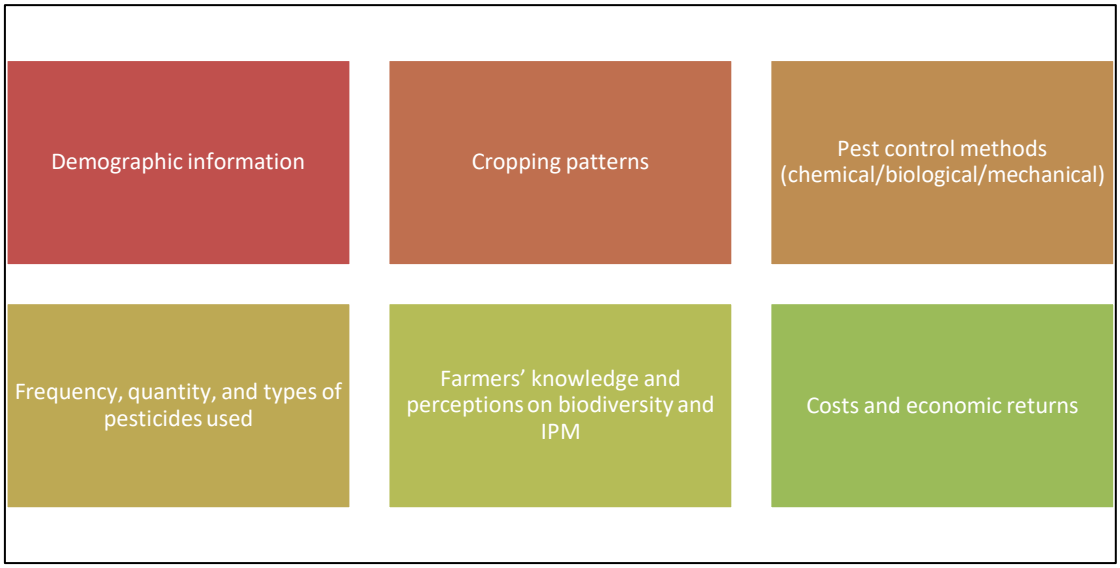


Figure 4. Structured questionnaire survey

Ecological and biodiversity assessment consisted of transect and quadrat sampling to assess insect diversity, especially pollinators, natural enemies, and pest species, pitfall and sweep netting methods for ground and aerial insect sampling, soil and water quality sampling to detect pesticide residues and ecological stress markers, species richness and Shannon-Weiner Diversity Index will be used for biodiversity quantification.

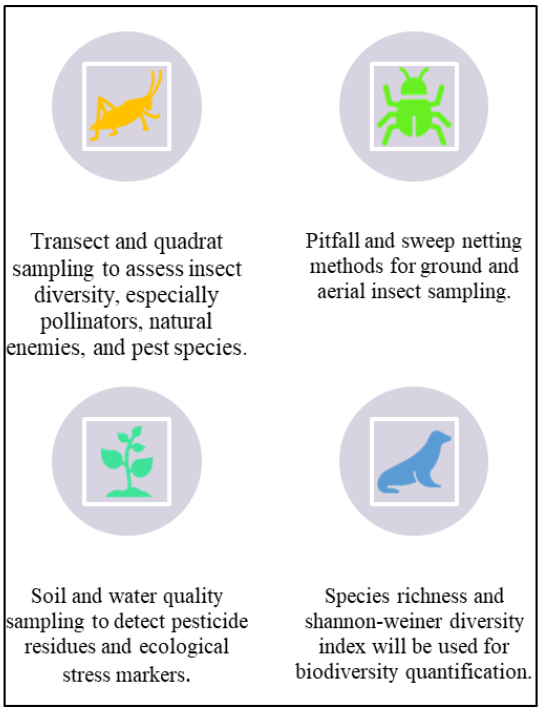


Figure 5. Ecological and biodiversity assessment

Pesticide residue testing. Sample collection: Soil, water, and crop samples from each site. Testing protocols: Gas Chromatography-Mass Spectrometry (GC-MS)

and High-Performance Liquid Chromatography (HPLC) will be used to detect pesticide residues. Samples will be processed in collaboration with BCSIR or other accredited laboratories.

Interviews and FGDs is guided by semi-structured checklists, interviews will cover: Institutional support for pest management, Barriers to IPM adoption, Knowledge of biodiversity impacts. Policy implementation status. FGDs will provide community-level perspectives and gender-specific issues in pest management.

Data Analysis consisted of quantitative and qualitative data. Quantitative data used descriptive statistics which included frequencies, means, and percentages (SPSS or STATA). Secies diversity indices: Shannon-Weiner and Simpson's Index. Richness and abundance analysis using R or PAST software. Cluster and principal component analysis for habitat and species associations. Qualitative data consisted of thematic content analysis using NVivo, and manual coding and triangulation to cross-validate with quantitative data.

This study was Informed written consent will be obtained from all participants. Data confidentiality and anonymity will be strictly maintained.

RESULTS AND DISCUSSION

This study generated a comprehensive dataset on pest control practices, biodiversity status, and the impacts of pesticide use. The results are organized and presented below under five key domains: (1) Pest management practices, (2) Ecological impacts of pesticide use, (3) Status of Integrated Pest Management (IPM) adoption, (4) Biodiversity status in agricultural landscapes, and (5) Economic and perceptual aspects of pest control.

Pest Management Practices in Study Areas

Frequency and Type of Pest Control Measures Used

In the figures the data from 500 surveyed farmers across five agro-ecological zones revealed a high dependence on chemical pesticides. About of 500 farmers surveyed, the majority (84.2%) reported using only chemical pesticides for pest management. A smaller proportion (12.4%) adopted an integrated approach, combining chemical and biological methods. Only 2.8% of the farmers relied solely on biological or organic pest control techniques. Notably, 0.6% of respondents reported not using any pest control measures.

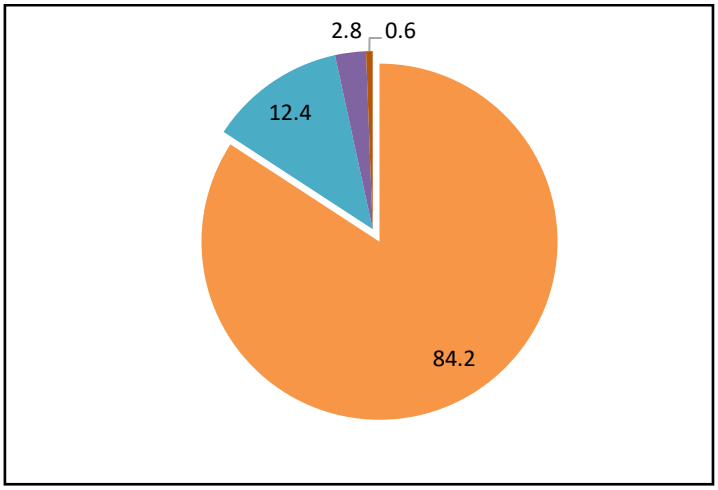


Figure 6. Pest management practice in the study area

Criteria for Initiating Pesticide Use

Most farmers applied pesticides based on crop appearance rather than scientific threshold levels. The findings reveal that the majority of farmers (71.4%) decide to apply pesticides based on visual symptoms, such as leaf discoloration or apparent pest damage. A smaller proportion (13.2%) rely on advice from pesticide retailers, while 12.2% consult agricultural extension agents. Only 3.2% of farmers reported using pest threshold monitoring a scientific approach for determining the need for pesticide application. This indicates a strong reliance on visual cues and informal advice rather than systematic pest assessment methods.

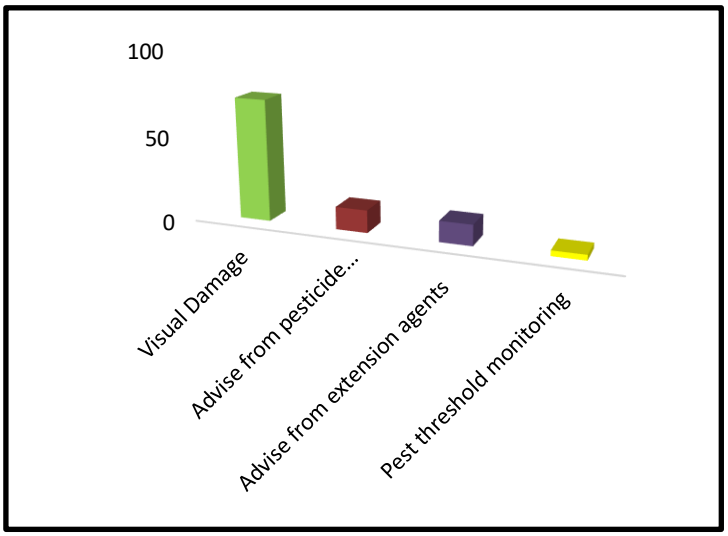


Figure 7. Criteria for Initiating pesticide use decision basis

Ecological Impacts of Pesticide Use Pesticide Residue Levels in Soil, Water, and Produce

Residue testing was conducted using GC-MS and HPLC for 50 composite samples. The analysis of different environmental and food samples revealed widespread pesticide contamination:

Soil samples (n = 20): 80% were contaminated, with 40% exceeding the Maximum Residue Limit (MRL). The most detected pesticides were Chlorpyrifos and Cypermethrin.

Surface water samples (n = 10): 60% were contaminated, and 20% had pesticide levels above the MRL. The main contaminants were Carbendazim and Dimethoate.

Vegetable samples (n = 20): 85% showed contamination, and 45% exceeded the MRL. Frequently detected pesticides included Imidacloprid, Malathion, and residual DDT (Table 1).

Table 1. Pesticide Residue Detection by Sample Type

Sample Type	% Contaminated Samples	Above MRL (%)	Commonly Detected Pesticides
Soil (n = 20)	80%	40%	Chlorpyrifos, Cypermethrin
Surface Water (n=10)	60%	20%	Carbendazim, Dimethoate
Vegetable (n = 20)	85%	45%	Imidacloprid, Malathion, DDT residues

MRL: Maximum Residue Limit

Impact on Non-Target Organisms (Field Transects)

Biodiversity assessments through sweep net and pitfall sampling showed drastic differences in organism diversity and abundance between low- and high-chemical use areas. Aquatic sampling also showed pesticide runoff effects, particularly in rice-fish zones of Khulna. The impact of chemical pesticide use on different insect groups shows a clear contrast between high and low pesticide application environments: Under high chemical use, the presence of pollinators was only 11.6%, compared to 45.2% under low chemical use. Similarly, natural enemies (e.g., predators and parasitoids of pests) were much less prevalent in high chemical environments (6.8%) than in low chemical settings (30.7%). In contrast, pest populations were significantly higher in high chemical use fields (91.3%), but notably lower (47.4%) in areas with reduced chemical input.

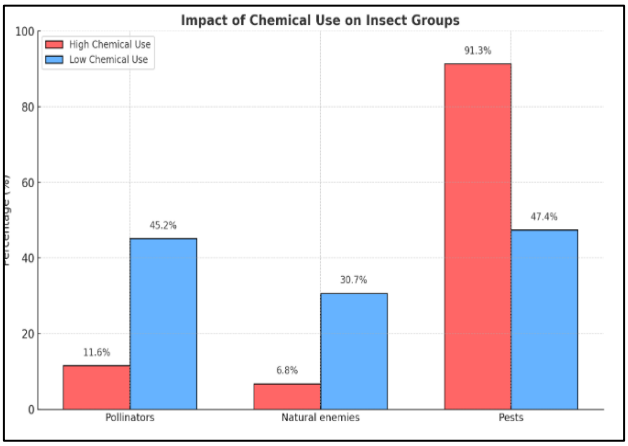


Figure 8. Impact on non-target organisms (field transects)

IPM Adoption and Institutional Engagement

Survey and KII data indicated low but promising engagement with Integrated Pest Management (IPM). The survey findings reveal limited awareness and adoption of Integrated Pest Management (IPM) among the respondents: Only 24.6% of the farmers reported that they had heard of IPM. A smaller proportion, 13.2%, had received any formal IPM training. Just 10.8% were currently practicing any IPM techniques in their farming activities. Adoption was highest in regions with Farmer Field Schools or NGO intervention (e.g., Mymensingh, Sylhet) (Table 2).

Table 2. Awareness and Adoption of IPM (N=500)

Indicator	% of Respondents
Heard of IPM	24.6%
Received any IPM training	13.2%
Currently practicing any IPM technique	10.8%
None to idea	51.40%

Constraints to IPM Adoption (from FGDs and KIIs)

The survey identified several key constraints hindering the adoption of Integrated Pest Management (IPM) among farmers: The most commonly reported barrier was a lack of knowledge and training, cited by 73% of respondents. Perceived low effectiveness of IPM methods was mentioned. Unavailability of bio-inputs (e.g., biopesticides, natural enemies) was a constraint for 58% of farmers. Time-consuming practices associated with IPM discouraged 43% of respondents. Finally, 39% of farmers indicated that the absence of financial incentives or market access reduced their motivation to adopt IPM (Table 3).

Table 3. Reported Constraints to IPM Uptake

Constraint	% of Respondents Reporting
Lack of knowledge and training	73%
Perceived low effectiveness	61%
Unavailability of bio-inputs	58%
Time-consuming practices	43%
No financial incentive or market access	39%

Biodiversity in Agricultural Landscapes

Species Richness and Diversity Indices

Ecological indicators (e.g., Shannon-Weiner Index) showed significant loss of biodiversity in high pesticide areas. The analysis of pollinator diversity across three locations with varying pesticide use levels revealed clear trends: Khulna, characterized by high pesticide use, showed the lowest biodiversity, with a Shannon Index (H′) of 1.19 and pollinator species richness of 6. Rajshahi, with medium pesticide use, exhibited moderate diversity, reflected by a Shannon Index of 1.92 and species richness of 11. In contrast, Sylhet, where pesticide use was low, had the highest biodiversity, with a Shannon Index of 2.68 and pollinator species richness of 18 (Table 4).

Table 4. Species Diversity by Cropping System and Pesticide Use

Location	Pesticide Use Level	Shannon Index (H′)	Pollinator Species Richness
Khulna	High	1.19	6
Sylhet	Low	2.68	18
Rajshahi	Medium	1.92	11

Habitat Features and Biodiversity Status

Landscape metrics indicated the greater species richness near hedgerows, uncultivated margins, and riparian buffers, homogenous, pesticide-intensive fields showed significantly lower ecological connectivity.

Economic and Perception-Based Findings

Cost-Benefit Analysis of Pest Management Approaches

IPM farmers experienced slightly lower yields but higher net income due to reduced input costs and lower pest resurgence. The comparison between chemical-only users and IPM (Integrated Pest Management) users revealed notable differences in pesticide costs, crop yields, and net income. Chemical-only users incurred an average pesticide cost of 7,200 BDT (US$60) per acre, which was more than double the cost for IPM users, who spent 3,200 BDT (US$26) per acre. Despite the lower expenditure on pesticides, IPM users achieved a higher average yield of 1,970 kg per acre compared to 1,720 kg per acre for chemical-only users.

Consequently, the net income after pesticide costs was slightly higher for IPM users at 25,400 BDT per acre, compared to 25,100 BDT per acre for chemical-only users. These findings suggest that the adoption of IPM practices can reduce input costs while improving crop productivity and profitability.

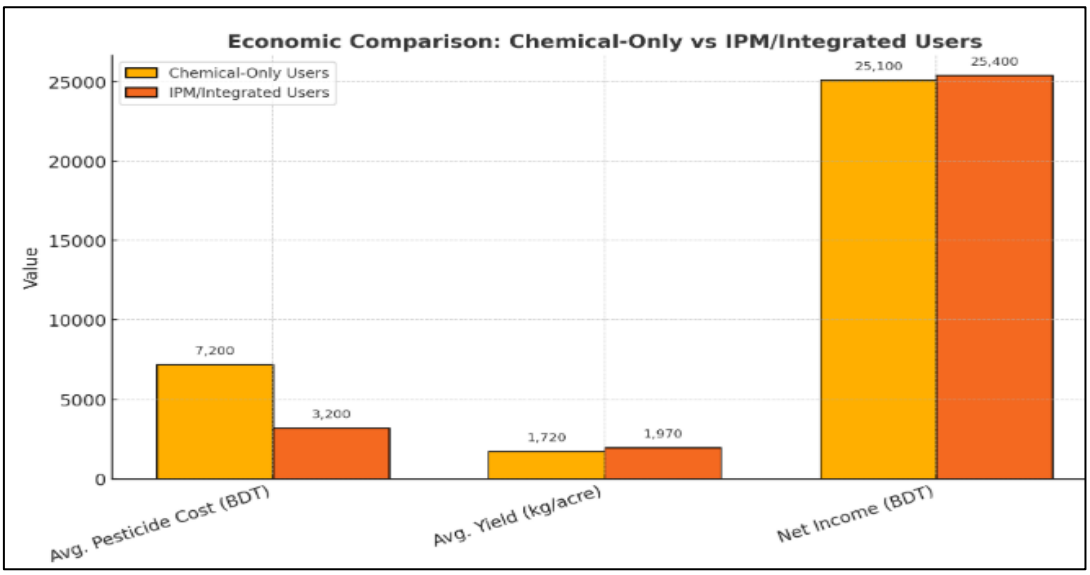


Figure 9. Comparative economic analysis per acre (mean across crops)

Farmer Awareness and Perceptions

The survey revealed respondents' perceptions regarding pesticide use and pest management practices. A majority (66.2%) agreed that pesticides harm beneficial insects and biodiversity. Similarly, 63.8% expressed interest in adopting non-chemical pest control methods, provided crop yield could be maintained. Concerns about health impacts were prominent, with 71.4% agreeing that pesticide use causes health problems within their families. Additionally, 58.9% of respondents supported the inclusion of women in pest management training programs, highlighting the importance of gender-inclusive approaches in agricultural practices (Table 5).

Table 5. Farmer Responses on Biodiversity and Health Concerns

Statement	Agree (%)
Pesticides harm beneficial insects and biodiversity	66.2%
Interested in non-chemical pest control if yield is maintained	63.8%
Pesticides cause health problems in the family	71.4%
Women should be included in pest management training	58.9%

Discussion

This study highlights the critical intersection between pest management practices and biodiversity conservation in the agricultural landscapes of Bangladesh. The findings reveal a widespread dependence on chemical pesticides, limited adoption of Integrated Pest Management (IPM), and significant ecological consequences for pollinators and other non-target organisms. These outcomes resonate with global trends in pesticide-driven ecological degradation and underscore the urgent need for policy and practice reform.

Chemical Pesticide Overuse and Ecological Consequences

The predominance of synthetic pesticide use among Bangladeshi farmers aligns with long-standing national trends (87% of surveyed farmers used chemical inputs exclusively). While these products provide short-term pest suppression, they have increasingly become ineffective due to pest resistance, resurgence, and collateral damage to beneficial species—a phenomenon widely described as the "pesticide treadmill" (Hossain *et al.*, 2024). In this study, frequent and non-threshold-based spraying contributed to increased pest populations, particularly secondary pests, a finding consistent with global observations from intensively farmed systems (Sadique, 2022).

The environmental and health impacts are equally concerning. Laboratory tests confirmed the presence of residues above maximum residue limits (MRLs) in vegetables, soil, and water. This is in agreement with past research in Bangladesh showing pesticide contamination in food chains and aquatic ecosystems (Altieri & Nicholls, 2020). Such contamination is known to disrupt aquatic trophic dynamics, affect fish reproduction, and reduce the abundance of indicator species such as dragonflies and amphibians (Nazarczuk *et al.*, 2024).

Most critically, pollinator populations, especially native bees and butterflies were

substantially reduced in high pesticide-use fields. This supports broader global findings that associate insect population collapses with neonicotinoid and organophosphate exposure (FAO, 2021). Given that over 70% of crops globally rely on animal pollination, including key Bangladeshi crops such as litchi, watermelon, and mustard (FAO, 2021), the observed decline threatens both biodiversity and national food security.

Integrated Pest Management (IPM): Gaps and Opportunities

Although IPM has been promoted in Bangladesh since the 1990s, only 13% of farmers in this study had received any formal IPM training, with just 11% practicing IPM methods. Barriers included lack of knowledge, limited access to biological control agents, and weak extension support similar to findings in South Asia and Sub-Saharan Africa where institutional capacity and input supply systems are underdeveloped (Lloyd & Kossmann, 2021).

Interestingly, farmers using IPM approaches reported similar yields and higher net income than those relying solely on chemicals, due to reduced input costs and more stable pest dynamics. This aligns with findings from Vietnam and Indonesia, where participatory IPM led to 40–60% reductions in pesticide use without compromising yields (Nyamboga *et al.*, 2024). Moreover, IPM encourages ecological literacy, empowering farmers to identify pests and natural enemies, use botanical pesticides, and improve soil and plant health—elements essential for agroecological transformation (Altieri & Nicholls, 2020).

The limited diffusion of IPM can also be attributed to market failures and policy misalignment. Pesticide retailers often serve as the primary source of pest management advice, promoting products over ecological alternatives. This commercial bias impedes knowledge-sharing and reflects a broader need for reforming agro-input markets and strengthening regulatory oversight (Alliot *et al.*, 2022).

Biodiversity Ecosystem Services Linkage

Biodiversity is foundational to ecosystem resilience. In this study, species richness, measured through Shannon-Weiner indices, was significantly higher in ecologically managed fields (Schut & Giller, 2020). Non-crop vegetation (e.g., hedgerows, fallow patches, riparian strips) enhanced habitat connectivity and supported higher levels of pollinators, spiders, parasitoids, and soil organisms. These findings echo the theory of ecological intensification, which posits that biodiversity and ecosystem services can substitute for chemical inputs when habitat complexity is maintained (Sharma, 2021).

However, modern monoculture systems continue to simplify landscapes and reduce biodiversity. In high-pesticide fields, even beneficial birds and frogs were absent, which can lead to pest outbreaks and a need for increased chemical intervention creating a vicious cycle (Naz *et al.*, 2023). Similar patterns have been observed in the Indo-Gangetic plain and parts of Latin America, where biodiversity loss in agroecosystems has destabilized pest–

predator equilibria and reduced yields (Lupi *et al*., 2021).

Furthermore, the study observed that pesticide use and biodiversity decline disproportionately affect vulnerable groups, especially women and landless farmers. Women in particular have limited access to training and decision-making but bear health burdens through direct and indirect pesticide exposure. Addressing such inequities is essential for achieving Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Islam *et al*.,2022).

Policy and Institutional Implications

The study's findings expose critical policy gaps. Although Bangladesh has laws regulating pesticide registration, import, and use (e.g., the Pesticide Act of 2018), enforcement remains weak. Illegal and highly hazardous pesticides are still accessible in local markets, and public sector oversight is undermined by budget and manpower constraints. A reorientation is needed toward a preventive, ecosystem-based pest management system, as advocated by the FAO and IPPC (Food and Agriculture Organization (FAO, 2021).

Opportunity: This study was found out to integrate biodiversity considerations into national agricultural policy through. Incentives for IPM and agroecological practices, Training of extension officers in ecological methods, Public-private partnerships for biopesticide production and distribution, strengthened enforcement against illegal pesticide sales.

The successful upscaling of biodiversity-friendly farming also requires cross-sectoral collaboration involving agriculture, environment, education, and health ministries. Moreover, community-driven models such as Farmer Field Schools (FFS), village biodiversity registers, and local seed banks can build farmer capacity while preserving local ecological knowledge.

CONCLUSION AND RECOMMENDATIONS

This study affirms that unsustainable pest management is a critical driver of biodiversity loss in Bangladesh's agroecosystems, with cascading effects on ecological stability and economic sustainability. While chemical pesticides remain dominant, their long-term consequences necessitate an urgent transition toward biodiversity-integrated pest management approaches. Expanding IPM, conserving on-farm habitats, and reforming input policies are not only technically viable but also economically rational and ecologically imperative. A coordinated, knowledge-driven, and equity-sensitive pest management strategy is strongly recommended, one that aligns agricultural practices with environmental sustainability and public health objectives.

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CONTRIBUTION STATEMENT

Rana MM: Conceptualization, methodology, investigation, data curation, formal analysis, interpretation of results, and writing-original draft. Rahman MR: Methodology, investigation, data validation, interpretation of results, and writing-review and editing. Siregar AZ: Supervision, conceptualization, critical review, editing, and final approval of the manuscript. All authors read and approved the final version of the manuscript.

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