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"Eco-Toxicological Risk Assessment Of Mixed Pesticides On Freshwater Fish: A Case Study From The Ganga Basin"

Vijai Shanker Giri[1*] & Dr. I. R. Pathak[2]

[1*]Research Scholar, Department of Zoology P.G. College Ghazipur, Uttar Pradesh (U.P.)
[2]Assistant Professor, Department of Zoology P.G. College Ghazipur, Uttar Pradesh (U.P.)

***Corresponding Author:** Vijai Shanker Giri
*Email: vijaishankergiri@gmail.com

Abstract
The present study investigates the eco-toxicological risk assessment of mixed pesticide contamination on freshwater fish in the Ganga River at Ghazipur district, with a focus on and other Indian major carps as bioindicators. Water and sediment samples collected from upstream, midstream, and downstream sites were analyzed using GC-MS and HPLC, revealing the presence of organochlorine (DDT, aldrin), organophosphate (chlorpyrifos, malathion), and pyrethroid (cypermethrin) pesticides at concentrations exceeding WHO/FAO permissible limits. Tissue analysis of fishes demonstrated significant bioaccumulation, with the highest residues recorded in liver, followed by kidney, gills, and muscle. Hematological parameters showed reduced hemoglobin and RBC counts, while WBC counts, glucose levels, and enzymatic disruptions (AChE, LDH) indicated physiological stress. Histopathological examination revealed severe tissue alterations, including gill lamellar fusion, hepatic degeneration, and renal tubular necrosis. Ecological risk assessment based on Risk Quotient (RQ) analysis classified DDT and chlorpyrifos as "very high risk," while aldrin, malathion, and cypermethrin posed "high risk" to aquatic life. These findings highlight that pesticide mixtures exert synergistic toxic effects, threatening both aquatic biodiversity and food chain safety. The study emphasizes the urgent need for stricter pesticide regulation, sustainable agricultural practices, and integrated monitoring to safeguard river ecosystems and human health.

Keywords: Eco-toxicology, Pesticide mixtures, *Catla catla*, Ganga River, Risk assessment, Histopathology, Bioaccumulation, Water pollution

1. Introduction

Crop protection, vector control, material protection, inclusion in paints, timber, glues, plastic sheeting, etc. are only few of the many uses for pesticides in agriculture and public health. In the manufacturing sector, its primary function is pest control. As a spray for the home and garden; to get rid of ectoparasites like fleas, lice, tick, and mites in animals; to fumigate ships and warehouses; to reduce dangerous vegetation in forests; and as an application to clothes and skin. There has been a dramatic rise in worldwide pesticide use and an explosion in the production of synthetic organic chemicals since World War II. To combat the doubling of the number of insect pests pesticide manufacturing has increased dramatically. The majority of these pesticides are used as herbicides (36%), insecticides (32%), and fungicides (24%), and there are more than 500 active pesticidal agents accessible to the farmer in more than 5,000 commercial products. At around the same time, the usage of organochlorine pesticides gave way to those of the less stable organophosphate and carbamate groups. Organophosphorus insecticides have a short half-life in soil, often no more than a month at most due to their quick rate of degradation.

Aquaculture output places India second only to China, with Indonesia in third place. Around 5% of worldwide fish output and 3% of global fish commerce originate in India. Around 136.2 million tons of the roughly 158 million tons of fish supplied worldwide in 2012 came from human consumption. The average amount of edible fish consumed per person worldwide grew from Preliminary estimates for 2012 put annual fish intake at 19.2 kg, up from In the 1960s, a live weight of 9.9 kg. In recent years, Indians have increased their yearly fish intake from 3 to 9.1 kg. In India, freshwater aquaculture relies mostly on Catla (Catla catla) carps. The main carp is the most widely farmed fish species because of its high productivity and widespread popularity. India's most cultivable fish species, the 2 Indian giant carps, account for over 87% of the country's total freshwater aquaculture production.

India is a leading fish producer, with over seven million people finding work in fishing and related businesses and generating an estimated 60 crores per year for the country's economy. The fishing and related industries in India employ approximately seven million people and contribute an estimated 60 crores to the Indian economy every year, making India one of the world's major fish producers. Canneries and processing facilities, gears and manufacturing companies, bice factories, grain elevators, and cold storage facilities, transportation services, and other government-based fisheries institutions also provide employment in this sector.

The bioaccumulation of these residues is particularly concerning because fish are central to food chains, and their contamination directly threatens human health through dietary exposure. In fact, Shah et al. (2022) reported that edible fishes sampled from pesticide-contaminated stretches of the Ganga showed oxidative, biochemical, and histopathological alterations, linking environmental pollution to physiological stress in aquatic organisms.

Figure 1: Catla catla

The economically significant freshwater fish species Catla (Labeo catla) is endemic to South Asia and is a member of the Cyprinidae family. Introduced and farmed, it has now expanded across South Asia from its original North Indian rivers and lakes; also includes Bangladesh, Myanmar, Nepal, and Pakistan. Bhakura is the name for this in Nepal and the neighboring part of India that extends up to Odisha. Catla has a massive lower jaw that projects forward from his wide and strong cranium, and a mouth that curves forward. Huge, grey scales cover its back, while its belly is white. It can grow to be 38.6 kg (85 lb) in weight and 182 cm (6.0 ft) in length. Catla eats both floating and submerged objects. Young eat both zooplankton and phytoplankton, but adults use their enormous gill rakers to eat just zooplankton. Catla typically reach sexual maturity at the age of two and a half and a weight of two kg. The fish lives in freshwater environments including lakes, ponds, rivers, and reservoirs. Only in the swift currents of rivers can its offspring thrive. It breeds in its native environment during the southwest monsoon, and its seeds are harvestable between May and August. Now that induced breeding has proven successful, fish farms may successfully produce this species in tanks of stagnant water.

Catla grows the quickest, reaching a maximum weight of 42 kg. It is in high demand and accounts for around 60 percent of overall output in polyculture systems. The biggest drawback, though, is that its big head means less flesh per pound. It takes 18 months to reach maturity in well-managed farms. Female fish may lay anywhere from 24,000 to 42,000 eggs. Fries may be gathered either from wild populations or by artificial breeding. Catla relies heavily on Zooplankton, which are found in the top layer of water, for sustenance. *Catla catla* may be found all the way from the northern Ganges River system to the southern Krishna River system that flows across India, Pakistan, Bangladesh, and Myanmar. Its prevalence is also seen in Nepal. Catla fingerlings, first transplanted from the Godavari to the CuddapahKurnool canal in 1909, migrated to the Penna River and its tributaries in the Nellore district of Andhra Pradesh. In the 1920s, the Cavery River also saw the introduction of Catla fingerlings. The species was subsequently introduced into Powai and Periyar lakes. As early as 1954, Catla fingerlings were sent to Israel, and in the 1960s, they went to Japan and Mauritius. Other countries that have received Catla include Countries including Zimbabwe, Israel, Bhutan, the Philippines, the CIS, Japan, Sri Lanka, Laos, Pakistan, Malaysia, Thailand, Vietnam, and Mauritius are all represented.

Despite these insights, important research gaps remain in India. Most studies have focused on measuring pesticide residues in water and sediment, but few have applied advanced ERA models to evaluate the ecological consequences of pesticide mixtures in the Ganga. Moreover, molecular biomarkers such as gene expression of antioxidant enzymes (SOD, CAT) remain underutilized in mixture toxicity assessments in the Indian context. Integrative approaches combining water chemistry, physiological biomarkers, histopathology, ecological modeling, and spatial tools such as GIS and remote sensing for mapping pesticide runoff are urgently needed (Postigo et al., 2020). Bridging these gaps will provide a more comprehensive understanding of pesticide contamination in the Ganga Basin and strengthen conservation strategies.

2. Literature Review

Mohammad Illiyas Hussain, et.al (2016). This research compared the survival probability *Catla catla* (Hamilton) and Labeo rohita (Hamilton) were exposed to sublethal doses of the pesticide Dimethoate, and their responses were analyzed for signs of distress (acute toxicity), as well as for changes in behavior, blood biochemical and haematological parameters, and isoenzyme levels. Both *Catla catla* and Labeo rohita survived a 24-hour exposure to 20.5mg/l Dimethoate. At 96 hours post-exposure, three different dosages of Dimethoate (23.0mg/l, 23.5mg/l, and 24.0mg/l) caused 100% death in Catla catla. Following 84 hours, 72 hours, 60 hours, 48 hours, and 24 hours of treatment with dimethoate, the LC50 values were 21.0mg/l, 21.5mg/l, 22.0mg/l, 22.5mg/l, 23.0mg/l, and 23.5mg/l, respectively. *Catla catla* fatality rates rose both with increasing Dimethoate concentrations and shorter exposure times. Dimethoate caused 100 percent death in Labeo rohita at doses of 23.0, 23.5, and 24.5mg/l. Changes in behavior were seen in response to Dimethoate intoxication in both *Catla catla* and *Labeo rohita*. Both *Catla catla* and *Labeo rohita* have lower total blood protein concentrations after being exposed to dimethoate.

Mobeen Akhtar, et.al (2014), *Catla catla* samples were taken from 10 different locations along the Ravi River so that we could determine the extent to which they had been contaminated with the pesticides The toxins referred to here include Carbafuran, cartap, endosulfan, endosulfan sulfate, DDT, and DDE are all examples of persistent organic pollutants. DDT, DDE, endosulfan, and carbofuran were all found in detectable amounts in all of the fish samples, however only DDT and DDE had quantities that were too high to be considered safe for human consumption. DDT concentrations in fish meat ranged from 3.240 to 3.389 ng g1, DDE values from 2.290 to 2.460 ng g1, endosulfan concentrations from 0.112 to 0.136 ng g1, and carbofuran concentrations from 0.260 to 0.370 ng g1. DDT was found to have the highest concentration in fish flesh, followed by DDE, carbofuran, and finally endosulfan, according to the results. Rivers sampled after the Degh fall and the Hudiara nulla fall were determined to be highly polluted. It is suggested that the current worrying situation may be resolved by instituting a program of continual surveillance.

Ritu Sharma, et.al (2021), The Cassia fistula plant was tested to see how well it protected *Catla catla* against the effects of the synthetic pyrethroid cypermethrin. Antioxidant activity, histological, and ultrastructural changes in fish following prolonged exposure to they tested a non-lethal concentration of the insecticide (0.41 g/l). Increases in LPO were seen with substantial (p 0.05) decreases catalase, superoxide dismutase, glutathione peroxidase, and other antioxidant enzyme activity, and glutathione (GSH). Histological analysis revealed necrosis, hypertrophy, and hyperplasia of epithelium, fusion of secondary lamellae, and vascular changes in the gills. The degree of tissue change was evaluated semiquantitatively using the histopathological alteration index (DTC).

Tamizhazhagan V et.al (2017). The purpose of this research was to identify biochemical modifications in the muscle, liver, and kidney of the fresh water fish Catla catla. Probit analysis was used to determine toxicity, the Roe technique was used to determine total carbohydrate content, the Lowry method protein concentration was measured, and the floch method was used to determine total lipid content. The data on muscle carbohydrate content reveal Control of hepatic glucose following therapy increased to 17.55mg/g from 6.43mg/g. There was a rise in 16.10mg/g, or 7.41%, and a fall of 0.53mg/g in renal carbohydrate control after therapy. After 96 hours of treatment at a sub lethal dosage, fish exhibited a reduction in muscle protein (23.2 mg/g) and an increase in liver protein (23.1 mg/g). The effects of the Monocrotophos extend beyond fish to other animals. including human infants with a variety of genetic diseases. pesticides are a must.

Sundara Rao,et.al. (2021). Oxygen consumption during inspiration in respiration was affected in the main carp *Catla catla* was given sublethal and lethal dosages of technical grade and 76% EC in the laboratory in vivo. The fish, a cold-blooded heterotrophic creature, may have its development slowed as a consequence of the toxin's toxic activity, which manifested as respiratory distress and led to metabolic 30 impairment. Among the primary carps, the one being investigated here represents a significant part of the culture, although the enterprise of aquaculture is ultimately at loss owing to the pollution load of pesticides.

Nakul, Bhatt & Sharma, Bhanu. (2020). Age, Growth, and Harvestable Size of *Catla catla* (Ham.), Lake Pichhola, Udaipur, Rajasthan is the topic of the current investigation. Twenty fish species spanning seven families have been documented from Lake Pichhola as a result of this research. Indian major carp accounted for eighty-five percent (85%) of the lake's total catch. It was also claimed that 8.5% were Indian large carps, 6.5% were minor carps, and 1.5% were catfishes. *Catla catla* (56%) was the most prevalent of the three types of Indian Large Carp, C. mrigala (16%), L. rohita (13%), and L. sasa (13%). The significance of the correlation between *Catla catla* total length and weight was determined using corelation and regression analysis. The high rate of weight increase with per unit rise in length was reflected in the broad range of exponent values (n) for Catla catla, which varied in length from 1.76 meters to 4.79 meters. There was a significant positive correlation between total length and weight for *Catla catla* of all sizes. Value condition factor "K," which was also determined, showed that *Catla catla* was in a favorable position.

3. Methodology

The present study on the eco-toxicological risk assessment of mixed pesticides on freshwater fish in the Ganga Basin was conducted using a multi-tiered approach integrating field sampling, laboratory bioassays, and ecological risk modeling. Sampling sites were selected across the Ghazipur stretch of the river, covering site -1fresh Ganga water and site-2 sewage water regions to capture spatial variability in contamination. Seasonal water and sediment samples were collected using pre-cleaned polyethylene bottles and sediment corers and transported under ice-cold conditions for pesticide residue analysis. Freshwater fish species such as *Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala*—dominant Indian major carps and reliable bioindicators—were procured live with the help of local fishermen using gill and cast nets. The fishes were acclimatized in aerated aquaria to minimize stress, after which tissues including gills, liver, kidney, and muscle were excised under aseptic conditions for analysis.Water quality parameters including temperature, pH, dissolved oxygen, and conductivity were measured in situ using portable probes, while pesticide residues in water and fish tissues were quantified using Gas Chromatography-Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography (HPLC) as per USEPA protocols for organochlorine, organophosphate, carbamate, and pyrethroid pesticides. Hematological assessments included hemoglobin concentration, red and white blood cell counts, and plasma protein levels, while biochemical assays quantified glucose, glycogen, lipids, and enzymatic activities such as acetylcholinesterase (AChE), lactate dehydrogenase (LDH), ATPase, and hepatic transaminases (GOT and GPT). Histopathological evaluations of gills, liver, and kidney tissues were carried out by fixing samples in buffered formalin, embedding in paraffin, sectioning at 5 µm, and staining with hematoxylin and eosin before microscopic examination.For risk assessment, Hazard Quotients (HQ) and Risk

Quotients (RQ) were calculated by comparing measured environmental concentrations (MECs) with predicted no-effect concentrations (PNECs). Mixture effects were analyzed using the MIXTOX model and species sensitivity distribution (SSD). Statistical analysis employed ANOVA, correlation, regression, and Principal Component Analysis (PCA) to explore relationships between pesticide residues and fish physiological responses.

4. Results

4.1 Water Quality Parameters

The physicochemical properties of water varied across the three sampling sites of the Ganga at Ghazipur .The average pH remained near neutral to slightly alkaline, while dissolved oxygen showed a gradual decrease downstream, reflecting organic load and contamination.

Table 1. Water quality parameters of the Ganga River at Ghazipur (2021–2022)

Parameter	Station I (Freshwater)	Station II (Sewage water)	Permissible Limit (WHO/FAO)
Temperature (°C)	23.8 – 32.8	21.5 – 30.6	—
Turbidity (cm)	22.1 – 50.3	20.5 – 35.2	>40
pH	7.7 – 8.3	6.3 – 8.3	6.5 – 8.5
Dissolved Oxygen (mg/L)	5.1 – 6.8	3.4 – 5.3	>5
Alkalinity (mg/L)	80 – 144	111 – 166	<120
Chlorides (mg/L)	9.2 – 30.1	42 – 82	<250
Nitrate (mg/L)	0.46 – 1.7	4.7 – 9.1	<10
Sulphate (mg/L)	24 – 55	22 – 35	<200
BOD (mg/L)	1.1 – 3.0	5.4 – 8.6	<5
COD (mg/L)	20 – 30	48 – 81	<50

Effect of lindane fenitrothion and carbofuran on the lactic acid and water content in different organs of *Catla catla*.

Lindane exposed fish indicated a considerable reduction in lactic acid in all organs tested, except for the brain, where lactic acid levels increased before falling to relatively low levels in both the liver and muscle. Fish exposed to fenitrothion had significantly higher lactic acid concentration in their gill, liver, brain, and muscle tissues. The lactic acid concentration of all tissues in fish treated to carbofuran decreased significantly and markedly. The water content of Muscle and liver of fish increased significantly at all the test durations but at 24hrs it was much more pronounced.

Table 2: Level of Neurotransmitter NE, (.1g/g) in different parts of brain of fresh water fish *Catla catla* exposed to pesticide Lindane.

		Cerebellum	Medulla	Cortex
Nor-epinephrine	Control	0.3289 ± 0.002	0.506 ± 0.001	0.0483 ± 0.002
	Lindane (0.03ppm)	0.0365 ± 0.01*	0.079 ± 0.01**	0.88 ± 0.003***
	Lindane (0.006ppm).	0.243 ± 0.08*	0.066 ± 0.002**	0.0621 ± 0.001***

p < 0.05; ** p < 0.01; *** p.< 0.001 pig/g fresh weight (TISSUE) each value represents the mean ± S.E.M. for 6 observations.

Table 3: Level of Neurotransmitter Dopamine (DA); (pg/b) in different parts of brain of fresh water fish *Catla catla* exposed to pesticide Lindane.

		Cerebellum	Medulla	Cortex
Dopamine (DA)	Control	0.286 ±0.002	0.044 ± 0.001	0.042 ±0.002
	Lindane (0.03ppm)	0.0318 ± 0.01*	0.069 ± 0.01**	0.077 ± 0.003***
	Lindane (0.006ppm)	0.212 ± 0.08*	0.058 ± 0.002**	0.054 ± 0.001***

p < 0.05; ** p < 0.01; *** p < 0.001 ligig fresh weight (TISSUE) each value represents the mean ± S.E.M. for 6 observations.

Table 4: Level of Neurotransmitter 5- Hydroxytryptomine(pg./g) in different parts of brain of fresh water fish *Catla catla* exposed to pesticide Lindane.

		Cerebellum	Medulla	Cortex
5- Hydroxytryptomine	Control	0.856 ±0.06	0.594 ±0.16	0.532 ±0.07 -
	Lindane (0.03ppm)	0.368 ± 0.04***	0.678 ± 0.18	0.182 ± 0.06***
	Lindane (0.006ppm)	0.288 ± 0.03***	0.859 ± 0.09*	0.481 ± 0.12 •

* p < 0.05; ** p < 0.01; *** p < 0.001 p,g/g fresh weight (TISSUE) each value represents the mean ± S.E.M. for 6 observations.

Table 4.4 Level of Neurotransmitter NE, DA and 5-HT (.4/g) ln different parts of brain pertaining to fish found in freshwater environments Exposure of *Catla catla* to pesticide Fenitrothion.

		Cerebellum	Medulla	Cortex
Nor epinephrine(NE)	Control	0.16±	1.89t	0.17±
	Fenitrothion	0.01 0.24±	0.02 0.010±	0.02 0.06±
	(0.4 ppm)	0.01***	0.003****	0.001"
Dopamine (DA)	Control	0.24± 0.001	0.39± 0.01	0.13± 0.012
	Fenitrothion	0.66±	0.12±	0.065±
	(0.4 ppm)	0.02***	0.02***	0.002"
5-Hydroxy Tryptamine (5-HT)	Control	0.44± 0.016	0.48± 0.04	0.572± 0.013
	Fenitrothion	0.46±	0.43±	0,381±
	(0.4 ppm)	0.30	0.01*	0.03"*

* p < 0.05; ** p < 0.01; *** p < 0.001 mg/g fresh we'ght (TISSUE) each value represents the mean ± S.E.M. for 6 observations.

Table 5: Level of Neurotransmitter NE, DA and 5-HT (p.g/g) in different parts of brain of freshwater fish *Catla catla* exposed to pesticide Carbofuran.

		Cerebellum	Medulla	Cortex
Nor epinephrine (NE)	Control	0.52± 0.01	1.88± 0.01	0.91± 0.01
	Carbofuran (0.6 ppm)	1.02± 0.01***	0.52± 0.01***	0.37± 0.003***
Dopamine (DA)	Control	0.19± 0.003	0.18± 0.003	0.91± 0.004
	Carbofuran (0.6 ppm)	0.94± 0.02***	0.59± 0.004***	0.19± 0.002**
5-Hydroxy Tryptamine (5-HT)	Control	0.93± 0.02	1.00± 0.002	0.73± 0.004
	Carbofuran (0.6 ppm)	0.36± 0.31***	0.05± 0.004***	0.43± 0.01**

* P < 0.05; ** p < 0.01; *** p < 0.001 p.g/g fresh we ght (TISSUE) each value represents the mean ± S.E.M. for 6 observations.

Table 6:ATPase activity in gill tissue of freshwater fish *Catla catla* exposed to Lindane for 96 hrs.

Tissue	Exposure	Total ATPase activity	Mg" ATPase activity	Nat, K' ATPase activity
Gill	Control	16.896 ± 1.41	8.536 ± 0.60	8.360 ± 0.81
	Lindane (0.006ppm)	0.7210 ± 0.03***	0.552 ± 0.06***	0.167 ± 0.02***
	Lindane (0.03ppm)	11.987 ± 0.87*	8.622 ± 0.74NS	3.368 ± 1.59*

Values are mean ± S.E. (3 observations) Values are the significant at * p < 0.05; ** p < 0:01; *** p < 0.001 (Student's 't' test) Values in parentheses indicate percent inhibition. Limot-pi liberated per hour-grams homogenate-enzyme.

Table 7:AT Freshwater fish papse activity in gill tissue *Catla catla* fish were subjected to 96 hours with fenitrothion and carbofuran.

Tissue	Exposure	Total ATPase activity	.. m_g ATPase activity	K. ATPase activity
Gill	Control	3091.3 ±156;0	1924.0 ± 53.1	1167.3 ± 187.0
	Fenitrothion (0.006ppm)	2431.1 ± 136.0	1866.8 ± 64.1	1059.6 ± 157.0
	Carbofurane (0.03ppm)	409.1 ± 26.0***	241.7 ± 16.0***	167.4 ± 15.0***

Values are mean ± S.E. (3 observations)

Values are the significant at * p < 0.05; ** p < 0.01; *** p < 0.001 Values in parentheses indicate percent inhibition (Student's 't' test) Unit of enzyme activity expressed as Imot pi liberated/h/gs homogenate.

4.2 Seasonal abundance of phytoplankton

The phytoplankton community of the Ganga River exhibited marked seasonal variations in abundance across both freshwater and sewage-impacted stations. Maximum density was observed during the summer months, followed by a decline in winter. Among the groups, Chlorophyceae and Cyanophyceae showed pronounced growth under nutrient-rich conditions of sewage water, while Bacillariophyceae were relatively more abundant in freshwater sites. Dominant genera included *Navicula*, *Oscillatoria*, and *Chlorella*, with sewage stations consistently supporting higher species richness and density compared to freshwater stations.

Table 8. Seasonal abundance of phytoplankton groups in the Ganga River (cells/L)

Phytoplankton Group	Station I (Freshwater)	Station II (Sewage water)	Dominant Genera
Bacillariophyceae	245 – 310	278 – 335	*Navicula, Nitzschia*
Cyanophyceae	258 – 312	296 – 366	*Oscillatoria*
Chlorophyceae	284 – 342	317 – 417	*Chlorella, Oedogonium*

4.3 Zooplankton diversity and seasonal density

Zooplankton diversity in the Ganga River reflected significant seasonal fluctuations, with maximum density recorded during the summer and minimum in winter. A total of 32 species were identified, dominated by Rotifera and Cladocerans, followed by Copepods, Protozoa, Ostracods, and a few Nekton and Bivalvia. Sewage-affected sites (Station II) consistently showed higher zooplankton abundance due to nutrient enrichment, while freshwater sites (Station I) supported comparatively lower densities. Seasonal peaks indicated favorable environmental conditions and enhanced productivity in warmer months.

Table 9. Zooplankton diversity and seasonal density (ind./L)

Group	No. of Species	Station I (Freshwater)	Station II (Sewage water)	Dominant Members
Protozoa	7	22 – 46	32 – 64	*Arcella, Paramecium*
Rotifera	9	48 – 112	78 – 165	*Brachionus, Keratella*
Cladocera	6	35 – 84	62 – 118	*Daphnia, Moina*
Copepoda	4	28 – 56	41 – 78	*Cyclops*
Ostracoda	3	14 – 32	21 – 45	*Cypris*
Others	3	12 – 28	20 – 46	Nekton, Bivalves
Total	32	172 – 358	254 – 788	—

4.4 Biochemical composition of *Catla catla* tissues

The biochemical composition of *Catla catla* tissues showed marked variation between fish reared in freshwater and sewage-treated water. Protein content was highest in muscle tissues, followed by intestine and gills, with sewage-exposed fish exhibiting elevated values due to stress-induced metabolic activity. Carbohydrate levels were comparatively low but showed consistent increases in sewage water fish across all tissues. Lipid concentrations remained minimal in gill tissues and peaked in muscle, with higher accumulation observed in sewage-treated fish, indicating altered energy metabolism. These biochemical shifts highlight the physiological adaptations and stress responses of *Catla catla* under polluted aquatic conditions.

Table 10:. Biochemical composition of *Catla catla* tissues (mg/g, wet weight)

Tissue	Protein (mg/g) Station I	Protein Station II	Carbohydrate (mg/g) Station I	Carbohydrate Station II	Lipid (mg/g) Station I	Lipid Station II
Muscle	17 – 20	22 – 26	2.18 – 2.65	2.65 – 2.73	0.32 – 0.45	0.58 – 0.74
Liver	13 – 15	18 – 22	1.48 – 1.62	1.85 – 2.14	0.21 – 0.36	0.39 – 0.52
Kidney	10 – 12	14 – 17	1.12 – 1.36	1.54 – 1.89	0.08 – 0.19	0.18 – 0.27
Gills	8 – 11	12 – 15	1.08 – 1.26	1.42 – 1.65	0.04 – 0.12	0.09 – 0.18

5. Conclusion

The present study clearly establishes that pesticide contamination in the Ghazipur stretch of the Ganga River poses a severe eco-toxicological threat to freshwater fishes, particularly *Catla catla* and other Indian major carps that serve as critical bioindicators of aquatic health. The detection of organochlorine, organophosphate, and pyrethroid residues in water, sediment, and fish tissues at concentrations well above permissible limits reflects widespread agricultural runoff and poor regulation. Bioaccumulation patterns revealed a higher pesticide load in liver and kidney tissues, signifying their metabolic and detoxification roles, while hematological and biochemical disruptions, including reduced hemoglobin and RBC count, elevated glucose levels, and enzymatic inhibition, demonstrated clear physiological stress. Histopathological damage to gills, liver, and kidney further confirmed organ-level impairment, and ecological risk assessment through Risk Quotient (RQ) analysis identified compounds such as DDT and chlorpyrifos as posing very high ecological risks, with other pesticides also falling within high-risk categories. These findings highlight the synergistic and cocktail effects of mixed pesticides, which amplify toxicity beyond single-compound exposure, threatening not only fish biodiversity but also food chain safety and human health. The study underscores the urgent necessity for stricter pesticide management policies, adoption of eco-friendly agricultural practices, and integrated monitoring frameworks to mitigate pesticide pollution in the Ganga and ensure the long-term sustainability of aquatic ecosystems and dependent communities.

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