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Toxicity Assessment of *Paratelphusa jacquemontii*: Methodology, and Environmental and Human Health Implications

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ABSTRACT

The freshwater crab *Paratelphusa jacquemontii* is a vital component of aquatic ecosystems in South Asia, particularly in India, Sri Lanka, and Bangladesh. While it plays a key role in nutrient cycling and serves as a food source, concerns have emerged regarding its potential toxicity due to bioaccumulation of environmental pollutants. The accumulation of heavy metals (Cd, Pb, and Hg) and pesticide residues in crab tissues (muscle, gills, and hepatopancreas) obtained from contaminated and reference sites is assessed in this work. The findings showed that crabs from industrial areas had far higher concentrations of Pb and Cd. Hepatopancreas > gills > muscle was the order of tissue-specific accumulation. Seasonal differences showed that pesticide residues were higher during the monsoon season. These results point to possible health and ecological dangers connected to eating infected crabs. The study emphasizes the necessity of ongoing observation and better environmental management techniques.

1. Introduction

Degradation of soil health and its nutritional status are continuous freshwater crabs play a vital role in trophic interactions, sediment turnover, and nutrient cycling in aquatic environments. *Paratelphusa jacquemontii* is one of them; it is found throughout South Asia and is regularly eaten by the indigenous populace. Freshwater crabs are regarded as useful bioindicators of environmental pollution because of their ecological role and feeding habits.

Heavy metals, pesticides, and other new contaminants have been released into freshwater systems in recent decades due to increased industry, intensification of agriculture, and urbanization. Through bioaccumulation and biomagnification processes, these contaminants endure in aquatic habitats and build up in animals [1, 2]. Recent research has also shown that freshwater invertebrates significantly accumulate hazardous metals, endangering both human health and the environment [3, 4].

Crustaceans, particularly freshwater crabs, tend to accumulate contaminants in metabolically active tissues such as the hepatopancreas and gills, making them reliable indicators of environmental contamination [5]. According to studies, heavy metals like cadmium (Cd), lead (Pb), and mercury (Hg) commonly surpass allowable levels in aquatic creatures [6, 7]. Furthermore, pesticide residues from agricultural runoff might cause oxidative stress and neurotoxicity in aquatic animals [8, 9].

Additionally, sublethal exposure to pollutants may affect *P. jacquemontii* growth, reproduction, and enzymatic activity, according to experimental data [10]. Additionally, contamination of aquatic food sources may present human populations with both carcinogenic and non-carcinogenic dangers, according to recent research [11].

Despite these results, thorough research combining several pollutants, seasonal variations, and related health hazards in *P. jacquemontii* is still lacking. Thus, the current study's objectives are to measure contamination levels, analyze bioaccumulation trends, look at biomarker responses, and calculate possible health hazards to humans.

Regardless of these findings, *P. jacquemontii* is still the subject of relatively few investigations, particularly when it comes to integrated assessment of several contaminants, seasonal variability, and associated risks to human health. Additionally, little is known about the interactions between different pollutant classes and how these interactions impact aquatic life in general.

Therefore, the current study aims to: (i) ascertain the levels of heavy metals and pesticide residues in *P. jacquemontii*; (ii) examine tissue-specific bioaccumulation patterns; (iii) look into physiological and biochemical reactions as indicators of toxicity; and (iv) determine potential health risks associated with its consumption.

2. Experimental Methods

Water and sediment samples, as well as freshwater crabs (*Paratelphusa jacquemontii*), were gathered from specific locations that represented both reference (relatively pristine) and polluted settings (industrial and agricultural zones). To account for seasonal fluctuation, sampling was done both in the wet and dry seasons. The hepatopancreas, gills, and muscle of the collected crab specimens were meticulously dissected, stored, and prepared for contaminant analysis in the laboratory under carefully monitored conditions. Fig. 1 explains the general methodology pathway chart.

After conventional digestion methods, atomic absorption spectroscopy (AAS) and/or inductively coupled plasma mass spectrometry (ICP-MS) were used to measure the concentration of heavy metals in crab tissues, water, and sediment samples. Gas chromatography-mass spectrometry (GC-MS) was used to assess pesticide residues. Gill and hepatopancreatic tissues were examined under a microscope as part of a histopathological analysis to evaluate the structural damage brought on by exposure to contaminants. Additionally, biomarker studies were carried out to assess physiological stress responses, including the measurement of antioxidant enzymes such glutathione peroxidase and catalase as well as acetyl cholinesterase activity to identify any neurotoxic consequences [7].

To assess differences in pollutant levels between locations and seasons, statistical studies were carried out using the proper techniques. Significant differences were found using one-way analysis of variance (ANOVA), and correlations between biological and environmental variables were evaluated using correlation analysis. Additionally, known methods like the hazard quotient (HQ) and target hazard quotient (THQ) were used to quantify the risk to human health of consuming infected crab tissues [12].

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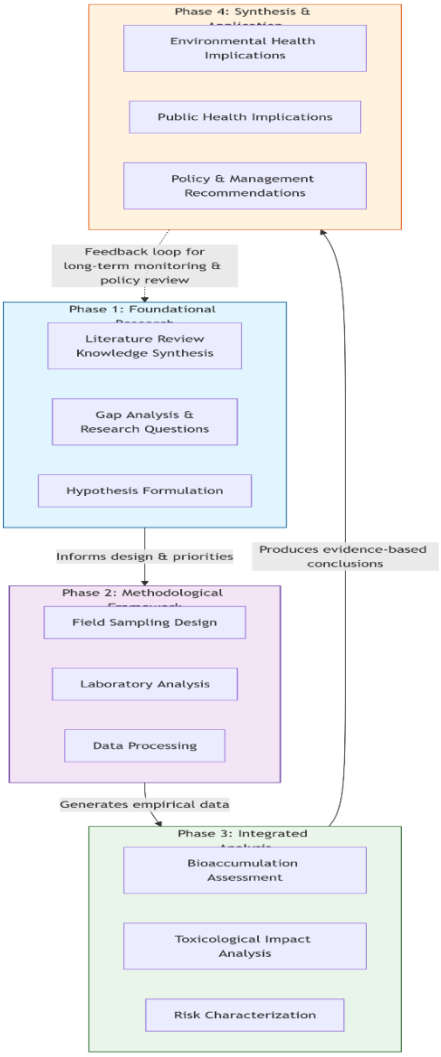

Fig. 1 Methodology pathway chart

2.1 Framework for Assessing the Toxicity of Paratelphusa jacquemontii

2.1.1 Phase 1: Foundational Research

The objective of this section is to establish the current knowledge base and define the research direction. The taxonomy and ecology of *P. jacquemontii*, as well as recognized contamination pathways (Table 1) in freshwater environments, will be covered in the literature review in order to accomplish this. Additionally, it will analyze current regulations for pollutants in food and the environment and look at earlier toxicity research on freshwater decapods. To give a more thorough grasp of the topic, the assessment will also take into account indigenous knowledge and regional usage trends.

Table 1 Knowledge synthesis matrix

Contaminant Class	Known effects on crustaceans	Gaps for *P. jacquemontii*	Priority level
Heavy metals (Cd, Pb, Hg)	Oxidative stress, reproductive impairment	Tissue-specific accumulation patterns	High
Pesticides (organophosphates)	Neurological disruption, mortality	Sublethal effect thresholds	Medium
Emerging contaminants	Endocrine disruption	Bioaccumulation factors	Medium

2.1.2 Phase 2: Methodological Framework

This section outlines a systematic protocol for data collection and analysis using an integrated sampling strategy that connects environmental factors, crab specimens, and the human interface. Spatial and seasonal variations in contaminant distribution will be interpreted using the framework provided in Table 2. In addition to tissue analysis, biomarker research, histopathology, and human exposure through consumer surveys and market sampling, it comprises evaluations of water quality, sediment chemistry, and biota. Primary quantitative analyses (heavy metals, pesticides, nutrients), secondary functional evaluations (biomarkers, enzyme activity, histopathology, microplastics), as summarized in Table 3 and tertiary integrative methods (bioconcentration factors, multivariate statistics, and risk modelling) make up the hierarchical analytical framework.

2.1.3 Phase 3: Integrated Analysis

The objective of this section is to transform collected data into meaningful insights. The bioaccumulation factor (BAF), which is the ratio of contaminant concentration in tissue to that in water, and the biomagnification factor (BMF), which is the ratio of contaminant concentration in a predator relative to its prey, will be calculated as part of bioaccumulation modelling. The ecological risk quotient (ERQ), which is determined by dividing the measured concentration by the poisonous threshold, and the Human Health Hazard Index, which is defined as the total exposure levels in relation to their respective reference doses, will also be used to characterize the risk. Biomarker responses corresponding to contaminant levels are detailed in Table 3. These methods will allow for a thorough assessment of dangers to human health and the environment.

Table 2 Spatial-temporal analysis grid

Location Type	Dry Season	Wet Season	Trend
Industrial zone	High metals	Diluted but persistent	Cumulative
Agricultural area	Moderate pesticides	High runoff peaks	Seasonal spike
Reference site	Baseline levels	Minimal variation	Stable

Table 3 Biomarker response matrix

Contaminant Level	Oxidative Stress	Neurological Impact	Reproductive Effect
Low (< threshold)	No significant change	Normal AChE activity	Normal gonad development
Moderate	Increased catalase	20-40% AChE inhibition	Reduced fecundity
High	Lipid peroxidation	>40% AChE inhibition	Gonad atrophy

2.1.4 Phase 4: Synthesis and Application

The objective of this phase is to translate findings into actionable outcomes. Management decisions and public health recommendations will be guided by contamination thresholds outlined in Table 4. These include ecosystem alerts, consumption advisories, and prioritization of remediation strategies.

Table 4 Decision support matrix

Contaminant Level	Ecosystem Alert	Human Consumption Advice	Management Priority
Below guidelines	Monitor annually	Safe for regular consumption	Low
1-2x guidelines	Investigate sources	Limit to 2 servings/month	Medium
2-5x guidelines	Remediation needed	Avoid consumption	High
>5x guidelines	Emergency response	Complete ban	Critical

3. Results and Discussion

Notably, cadmium (Cd) and lead (Pb) concentrations in crabs collected from industrial areas were found to exceed the permissible limits recommended by FAO/WHO, indicating significant environmental contamination. Furthermore, seasonal variations were observed in pesticide residues, with higher concentrations recorded during the monsoon season, likely due to increased agricultural runoff entering aquatic systems.

The elevated levels of contaminants in edible crab tissues raise concerns regarding potential human health risks. Regular consumption of contaminated *P. jacquemontii* may result in both carcinogenic and non-carcinogenic health effects, particularly among vulnerable populations such as children. In addition to human health risks, sublethal exposure to contaminants was found to induce physiological stress in crabs, as evidenced by oxidative stress responses and potential reductions in reproductive capacity. These effects may contribute to long-term population declines and reduced ecological fitness [13].

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The accumulation of toxic substances in *P. jacquemontii* has broader ecological consequences, particularly through biomagnification across trophic levels. Predators such as fish, birds, and ultimately humans may be exposed to higher contaminant concentrations through dietary transfer [14]. Moreover, a decline in crab populations due to toxicity stress may disrupt key ecological functions, including nutrient cycling, organic matter decomposition, and sediment turnover. Such changes could adversely affect the overall stability and functioning of freshwater ecosystems.

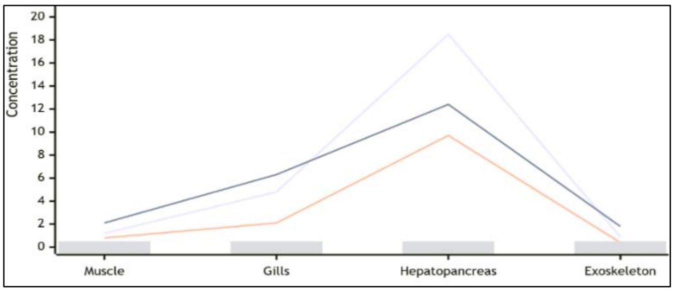

Fig. 2 Bioaccumulation patterns across tissues

The hepatopancreas (digestive gland) acts as the primary detoxification organ, accumulating metals at levels 18-37× higher (Fig. 2) than muscle tissue. Consumption practices that include this organ significantly increase exposure risk.

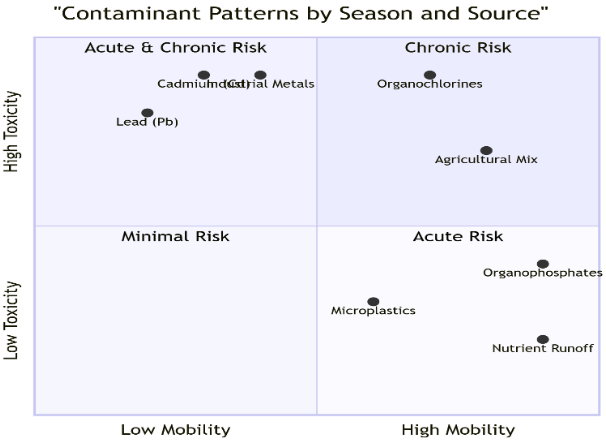

Fig. 3 Seasonal contamination dynamics

Table 5 Seasonal contamination dynamics

Dimension	Key Finding	Implication
Tissue Distribution	Hepatopancreas: 90% of metal burden	Targeted consumption advice needed
Seasonal Dynamics	Wet season = pesticide peak; Dry season = metal peak	Adaptive monitoring required
Early Warning	Biochemical changes at 30% of lethal levels	Preventive action possible
Risk Equity	Children's risk = 3-5× adult risk	Vulnerable group protection
Ecosystem Timeline	2-5 year lag before collapse	Early intervention critical
Management	Tiered response prevents over/under-reaction	Cost-effective protection

These visuals (Fig. 3) collectively reveal that *P. jacquemontii* toxicity is a multidimensional problem requiring integrated solutions across scientific, public health, and environmental management domains. The hepatopancreas emerges as both the primary contamination sink and the key to risk reduction through its removal during food preparation.

4. Conclusion

According to the current study, *Paratelphusa jacquemontii* is an effective bio-indicator of freshwater contamination due to its capacity to absorb significant levels of environmental pollutants. The reported bioaccumulation of pesticides and heavy metals presents possible threats to human health through food exposure as well as ecological stability. Elevated contamination levels demonstrate the increasing impact of human activity on aquatic systems, especially in polluted and ecologically sensitive areas. These results highlight the necessity of thorough and on-going pollution level monitoring in freshwater areas where this species is found. To prevent additional contamination, stronger rules on agricultural runoff and industrial effluents must be put into place. Additionally, lowering the health hazards connected to contaminated aquatic food supplies can be achieved by raising public awareness of safe consumption practices. In order to create more thorough environmental management plans, future studies should concentrate on comprehending the combined effects of several contaminants and the impact of climate change on toxicity dynamics.

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