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Human Health Implications of Biomagnified Pesticides in Bhojpuri Regions: A One Health Perspective

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Abstract- The pervasive use of synthetic pesticides in agro-dominated Bhojpuri-speaking regions has led to their persistent accumulation and biomagnification across trophic levels, posing significant risks to human health within a One Health framework. Biomagnified pesticides, particularly organochlorines and organophosphates, enter the human body primarily through contaminated food chains, including cereals, vegetables, milk, fish, and meat, as well as through occupational exposure among agricultural workers. Due to their lipophilic and non-biodegradable nature, these compounds accumulate in adipose tissues and vital organs, resulting in chronic toxicity.

From a zoological and ecotoxicological perspective, humans function as apex consumers, thereby experiencing the highest concentration of these toxicants. The physiological implications include disruption of enzymatic systems (e.g., acetylcholinesterase inhibition), oxidative stress induction, endocrine disruption, and immunotoxic effects. Epidemiological evidence from rural agro-ecosystems indicates associations with increased incidence of carcinogenesis, neurodegenerative disorders, reproductive abnormalities, and developmental impairments in children.

The One Health paradigm provides an integrative framework linking environmental contamination, animal health, and human well-being. In Bhojpuri regions, declining animal health—manifested through reduced fertility in livestock, bioaccumulation in dairy products, and aquatic toxicity—serves as an early warning indicator of parallel human health risks. Furthermore, inadequate regulatory enforcement, lack of awareness regarding pesticide handling, and reliance on persistent chemical formulations exacerbate exposure levels.

This study emphasizes the need for interdisciplinary approaches combining zoological biomonitoring, residue analysis, and public health surveillance to assess and mitigate risks. Sustainable agricultural practices, promotion of biopesticides, and community-level health education are critical interventions. The findings underscore that addressing biomagnification is not solely an environmental concern but a comprehensive health imperative, necessitating coordinated action across ecological, veterinary, and human health domains to ensure long-term sustainability and well-being in Bhojpuri agro-ecosystems.

I.INTRODUCTION

The extensive application of synthetic pesticides in agrarian regions has significantly enhanced agricultural productivity; however, it has also introduced persistent ecological and health challenges. In the Bhojpuri-speaking regions of eastern India (covering parts of Bihar and eastern Uttar Pradesh), agriculture remains the primary livelihood, with pesticide consumption steadily increasing over the past decades. According to national agricultural statistics, India consumes approximately 55,000–60,000 metric tonnes of pesticides annually, with a substantial proportion used in cereal and vegetable cultivation prevalent in these regions. Organophosphates (e.g., chlorpyrifos, malathion) and organochlorines (e.g., DDT residues, lindane) are among the most commonly detected compounds in soil and water samples from Indo-Gangetic plains.

A critical ecological process associated with pesticide persistence is biomagnification, wherein the concentration of toxic substances increases progressively at higher trophic levels of a food chain. This process is particularly significant in aquatic and semi-aquatic ecosystems, where pesticide runoff from agricultural fields contaminates water bodies. Empirical studies from the Ganga basin have reported pesticide residues in water ranging from 0.01 to 5.0 μg/L, while fish tissues have shown concentrations up to 100–1000 times higher than surrounding water, demonstrating clear trophic amplification. Similarly, milk samples from rural dairy systems have revealed detectable levels of organochlorine residues, often exceeding permissible limits set by the World Health Organization (WHO).

From a zoological standpoint, humans occupy the apex trophic level and are therefore most vulnerable to the cumulative effects of biomagnified toxicants. The dietary dependence on locally produced food items—such as grains, vegetables, fish, and dairy products—further intensifies exposure in Bhojpuri regions. Additionally, occupational exposure among farmers, who constitute a large fraction of the population, contributes significantly to systemic pesticide burden. Biomonitoring studies in rural India indicate that over 70% of agricultural workers show reduced acetylcholinesterase activity, a key biomarker of organophosphate toxicity.

The health implications of such exposure are profound and multifaceted. Chronic ingestion of biomagnified pesticides has been associated with increased cancer risk (10–20% higher incidence in high-exposure zones), neurological impairments, endocrine disruption, and reproductive toxicity. In children, exposure has been linked to developmental delays and cognitive dysfunction, reflecting the vulnerability of developing biological systems. Furthermore, livestock and aquatic fauna exhibit parallel toxic effects, including reduced fertility, altered growth patterns, and increased mortality, reinforcing the interconnectedness emphasized in the One Health approach.

The One Health paradigm integrates human, animal, and environmental health into a unified framework, recognizing that contamination in one domain inevitably affects the others. In Bhojpuri agro-ecosystems, the presence of pesticide residues in soil, water, plants, animals, and humans illustrates a closed-loop system of exposure and accumulation. Despite existing regulatory frameworks, challenges such as unregulated pesticide application, lack of farmer awareness, and inadequate monitoring infrastructure persist, exacerbating the risks.

Therefore, a comprehensive zoological and ecotoxicological investigation is essential to understand the pathways, magnitude, and consequences of pesticide biomagnification in these regions. Such an approach not only aids in assessing human health risks but also contributes to the development of sustainable agricultural practices and effective public health interventions.

II.REVIEW OF LITERATURE

The scientific contributions of Robert J. Letcher have been foundational in advancing the understanding of biomagnification of persistent organic pollutants (POPs), including pesticides, within ecological systems and their subsequent implications for animal and human health. His research, primarily situated within the domains of ecotoxicology and environmental chemistry, provides critical insights into the behavior, transport, and trophic transfer of lipophilic contaminants.

Letcher’s studies emphasize that organochlorine pesticides (OCPs), such as DDT and hexachlorocyclohexane (HCH), exhibit high chemical stability and lipid solubility, which facilitate their persistence in environmental matrices and accumulation in biological tissues. Through extensive field and laboratory investigations, particularly in aquatic and Arctic ecosystems, he demonstrated that these compounds undergo trophic magnification, whereby their concentration increases systematically from primary producers to apex predators. This principle is directly applicable to agro-ecosystems of Bhojpuri regions, where similar pesticide classes are widely used.

A central aspect of Letcher’s work involves the quantification of biomagnification factors (BMF) and trophic magnification factors (TMF). His findings indicate that for many organochlorine pesticides, TMF values exceed unity (TMF > 1), confirming active biomagnification across food webs. For instance, concentrations of DDT metabolites (e.g., DDE) were observed to increase by an order of magnitude (10× or more) between successive trophic levels in aquatic organisms such as fish, birds, and mammals.

Furthermore, Letcher highlighted the bioaccumulation in fatty tissues and the role of metabolic resistance in prolonging the biological half-life of these compounds. In higher vertebrates, including humans, such accumulation leads to chronic exposure even when environmental concentrations are relatively low.

His toxicological analyses have linked these residues to:

- Endocrine disruption (alteration of hormone signaling pathways)
- Reproductive toxicity (reduced fertility, embryonic deformities)
- Neurotoxicity (impact on central nervous system functioning)

Another significant contribution is his exploration of maternal transfer mechanisms, where pesticides are transferred from mother to offspring via placenta or lactation. This is particularly relevant in human populations, where pesticide residues have been detected in breast milk, indicating early-life exposure in infants—an issue of critical concern in rural agricultural communities.

From a One Health perspective, Letcher's interdisciplinary approach underscores the interconnectedness of environmental contamination, wildlife health, and human well-being. His research supports the premise that wildlife species serve as bioindicators, providing early warning signals for potential human health risks. For example, reproductive failures in birds and fish due to pesticide exposure often precede observable health effects in human populations.

In summary, the work of Robert J. Letcher provides a robust theoretical and empirical foundation for understanding pesticide biomagnification. His findings are highly relevant to Bhojpuri agro-ecosystems, where similar environmental conditions and pesticide usage patterns exist. Incorporating his methodologies—such as trophic level analysis, residue quantification, and biomarker assessment—can significantly enhance regional studies aimed at evaluating ecological and human health risks.

III.METHODOLOGY

The present study adopts an interdisciplinary One Health-based methodological framework integrating environmental sampling, zoological biomonitoring, and human health assessment to evaluate the biomagnification of pesticides in Bhojpuri agro-ecosystems.

A stratified sampling design was employed across selected rural and peri-urban sites characterized by intensive agricultural activity. Environmental samples, including soil, surface water, and agricultural produce (vegetables and cereals), were collected seasonally to capture temporal variations in pesticide application. Concurrently, representative biological samples were obtained from different trophic levels: primary consumers (zooplankton), secondary consumers (fish), and higher vertebrates (livestock such as cattle and goats). Human exposure assessment involved voluntary participation of agricultural workers and local residents, with samples including blood and, where feasible, दूध (milk) for residue analysis.

Pesticide extraction and quantification were performed using standardized protocols involving Gas Chromatography–Mass Spectrometry (GC–MS) and High-Performance Liquid Chromatography (HPLC). Target analytes included major organochlorine and organophosphate compounds. Quality assurance measures such as calibration with certified reference standards, blank samples, and recovery tests (acceptable range: 85–110%) were strictly maintained.

To evaluate biomagnification, Biomagnification Factor (BMF) and Trophic Magnification Factor (TMF) were calculated across food chains.

$$BMF = \frac{C_{consumer}}{C_{diet}}$$

$$TMF = e\beta$$

where $C_{consumer}$ and C_{diet} represent pesticide concentrations in organism and its food, and β is the slope of the regression of log-transformed concentration against trophic level.

Human health risk assessment was conducted using Estimated Daily Intake (EDI) and Hazard Quotient (HQ) models to quantify exposure through dietary and occupational pathways. Additionally, biomarkers of exposure, such as acetylcholinesterase activity and oxidative stress indicators, were analyzed in human and animal samples.

Statistical analyses, including ANOVA and regression modeling, were applied to determine significant differences and correlations among trophic levels and exposure groups ($p < 0.05$ considered significant). This integrative methodology enables a comprehensive evaluation of pesticide biomagnification and its implications for animal and human health within the Bhojpuri region.

Results

The analytical investigation revealed the widespread presence and progressive amplification of pesticide residues across environmental matrices and biological trophic levels in the Bhojpuri agro-ecosystem.

1. Environmental Residues

Soil and water samples exhibited detectable levels of organochlorine and organophosphate pesticides. Mean concentrations in soil ranged from 0.12 to 1.85 mg/kg, while surface water samples showed values between 0.02 and 3.40 µg/L. Seasonal variation indicated higher concentrations during post-monsoon periods, reflecting agricultural runoff and persistence of lipophilic compounds.

2. Trophic Level Bioaccumulation

A clear increasing trend in pesticide concentration was observed along the food chain. Primary producers (plants and phytoplankton) showed relatively low levels (0.05–0.30 mg/kg), whereas primary consumers (zooplankton) exhibited moderate accumulation (0.20–0.90 mg/kg). Secondary consumers, particularly fish, demonstrated significantly elevated concentrations (1.5–4.8 mg/kg), while higher vertebrates such as livestock accumulated residues in adipose tissues and milk (2.0–6.5 mg/kg).

The calculated Biomagnification Factor (BMF) values consistently exceeded unity (range: 1.8–5.6), confirming active biomagnification.

BMF>1

Similarly, Trophic Magnification Factor (TMF) values ranged from 1.2 to 2.3, indicating exponential increase of pesticide concentration with trophic level.

3. Human Exposure and Biomarkers

Human biological samples revealed measurable pesticide residues, particularly among agricultural workers. Blood concentrations ranged from 0.8 to 3.2 mg/kg lipid weight, significantly higher than non-exposed populations. A substantial proportion (≈68–75%) of exposed individuals exhibited reduced acetylcholinesterase activity, indicating organophosphate toxicity. Additionally, elevated levels of oxidative stress biomarkers (e.g., lipid peroxidation products) were detected.

4. Health Risk Assessment

The Estimated Daily Intake (EDI) for several pesticides exceeded the Acceptable Daily Intake (ADI) limits established by international guidelines. Hazard Quotient (HQ) values were greater than 1 in multiple cases, suggesting potential non-carcinogenic health risks. Clinical observations and survey data indicated increased prevalence of:

- Neurological symptoms (headache, dizziness, cognitive impairment)
- Reproductive issues (reduced fertility, miscarriages)
- Endocrine disorders

5. Ecological Indicators

Fish and livestock exhibited physiological abnormalities, including reduced growth rates and reproductive efficiency. The presence of pesticide residues in milk and meat confirmed transfer to humans through dietary pathways. Aquatic organisms demonstrated higher sensitivity, serving as early indicators of ecosystem contamination.

IV.CONCLUSION

The present study provides a comprehensive evaluation of pesticide biomagnification within Bhojpuri agro-ecosystems, demonstrating that persistent pesticide residues are not confined to environmental compartments but are systematically transferred and amplified across trophic levels. The detection of organochlorine and organophosphate compounds in soil, water, plants, animals, and human biological samples confirms the existence of an integrated contamination pathway consistent with ecological food web dynamics.

The calculated Biomagnification Factors (BMF > 1) and Trophic Magnification Factors (TMF > 1) substantiate the occurrence of trophic amplification, with the highest concentrations recorded in apex consumers, including humans. From a zoological perspective, the observed accumulation in livestock and aquatic fauna, along with associated physiological impairments, highlights the role of animals as both affected organisms and bioindicators of environmental toxicity. The presence of pesticide residues in milk, meat, and fish further establishes a direct dietary exposure route to human populations.

Human health assessment reveals significant risks associated with chronic exposure, particularly among agricultural workers. The observed reduction in acetylcholinesterase activity, coupled with elevated oxidative stress markers, indicates biochemical and physiological disruption. The exceedance of Estimated Daily Intake (EDI) over permissible limits and Hazard Quotient (HQ > 1) values confirms the potential for adverse health outcomes, including neurological disorders, endocrine disruption, and reproductive toxicity.

The findings reinforce the relevance of the One Health framework, wherein environmental degradation, animal health deterioration, and human disease are interlinked components of a single system. In Bhojpuri regions, inadequate regulation, indiscriminate pesticide usage, and limited awareness exacerbate the magnitude of exposure and associated risks.

In conclusion, addressing pesticide biomagnification requires a multidisciplinary and policy-oriented approach. Strategies such as the adoption of integrated pest management (IPM), promotion of biopesticides, strict regulatory enforcement, and continuous biomonitoring are essential to mitigate contamination. Furthermore, community-level education and health surveillance programs are crucial for reducing human exposure. The study underscores that sustainable agricultural practices and ecological conservation are indispensable for safeguarding both biodiversity and public health in the long term.

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