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Review Paper

Global and Indian Perspectives on Pesticide Impact: Risks to Soil, Water, and Human Health

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ABSTRACT

Pesticides are vital for agricultural disaster control and public health pest management. The widespread application of pesticides leads to extensive harm to soil conditions and water degradation and adverse effects on human well-being. Research investigates how pesticides harm soil structure and fertility and water spaces, as well as damage useful microorganisms, while showing a risk of enduring ecosystem contamination and substance accumulation. The report examines pesticide intake patterns across both India and worldwide while presenting their extensive adoption together with their safety hazards. Developing nations face a crucial public health problem from pesticide poisoning, where farmers together with children stand as the most exposed groups. This review demonstrates the requirement for immediate enforcement of strict rules, together with protective handling procedures and awareness campaigns for public safety. The approach promotes evaluation of pesticide advantages in addition to their environmental and health harms in order to enhance sustainability levels while shielding vulnerable groups from chemical exposure.

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INTRODUCTION

The United Nations Food and Agriculture Organization (FAO) has defined pesticides as any substance or mixture of substances intended to prevent, destroy, or repel any pest. Pesticides constitute a class of chemicals that have proven extremely beneficial to humans in agriculture, industry, and medicine, but their toxicity to animals and humans has always been a concern (Mostafalou & Abdollahi, 2016b).

Pesticides can be applied in various forms: in farming, to ward off insects and weed plants from crops; in healthcare, to prevent the spread of diseases through vectors; and in other sectors, to make products free from contamination. Various pesticides can be employed based on the pests to be eliminated, such as insecticides for insects, herbicides for weeds, and fungicides to control fungi and mildews. Although pesticides are effective in pest control, they have also been found to have negative effects on human health and the environment (Tudi *et al.*, 2021).

Pesticides that cause temporary or short-term adverse effects after brief exposures are called acute toxic exposures. Prolonged exposure to substances that trigger gradual and permanent adverse effects is classified as chronic toxicity. An individual's reaction to pesticide exposure depends on personal characteristics like health status and age as well as weight and

genetic profile, together with personal medical conditions. The rapid absorption of toxins through the stomach results in fatal consequences when an individual ingests pesticides instead of touching the skin with them (Damalas & Koutroubas, 2016).

1.1 Pesticides Impact on Health and Environment- The Global Scenario

The use of pesticides continues to increase as an environmental health risk because their hazardous chemicals affect people, along with wildlife and plants that pesticides do not target. The poisoning happens in different ways, which include swallowing and breathing exposure, along with skin contact. Several factors determine whether pesticide poisoning leads to death or survival exposure as nonlethal. A pesticide's toxicity level gets measured through its LD_{50} or LC_{50} determinations, which represent Lethal Dose 50 and Lethal Concentration 5,0, respectively. The value of LD or LC provides evidence for evaluating the toxicity level of a substance (Mostafalou & Abdollahi, 2016b).

Global pesticide monitoring happens through the FAOSTAT Pesticides Use database. The worldwide total of agricultural pesticide use reached 3.70 million tons during 2022, while showing a 4% yearly increase and reaching double its level from 1990. Between 1990 and 2022, pesticide utilization grew 94% across cropland area, although agricultural output value rose only 5%, and per capita consumption increased by 35%. Asia maintained its position as the leading exporter of pesticides in 2022 despite a decreasing volume pattern, which led to an increase in value. From 1990 up to this point, Europe has experienced a reduction in their chemical pesticide usage, but the Americas have witnessed an upward trend. The insecticide applications in Oceania depend heavily on biopesticide usage (*Pesticides Use and Trade, 1990–2022*, n.d..).

Human poisoning from pesticides continues to be a serious public health concern. Per year, more than 20,000 individuals die from pesticide exposure accidents, based on calculations by the 1990 World Health Organization task force. Pesticide usage has grown, but worldwide estimates have not been revised yet. The organized review processed data from 157 studies, and WHO mortality documents demonstrated that pesticide exposure continuously affects about 385 million patients globally per year, leading to 11,000 deaths. The highest number of cases occurs in Southern Asia, and both East Africa and South-Eastern Asia rank next. Southern Asia leads in terms of estimated fatal cases (9,401) and non-fatal cases (180.3 million) based on research data from Asian subregions, while the study revealed that annual acute pesticide poisoning affects nearly 44% of farmers across 141 countries. Preventive measures require urgent improvement because farming communities still use extremely dangerous pesticides. The research conducted by Wolfgang Boedeker, along with Meriel Watts and Peter Clausin, and Emily Marquez, sheds light on the current public health crisis and future research and policy demands by evaluating global acute unintentional pesticide poisoning occurrence (Boedeker *et al.*, 2020).

Multiple Factors, like airborne pesticide drifts combined with inadequate safety gear during pesticide application, put agricultural area at great risk of pesticide exposure. The death of Pravin Soyam occurred because his father sprayed pesticides without protection, and the child received accidental exposure through this mistake. (Hardikar, n.d.) The Hiraman Sayam family endures medical issues and financial struggles as a result of continuous pesticide exposure, which led to school abandonment by their children, according to Sah 2023).

1.2 Pesticide usage in India 2022-23

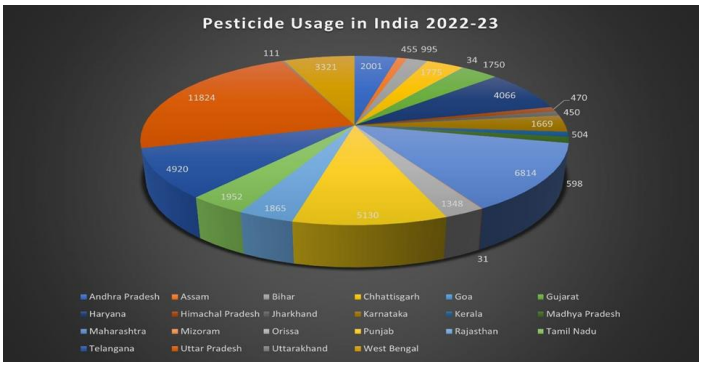

Fig. 1: State-Wise Pesticide Usage in India (2022-2023) with Highest and Lowest Consumption Trends

Source:*https://www.data.gov.in/resource/stateut-wise-details-percentage-use-chemical-pesticides-and-bio-pesticides-2021-22-2023-24*

This pie chart represents the usage of pesticides in India in the year 2022-2023. The highest usage of pesticide, 11,824 M.T, can be noted for Uttar Pradesh among all the states. States like Maharashtra and Punjab also show high consumption of pesticides, according to the data. The pie chart indicates states with 31 M.T and 34 M.T usage of pesticide, Mizoram and Goa, respectively, and other states not listed below have been declared as organic states due to zero pesticide use in farming. Data was taken from a statistical database of the government of India, the Directorate of Plant Protection, Quarantine, and Storage.

1.1.2 The Impact of Pesticides on Soil Quality

Pesticides may have a remarkable effect on soil structure and fertility, reducing the porosity and compaction of the soil which in turn affects the physical composition, which affects the water filtration process and the development of roots. Soil contamination of soil by pesticide residues is a cause for concern, as pesticides remain in soil for a long time and can be toxic to human health, as large quantities of pesticides are used

in agroecosystems worldwide. Potentially harmful microorganisms, which are important for the nutrient cycle, may be harmed by the use of pesticides, leading to soil infertility and reduced crop yield over time. Pesticides could also affect other soil microorganisms such as bacteria, fungi and earthworms, altering the food web and reducing the ability of the soil to support plant growth. Pesticides that remain in the soil for long periods contaminate the soil and result in potential bioaccumulation in the food chain, affecting the reproduction and growth of organisms in the soil. "An increasing number of pesticides have been used in agriculture for protecting the crops from pests, weeds, and diseases but as much as 80 to 90% of applied pesticides hit non-target vegetation and stay as pesticide residue in the environment"
[Sun *et al.*, 2018]. In agricultural ecosystems, the risk of this accumulation could, therefore, be very significant. Numerous pesticides found in soil can compromise microbial communities in the soil and aquatic environment, harm ecosystems, degrade water quality, and leach into surface and groundwater. It also poses a long-term risk to food security because it includes a number of elements that could cause the world's food supply to become unstable. " In just over 70% of these trials, pesticides were found to harm organisms essential to preserving soil health, and in just over 70% of those experiments, a harm that the EPA has never taken into account in its safety reviews. Pollution and pesticide-intensive farming intensive pesticide us,e are the main causes of the sharp, rapid decline in of many soil organisms, including ground-nesting bees and ground earth beetles. They have been found to be the main cause of the decline in soil biodiversity over the past decade." [Donley & Gunstone, 2024]
Pesticide residues in Indian soils have been extensively studied due to the substantial influence on soil quality and environmental health. A brief summary of numerous Indian studies that looked into the existence, distribution, and ecological risks of pesticide residues in soils can be found below:

Geographical Spread and Ecological Threat of Organochlorine Pesticides in Hyderabad
(Kata *et al.* 2015) Conducted a study in the northwest part of Hyderabad city and analysed soil samples for residues of organochlorine pesticides. The results showed that the most commonly identified pesticides were CYP, p, p, p′-DDE, endrin ketone, and endosulfan sulfate. Total OCP concentrations varied from 129 to 1,001 μg kg^{-1}. The study highlighted the persistence of these pesticides and their potential ecological risks and underlined the need for continuous monitoring and management strategies to control soil contamination.

Residues of Pesticides in Soils from Areas Cultivating Vegetables in Bihar
(Sah *et al.* 2021) analysed soil samples from vegetable-growing regions in Bihar and detected a number of pesticide residues, including HCH, endosulfan, DDT, quinalphos, and chlorpyrifos. The study showed that 10 samples had contaminated with endosulfan (ND-0.078 mg kg^{-1}) and 9 samples had were contaminated with HCH. The presence of these residues raised concerns about soil contamination and the potential food chain transmission and stressing the need for strict legislation on the use of pesticides.

Persistent Organochlorine Pesticide Residues in Northern Indo-Gangetic Alluvial Plains:
(Singh *et al.* 2007) examined the distribution patterns and concentration patterns of OCP residues in soil and surface water samples from the northern Indo-Gangetic alluvial plains in 2007. β- and δ-isomers of HCH were found to be the most common, according to the study, and total OCP levels in soil samples ranged from 0.36 to 104.50 ng g^{-1}. The compounds' long-term environmental persistence and potential for bioaccumulation, which could be harmful to human health and the environment, were questioned.

Biodegradation of Pesticide Residues via Bacillus velezensis SKRB5
(Kadarla and Rajani 2024) conducted a study in Mahabubabad, Telangana, identifying that agricultural soils contained pesticides like mancozeb, atrazine, and monocrotophos. The research analysed the potential of *Bacillus velezensis* SKRB5 capacity to degrade these pesticides, showing notable degradation capabilities under optimal conditions (pH 7, 37 °C, and pesticide concentration of 250 mg/L). This points to a potentially effective bioremediation strategy to lessen soil contamination.
The study, conducted in Korba, India, aimed to determine the concentrations of Dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) along with their isomers, in residential soil. Using accepted analytical techniques, researchers collected and analysed soil samples to ascertain the levels of total HCH and total DDT. They conducted a health risk assessment to assess the potential effects on human health, weighing the risks of carcinogenic and risks of non-carcinogenic exposure from the consumption of soil containing HCH and DDT The results revealed that the concentrations of ΣHCH and ΣDDT in the residential soils ranged from 0.9 to 20 μg kg−1 and 2 to 315 μg kg−1, respectively. These levels were comparatively similar to those found in other regions of India and worldwide. Notably, the concentrations were below the suggested limits for proposed soil quality, quality limits, indicating a low ecotoxicological risk from contaminated soil. The study also estimated the incremental lifetime cancer risk (ILCR) and non-cancer health hazard quotient (HQ) for both adults and children. The findings showed that HQ and ILCR values are within safe and acceptable limits, which suggests that exposure to organochlorine pesticides (HCH and DDT) in Korba soils poses little to no significant risk to humans **(Kumar *et al.*, 2013).**

1.1.3 The Impact of Pesticides on Soil Quality
In a 2005 study, the organochlorine and organophosphorus pesticide residues in surface and groundwater samples in Kanpur, northern India, were analyzed.
A liquid-liquid extraction followed by gas chromatography with an electron capture detector (GC-ECD) was employed to

determine the levels of pesticides. Both categories of pesticides were detected in considerable amounts. Surface water samples from the Ganges River contained significant levels of gamma-HCH (0.259 µg/l) and malathion (2.618 µg/l). Hand-pump groundwater samples from the agricultural and industrial zones showed the presence of gamma-HCH, malathion, and dieldrin. The highest concentrations detected in groundwater were gamma-HCH (0–900 µg/l), malathion (29–835 µg/l), and dieldrin (16–227 µg/l). Meaningfully, the concentration of malathion in industrial groundwater was above the European Commission groundwater quality standards which is a serious health concern. The samples, however, lacked endosulfan, methyl parathion, aldrin, ethion, DDE and DDT (Sankararamakrishnan *et al.*, 2004).

Hyderabad's Organochlorine Pesticide Contamination
Shukla *et al.* (2006) conducted a research study to determine the level of organochlorine pesticide (OCPs) contamination in the groundwater across various sites in Hyderabad City. Because of the stubborn nature of OCPs, the study highlighted the importance of groundwater monitoring and control techniques to curtail pollution.

Gangetic Plains Alluvial Groundwater Aquifers: Persistent Organochlorine Pesticide Residue
The research conducted by Singh *et al.* (2005) revealed that the organochlorine pesticides, alluvial groundwater aquifers in the Gangetic plains. The findings raised concerns regarding the ecological risks associated with these pesticides, primarily their environmental degradation, bioaccumulation, and potential threats to human health and well-being.

Organochlorine Pesticide Residue Prevalence in Kasargod District Groundwaters
Yogannathan and Shanthi (2013) highlighted the degrees of organochlorine pesticide contamination in the district's open wells from 2010 to 2011. The levels of residues detected were much greater than the permissible limit, which showed that the groundwater was severely contaminated.

Remainders of Organochlorine Pesticides in Drinking Water in Rural Haryana, India
A study conducted in 2011 focused on the organochlorine pesticide residue contamination levels of drinking water in rural areas of Haryana, India. To investigate seasonal changes, researchers sampled water from Ambala, Gurgaon, and Hisar during pre- and post-monsoon periods. Analysis of the samples indicated that sources of drinking water were contaminated with endosulfan, isomers of HCH, and metabolites of DDT. Dieldrin, however, was absent. Each district had a different mean concentration of Endosulfan, DDT, and total HCH. Ambala and Gurgaon had mean values of HCH, DDT, and Endosulfan as 87.6 ng/L, 848.2 ng/L, and 27.4 ng/, L, respectively, while Hisar had averages of HCH 78.5 ng/L, 115.9 ng/L DDT, and 53.0 ng/L Endosulfan. Surprisingly, in accordance with the European Economic Community Directive (EECD) drinking water standards, 37% of the samples exceeded 500ng/L total pesticides. The study also noted seasonal differences in the concentration of pesticide residues (Kaushik *et al.*, 2011).

The health impacts linked with pesticide residuals on water resources in Upper Jhelum
The health implications of pesticide contamination in drinking water from the Upper Jhelum Region of the Kashmir Valley, India, were examined in a 2023 study. The upper Jhelum basin has 15 sampling sites, and 60 water samples were collected from these sites for analysis. Residue extraction from water samples was performed using gas chromatography tandem mass spectrometry (GC-MS/MS). The study found 10 out of 26 popular pesticides to be present in the water samples. Among the detected pesticides, difenoconazole was found in the highest concentration. For the associated risks, no carcinogenic health risk assessment was performed using the target hazard quotient (THQ) method. A few sampling sites were found with higher concentrations of chlorpyrifos and quinalphos above the threshold (>1), indicating that consumption of such water would pose a health risk. One of the shortcomings of this study is that it was conducted during the spring and summer seasons, which may have excluded other seasonal contamination variations. Also, only 5 out of 13 pesticide families were included, leading to an underestimation of the total risk. Contamination from other sources not related to horticulture or agriculture was ignored by the study, which may lead to the omission of other relevant study factors (Ganaie *et al.*, 2023).

CONCLUSION

Pesticides play an essential role in controlling pests in agriculture and public health, but their use can have negative effects on soil quality and human health. They degrade soil structure and fertility, harm beneficial microorganisms, and contribute to long-term contamination and bioaccumulation in ecosystems. Pesticide poisoning is a significant public health concern, particularly in developing countries, where farmers and children are most vulnerable due to occupational and residential exposure. The review emphasizes the need for stringent regulations, safe handling practices, and public education to mitigate the risks associated with pesticide use. Striking a balance between the benefits of pesticides and their potential environmental and health impacts is crucial for ensuring sustainability and protecting vulnerable populations from harmful pesticide exposure.

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