

Agricultural Chemical Exposure and Worker Health: An Epidemiological Review

Nayanabai Shabadi

Associate Professor, Department of Community Medicine, JSS Medical College, JSS Academy of Higher Education and Research, Mysuru, Karnataka, India.

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Abstract

Agricultural workers are susceptible to a range of chemicals, such as pesticides, fertilizers, and other agrochemicals, which pose significant risks to their health. Understanding the epidemiology of exposure to these chemical hazards is crucial for developing effective preventive strategies and improving occupational health standards among agricultural workers. The review aims to synthesize existing research on the prevalence, types, and health effects of chemical exposures among agricultural workers. The prevalence of chemical exposures was high, with significant regional variations. Health effects ranged from acute symptoms like skin irritation and respiratory issues to chronic conditions such as cancer, neurotoxicity, and reproductive problems. Several studies highlighted the increased vulnerability of certain subgroups, including women, children, and migrant workers. Additionally, the review found that chemical hazards not only impact human health but also pose serious threats to environmental safety, leading to soil degradation, water contamination, and biodiversity loss. There is a critical need for enhanced regulatory measures, improved safety practices, and targeted interventions to mitigate these risks. Furthermore, the environmental impact of these chemicals underscores the necessity for sustainable agricultural methods that protect both human well-being and the ecosystem. Future research must assess combined chemical exposures and preventive strategies across agricultural settings.

Keywords: Agrochemicals, Agriculture, Occupational health, Epidemiology, Toxicology

Introduction

Agriculture is essential worldwide, providing food and driving economic growth in both developed and developing countries. [1] India, the second-largest agricultural producer globally, employs over 50% of its work force in this sector, contributing 20.2% to its

GDP. [2] With a major net cropped area, agriculture is vital for rural employment in India, which has 70.6% of its workforce in agriculture. [1] Globally, agriculture employed 768 million people to feed a growing population, with output tripling in real terms from 1960 to 2011. [3]

Corresponding Author: Nayanabai Shabadi, Associate Professor, Department of Community Medicine, JSS Medical College, JSS Academy of Higher Education and Research, Mysuru, Karnataka, India.

E-mail: nayanabaishabadi@jssuni.edu.in

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In the 20th century, global food production and population growth were heavily reliant on pesticides, which are crucial for crop yields and disease control. Without pesticides, fruit, vegetable, and cereal production would have significantly declined. [4] In India, where agriculture employs 70% of the workforce, the country ranks 12th globally in pesticide use, consuming 58,160 tons in 2018. [5] Despite their importance, pesticides harm non-target organisms and the environment, with only 0.1% reaching their intended targets. Bio-pesticides are being explored as potential alternatives. [6]

Agriculture is highly hazardous, with workers facing physical, chemical, biological, ergonomic and physiological risks, especially the migrant and seasonal workers. Pesticides pose significant health risks, including cancer and neurotoxicity. Managing chemical safety can reduce injuries and improve productivity. [7] The review addresses chemical hazards, safety practices, research gaps, and recommends policy changes and training to enhance worker safety.

Methodology

The review discusses the epidemiology of chemical hazards among agricultural workers. Peer-reviewed articles were sourced from major databases including PubMed, Google Scholar, and Cochrane library from 2010 to 2024.

Inclusion:

- Articles published in English
- Articles involving human participants

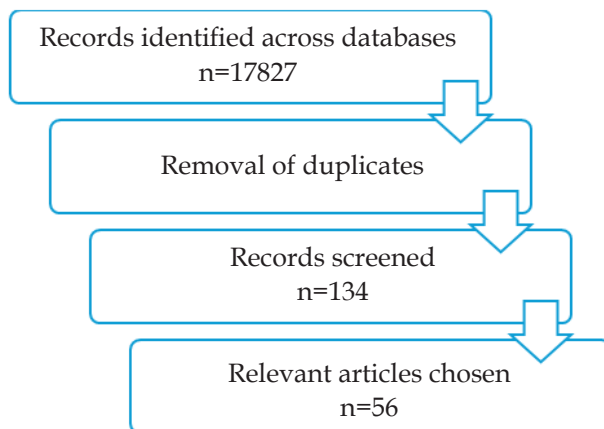
Exclusion:

- Editorials and papers without epidemiological data on the health consequences of pesticides on agricultural workers were not included

Relevant keywords used:

- “pesticides”, “hazards”, “agricultural workers”, “pesticide exposure”, “occupational health”, “epidemiology”, “herbicides” and “toxicology”

Screening and Selection:



Data were extracted using variables like pesticide poisoning, neurotoxicity, reproductive effects, immunological effects and other health effects. Also, variables like specific exposures (type of chemical, PPE), environmental consequences were also studied. The prevalence of health effects due to chemical exposure were searched for the results. Key data points such as study location, population characteristics, types of chemical hazards, exposure levels, health outcomes, and study methodologies were extracted.

Furthermore, details used some keywords like personal protective equipment, morbidity, health safety.

The overview of the studies in the review is shown in Table 1.

Table 1: List of studies included in review

Author	Type & Year	Title	Main findings
Hazarika, Ranjit. [51]	A Cross-sectional observational study, 2011	Effect of occupational exposure of pesticides on health of farmers of the agricultural fields of Sorbhug area of lower Assam	A study of 150 farmers in Sorbhug, Assam found over 60% using highly hazardous pesticides, causing health issues like dizziness (90%), itchy eyes (60%), and depression (73%). The study emphasizes how crucial it is to have better safety practices and education.

Continue....

Fareed, Mohd, et al. [35]	A Cross-sectional study, 2013	Adverse respiratory health and hematological alterations among agricultural workers	36.75% of pesticide applicators reported respiratory issues. Tests confirmed significant declines in PEFR, FEV ₁ , and FEV ₁ /FVC ratios ($p < 0.05$). Coupled with blood health risks linked to exposure, this highlights an urgent need for better protection and monitoring.
Rakesh, P. S., et al. [50]	A Cross-sectional study, 2017	Chemical use in farming and its health and environmental implications in a rural setting in southern India	98 Tamil Nadu farmers revealed hazardous practices: 43% reused pesticide containers, 39% mixed without gloves, and 33% discarded waste openly. Only 28% used protective gear, highlighting an urgent need for safety education.
Meenakshi, J. Raja, and SigamaniPanneer [39]	A Review article, 2020	Occupational health of agricultural women workers in India	The study proposes better social security and welfare programs to improve the physical and mental health of agricultural women workers, highlighting the substantial negative effects of occupational hazards on their well-being.
Nayak, Pragati, and Hitesh Solanki [5]	A Review article, 2021	Pesticides and Indian Agriculture - A review	Despite India's low global pesticide share (1%), heavy insecticide use in cotton causes significant harm. The review recommends shifting to Integrated Pest Management (IPM) and biopesticides (currently 8%) to ensure agricultural safety
Khode, Dipali et al [2]	A narrative review, 2024	Health-Related challenges and programs among agriculture workers: A Narrative Review	Agricultural workers face significant health risks, often due to inadequate safety practices. Existing health programs focus on education and safety enforcement, but challenges remain in coverage and effectiveness.
Mittal, Chaitanya, et al. [29]	A systematic review and meta-analysis, 2021	Toxicoepidemiology of poisoning exhibited in Indian population from 2010 to 2020: a systematic review and meta-analysis	Pesticides account for over 60% of Indian poisoning cases, peaking in North India (79.1%). Organophosphates and aluminium phosphide dominate, with the latter causing 31.6% mortality. Stricter regulation and better treatment protocols are urgent.
Kumar, Dileshwar, et al. [8]	A data article, 2024	Biomonitoring of pesticide exposure and its health implications in agricultural areas of Telangana, India: A brief data report	Bio-samples revealed multiple pesticide metabolites and significantly lowered acetylcholinesterase activity, confirming hazardous absorption and the need for stricter safety measures

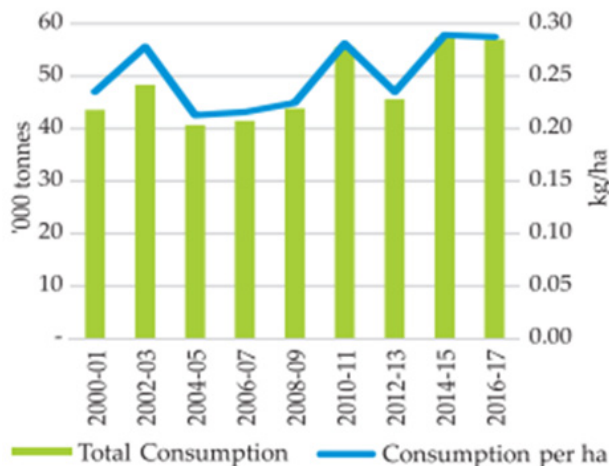
Review Outcomes

Chemical use in agriculture in India

India ranks tenth in terms of chemical pesticide use and fourth in terms of production. Despite all modernization efforts, the nation’s dependence on chemical pesticide in conventional agriculture poses a serious threat to public health, environmental sustainability, and crop protection. [8] Currently, 946 pesticide formulants are registered for use in India under the insecticides act, 1968. [9]

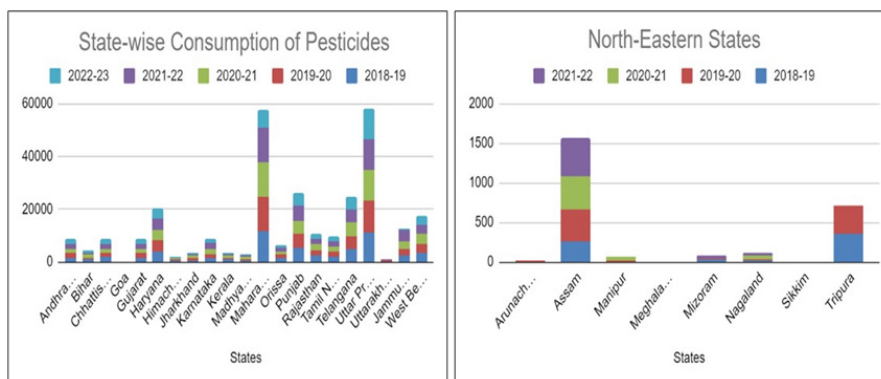
In agriculture, insecticides, herbicides and fungicides are frequently employed for pest management. In India, however, insecticides account for the largest portion of all pesticide use. Following 2009-2010, India’s pesticide consumption, both overall and per acre, significantly increased (Figure 1). [10] In the report of 2022-23, Uttar Pradesh is the state with the most pesticide consumption, followed

by Maharashtra and Haryana. States with large drops in overall consumption include Jammu and Kashmir, Uttarakhand, Goa and Mizoram (Figure 2). [9]



(Source: Based on data from Ministry of Chemicals and Fertilizers) [10]

Figure 1: Pesticide composition trends in India



(Source: Directorate of Plant Protection, Quarantine, and Storage) [9]

Figure 2: State-wise consumption of pesticides

Pesticides

Pesticides are more than a thousand chemical compounds used in agriculture for the purpose of controlling, eradicating, or preventing weeds, insects, and fungal diseases. [11] Because of their high biological activity and prolonged environmental persistence, pesticides pose a risk to human health as well as the environment. [12]

FAO statistics indicate that India uses 58160 kg/ha of pesticides annually. In the meantime, the respective amounts of pesticides consumed in China, Japan, and the US were roughly 13.07, 11.76, and 3.57 kg/ha. India clearly uses less pesticides per acre of agriculture than

other nations, but the high amounts of agrochemicals observed in natural systems are the result of negligent and unregulated pesticide usage. [5, 13]

The farmers are more exposed to pesticides than consumers. They are exposed mostly during mixing, application of pesticides and during cleaning of spraying equipment.

Early pesticide poisoning symptoms often mimic flu or gastroenteritis, leading to misdiagnosis. Exposure occurs via ingestion, inhalation, and dermal contact. [14] Common pesticides can cause acute poisoning, ranging from mild symptoms to severe neurotoxicity or death. Organophosphates

may cause delayed peripheral neuropathy, leading to lasting damage. [15]

Types of Pesticides

Insecticides

Insecticides are chemical or biological compounds used to prevent pest-borne diseases and control insect pests in crops. They are divided into classes like pyrethroids, carbamates (like carbaryl), organochlorines (like endosulfan), and organophosphates (like monocrotophos). 50% of all pesticides consumed in India are insecticides, with chlorpyrifos being the most commonly used substances. [5]

Herbicides

Herbicides are agrochemicals that are employed in ancient agriculture to stop or hinder the growth of undesirable plants. Herbicides are now widely used in modern agriculture. The quantity of herbicides produced in India decreased by 3,000 metric tonnes in 2019-20 compared to previous years and the percentage of herbicides increased from 17% in 2015-16 to 20% in 2019-20 which suggests that the use of herbicides is gradually increasing. [16]

Assessing herbicide exposure and its effects on non-target fauna and flora in aquatic environments is crucial, especially for herbicides sprayed directly on water or those contaminating it indirectly. [17] The common practice of uniform pesticide spraying in agriculture, without considering crop and weed distribution, leads to overuse, which contaminates water and soil, and greatly increases surface and groundwater pollution, endangering human health as well as the environment. [18] Examples include salt

and olive oil lees. Glyphosate is most commonly used in India.

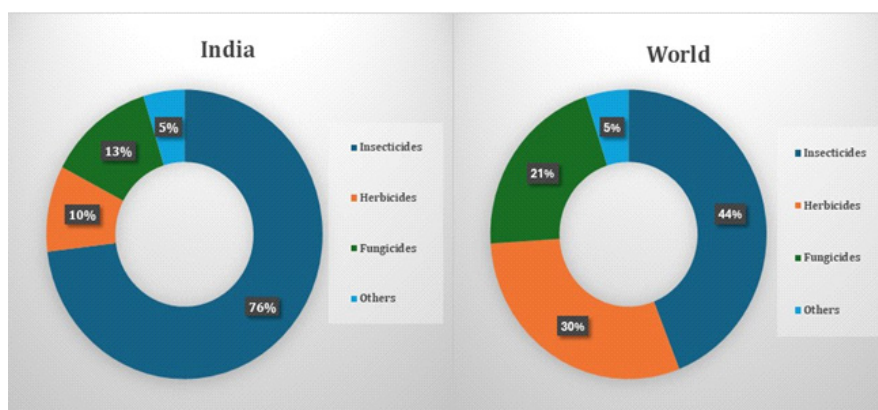
Fungicides

Fungicides are used to regulate mycotoxins and controlling wide range of fungal diseases in agriculture. They are used for crops like potatoes, melons, and grapes. In Indian agriculture, sulfur-based compounds, copper formulations, dithiocarbamates, triazoles, and benzimidazoles are often used fungicides. [19] Approximately 12% of India's agrochemical sector, which is worth more than ₹4,800 crore, is made up of fungicides. [19] Using fungicides leads to development of neurological diseases like Parkinson's disease, cognitive dysfunction, neural tube defects, and motor neuron disease. [20]

Fertilizers

Fertilizers-principally urea, ammonium sulfate, diammonium phosphate (DAP), and NPK blends-are pivotal for Indian agriculture, [21] however, their irrational application has precipitated extensive environmental pollution and biodiversity attrition. Despite a usage intensity (145 kg/ha) below the SAARC average (174 kg/ha), these inputs have accelerated eutrophication and soil degradation. Moreover, exposure poses serious health risks, ranging from acute dermatological reactions to chronic cardiovascular and respiratory pathologies [22]

Similarly, Figure 3 highlights a divergence in pesticide patterns: India's usage is heavily skewed toward insecticides (76% vs. 44% globally), with disproportionately lower fungicide and herbicide application. [23]



(Source: Developed by author)

Figure 3: Consumption pattern of agrochemicals in India and in World

Health impacts of chemical hazards

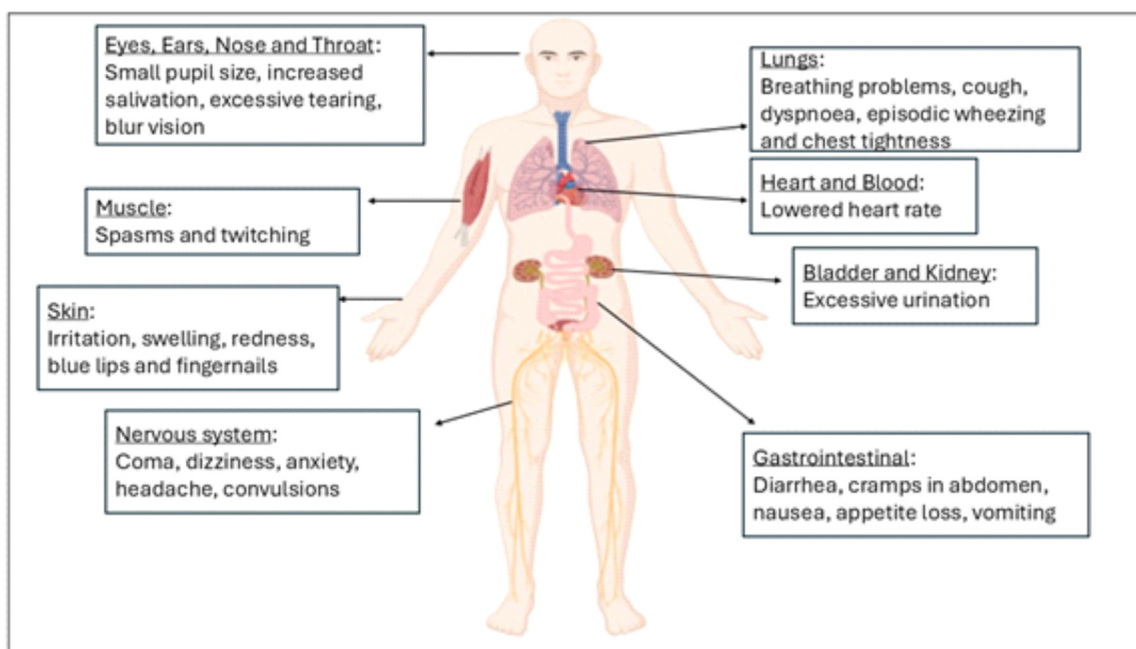
Agricultural workers are most frequently exposed to agrochemicals through dermal contact, where chemicals are absorbed by the skin due to leaks, spills, or handling treated crops. Other critical routes include inhalation of sprays and dusts, absorption through the eyes from splashes, and accidental ingestion caused by poor hygiene or clearing nozzles with the mouth.

Acute Pesticide Poisoning

Acute pesticide poisoning (APP) remains a severe public health concern in India, resulting in hundreds of fatalities annually. Defined as any illness occurring within 48 hours of suspected exposure, APP encompasses cases arising from occupational hazards, accidental contact, and intentional self-harm. [24] With approximately 10,000 cases reported each year, pesticide ingestion is a prevalent method of suicide.

High incidence rates in developing nations are driven by systemic issues, including weak regulatory frameworks, insufficient oversight, and a lack of safety training [24]. Furthermore, the agricultural sector often relies on pesticide application without adequate personal protective equipment (PPE) [2]. This exposure frequently leads to acute toxicity in farmers, commonly manifesting as skin conditions and allergic reactions. [25]

Historically, India's first major outbreak occurred in Kerala in 1958, where parathion-contaminated wheat caused over 100 deaths. [26] Today, WHO Class II organophosphates are the most common agents; while accidental exposure is often treatable, intentional ingestion is highly lethal. [27] Regional data from Bijapur, Karnataka, indicates that 95.33% of poisoning cases involved suicidal ingestion, primarily among men aged 15 to 35. [28] Systemically, APP affects multiple organ systems (Figure 4), potentially causing life-threatening paralysis or death. [27]



(Source: Developed by author)

Figure 4: Pesticidal poisoning of different human systems

Nationally, pesticides account for 63% of poisoning hospitalizations, predominantly affecting most commonly among 15–35 age group. While rates vary across India, the highest prevalence occurs in North India (79.1%) followed by the South (65.9%), highlighting a critical countrywide challenge. [29]

Chronic illnesses

Pesticide exposure results in a wide spectrum of health issues, ranging from immediate skin irritation to severe, long-term chronic diseases. [30] Epidemiological studies link regular agricultural exposure to multiple chronic diseases like

cancer, hormonal imbalances, and neurological impairments. Neurodegenerative disorders and respiratory conditions are frequently more common among workers who handle pesticides. [31] [32] Mechanistically, pesticides induce oxidative stress and disrupt enzymatic systems, causing DNA damage and mutations. [33] Chronic exposure to pesticides can lead to memory deficits, mood changes, vision impairments, and delayed neuropathy. [30]

Respiratory health

Respiratory health is also severely compromised by the agrochemicals. Farmers face elevated risks from inhaling chemical vapors and organic dust, leading to conditions such as asthma, COPD, and lung toxicity. [34] A study in North India highlighted this occupational hazard, finding respiratory distress in 36.75% of pesticide sprayers compared to only 3.89% of the control group. [35]

Neurotoxicity

Organochlorine pesticides like DDT, dieldrin, and endosulfan are strongly linked to neurotoxicity. DDT disrupts nervous system function causing hyperactivity [36], while dieldrin exposure correlates with Parkinson's disease. [37] Although banned, endosulfan remains a hazard, causing epilepsy and cognitive deficits in exposed workers. [38]

Reproductive and developmental effects

Beyond chronic diseases, pesticide exposure significantly impairs reproductive health. Research indicates that women exposed to hormonally active pesticides face 60–100% higher odds of gynecological disorders, including irregular menstruation, severe pelvic pain, and recurrent miscarriages. [39] Furthermore, accumulated toxins can be transferred from mothers to infants through breastfeeding. [40]

Male occupational exposure is equally damaging; studies link it to increased rates of stillbirths, birth defects, and lower survival rates in offspring. [41]

Mechanistically, many pesticides function as endocrine disruptors. By mimicking estrogen or blocking androgens, they alter hormonal balance, resulting in lowered sperm counts and infertility across both sexes. [42]

Immunological effects

Research indicates that pesticide exposure compromises immune function, impairing defenses against pathogens and cancer. By altering cytokine signaling and inducing oxidative stress (ROS/RNS), pesticides affect both innate and adaptive immunity. [43] This interference disrupts immunological homeostasis, leading to chronic inflammation and systemic dysfunction. [44]

Cancer

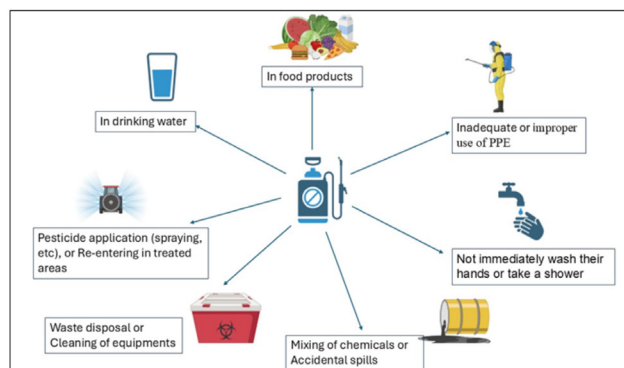
Studies reveals that regular exposure among farmers and agricultural workers is associated with leukemia, lymphoma, multiple myeloma, and malignancies of the brain, prostate, and skin. [31] Approximately 300 million agricultural acres receive an annual application of 280 million pounds of glyphosate, which has been linked to an increased risk of lymphoma. 12 of 30 pesticides under observation have been linked to cancer, including prostate and leukemia. [45] The 2017 International Agency for Research on Cancer (IARC) report deemed major organophosphates are carcinogenic, with more recent evidence expanding the list of harmful pesticides. DDT's long half-life further increases cancer risk. [46, 47]

Local practices and their contribution to chemical exposure

Pesticide toxicity varies by dosage and bioaccumulation, often leading to delayed illness. [48] While Personal Protective Equipment (PPE) mitigates these risks, its effectiveness requires strict adherence to safety protocols. Consequently, proper handling is essential to prevent occupational exposure and residues in food and water. [2] Many farmers work without proper protective gear and combine pesticides with their bare hands despite being aware that pesticide exposure can be detrimental to both the environment and human health. Some farmers kept pesticides inside their homes or threw empty containers in open fields, which raises the danger of contamination and poisoning. These storage and disposal practices were especially hazardous. [49]

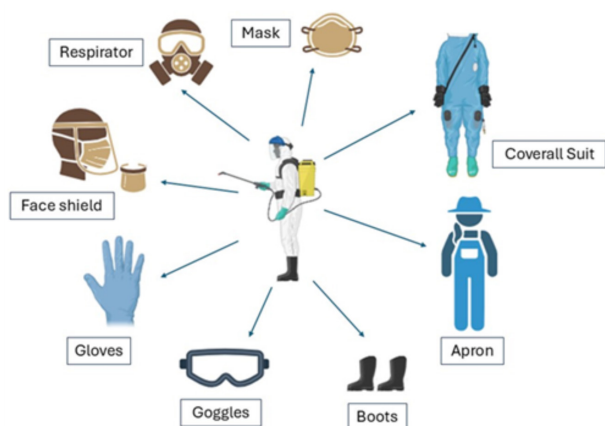
A study in Kaniyambadi block Tamil Nadu revealed hazardous practices, including mixing chemicals with bare hands and reusing containers. Only 28% of farmers utilized PPE, a deficiency strongly

linked to lower education levels. [50] This highlights a critical lack of awareness regarding toxicity and disposal, posing severe occupational risks. Common exposure activities and appropriate safety gear are depicted in Figures 5 and 6, respectively.



(Source: Developed by author)

Figure 5: Activities with potential exposure to chemical products



(Source: Developed by author)

Figure 6: PPE Elements

Food safety and public health concerns

Global food production has benefited greatly from pesticides, yet many of them particularly lindane and DDT remain in the environment and contaminate food. Approximately 28% of food samples in India above permissible residual levels, posing serious health hazards associated with pesticides. [51]

Environmental contamination and ecosystem effects

Pesticides can contaminate turf, water, soil, and vegetation, affecting not only weeds and insects but also fish, birds, and non-target plants. [23] Insecticides are particularly harmful to non-target organisms,

though herbicides can also pose risks. Runoff from treated areas commonly contaminates surface water, with over 90% of fish and water samples showing pesticide residues. [52] Pesticides can leach from soil, threatening clean drinking water and reducing beneficial soil microbes. [23]

Overview of chemical hazard management in India

To safeguard the environment and public health, pesticide management must be done appropriately. To lower pesticide hazards and increase sustainable crop production, India implemented Integrated Pest Management (IPM) in 1985. Through national initiatives, IPM combines cultural, mechanical, biological, and selective chemical approaches. [9] The WHO and FAO's International Code of Conduct guides pesticide manufacture and distribution, urging sustainable practices and strong regulations. [53] Additionally, the Strategic Approach to International Chemicals Management (SAICM), which India supports, focuses on global chemical safety and responsible pesticide management. [53]

National policies and their effectiveness

The Insecticides Act of 1968, which initially governed pesticides in India, was replaced by the Pesticide Management Bill 2020 due to flaws in environmental and safety regulation. With enhanced protections and greater penalties, the new law improves control over the manufacture, use, and disposal of pesticides. [54] Biopesticides, making up 3% of the market, offer a sustainable alternative, with studies showing they can significantly reduce chemical pesticide use in crops like cotton and cabbage. [55]

In India, companies must register pesticides and obtain licenses from the Central Insecticides Board. [54] State governments can issue temporary bans on harmful pesticides, but enforcement is challenging. Panchayats play a role in regulating pesticide use at the village level. The National Youth Policy 2014 highlights the need to address pesticide poisoning linked to mental health issues. [56] Consumer protection laws cover deceptive practices, and personal protective equipment (PPE) is required for pesticide use. [54] Multiple laws, including the Environmental Protection Act and the Insecticide Act, govern pesticide management. The government

must enhance social security for agricultural workers and ensure better occupational health protections. [2]

Conclusion

In India, the extensive usage of hazardous pesticides has resulted in serious health issues for farmers including cancer, neurotoxicity, reproductive problems, and respiratory disorders. Despite regulations, improper PPE use and varied application methods exacerbate these problems. Environmental contamination further threatens ecosystems. Addressing these issues requires stricter laws, better enforcement, improved farmer education, and promotion of sustainable practices. A comprehensive strategy involving government, NGOs, and the agricultural community is crucial.

Future directions

Develop targeted health education materials for farmers, including posters and brochures on hygiene, PPE use, first aid, and pesticide safety. Implement administrative controls such as regular health checks, hazard training, and ensuring access to sanitation and ergonomic equipment. Ensure proper PPE use, ventilation, and mental health support for chemical-exposed workers. Promote policies for PPE use, maintain records of pesticide use and worker exposure, and provide ongoing training on safe handling and emergency response.

Conflicts of interest: The author declares no conflict of interest.

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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