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Navigating the Hazards: A Review of Pesticides and Their Effects on Human Well-Being

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ABSTRACT

Chemicals of synthetic or natural origin and pesticides are used to kill insects and other pests. These are essential to improved crop productivity in agricultural processes. The purpose of using pesticides is to increase agricultural yield while shielding the plants from harm and illness. Because pesticides are by nature harmful to people and other creatures, they must be handled carefully and disposed of properly. When pesticide contamination moves outside of the intended plant targets, it can lead to environmental damage. Older pesticides like dichlorodiphenyltrichloroethane (DDT) and lindane can linger longer in soil and water. They harm the ecosystem by building up in different areas of the food chain. When it comes to managing pest control, biological methods like importation, augmentation, and conservation, together with their corresponding procedures, are more cost-effective, environmentally sound, and efficient than alternative approaches. This review primarily addresses the effects of pesticide use and toxicity on both targeted and non-targeted creatures, including human health and welfare. These groups of pesticides comprise pyrethroids, carbamates, organochlorides, organophosphorus, and other compounds. The current study includes the identification of pesticides' impact on humans and their risk assessment.

Keywords: *Pesticide, Environment, Toxicity, Human health*

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INTRODUCTION

Numerous international patents and licensed goods connect farming with unusual technology globally, to give humanity access to various commodities like wood, fuel, and food. Generally speaking, the goal of agrochemical technology is to safeguard agricultural areas from pests (diseases, dangerous insects, parasitic weeds) that reduce output and productivity. However, the indiscriminate use of pesticides for harmful pests and insects has also hurt productivity, leading to the development of pathogen and insect resistance, an increase in the need for new agrochemicals, and an imbalance in the environment (Chaud *et al*., 2021). Many of the most widely used pesticides are systemic, meaning they protect—and contaminate—all plant organs, including flowers, which in turn produce nectar and pollen (Tosi *et al*., 2018). Concerns about customers being exposed to high acute toxicity pesticide residues have been highlighted in recent years (Ambrus, 2000). The risks of using pesticides are not well understood by many workers, especially in developing nations, and the health risk is increased when workers lack the tools and training necessary to handle pesticides safely (Gangemi *et al*., 2016). It was acknowledged that the effects of pesticide poisoning were most severe for those living in underdeveloped nations and that the true number of cases was likely much greater because many went unreported (Boedeker *et al*., 2020).

Permethrin, malathion, piperonyl butoxide, and isododecane are used by the public health sector (PHS) to control important insects for public health in homes, schools, offices, and retail spaces (Mekonen *et al*., 2016). These factors also hurt agriculture. In recent decades, however, we have come to understand that pesticide residues do permeate throughout the environment, seriously contaminating terrestrial ecosystems and tainting human food supplies (Carvalho, 2017). Organic farms are now very varied from one another in terms of labor input, intensity, size, complexity or specialty, mechanization, profitability, and marketing (Niggli, 2015). It was acknowledged that the effects of pesticide poisoning were most severe for those living in underdeveloped nations and that the true number of cases was likely much greater because many went unreported (Bonvoisin *et al*., 2020).

Pesticides are widely employed in contemporary agriculture because they are a cost-efficient and efficient technique to improve product quality and quantity, maintaining food security for the world's expanding population. An estimated 2 million tons of pesticides are used globally each year; China is the country that contributes the most, followed by the United States and Argentina, whose use is growing at a rapid pace. However, it is predicted that the amount of pesticides used worldwide will rise to 3.5 million tonnes by 2020. The global pesticide usage is represented in **Figure 1**, pesticide use in India and states are mentioned in **Figures 2 and 3,** respectively.

Pesticides are a mixed class of organic and inorganic substances. The WHO categorizes toxins into four classes: very hazardous (Ib), extremely hazardous (Ia), moderately hazardous (II), and slightly harmful (III). Eighty-six pesticides, of which five are herbicides, eight are fungicides, fifty-one are insecticides, and twenty-two are other categories of compounds used to eradicate plant infections make up Classes Ia and Ib, the most harmful ones (Wołejko *et al*., 2020). While pesticides are advantageous when it comes to crop production, their persistent nature and bio-magnification can have major negative effects when used excessively. Numerous pesticides have contaminated the air, water, soil, and ecosystem as a whole, either directly or indirectly, posing a major risk to human health (Sharma *et al*., 2019) and there are possible dangers and problems associated with the significant persistence of pesticides in environmental compartments and their limited service efficiency (Zhang *et al*., 2020). Pesticides are pervasive environmental pollutants detected in samples of human and animal tissues from all over the world, as well as in the air, soil, and water. Research on pesticides is seen to be crucial for lowering dangers associated with them and enhancing public health regulations (Cataudella *et al*., 2012), state wise pesticide consumption in India is plotted as a pie chart in **Figure 3**. Buffer zones, like vegetative filter strips, can be used to restrict the migration of phosphate, nitrate, and pesticide contamination into water when they are placed next to agricultural regions or artificial wetlands. Organic contaminants, like the ubiquitous hydrocarbon toluene, can be changed into innocuous molecules by soil biota (Lehmann *et al*., 2020).

Three eras can be distinguished in the history of pesticide use. Initially, before the 1870s, pests were managed with a variety of natural substances. The Sumerians are credited for using pesticides for the first time approximately 4500 years ago (Tudi *et al*., 2021). In 25% of the soil samples, a single pesticide residue was found, but in 35% of the soil samples, several residues were found. The amount of residues varied greatly depending on farming practices, vegetable fields, and soil depth. Pesticide residues were more commonly detected in the topsoil (0–5 cm) and less frequently in the depths of 35–40 cm (p ¼ 0.001). Up to seven pesticide residues were found in 2% of the top soils that were analyzed (Bhandari *et al*., 2020). The Insecticides Act was passed sixty years ago, and since then, worldwide guidelines have changed and our understanding of pesticide management and the risks connected with its usage has improved. Currently, the Act prevents state governments from enacting permanent pesticide bans (Bonvoisin *et al*., 2020). Pesticides are categorized into many classes according to the user's or applicant's needs. The following are the three primary classifications: Pesticides are categorized (1) based on their chemical composition, (2) based on the type of pest they eradicate, and (3) based on how they enter the environment (Alengebawy *et al*., 2021).

This review primarily addresses the effects of pesticide use and toxicity on both targeted and non-targeted creatures, including human health and welfare. These groups of pesticides comprise pyrethroids, carbamates, organochlorides, organophosphorus, and other compounds. The current study includes the identification of pesticides' impact on humans and their risk assessment.

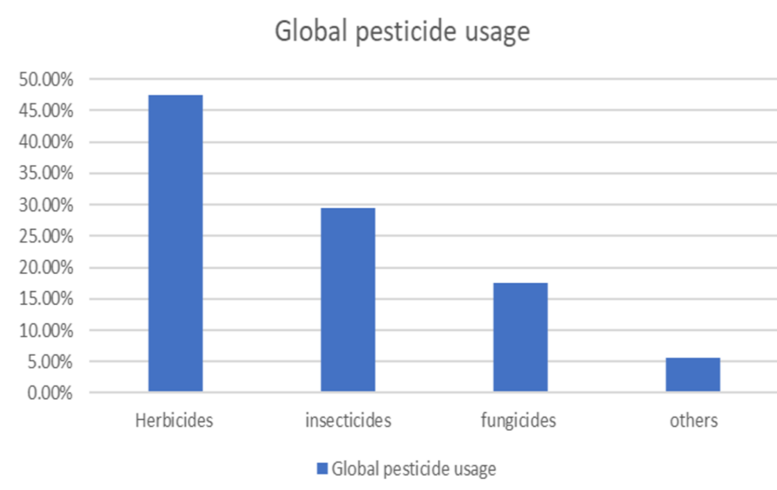

Figure 1. Percentage of global pesticide use (Alengebawy *et al*., 2021).

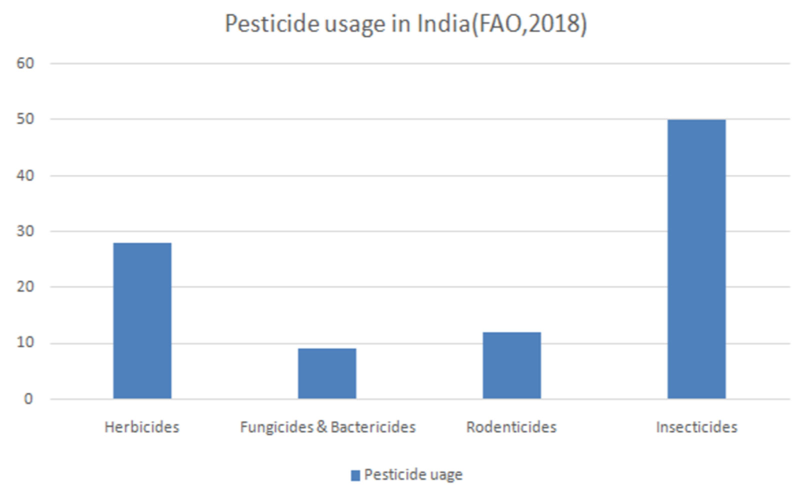

Figure 2. Pesticide usage in India (Sood, 2023).

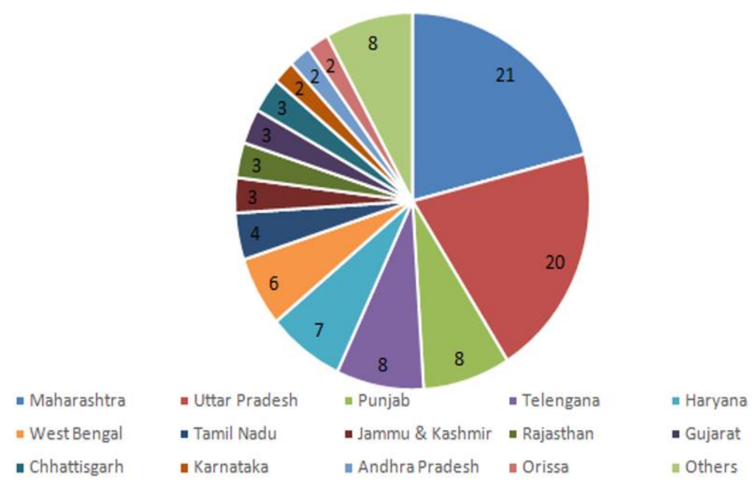

Figure 3. State-wise pesticide consumption in India (Nayak & Solanki, 2021).

MATERIALS AND METHODS

Information reported in this article, including pesticide-related details, was obtained through published materials from 2015-2024. The study includes the pesticides nature, types of pesticides, risk assessment, and exposure to pesticides on human beings. We employ the Zotero connector for citation and bibliography purposes, and Microsoft Word for text input, while the creation of graphs and tables was facilitated through the utilization of Microsoft Excel. The majority of the studies were identified through Google Scholar using the following terms "pesticides", "toxicity, environment", "exposure", "route of pesticide", "soil health", "acute infection", "long term effects", "global pesticides usage", "pollutants", "immunology". Moreover, further publications were identified among the reference list of screened articles.

RESULTS AND DISCUSSION

Classification of pesticides

Based on the chemical makeup and makeup of active components, pesticides are categorized most popularly and practically. This type of classification **(Figure 4)**, provides information about the chemical, physical, and efficacious characteristics of the individual pesticides. Pesticides are divided into four primary classes based on their chemical makeup: carbamates, pyrethrin and pyrethroids, organochlorines, and organophosphorus. The classification of pesticides based on their chemical makeup is somewhat intricate. Modern insecticides are often made of organic compounds. They consist of both synthetic and plant-based insecticides. Nonetheless, several inorganic compounds are also employed as herbicides (Yadav & Devi, 2017).

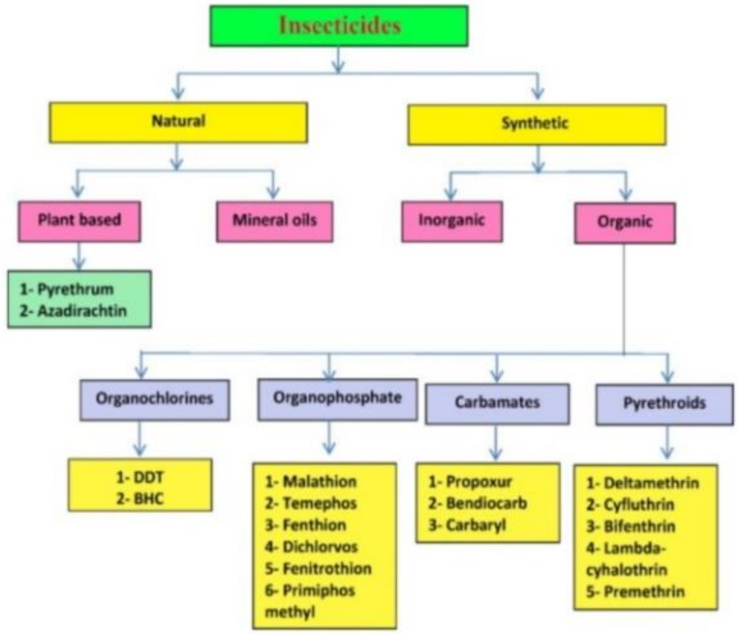

Figure 4. Classification of pesticides (Hassaan & El Nemr, 2020).

Types of pesticides

Natural pesticides are made of natural substances that act as repellents or killers to minimize, eliminate, and kill pests including weeds, fungi, insects, and other undesired creatures that harm crops, people, and the environment (Dhouib *et al*., 2016). Organochlorines have a wide range of structures and chemical characteristics. These compounds can be made using various chlorinating agents, hydrogen chloride, and chlorine. Organochlorines can enter an organism's body through the skin, the lungs, and the intestinal wall. The skin can readily absorb cyclodienes, hexachlorocyclohexane, endosulfan, and lindane, but less so dicofol, toxaphene, DDT, mirex, and methoxychlor can be absorbed (Singh, 2016). Organophosphate pesticides are primarily divided into two categories: the first is based on the toxicity level of the pesticide, and the second is based only on its chemical makeup. The enzyme that breaks down acetylcholine, acetylcholinesterase (AChE), is irreversibly inhibited by high levels of OP exposure (Judge *et al*., 2016). O-(4-Bromo-2-chlorophenyl) O-ethyl-S-propyl phosphorothioate, or profenofos, is an organophosphorus insecticide that is minimally soluble in water and easily miscible in organic solvents. It poses a risk to water quality (Pandey *et al*., 2018). The majority of these insecticides dissolve in water with a relatively low vapor pressure and a high oil-water partition coefficient. Except for dichlorvos, which is extremely volatile, the majority of these pesticides have rather low volatility (Kaushal *et al*., 2021).

The acute toxicity of carbamate insecticides is considerable. Chemically speaking, carbamate insecticides persist as organic components made from N-methyl carbamic acid (C_2H_5NO) and esters of carbamates, which take weeks or months to decompose in the soil. Insecticides, herbicides, and fungicides known as carbamates work by inhibiting acetyl-cholinesterase, much as organophosphate pesticides for insecticides and nematocides, but with a reversible effect (Mustapha *et al*., 2019). A class of synthetic pesticides is called pyrethroids. Their molecular structure is derived from pyrethrins that are present in *Chrysanthemum cineraraefolum* blooms naturally. The majority of pyrethroids are chiral compounds that exist as enantiomer mixes. One of the most widely used pesticides, pyrethroids are used in many agricultural formulations that are intended to control insect pests in gardens, horticulture, forestry, and crops (Saillenfait *et al*., 2015). The efficacy of pyrethroid breakdown is contingent upon various soil parameters, including texture, organic matter content, moisture content, pH, and temperature, in addition to the catabolic activity of soil microbes (Cycoń & Piotrowska-Seget, 2016)

Toxicity of pesticides on the environment

Pesticides have long-term effects on the environment, (A schematic representation of pesticide transport routes after application is mentioned in **Figure 5**, because of their toxicity to non-target species, persistence in the environment, and other factors. It has been discovered that pesticides are extremely hazardous to fish as well as the other creatures that make up the food chain (Srivastava *et al*., 2016). Pesticides have the immediate and direct ability to destroy Monopteruscuchia and other aquatic life (Chakraborty, 2023). It has long been known that substances like these, which are organohalogen compounds, build up in the atmosphere and affect the environment worldwide (Hough, 2003). When it comes to a variety of regulated stressors that are relevant to bees and fall under its purview, such as plant protection products, animal illnesses and pests, and genetically modified species, EFSA offers scientific advice and assistance on bee risk assessments (Rortais *et al*., 2017). Even after many years of use, the features of pesticides, such as high lipophilicity, bioaccumulation, long half-life, and capacity for long-range transport, have increased the likelihood of contaminating the air, water, and soil (Jayaraj *et al*., 2016).

Persistent organic pollutants (POPs) are pollutants that have been present in our environment for an extended period. These contaminants are persistent and can travel over international borders as well as different locations. These bioaccumulate into the food chain, affecting both humans and animals and causing several well-known health risks and environmental consequences (Alharbi *et al*., 2018). Because of its significant environmental persistence, the synthetic pyrethroid insecticide permethrin has the potential to move into surface and groundwater during or after spraying (Banaee *et al*., 2015).

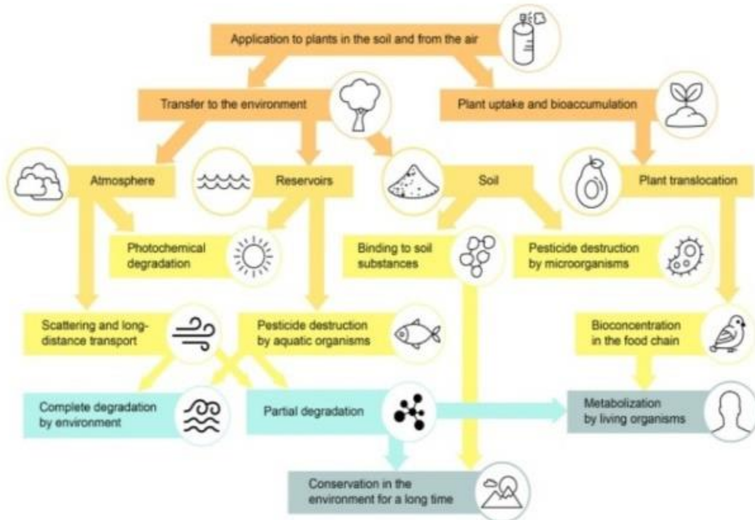

Figure 5. A schematic representation of pesticide transport routes after application (Kalyabina *et al*., 2021)

Toxicity of pesticides on human

The degree of exposure as well as the toxicity of the substances determine the likelihood of health risks from pesticide use. Furthermore, particular groups of people may be more vulnerable to the negative effects of pesticides than others, including children, pregnant women, and older populations (Kim *et al*., 2017). In the agricultural industry, professional pesticide applicators and farmers are usually the ones who are exposed to pesticides. In terms of the general public, people could regularly come into contact with pesticide residues in food and drink, as well as pesticide drift in residential areas near spraying locations (Damalas & Koutroubas, 2016).

Pesticides can enter the human body through three main routes: the skin, the respiratory system, and the digestive system. Ingested stomach toxins, contact exposure, expectorant, and evaporators are the routes of exposure (Hassaan & El Nemr, 2020). The identification of the source of exposure is made particularly difficult by intermittent exposure, non-continuous usage of changing combinations of active chemicals, and intraseasonal fluctuation of the active substances utilized (Zaganas *et al*., 2013).

About 97% of the exposure that pesticide users receive from non-fumigant pesticides comes from dermal (skin) contact. It can happen whenever a pesticide is handled, combined, or administered, and it frequently goes unnoticed. Contact with pesticide residues on treated surfaces or contaminated equipment during cleaning or repair can potentially lead to skin exposure. The following factors determine how harmful dermal exposure is: the pesticide's dermal toxicity; the rate of absorption through the skin; the size of the contaminated skin region; the duration of the material's contact with the skin; and the quantity and concentration of pesticide on the skin (Fishel, 2015). One important way that workers are exposed in a variety of jobs is through their skin, particularly in manufacturing, agricultural, and Service industries (Mandic-Rajcevic *et al*., 2019).

An inflammatory state brought on by or made worse by viruses, bacteria, fungi, and environmental factors characterizes chronic respiratory disorders, which affect the entire airway from the ear, nose, and throat to the pulmonary alveoli. Among these are substances that can harm the respiratory system, such as pesticides, chemicals, smoke from tobacco, gaseous or particle air pollution, and allergies (Mamane *et al*., 2015). The gastrointestinal tract, skin, eyes, and respiratory system are the main entry points for pesticides into the human body (Ssemugabo *et al*., 2017).

Health impact of pesticide exposure

We know that pesticides are neurotoxins. Long-term low-dose exposure to pesticides including paraquat, dieldrin, organochlorine, and organophosphates has long been suspected, even if the mechanisms underlying their influence on neurodegenerative illness are still unclear. Numerous characteristics are shared by the majority of pesticides, including the capacity to cause neuronal death, α-synuclein fibrillization, mitochondrial dysfunction, and oxidative stress (Yan *et al*., 2016). Inadequate control over the use of pesticides in food production poses threats to farmers' safety at work as well as the environment and agricultural ecosystems (Lu *et al*., 2015).

Table 1. Chemical Basis and Toxicity Profile of Pesticides

Chemical basis	Pesticides	Site of toxicity	Signs and symptoms	Chronic diseases
Chlorinated hydrocarbons	Hexachlorobenzene, Methoxychlor, chlordane, lindane, toxaphene, and dieldrin	Neurotoxic action via disrupting ion exchange kidney, liver	Hyperesthesias, Irritability dizziness, headache, disorientation, Weakness, confusion, convulsion, aplastic anemia	Testicular cancer, thyroid cancer, non-Hodgkin's lymphoma, autoimmune response, Parkinson's
OPs	Dichlorovos, diazinon, terbufos, and chlorpyrifos	Neurotoxin	RADS, IIA, asthma, fatigue, blurred vision, dizziness, numbness of extremities, nausea, vomiting, excessive sweating, stiffness in chest, weakness, muscular cramps, unconsciousness, paralysis, respiratory difficulty, chronic cough	Prostate cancer, lung cancer, colorectal cancer, leukemia
Fungicides	Captofol, fluazinam And chlorothalonil	Lungs, CNS, liver, kidney	Chronic cough, occupational asthma headache, nausea, vomiting, dyspnea, pulmonary edema	Pancreatic cancer, lung cancer, bone cancer, liver cancer,
Phenoxy derivative	2,4-D and 2,4,5-T	Skin, eyes, respiratory and GI tract	Birth defects, cleft palate, skeletal abnormalities, burning sensation in the nasopharynx and chest, light-headedness vomiting, stomach pain, diarrhea, muscle firmness, and metabolic acidosis	Lung cancer, gall bladder, pancreatic cancer, esophageal cancer
Dipyridyls	Diquat and paraquat	Injury to epithelium, cornea, liver, kidney, and lining of GI oliguria, jaundice, cough, dyspnea	Ingestion early, nausea, vomiting, 48-72h After exposure oliguria, jaundice, cough, dyspnea	Gallbladder, lung cancer, testicular cancer, stomach cancer

RAD: Reactive airway dysfunction syndrome, IIA: Irritant-induced asthma, CNS: central nervous system, GI: Gastrointestinal, Ops: Organophosphates

Pesticides have been shown to have both short-term and long-term negative effects on human health in environmental systems. Human health illnesses that are frequently reported include those about the immune system, hormones, delusions, reproduction, and even cancer **(Table 1)** (Srivastav, 2020).

Table 2. Different Pesticides and their hormone disturbance effects (Sood, 2023).

Pesticide	Hormone Disturbance effects
Aldicarb	Inhibition of progesterone & estrogen
Aldrin	Testosterone receptor binding
Carbofuran	Increase in estradiol & progesterone & decrease in testosterone
Dieldrin	Androgen receptor binding
Deltamethrin	Increased estrogens
Chlordane	Androgen receptor binding
Fenoxycarb	Decrease in luteal progesterone, increase in androgens
Lindane	Testosterone metabolism disruption
Parathion	Inhibition of gonadotrophic hormone synthesis
Methoxychlor	Estrogen antagonism in females
Tetramethrin	Estrogenic effects

We can differentiate between two distinct forms of toxicity based on the duration of exposure to toxicants: Acute toxicity is seen shortly after a brief or one-time chemical exposure; chronic toxicity develops over an extended period or from recurrent exposure to reduced chemical doses (Farcas *et al.*, 2013). There is disagreement on the true effects of these changes on human humoral cytokine levels and, specifically, the lowest dosages that may encourage the onset of chronic illnesses (Gangemi *et al.*, 2016). Many pesticides that are widely used throughout the world are known to be human nephrotoxins, even though they cause acute kidney injury (AKI) rather than chronic kidney disease (CKD). These include deltamethrin, glyphosate, paraquat, carbofuran, and some organophosphate (OP) and organochlorine (OC) insecticides. These findings are based on experimental and occasionally clinical evidence (Valcke *et al.*, 2017).

Chronic/long-term effects of pesticides

Insecticide (Ngowi *et al.*, 2016) exposure for an extended period, whether from the workplace or the environment, can interfere with the normal functioning of many bodily organ systems, such as the neurological, endocrine, immunological, reproductive, renal, cardiovascular, and respiratory systems **(Table 2)** (Sule *et al.*, 2022). Certain people may be exposed to non-lethal dosages and develop significant non-lethal pathological aftereffects that manifest days, weeks, or years later. Seizures and hypoxia are probably the root causes of this severe morbidity, which can happen in a matter of minutes to days and result in brain damage (Jett & Spriggs, 2020). Pesticide exposure has also been linked to chronic illnesses in humans, including adult brain cancer, lymphocytic leukemia (CLL), prostate cancer, childhood cancer, Alzheimer's disease (AD), Parkinson's disease (PD), reproductive disorders and hormonal imbalance, respiratory diseases, breast pain, and infertility (Amenyogbe *et al.*, 2021).

Acute/short-term effects of pesticides

Usually, acute disease develops soon after coming into touch with or being exposed to the chemical. Acute illnesses in humans are typically caused by chemical drift from agricultural fields, exposure to pesticides during application, and purposeful or inadvertent poisoning (Islam *et al*., 2017). Headache, eye and skin stinging, throat and nose irritation, skin itching, breakouts and blisters on the skin, dizziness, diarrhea, stomach discomfort, nausea, vomiting, blurred vision, blindness, and, very rarely, death are some of the immediate symptoms of pesticide exposure. The short-term consequences of pesticide exposure are not severe enough to warrant seeking medical attention (Mahmood *et al*., 2016).

Threatening reports on hazardous effects of pesticides

Endosulfan is a member of the class of organochlorine insecticides and is classified as an organochlorine pesticide within the Cyclodiene subgroup (Odukkathil & Vasudevan, 2016). In 1954, endosulfan was originally registered as a pesticide in the US. There is currently just one known producer of endosulfan in the UNECE region, and it is based in Germany (Rehman *et al*., 2016). When endosulfan is mistakenly consumed, tainted food or water, or used in suicide instances, it is linked to a high death rate in humans. Furthermore, it mimics or amplifies the effects of the female hormone estrogen, which implies that it can harm an animal's or human's reproductive system and development. Researchers have connected exposure to endosulfan to delays in boys' sexual maturity while observing kids from a remote hamlet in Kerala, India (Patočka *et al*., 2016).

Endosulfan has an impact on the female hormone estrogen, which can harm an animal's or human's reproductive system and development. Endosulfan poisoning primarily affects the central nervous system, and endosulfan exposure also damages liver tissue in tandem. In addition to its neurotoxic properties, endosulfan also functions as a hematoxylin, a genotoxin, and a nephrotoxin. Endosulfan has been linked to innate bodily illnesses, psychological issues, and fatalities in communities and farmworkers worldwide. Large-scale symptoms of endosulfan poisoning include coma, convulsions, headaches, nausea, upset stomach, seizures, depression of the metabolic process, vomiting, and in extreme cases, death (Karn *et al*., 2022). Endosulfan causes chronic symptoms like testicular and prostate cancer, breast cancer, and sexual abnormalities in many mammalian species (Vivekanandhan & Duraisamy, 2012).

Strategies for protection from pesticides

Techniques used to address issues brought on by pesticide introductions can be broadly divided into two categories: mitigating and preventive approaches.

Preventive strategies

In recent years, traditional techniques, including non-chemical alternatives are viewed as technology options that could help in decreasing or avoiding the need for undesirable chemical inputs and create sustainable systems. Numerous models exist and have been advocated in this regard viz, Integrated Pest Management (IPM), Low External Input Sustainable Agriculture (LEISA), and Organic Agriculture.

Integrated pest management (IPM)

Early in the 1970s, the phrases "Integrated Pest Management" and "IPM" were coined. IPM developed from the ideas of pest management, which uses a variety of strategies, such as monitoring and action thresholds, to keep pest populations below harmful levels, and integrated control, which was created in the 1950s in response to pest populations that were resistant to pesticides and pest outbreaks brought on by pesticide impacts on beneficial insects (Baker *et al*., 2020). IPM supports natural pest management methods and the development of a healthy crop with the least amount of disturbance to agroecosystems (Deguine *et al*., 2021). IPM provides a framework for controlling risks to the economy, health, and environment while minimizing unfavorable effects on crop productivity (Jepson *et al*., 2020).

Low external input sustainable agriculture (LEISA)

By using the LEISA system, farmers may cultivate potatoes with less reliance on chemical fertilizers and maintain the system in an environmentally friendly way (Setiyo *et al*., 2017). In LEISA, modest concentrations of PBRs are sprayed foliar to the crop to modify the signaling linked to plant growth and yield; in contrast, priming is mostly administered during the seed soaking stage to activate the stress tolerance mechanism, which improves plant performance under subsequent stress exposure (Srivastava *et al*., 2016)

Organic agriculture

"Organic agriculture" refers to practices that comply with EU regulations or comparable standards for organic production, which include using organic fertilizers like a farmyard and green manure, relying primarily on ecosystem services and non-chemical methods for controlling pests, and providing livestock with access to roughage feed and open-air (Mie *et al*., 2017). Organic agriculture has a history of being contentious and is considered by some as an inefficient approach to food production (Reganold & Wachter, 2016).

Mitigating strategies

The truth is that the application of mitigation models to unsuitable scenarios where the fundamental biological, ecological, genetic, or logistical presumptions cannot be satisfied limits the models' potential for success. It is challenging to foresee which model would work best in a given circumstance; in certain cases, implementing the model will speed up the development of resistance rather than slow it down if the assumptions of the model cannot be followed (Hoy, 1998).

CONCLUSION

In summary, the effects of pesticides on people highlight a complicated web of environmental consequences, socioeconomic dynamics, and health issues. Furthermore, the long-term effects of pesticide residues in the food chain and environment continue to endanger both ecological stability and human health. To reduce the harmful effects of pesticides on human health and protect present and future generations, comprehensive regulatory frameworks, integrated pest management tactics, and enhanced public knowledge are thus desperately needed. Adoption of alternative pest control techniques, which reduce dependency on chemical interventions, such as crop rotation, biological controls, and organic farming methods, must be given top priority in efforts to reduce the dangers associated with pesticide use. Moving toward more sustainable agricultural systems can also be aided by providing farmers with information, training, and safer options. By giving these initiatives top priority, society may strive toward a more just and resilient food system that strikes a balance between agricultural output and the preservation of the environment and public health.

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