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Review Article

To Study of Harmful Effects of Pesticides on Human Body and Environment

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ABSTRACT

Pesticides, widely used in agriculture and pest control, pose significant risks to both human health and the environment. While their primary function is to protect crops and reduce disease vectors, the excessive and indiscriminate use of pesticides has led to unintended consequences. This review examines the harmful effects of pesticides on the human body, including acute and chronic health issues such as respiratory problems, skin conditions, neurotoxicity, endocrine disruption, and carcinogenicity. The vulnerability of agricultural workers, communities near pesticide application areas, and consumers exposed to pesticide residues is highlighted. Additionally, the environmental impact is explored, with emphasis on soil degradation, water contamination, loss of biodiversity, and the disruption of ecosystems. The bioaccumulation of harmful chemicals in non-target species, such as aquatic life and pollinators, exacerbates these effects. In conclusion, there is a need for stricter regulations, safer alternatives, and public awareness to mitigate the detrimental effects of pesticide use, thereby protecting both human health and the environment.

INTRODUCTION

Humans have faced numerous challenges in protecting their crops since the establishment of agriculture during the New Stone Age, between 7000 and 10,000 years ago, including threats from insects, plant diseases, weeds, and destructive animals. Various organic and non-organic substances derived from animals, plants, minerals, and microorganisms have been documented as effective pest control methods. Among these, plant extracts, known as natural pesticides, have the longest history. Nicotine, the earliest agricultural natural pesticide, was used in the 17th century to control plum beetles. By the mid-20th century, due to advancements in the chemical industry, affordable and effective synthetic pesticides were developed. Pesticides are extensively utilized in agriculture to control pests, diseases, weeds, and

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other pathogens, aiming to minimize yield losses and maintain product quality. Pesticides are also used to protect animals from pests. However, it is crucial to recognize that pesticides are essentially active poisons. In light of sustainable agriculture, environmental protection, and human health, the significance of pesticide use has gained global attention, particularly following the 1992 Earth Summit. Despite stringent regulatory processes in place to ensure pesticides function with reasonable safety, concerns have been raised about health risks stemming from occupational exposure and residues in food and water. The use of pesticides has also raised alarms about their impact on wildlife and sensitive ecosystems. The World Health Organization estimates that three million severe acute pesticide poisonings occur annually worldwide, with approximately 220,000 deaths, of which 1% are in industrialized countries. Pesticide usage patterns in India differ from global trends, with 76% used as insecticides, compared to 44% worldwide. Cotton crops in India account for 45% of pesticide use, followed by paddy fields and wheat farming. Repeated low-dose applications have had significant impacts on agroecosystems. Currently, India is the largest producer of pesticides in Asia, ranking 12th globally, with an annual production of 90,000 tons. A majority (56.7%) of India's population is engaged in agriculture, making them vulnerable to pesticide exposure through various routes such as inhalation, ingestion, and dermal contact. Pesticides are chemicals designed to kill pests, including herbicides, insecticides, rodenticides, fungicides, and more. Herbicides are the most commonly used, accounting for 80% of all pesticide use. Most pesticides serve as crop protection agents, defending plants from weeds, fungi, or insects. Pesticides can be chemical or biological agents that deter, incapacitate, or kill pests, including insects, weeds, mollusks, birds, mammals, and microbes. The present paper aims to review literature assessing the safety and impact of pesticides on human health, animal life, and the environment [1-4].

HISTORY OF PESTICIDES:

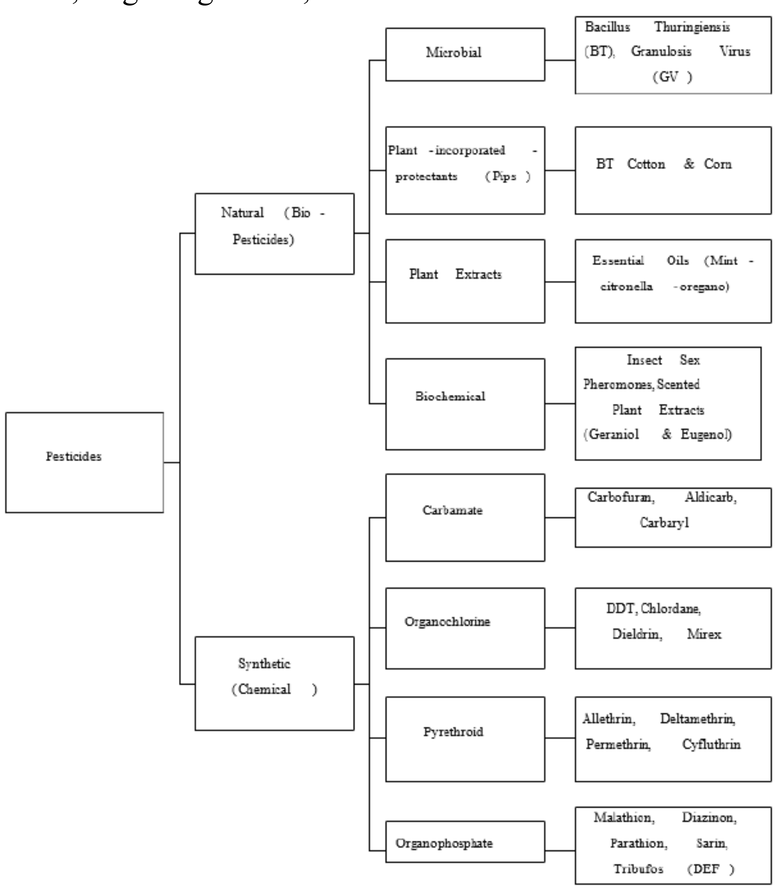
The use of pesticides dates back thousands of years, as humans have consistently sought methods to safeguard crops from pests and diseases. Early agricultural societies discovered that certain naturally occurring substances could repel or eliminate insects, rodents, and other pests that posed a threat to their crops. The earliest recorded pesticide was sulfur dusting, used around 4500 years ago in ancient Sumer, Mesopotamia. The Rig Veda, which is approximately 4000 years old, also references the use of poisonous plants for pest control. In the 17th century, nicotine sulfate was extracted from tobacco leaves and used as an insecticide. The 19th century saw the introduction of natural pesticides derived from tropical plant roots. The first major synthetic organic pesticide, DDT, was discovered in 1939 by Swiss chemist Paul Muller. Although DDT was an effective insecticide, by 1975, it had been replaced in the U.S. by organophosphates and carbonates. The U.S. Environmental Protection Agency was established in 1970, and significant amendments to pesticide regulations were made in 1972. Pesticide use has since increased, with 2.3 million tons of industrial pesticides now applied annually. While 75% of the world's pesticides are used in developed nations, usage is on the rise in developing countries. In recent times, chemical pesticides have emerged as the most widely and intentionally used form of pest management, particularly in crops grown in the same region. These pesticides are typically more water-soluble and often exhibit higher acute toxicity. Their effects on animal life—such as fish, birds, reptiles, and insects—pose a severe threat to biodiversity. [5,6]

DEFINITION OF PESTICIDES:

- Pesticides stand out among toxic substances because they are intentionally developed for harmful purposes. While most environmental toxins result unintentionally from other processes, pesticides are specifically engineered to be dangerous to target pests. They are deliberately released into the environment to control insects, bacteria, weeds, rodents, or other unwanted organisms. [7]
- Pesticides are often thought to mean insecticides, but they encompass much more than that. The term pesticide includes not only insecticides but also many other types of chemicals. According to state and federal laws, a pesticide is any substance aimed at controlling, destroying, repelling, or attracting a pest. [2]

CLASSIFICATION OF PESTICIDES:

Pesticides can be classified into several categories based on their applications, target organisms, and chemical composition. In terms of application, pesticides are divided into agricultural (used for protecting crops from pests, insects, and weeds), public health (utilized to eliminate vectors that transmit diseases), and domestic pesticides (used to exterminate insects like cockroaches, bacteria, protozoa, mice, etc.). Based on the target organisms, pesticides are grouped as insecticides (chemicals used to kill insects), fungicides (substances applied to inhibit or destroy fungi), herbicides (chemicals used to manage or eliminate weeds), rodenticides (pesticides designed to kill rodents), fumigants (gaseous pesticides used to control or exterminate pests like bedbugs), and insect repellents (applied to the skin or clothing to deter insects from coming into contact with them). Regarding their chemical nature, pesticides are categorized into Natural (biopesticides) and Synthetic (chemical-based pesticides). [8]



TYPES OF PESTICIDES:

Pesticides are categorized based on the type of pests they target. Additionally, pesticides can be classified as biodegradable or non-biodegradable. Biodegradable pesticides are broken down by microbes and other organisms, preventing their accumulation in the food chain, which could otherwise result in the deaths of top predators. Another classification divides pesticides into chemical types based on their source or production method.

- **Organophosphate Pesticides**: These pesticides impact the nervous system by inhibiting the activity of acetylcholinesterase, an enzyme responsible for regulating the neurotransmitter acetylcholine. While organophosphates are predominantly insecticides, developed in the early 19th century, their adverse effects on insects (similar to their effects on humans) were discovered in 1932. Some are highly toxic, though they usually degrade quickly in the environment.
- **Organochlorine Insecticides:** These were widely used in the past, but many have since been banned due to their harmful health and environmental effects, as well as their persistence in the environment (e.g., DDT, chlordane, and toxaphene).
- **Carbamate Pesticides:** These pesticides also affect the nervous system by inhibiting an enzyme that regulates acetylcholine. However, unlike organophosphates, the effects of carbamates are typically reversible. Carbamates have several subcategories.
- **Pyrethroid Pesticides:** Developed as synthetic versions of the natural pesticide pyrethrin, which is derived from chrysanthemums, pyrethroids have been modified to enhance their environmental stability. Some synthetic pyrethroids are toxic to the nervous system.
- **Neonicotinoid Pesticides:** Neonicotinoids are neuro-active insecticides chemically related to nicotine. As the most widely used insecticide globally, neonicotinoids came under scrutiny in the late 1990s for their environmental impact. Research linked them to adverse ecological effects, including honeybee colony collapse disorder and the decline of bird populations due to reduced insect numbers. In 2013, the European Union and several nonEU countries imposed restrictions on certain neonicotinoid pesticides.
- **Herbicides:** These chemicals are commercialized for weed control. Chlorsulfuron, a broad-spectrum herbicide, works by inhibiting the enzyme acetolactate synthase. In the 1960s, more than 1 kg/ha (0.89 lb/acre) of crop protection chemicals was typically applied, while newer herbicides like sulfonylureas and sulfosulfuron allow for as little as 1% of that amount to achieve similar effects.
- **Herbal Pesticides (Biopesticides):** Also known as biopesticides, these pesticides are derived from natural materials such as animals, plants, bacteria, fungi, or viruses. Their use is controversial, particularly in some European countries. Pesticides, regardless of origin, are classified based on their toxicity, and they can be equally dangerous. Pesticide labels use colors to indicate toxicity levels: red for extremely toxic, yellow for toxic, green for moderately toxic, and blue for low toxicity. The red-labeled pesticides are highly restricted, with many now banned. [9-11]

Sr. No.	Types of The Pesticides	Name of The Pesticides	Safe Concentration of The Pesticides In Agriculture Field
1	Organophosphate	Monocrotophos	0.04 To 0.06
		Dimethoate	0.001 To 0.003

		Choloropyriphos	0.001
		Dichlorovos (DDVP)	0.001
		Phosphamidon	0.003
		Phosalone	0.004
		Malathion	0.001
		Endrin	0.0001 To 0.0002
2.	Organochloride	Endosulfan-I	0.001
		Endosulfan-II	0.002
		DDT	0.001 (2kg/Ha)
3.	Carbamate	Carbofuran	0.001- 0.009
		Carbosulfan	0.001
4.	Synthetic Pyrithroids	Permethrin	0.001- 0.003
		Cypermethrin	0.001- 0.002

BENEFITS OF PESTICIDES:

While much of the literature focuses on the disadvantages and negative perceptions of pesticides, it is undeniable that pesticides have played a significant role in historical events, including wars, natural disasters, and pandemics. DDT serves as a prime example of the impact of pesticides throughout history. In the mid-20th century, following World War II, many nations began using DDT to spray streets, homes, and people in an effort to curb the spread of diseases transmitted by insects, ultimately aiming to save more lives. Additionally, during this same period, DDT was utilized to boost agricultural production, as many countries faced food shortages, particularly concerning cereal crops. Pesticides fulfill three key roles: (1) the primary and urgent role of ensuring agricultural and food production to meet the demands of a growing global population, which has been increasing at approximately 1.3% annually. The world population reached 7.8 billion in 2020 and is projected to reach 9.8 billion by 2050 (UN 2020). The use of pesticides has been credited with increasing crop yields by 1.5 to 2 times. Damage to fruits caused by the apple worm was reduced to 1% to 2%, and the marketable percentage of production rose to 80% to 90% when pesticides were applied. Similarly, it has been reported that the financial investment in pesticides yields returns of four to six times in increased yields. In the absence of herbicides, the losses in the U.S. due to weeds have surged from $4 billion to $20 billion. Furthermore, it was noted in Britain that "considerable economic losses" would occur without pesticide use, leading to a 50% increase in quantitative yields in British wheat production attributed to pesticides. Not only do pesticides protect existing crops from loss, but they also enhance the utilization of agricultural land by expanding the variety of crops that farmers can cultivate during different seasons. For example, in Zimbabwe, farmers can only grow tomatoes during the rainy season; by using fungicides to prevent late blight, they avoid what could otherwise result in complete crop failure. Additionally, there is an indirect benefit from pesticide use as it contributes to increased food availability in communities, which improves nutrition and promotes better health and productivity. Besides its role in ensuring food production and maintaining health, pesticides also have a social dimension by enabling abundant crop yields, leading to higher incomes for farmers, which in turn supports better education and healthcare for their families. The second benefit of pesticides lies in their ability to control diseases transmitted by insect vectors and microorganisms. In warm and humid climates, insects can transmit serious human diseases such as malaria, Zika virus, river blindness, and various severe fevers and deformities. For instance, insecticide-treated bed nets have significantly reduced neonatal mortality in western Kenya without increasing mortality rates in older children due to delayed immunity acquisition to malaria. It has been stated that insecticides are often the only effective means of controlling these vectors, although their potential has not been fully realized. Houseflies and cockroaches are recognized as vectors for numerous microorganisms that cause diarrheal diseases, which UNICEF estimates as the leading cause of death for children under five years old. The impact of biting flies is not confined to developing nations; even in developed countries like Canada and the United States, pesticides are employed to manage mosquitoes, black flies, ticks, and other insects, enabling people to enjoy a higher quality of life and leisure time. Without such control measures, there would be significant repercussions on quality of life, tourism, and income levels. The third benefit of pesticides is their role in reducing negative effects on human activities and environmental safety. Various pests adversely affect human endeavors and the environment; for example, herbicide use can save both time and costs associated with mechanical weed control. Moreover, herbicides offer long-term environmental benefits by decreasing reliance on nonrenewable energy sources, preserving soil moisture, preventing soil erosion, and minimizing soil degradation. There is also a less obvious benefit of pesticides in reducing road accidents and driving hazards; the transportation sector uses herbicides to keep roads and railways clear of vegetation that could pose risks or obstacles. For instance, if roadside vegetation is allowed to grow too tall, it can obstruct drivers' visibility at intersections and increase the likelihood of branches or vegetation falling onto the road, creating hazards or slippery conditions. [12-15]

IMPACTS OF PESTICIDE:

The use of pesticides presents several environmental issues. More than 98% of applied insecticides and 95% of herbicides end up in locations other than their intended targets, affecting non-target species as well as air, water, and soil. Pesticide drift occurs when airborne pesticide particles are transported by the wind to different areas, potentially leading to contamination. Pesticides contribute significantly to water pollution, with some classified as persistent organic pollutants that further exacerbate soil contamination. Biological magnification refers to the process where these pesticides become increasingly concentrated at each level of the food chain. Among marine organisms, the concentration of pesticides is particularly high in carnivorous fish, and this trend is even more pronounced in birds and mammals that consume these fish, situated at the top of the ecological pyramid. Global distillation describes how pesticides are moved from warmer regions to colder areas of the Earth, especially the poles and mountaintops. Pesticides that vaporize at relatively high temperatures can be transported over considerable distances by the wind to cooler regions, where they condense and eventually return to the ground as precipitation. It is essential for pesticides to be degradable or, at the very least, rapidly deactivated in the environment. The reduction of pesticide activity or toxicity results from both the inherent chemical properties of the compounds and environmental factors or conditions. The presence of certain chemical structures can hinder degradation in aerobic environments. While adsorption to soil may slow the movement of pesticides, it can also diminish their bioavailability to microbial degraders. The toxicity of pesticides poses significant risks to plants, soil, humans, birds, and other wildlife. Their effects are toxic, leading to numerous physiological changes in affected systems. Due to the pollution of soil, air, and water, these chemicals and pesticides can enter the human body. Pesticide toxicity can lead to various adverse health effects, ranging from minor skin and eye irritation to more serious consequences, including neurological impacts, hormone disruption leading to reproductive issues, and even cancer. [16-18]

Impact Of Pesticides on Environment:

Human activities have resulted in elevated levels of pollution, which have significantly increased over time. To maintain a rapid food supply, the application of pesticides in agriculture has risen dramatically. Over the past decade, substantial amounts of pesticides and other related pollutants have been released into the atmosphere due to agricultural and industrial expansion. Pesticides are employed to manage and eradicate disease vectors, enhance agricultural productivity, and safeguard stored agricultural products. They include insecticides, herbicides, nematicides, fungicides, growth regulators for insects and plants, fumigants, attractants, and repellents. The use of pesticides is prevalent in modern agricultural practices worldwide, albeit in varying quantities. While they contribute to increased crop yields, they pose significant threats to the environment, public health, and safety, affecting terrestrial ecosystems as well as living organisms, including humans, animals, and plants. The introduction of pesticides into the environment leads to a wide range of effects on both target and non-target organisms. Many pesticides exhibit a broad spectrum of biological activities that extend beyond their intended functions as specified by manufacturers. This is attributable to their effects and the unintended actions of certain compounds, which may also alter the behavior of pathogens and exacerbate disease severity. Consequently, due to the toxic nature of these substances, several pesticides, such as DDT (an organochlorine) and more recently glyphosate (an organophosphorus compound), have been banned in numerous countries. In certain regions of Africa, DDT is still used to combat malaria larvae, while glyphosate is utilized for agricultural purposes in Latin America and the United States. However, the excessive use of agrochemicals in agriculture has resulted in contamination of various environmental matrices, including air, soil, and aquatic ecosystems. [19-21]

Impact of Pesticides on Human Health:

Workers engaged in pesticide manufacturing, agricultural fields, pest control, and greenhouse operations are particularly vulnerable to pesticide exposure. The risk of exposure is highest during the production and formulation stages, where the danger is significantly elevated. Manufacturing environments pose a considerable threat due to the handling of various hazardous substances, including pesticides, raw materials, and toxic solvents. Direct exposure and handling of pesticides or pesticide residues in food can lead to a range of health issues, such as cancer, diabetes, respiratory problems, neurological disorders, reproductive syndromes, and oxidative stress. [2224]

1. **Cancer:** Direct pesticide exposure is a leading global cause of cancer. This issue has gained international attention, prompting research efforts worldwide. Among 43 studies in the agricultural health study, 12 reported no significant correlation between pesticide exposure and increased cancer risk among farmers, while the remaining 31 indicated a strong association between certain pesticides and cancer risk. Evidence from these studies suggests an elevated risk for prostate, breast, bladder, lung, colon cancers, leukemia, and multiple myeloma due to prolonged exposure to specific pesticides. The International Agency for Research on Cancer (IARC) assesses the carcinogenic risks of pesticides, providing crucial data to identify environmental carcinogens and guiding policymakers in public health protections

against cancer risks related to food, environment, and occupational carcinogens. The IARC categorized two pesticides (arsenic and 2,3,7,8-tetrachlorodibenzodioxin) as carcinogenic (IARC, 1991). A cohort study involving 57,310 individuals in the United States identified a positive correlation between bladder cancer risk and exposure to pesticides like imidazolinone, imazethapyr, and imazaquin herbicides. Furthermore, a study of 953 individuals, including 881 controls in the agricultural sector, indicated an increased bladder cancer risk due to pesticide exposure with an odds ratio (OR) of 1.68. According to a hospital-based control study of 462 glioma and 195 meningioma patients in the United States, women exposed to herbicides exhibited a higher risk of meningioma compared to those without any herbicide exposure, with an OR of 2.4. Results from an investigation in Jaipur showed significantly higher organochlorine pesticide residue levels in cancer patients compared to the control group. Health risk assessments indicated that daily dietary exposure to organochlorine pesticides was higher in children than in adults. The hazard quotient and lifetime cancer risk from dietary exposure to these vegetables exceeded acceptable limits. [25-28]

2. **Diabetes:** Several studies have confirmed a link between pesticide exposure and diabetes, indicating that prolonged contact with pesticides increases diabetes risk. A significant correlation between organochlorine compounds and diabetes has been observed, as well as a similar relationship with organophosphates in type 2 diabetes risk. However, many studies are cross-sectional, which limits the reliability of the findings. Some studies suggest a notable correlation between type 2 diabetes risk and exposure to organochlorine pesticides across different populations. A study involving 11,273 women explored the relationship between pesticide exposure and gestational diabetes incidence, revealing that women using pesticides at home or in gardens did not exhibit an increased risk of gestational diabetes during pregnancy. Conversely, women with lifetime agricultural exposure to herbicides and insecticides had the highest risk of gestational diabetes during pregnancy. Additionally, a cross-sectional study in Bolivia comparing 116 pesticide applicators to 92 non-exposed controls found abnormal glucose control at 6.1% for pesticide applicators compared to 7.9% for non-exposed individuals. Increased levels of pesticides such as DDT and heptachlor epoxide in human blood have been linked to diabetes and diabetic nephropathy. Growing evidence also associates obesity with persistent pesticide exposure, including DDT and its metabolite DDE. A case-control study in Bang Rakam suggested an elevated risk of diabetes due to pesticide exposure. Research indicates that the imazamox-based herbicide preparation reduced β-islet cell size and increased blood glucose and calcium levels. Evidence from both human and experimental studies supports the notion that endocrinedisrupting chemicals (e.g., DDE) may contribute to diabetes development. A case-control study in India indicated high levels of DDE pesticide in Delhi, yet no significant association was found between DDE levels and type 2 diabetes. Studies have also linked organophosphate exposure to metabolic dysregulation in rodent models and humans. A cross-sectional study assessed the relationship between occupational exposure to organophosphate insecticides and hyperglycemia, demonstrating a positive association. The risk was estimated to increase approximately 1.6 for fonofos, parathion, trichlorfon, and phorate organophosphate

insecticides. Two cohort studies indicated a positive association between occupational exposure to phenoxy herbicides and increased diabetes incidence (HR; 1.6). Additionally, a positive relationship was observed in ecological and crosssectional studies with odds ratios of 2.7 and 1.04, respectively, among Korean Vietnam veterans. [29-32]

3. **Respiratory Disorders:** Lung diseases such as asthma, bronchitis, organic dust lethal conditions, hypersensitivity pneumonitis, silo filler's lung, and neuromuscular respiratory failure can result from exposure to organic dust, chemicals, and toxic gases among farm workers. Numerous studies indicate a positive correlation between asthma and pesticide exposure. Exposure to pesticides can lead to asthma development through inflammation, swelling, endocrine disruption, or immune suppression. Evidence suggests that agricultural exposure to pesticides correlates with increased lung disease incidence, particularly with exposure exceeding two days per month. A study investigating wheezing in farmers and commercial applicators highlighted the role of organophosphates in respiratory disorders. The agricultural health study proposed that pesticides might induce atopic asthma but not non-atopic asthma in women working in agriculture. Colorado farm residents exhibited a positive correlation between pesticide poisoning and respiratory symptoms. A crosssectional study conducted in northern India found that pesticides caused various respiratory ailments, including dry cough, wheezing, hemoptysis, and respiratory irritation. An investigation involving 926 adult pesticide applicators with asthma suggested that glyphosate and paraquat use may exacerbate asthma symptoms in allergic individuals. Pesticide exposure could elevate the risk of lung disorders, leading to significant morbidity and mortality. Occupational exposure among crop farmers was linked to a higher incidence of pulmonary symptoms, lung dysfunction, and chronic respiratory diseases. Studies evaluating pesticide levels in indoor dust and blood samples from asthma cases and controls showed a positive association between asthma occurrence and exposure to alphahexachlorocyclohexane (α-HCH) and DDE (ORs 1.02 and 1.8). Further analysis in an agricultural health cohort study revealed a positive relationship between pesticide application and asthma, with pendimethalin exposure showing an OR of 2.1 and aldicarb showing an OR of 10.2. Additionally, a positive correlation was established between exposure to Agent Orange and chronic bronchitis (OR: 1.05) among a cohort of Korean Vietnam veterans. [33-35]
4. **Neurological Disorders:** Exposure to pesticides significantly contributes to the development of neurological syndromes. Evidence has established a correlation between pesticide exposure and the occurrence of neurological illnesses, with Parkinson's disease (PD) and Alzheimer's disease being the most common conditions associated with the neurotoxic effects of pesticides. [36]
   - **Parkinson's Disease (PD)**: PD is characterized by the loss of dopaminergic neurons in the substantia nigra, leading to symptoms such as rigidity, akinesia, and tremors, with the severity of the disease worsening over time. Previous research has identified pesticides as a factor in the onset of PD. Rotenone, a broad-spectrum herbicide, primarily causes the degeneration of nigrostriatal dopaminergic neurons by inhibiting mitochondrial complex I, resulting in motor dysfunction. Additionally, benomyl (a fungicide) and its thiocarbamate sulfoxide metabolite inhibit

aldehyde dehydrogenase, causing an accumulation of 3,4-dihydroxyphenylacetaldehyde (a metabolite of dopamine) and contributing to the deterioration of dopaminergic neurons. The risk of PD is notably associated with paraquat and crop rotation. Meta-analysis data also indicate that pesticides play a role in genetic alterations linked to PD pathogenesis, including mutations in multidrug resistance 1, paraoxonase 1, and glutathione transferases. A study in California examining 36 commonly used pesticides found a strong correlation between pesticide exposure and the prevalence of idiopathic PD. Rotenone and paraquat are well-known for creating toxin-based PD animal models, as they induce neuroinflammation and result in the loss of dopaminergic neurons. Swiss albino mice treated with rotenone exhibited PD symptoms due to the degeneration of dopaminergic neurons and those rich in dihydroxyphenylalanine decarboxylase. C57BL/6 mice injected weekly with paraquat over 4, 8, 12, and 24 weeks demonstrated dose- and age-dependent degeneration of dopaminergic neurons, indicating that a single dose did not have the same harmful effects as repeated treatments. A positive correlation was identified between pesticide exposure and PD in a population-based study involving 133 cases and 128 controls from the French population. Additionally, the risk of PD increased by 3% for every 1.0 µg of pesticide per liter of groundwater in the 'Colorado Medicare Beneficiary Database.' A study in the Netherlands found a positive relationship between PD-related deaths and occupational pesticide exposure. A strong association was noted for PD in individuals with nitric oxide synthase (NOS) genotypes exposed to commonly used organophosphates, supporting the role of NOS2A genetic variants in PD susceptibility among those exposed to organophosphates. However, the association between PD and factors like farm living, well-water consumption, and pesticide use was less pronounced than that of cigarette smoking. Evidence suggests that prolonged exposure to pesticides may contribute to the progression of neurodegenerative diseases, though the findings are controversial. A 5- to 10-year history of pesticide exposure was linked to a 5% and 11% increase in PD risk, respectively. Additionally, occupational exposure to the 2,4-D herbicide was associated with an approximately 2.6 times higher risk of PD. Further, exposure to β-HCH increased the PD risk by about 4.4 times, with another case-control study revealing that β-HCH was more prevalent in the blood of PD patients compared to controls. [37,38]

- **Alzheimer's Disease (AD):** Alzheimer's disease is a type of dementia that leads to progressive memory impairment and cognitive decline due to neurodegeneration in the cerebral cortex. Various reviews have connected pesticide exposure with neurological disorders, noting that men tend to experience higher levels of pesticide exposure than women due to differences in occupational activities. In terms of neurodegenerative disorders, alterations in cognitive function in school-aged children have been linked to prenatal exposure to organophosphates. Other studies indicated that maternal or prenatal exposure to organochlorines is associated with cognitive, motor, and autism disorders in children. Pesticide exposure has been shown to damage cholinergic neurons in the basal forebrain, leading to memory, motor, and sensory dysfunction. Members of the U.S. armed forces exposed to sarin and cyclosarin during the Gulf War in 1991 subsequently developed neurological disorders. In 1995, the sarin gas attack in Tokyo resulted in some fatalities and long-term mental health issues for survivors. Chronic mental health problems from accidental or suicidal organophosphate poisoning have led to significant losses in productivity. A study on residents of Cache County, an agricultural community, found that exposure to organochlorine pesticides was associated with a greater likelihood of developing dementia and AD later in life. Evidence suggests that cumulative lifetime exposure to pesticides may result in lasting brain damage and contribute to AD development. A meta-analysis confirmed a direct relationship between pesticide exposure and AD, reinforcing the notion that pesticide exposure is a significant risk factor for AD. Two different casecontrol studies assessed pesticide exposure related to Alzheimer’s disease and matched controls. The first study indicated that the risk associated with pesticide exposure had an odds ratio (OR) of approximately 1.1. The second study found a positive association between increased levels of DDE in the blood and Alzheimer's disease, with an OR of approximately 4.2. [39,40]

5. **Reproductive Syndromes:** The link between environmental and occupational pesticide exposure has been extensively analyzed, with numerous studies confirming that exposure to pesticides can lead to fertility disorders in both females and males. Endocrine-disrupting chemicals (EDCs) can affect hormone signaling, including that of estrogens, thyroid hormones, and androgens, all of which are crucial for normal embryonic development. Examples of EDCs include bisphenol (found in baby bottles), diethylstilbestrol, and specific pesticides such as vinclozolin and atrazine. Moderate increases in the risk of spontaneous abortions have been linked to preconception exposure to phenoxyacetic acids and triazines. Postconception exposure has been more closely associated with late-stage spontaneous abortions, with advanced parental age being a significant risk factor. A strong association exists between delayed abortions and the use of thiocarbamate and glyphosatetype pesticides. In contrast, a study of women working in greenhouses found no significant connection between pesticide exposure and the incidence of natural abortions, premature deliveries, or birth defects. Male exposure to pesticides can impact blood and sex hormone levels, sperm morphology, concentration, motility, semen quality, and gonadal structure. A decline in sperm count was observed in men working in greenhouses for more than ten years. A study involving a randomly chosen couple population showed a higher incidence of infertility, stillbirths, and spontaneous abortions among those working in farming. Exposure to pesticides, whether environmental or occupational, may correlate with decreased sperm quality, which is crucial for male fertility. Positive relationships were observed between pesticide exposure and reduced semen quality, with individuals exposed to abamectin showing decreased sperm maturity and motility. Furthermore, occupational pesticide exposure in pregnant women has been linked to lower birth

weights, with an OR of about 2.4 as evaluated by a JEM-based cohort study. A case-control study using questionnaires indicated that pesticide exposure in pregnant women doubled the risk of neural tube defects. Another study comparing organochlorine levels in placental tissues found maternal exposure to DDT and α-HCH was positively associated with neural tube defects, with ORs of approximately 5.2 and 3.9, respectively. A JEM-based case-control study demonstrated a twofold increase in spina bifida cases among children of mothers who had occupational exposure to pesticides. Additionally, a study among sons of mothers in horticulture and farming evaluated cryptorchidism, resulting in a hazard ratio (HR) of 1.3. Another defect, gastroschisis, was also linked to parental pesticide exposure in a JEMbased case-control study, showing an OR of approximately 2. The incidence of gastroschisis increased in young mothers living in areas with high atrazine levels in surface water. [41,42]

PESTICIDES CONTROL AND REGULATIONS:

In India, the Central Insecticides Board and Registration Committee oversee the control and regulation of pesticides, while the Food Safety and Standards Authority of India has sanctioned the MRLs (maximum residue limits) for registered pesticides. Conversely, in China, the regulation of pesticides is managed by the Institute for Control of Agrochemicals. China adheres to the Codex MRLs as governed by the National Pesticide Residues Committee within the Ministry of Agriculture (MOA). Additionally, in China, the MOA and the Ministry of Health are responsible for establishing pesticide residue limits, which are linked to testing methodologies and protocols. However, several countries in Southeast Asia lack specific legislation and regulations pertaining to pesticides. [43-44]

PREVENTIVE STRATEGIES:

To reduce pesticide usage, the following measures should be adopted in agricultural practices:

- **Agronomic Practices:** Implementing appropriate agronomic practices is crucial for cultivating healthy crops and preventing diseases, as well as minimizing pest and weed pressure. This includes ensuring adequate plant nutrition, managing soil fertility, optimizing irrigation, rotating crops, and timing sowing or planting effectively to decrease pest attacks. Intercropping and using a mixture of varieties can help restrict and prevent the spread of pests and diseases. This approach also provides food and habitat for the natural enemies of pests.
- **Practices with Resistant Crops:** Selecting crop varieties that are well-suited to local conditions is fundamental for an effective preventive pest management system. Utilizing disease-resistant varieties in conjunction with rotations of non-susceptible crops helps sustainably manage pest outbreaks within fields.
- **Natural Pesticides and Biocontrol:** Natural pesticides and biocontrol methods incorporate pathogens (such as bacteria, fungi, and viruses), insect predators or parasitoids, insect traps, and pheromones to help maintain pest populations at low levels.
- **Integrated Pest Management (IPM):** IPM adopts an ecosystem-based approach that aims to manage rather than eradicate pests. A healthy agroecosystem, where biological processes supporting production are safeguarded, fostered, and enhanced, serves as the primary defense against pests and diseases in agriculture. The strategy emphasizes pest prevention through good agronomic practices, resistant varieties, pest

identification, and monitoring biological pest control.

- **Agroecology:** The primary goal of agroecology is to maintain a natural balance within the ecosystem. Pest control in this context focuses on enhancing the interactions between pests and their natural enemies.
- **Organic Agriculture:** Organic agriculture promotes the health of soils, ecosystems, and communities. The use of synthetic pesticides and chemical fertilizers is completely prohibited. Crop protection in organic farming is achieved through organic green manures, disease-resistant seed varieties, and biocontrol measures to prevent damage from pests and diseases.
- **Use of Less Toxic Pesticides:** Pesticides can be categorized based on their toxicity to humans and the environment. It is essential to replace highly hazardous pesticides with eco-friendly alternatives that are less harmful. Pesticides should be applied within safe, recommended doses to minimize their impact on both people and the environment. Encouraging the use of plant-based pesticides for controlling agricultural pests and pathogens is recommended, with numerous reports available on the pesticidal effects of plant extracts or compounds. [45,46]

MEASURE PESTICIDES IN SOIL CONTAMINATION:

1. Soil Sampling:

The initial phase of assessing pesticide contamination in soil involves systematic collection of soil samples. These samples are gathered from various depths and locations within a contaminated site. To ensure representativeness, composite sampling is employed, which entails mixing multiple samples from different sites. It is essential to store the samples in suitable containers and maintain low temperatures to prevent the degradation of pesticide residues prior to analysis.

2. Extraction of Pesticides:

In order to analyze pesticides present in the soil, it is necessary to extract them from the soil matrix first. Various extraction methods are commonly utilized:

- **Solvent Extraction:** Organic solvents such as acetone or hexane are utilized to extract pesticide residues from the soil samples.
- **Supercritical Fluid Extraction (SFE):** This method employs supercritical CO_2 as a solvent, offering a cleaner extraction process with minimal residual solvents.
- **Solid-Phase Microextraction (SPME):** This technique involves using a fiber coated with an extracting phase that absorbs pesticide compounds from the soil.

3. Analytical Techniques:

After the extraction of pesticides, several analytical techniques are employed to identify and quantify the residues:

- **Gas Chromatography (GC):** One of the most prevalent techniques, GC separates volatile pesticide residues present in the sample. This method is frequently combined with mass spectrometry (GC-MS) for precise identification.
- **High-Performance Liquid Chromatography (HPLC):** HPLC is employed for the analysis of non-volatile pesticides. It can be coupled with mass spectrometry (HPLC-MS) to enhance detection accuracy.
- **Enzyme-Linked Immunosorbent Assay (ELISA):** This biochemical technique is used to detect specific pesticides through antigen-antibody interactions, providing a quick screening method.

4. Quantification and Interpretation:

Quantification of pesticide residues is performed by comparing chromatographic data or spectral results against standards of known concentrations. Typically, the concentration of pesticides in the soil is expressed in micrograms or milligrams per kilogram (µg/kg or mg/kg) of soil. The results are subsequently compared to established safety thresholds set by regulatory entities such as the Environmental Protection Agency (EPA) or the pesticide residue guidelines of the European Union.

5. **Monitoring and Reporting:** Following the measurement of pesticide levels in the soil, ongoing monitoring is crucial to observe fluctuations in contamination levels. The findings are reported to environmental and health authorities to evaluate the environmental implications and potential risks to human health. [47-49]

CONCLUSION

Pesticides, while essential for increasing agricultural productivity and controlling pests, pose significant risks to both human health and the environment. Prolonged exposure to these chemicals has been linked to a range of serious health conditions, including respiratory problems, neurological disorders, reproductive issues, and cancers. Vulnerable populations, such as agricultural workers, children, and those living near farmlands, face greater risks due to higher levels of exposure. In addition to human health, pesticides have far-reaching consequences for the environment. They contaminate soil, water, and air, disrupting ecosystems, harming wildlife, and reducing biodiversity. Many pesticides persist in the environment, leading to long-term ecological damage and the degradation of natural resources. The decline in pollinator populations, essential for crop production, is another critical consequence of pesticide misuse. To mitigate these harmful effects, stricter regulations, the promotion of integrated pest management (IPM), and the development of safer, eco-friendly alternatives are crucial. By adopting sustainable practices and raising awareness of the potential hazards, we can reduce the adverse impact of pesticides on both human health and the environment, ensuring a healthier future for all.

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