**A comprehensive review of pesticide effects on the environment, human health, and sustainable management as bioremediation**

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**Abstract**

Pesticides are utilized to control pests and increase agricultural production. These chemical compounds are employed to repel, mitigate, or eradicate harmful pests that pose a threat to humans. While pesticides provide benefits to crops, their usage also has significant adverse effects on the environment. They impact both intended targets and unintended species, including humans. The detrimental effects of pesticides, including their parent compounds, degradation products, and metabolites, can harm ecosystems, the environment, and human health. To safeguard public health, the World Health Organization (WHO) categorizes pesticides based on their harmful effects. Minimizing pesticide usage and understanding their classification can help reduce their impact on both the environment and human health. Currently, bioremediation strategies are being employed to combat pesticide pollution, offering an inexpensive and environmentally friendly approach. This review covers various aspects of pesticides, including their global distribution, environmental impacts, human health concerns, and sustainable management through bioremediation.

**Keyword:** Pesticides, Bioremediation, Environmental hazards, toxicity, health effects, Eco- sustainable technology.

**1. Introduction**

Agriculture plays a crucial role in the Indian economy, serving as its mainstay. Approximately 65-70% of the population in India relies on agriculture for their livelihood (Sachdeva, 2007). A large part of agricultural land is depleting every year due to the rapid growth in human population, establishment of industries and urban encroachments which creates food scarcity. The agricultural landscape in India has undergone significant changes following the advent of the Green Revolution in the 1960s. Major part of population is being engaged with agriculture in India and for gaining self-sufficiency in food grains and in other agricultural commodities, pesticides and other chemicals were introduced on very large scale for high yielding crop varieties (Tudi et al., 2021). Application and consumption of pesticides are increasing due to increasing demand of agro product in regional climate changes (Strassemeyer et al., 2017).

The term pesticide covers a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, plant growth regulators and others. Pesticides contamination from a wide variety of compounds may result from manufacturing, improper storage, handling, and disposal of pesticides, as well as from agricultural processes. Pesticides have been employed for many years to prevent the transmission of diseases carried by pests such as mosquitoes and fleas in animals and humans. They also contribute to food production by eliminating insects and other pests found in agricultural areas, and they help protect the environment by controlling the growth of molds, algae, and weeds (Zhang et al., 2018). Pesticides are biologically active substances used to prevent, eradicate, and manage pests by interfering with their metabolic activities (Lamichhane, 2017). It issued globally and mostly in agrarian economy countries like India to fulfill growing populations food demand.

2. **Types of Pesticides and target organism**

 Pesticides are categorized into various types based on the organisms they target. Biocides are broad-spectrum pesticides designed to kill a wide range of living organisms. More specific substances are named according to their intended target. Herbicides are specifically formulated to destroy plants, insecticides target insects, and fungicides are used to combat fungi. There are also specific pesticides such as acaricides (targeting mites and ticks), rodenticides (used against rodents), and nematicides (designed to control nematodes) (Osman et al., 2011).

**2.1 Herbicides**

Herbicides are commonly referred to as weed killers and are utilized to eliminate unwanted plants. Selective herbicides are designed to target specific plants while minimizing damage to desired crops. Some herbicides interfere with the growth of weeds by imitating plant hormones. Non-selective herbicides, on the other hand, are not specific and will kill any plant they come into contact with. They are often employed to clear waste grounds, railway tracks, embankments, and industrial sites. In contrast, smaller quantities of herbicides are used in forestry, pasture systems, and the management of wildlife habitats (Aksakal et al., 2013).

**2.2 Fungicides**

Fungicides are substances, either chemical compounds or biological agents, used to kill or inhibit the growth of fungi or fungal spores. Fungi are small organisms that derive nourishment from living or non-living sources. Fungicides find applications in agriculture to combat fungal infections in animals and humans. It is worth noting that chemicals used to control oomycetes, which are not fungi but employ similar mechanisms to infect plants, are also referred to as fungicides (Toda et al., 2021). Fungicides can be categorized as contact, translaminar, or systemic. Contact fungicides protect the areas of the plant where the spray has been applied but do not penetrate plant tissue. Translaminar fungicides redistribute within the sprayed leaf, reaching the unsprayed lower surface. Systemic fungicides are taken up by the plant and transported through the xylem vessels to protect new leaf growth and upper plant parts for a limited period (Rathour et al., 2022).

**2.3 Insecticides**

Insecticides are substances specifically employed to combat insects. They encompass ovicides and larvicides, which target the eggs and larvae of insects respectively. Insecticides find widespread applications in various sectors such as agriculture, industries, households and medicine. The major factor behind increasing agriculture productivity in the 20th century is because use of insecticides, (Bowman and Zilberman, 2013). Almost all the insecticides have potential to significantly alter ecosystems; many are concentrated in the food chain and toxic to humans, (Landrigan et al., 2020).

**2.4 Acaricides**

Acaricides are substances that are utilized to kill members of the arachnid order Acari, which includes mites and ticks. These acaricides are employed in both agriculture and medicine, although the level of selective toxicity may vary between the two fields (Guo et al., 2021).

**2.5 Nematicides**

Nematicides are a specific type of pesticide that is utilized to eradicate plant parasitic nematodes. These nematicides are characterized by their broad-spectrum toxic properties and often possess high volatility or other properties that facilitate their migration through the soil (Gill and Garg, 2014).

**2.6 Rodenticides**

Rodenticides are a specific category of pest control chemicals designed to eliminate rodents. Some rodenticides are formulated as single-feed baits, meaning that a single dose is potent enough to be lethal (Tosh et al., 2011). Rodents are challenging to control using poisons due to their scavenging behavior. Therefore, an effective rodenticide needs to be unappealing, odorless in lethal concentrations, and exhibit delayed effects (Pelfrene, 2010).

On the basis of chemical nature, pesticides are classified into five groups which are synthetic pyrethroids, organochlorine, carbamate, organophosphate, formamidine and avermectin (Mandal, 2019). Organochlorine, Organophosphate and carbamates are of major group in concern because of their toxicity and persistence in the environment. All these pesticides are widely used worldwide for controlling agriculture and household pests. Organophosphate represent largest group of chemical insecticides which used in plant protection through out the world (Ghorab and Khalil, 2015). Organophosphate represent about half of the total insecticide used with annual application over 75 million pounds in the United States (Carvalho, 2017). 75% accounted by insecticides of the total market.

**3. Sources of Pesticides in the environment**

The rapidly growing population in world needs increase in the food production, for this one of main strategies to enhance crop productivity is effective pest management because more than 45% of annual food production is lost due to pest infestation (Dubey et al., 2011). So the application of a wide variety of pesticides becomes necessary in agricultural fields to combat pests. But improper, excessive, and misuse of pesticides in agriculture can heighten the risk of environmental contamination by causing the dispersion of pesticides into non-target areas. The extensive utilization of chemicals in agriculture has resulted in the accumulation of numerous hazardous compounds in the air, water, and soil, leading to environmental pollution (Sharma et al., 2019). Uncontrolled use of pesticides in agricultural areas attributes greatly to environmental and health hazards. The usage of pesticides in India is relatively low compared to other regions. there has been a widespread contamination of food commodities with pesticides residues, basically due to non-judicious usage. India unfortunately falls into the category of countries where the production and use of certain chlorinated pesticides, such as DDT and lindane, are still ongoing (Sharma et al., 2014). A survey conducted in Punjab and Haryana, focusing on pesticide application in agricultural fields by farmers, revealed various health issues including cancer, stillbirth, infertility, and kidney failure (Abhilash and Singh, 2009). Globally, it has been reported that over 2500 pesticides are currently in use (Stehle and Schulz, 2015). Pesticide poisoning leads to approximately 1 million deaths and chronic diseases worldwide each year (Boedeker et al., 2020). The US National Academy of Sciences has stated that the DDT metabolite DDE causes thinning of eggshells and that the decline in the bald eagle population in the United States was primarily due to exposure to DDT and its metabolites (Aktar et al., 2009).

Recent evidence suggests that pesticides have the potential to harm the immune system and act as hormone mimics, disrupting the endocrine system in both humans and animals, leading to various disorders. The United Nations reports that approximately 1 to 5 million cases of pesticide poisoning occur annually, resulting in several thousand fatalities among agricultural workers (Patel et al., 2012). The toxicity of pesticides is influenced by several factors, including the level of exposure, concentration of the pesticide, and duration of exposure. In India, the First report of poisoning due to pesticides was reported in Kerala in the year 1958, where over 100 people died after consuming wheat flour contaminated with parathion (Kumar et al., 2016). Due to those farmers of villages noted serious health problems to their cattle population due to water contamination. In children’s and women’s, the signs of serious ailments were seen (Mrema et al., 2017). In a study conducted on 356 workers in four HCH manufacturing units in India, it was found that 21% of the workers experienced neurological symptoms, and the intensity of exposure was linked to these symptoms (Hashim, 2015). Another study collected data on reproductive toxicity from 1,106 couples, specifically focusing on males involved in pesticide spraying (including OC, OP, and carbamates) in cotton fields (Hashim, 2015). Early investigations into health effects such as liver function, immune function, neurologic impairment, and reproductive effects yielded inconclusive results. However, an increased mortality rate due to cardiovascular and respiratory diseases was observed, potentially related to both the psychosocial consequences of the accident and chemical contamination. Additionally, a higher number of diabetes cases was found. Pesticides have the potential to contaminate soil, water, turf, and other vegetation. Insecticides are generally the most acutely toxic class of pesticides, but herbicides can also pose risks to non-target organisms.

Pesticide residues can be detected in soil, air, surface water, and groundwater in various countries, and the use of pesticides in urban areas contributes to this issue. Runoff from treated plants and soil can transport pesticides to surface water, leading to water contamination. A series of extensive studies conducted by the U.S. Geological Survey (USGS) in the early to mid-90s on major river basins across the country revealed alarming findings. More than 90 percent of water and fish samples collected from streams contained one or, in many cases, multiple pesticides (Aktar et al., 2009). The USGS also found that concentrations of insecticides in urban streams commonly exceeded guidelines for protection of aquatic life (Philips and Bode, 2004). According to the USGS, urban streams tend to contain more detected pesticides compared to agricultural streams (Philips and Bode, 2004). Groundwater pollution resulting from pesticide contamination is a global issue. The USGS has reported the presence of at least 143 different pesticides and 21 transformation products in groundwater, representing various chemical classes (Aktar et al., 2009). In a survey conducted in India, it was found that 58% of drinking water samples from hand pumps and wells around Bhopal were contaminated with Organochlorine pesticides above the EPA standards (Sarkar, 2019). Excessive soil treatment with pesticides can lead to a decline in populations of beneficial soil microorganisms. The indiscriminate use of chemicals may initially provide short-term benefits, but over time, the reduced presence of beneficial soil organisms can negatively impact nutrient retention (Gyawali, 2018). Pesticide sprays can have direct impacts on non-target vegetation or can drift and volatilize from the intended area, leading to contamination of air, soil, and non-target plants. Even with ground equipment, some pesticide drift can occur during every application (Gyawali, 2018). It has been observed that nearly all investigated pesticides have been detected in rain, air, fog, or snow at different times throughout the country (Philips and Bode, 2004). Many sites sampled nationwide have shown the presence of multiple pesticides in the air. Certain herbicides in ester formulation have been found to volatilize from treated plants, releasing vapors that can cause severe damage to neighboring plants (Nieder et al., 2018).

**4. Global scenario of pesticides usage**

At present, the global consumption of pesticides amounts to approximately 2 million tones. Herbicides account for 47.5% of the total usage, followed by insecticides at 29.5%, fungicides at 17.5%, and other pesticides at 5.5% (De et al., 2014). The United States, Brazil, China, Argentina, Russia, Canada, France, Australia, India, and Italy (Fig.1) are the top ten pesticide-consuming nations in the world (World atlas, 2018). Furthermore, it is predicted that global pesticide usage will rise to 3.5 million tones by 2020 (Zhang, 2018).

Fig.1: Global pesticide consumption

Although use of chemicals to control pest dates back to 2500 BC, but in the mid-1940s the production and use of synthetic organic pesticides increased rapidly and by 1991, approximately 23,400 pesticide products were registered with the U.S Environmental Protection Agency (EPA). In India use of pesticides began in 1948when BHC (Benzene hexachloride) for locust control and DDT (Dichloro-diphenyltrichloroethane) was imported for malaria control. The production of pesticide in India started with manufacturing plant for DDT and BHC near Calcutta in the year 1952 (Yadav et al., 2015). By the year 1958, India produced over 5000 metric tons pesticides including insecticides like BHC and DDT, and by the mid-nineties , approximately 145 registered pesticides were in use and later on production was increased to approximately by 85,5000 metric tons. Presently, India is the second largest manufacturer of pesticides in Asia after china and ranks 12th globally (Bhardwaj and Sharma, 2013).

In India pesticides are mainly used in public health and agriculture sector for controlling pests and diseases that affect man. The worldwide consumption of pesticides is about two million tons per year, in which 45% in Europe, 25% is consumed in the USA alone, and 25% in the rest of the world, in which India’s share is only 3.75% (Kumar et al., 2019). Approximately 77% of pesticide consumption is attributed to the agriculture sector, while industrial, commercial, and government organizations account for 12%, and private households account for the remaining 11% (Grude et al., 2011). In India, insecticides make up the largest percentage share of pesticide classes used, accounting for 76%. This is followed by fungicides at 13%, herbicides at 11%, and other pesticides at 1% (Sharma et al., 2019). The use of herbicides and fungicides is comparatively less. The main use of pesticides in India is for the cotton crops (45%) followed by paddy then wheat crops (Mahajan et al., 2013). According to the data provided by the Directorate of Plant Protection, Quarantine, and Storage, Government of India, from 2005-06 to 2009-10, Sulphur, a fungicide, was the most widely consumed pesticide in India, totaling 16,424 metric tons. This was followed by endosulfan, as indicated in Table 1.

**Table 1:** Example of most consumed pesticides in India (During 2005-06 to 2009-10)

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| --- | --- | --- |
| **S.NO.** | **Pesticide(Technical Grade)** | **Quantity consumed (metric tons)** |
| 1 | Sulphur (fungicide) | 16424 |
| 2 | Endosulfan ( insecticide) | 15537 |
| 3 | Mancozed ( fungicide) | 11067 |
| 4 | Phorate ( insecticide) | 10763 |
| 5 | Methyl parathion ( insecticide) | 08408 |
| 6 | Monocrotophos ( insecticide) | 08209 |
| 7 | Cypermethrin ( insecticide) | **07309** |
| 8 | Isoproturon ( herbicide) | 07163 |
| 9 | Chlorpyrifos ( insecticide) | 07163 |
| 10 | Malathion ( insecticide) | 07103 |
| 11 | Carbendazin ( fungicide) | 06767 |
| 12 | Butachlor ( herbicide) | 06750 |
| 13 | Quinalphos ( insecticide) | 06329 |
| 14 | Copper oxychloride | 06055 |
| 15 | Dichlorvos ( insecticide) | 05833 |

**Source-** Directorate of Plant Protection, Quarantine and Storage, Govt of India.

**5. Production and Usage of Pesticide in India**

Pesticide production in India began in 1952 with the establishment of a plant for the production of benzene hexachloride (BHC) in Rishra near Calcutta. This was followed by the establishment of two units for manufacturing DDT (1,1,1-trichloro-2,2-bis(4-chlorophenyl) ethane) by Hindustan Insecticides Ltd (Geetha and Fulekar, 2008). The Indian pesticide industry is currently the fourth largest industry in the world and the leading producer of pesticides among Asian countries. In the year 2005-06, India produced 82,000 MT of pesticides, ranking second in Asia (behind China) and twelfth in the world. The annual production of pesticides in India is around 90,000 MT (Boricha and Fulekar, 2009). Over the years, there has been a steady growth in the production of technical-grade pesticides in India, increasing from 5,000 MT in 1958 to 102,240 MT in 1998. The value of pesticide demand in India was estimated to be around Rs.22 billion (USD 0.5 billion) in 1996-97, accounting for approximately 2% of the total world market. The usage pattern of pesticides in India differs from the global trend. In India, around 76% of pesticide use is insecticides, compared to 44% globally (Geetha and Fulekar, 2008). The usage of herbicides and fungicides is comparatively lower. The major use of pesticides in India is for cotton crops (45%), followed by paddy and wheat crops.

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**Figure.** 2: Consumption pattern of pesticide

**6. Use of Pesticides in crop protection**

Pesticides are mixture or substances used for preventing, repelling, destroying or mitigating plants and animal’s pests in agriculture as well as domestic field According to census of India 2001, in Gujarat approximately 97% of workers in rural areas are engaged in agricultural activities. The main cash crops of the state are cotton, groundnut, tobacco, cumin, rice and other vegetables. The total estimated consumption of technical grade pesticides is approx. 3642 metric tons in the year 2001-2002 as per data available from department of agriculture, government of Gujarat.

 Pest infestations are responsible for depleting approximately 45% of annual food production (Abhilash and Singh, 2009). To protect crop plants from these pests, millions of tons of pesticides are released into the environment each year. India accounts for approximately 3% of the total pesticides used globally, and this usage is increasing at a rate of 2-5% per annum. In India, about 67% of pesticides consumption is in the agriculture and horticulture sectors, with insecticides accounting for 75% of the total. The main types of insecticides used include organochlorines (40%), organophosphates (30%), carbamates (15%), synthetic pyrethroids (10%), and others (5%). The remaining 25% of pesticide usage in India is comprised of fungicides (10%), herbicides (7%), and others (8%). According to the Directorate of Plant Protection, Quarantine, and Storage, Government of India (2010), Uttar Pradesh is the state with the highest pesticide consumption during the period of 2005 to 2010, followed by Punjab, Haryana, Maharashtra, Rajasthan, Gujarat, and Tamil Nadu (Table 2).

**Table.2: Pesticide-consuming states in India during 2005-2010 (**Source: <http://www.indiaforsafefood.in/farminginindia.html>**).**

|  |  |  |
| --- | --- | --- |
| **S. No.** | **State** | **Total pesticides consumed** |
| 1 | Uttar Pradesh | 39948 |
| 2 | Punjab | 29235 |
| 3 | Haryana | 21908 |
| 4 | Maharashtra | 16480 |
| 5 | Rajasthan | 15239 |
| 6 | Gujarat | 13430 |
| 7 | Tamil Nadu | 12851 |
| Total | All India | 210,600 |

 During the period of 2005-06 to 2009-10, Uttar Pradesh was the state that consumed the highest number of pesticides, followed by Punjab, with Gujarat ranking 6th (Table 2). In terms of pesticide consumption across agricultural crops in India, cotton accounted for 45%, followed by rice (22%), vegetables (9%), plantation crops (7%), pulses (4%), wheat (4%), and others (9%) (Subramanyam et al., 2012). In Gujarat, major cash crops include cotton, groundnut, tobacco, sugarcane, cumin, rice, and vegetables such as green chilies, which commonly require the use of pesticides for pest protection. According to the 2001 Census of India, approximately 97% of rural workers are engaged in agriculture-related activities and use pesticides to protect crops and increase production. The Department of Agriculture, Government of Gujarat, reported an estimated consumption of approximately 3643 metric tons of technical-grade pesticides during the 2001-2002 period.

**7. Effect of Pesticide on Environment**

Pesticides primarily enter the environment during planning and application. Application can happen through various procedures, contingent upon variables, for example, the controlled pest, the formulation type, and, the application timing. Pesticides can be applied to crops or to the soil in agriculture. Boom sprayers, tunnel sprayers, and aerial application are all common ways to apply liquid sprays to crops. Systemic pesticides are another option. Pesticides can be applied to soils as granules, sprayed onto the soil surface where they may be incorporated into the soil top layer or injected as a fumigant. Before planting, pesticides are sometimes applied to seeds (Long and Krupke, 2016).

 Pesticides can enter target organisms, become degraded, or migrate to groundwater following application. They can also contaminate surface water bodies, volatilize into the air, or affect non-target organisms through ingestion. The behavior and fate of pesticides are influenced by their physical and chemical properties, soil characteristics, site conditions, and management practices (Perez-Lucas et al., 2019).

 The process of adsorption is influenced by both the chemical properties of pesticides and the type of soil. Pesticide volatility refers to their tendency to transform into a gas, and higher volatility (higher vapor pressure) leads to greater loss to the atmosphere. Volatility can be influenced by humidity and temperature, and pesticide vapors can persist in soil, plants, or surface water for extended periods after application. Chemicals can be transported over long distances through the atmosphere, potentially resulting in surface water pollution through subsequent atmospheric deposition. Pesticide degradation plays a significant role in determining the behavior and fate of these compounds in the environment. Microorganisms, photodecomposition, and various physical and chemical reactions contribute to the degradation process, breaking down pesticides into different chemical forms (Gangola et al., 2022).

 The following site conditions that can influence pesticide behavior in the environment: depth to topographical circumstances, geology, groundwater, and environment. Because of shallow groundwater filters a lesser volume of water with chemicals and adsorbs and deteriorates fewer pesticides, contamination is a due to geological conditions are significant concern. As to land conditions, the presence of sinkholes, wells, and exceptionally porous materials, for example, stores, rock works with groundwater pollution. The presence of waste trenches, streams, lakes, and ponds expands the likelihood that precipitation or water system spillover will taint surface water. Flat landscapes, areas with closed drainage systems that direct water toward the center of a basin, and subsurface areas are particularly susceptible to groundwater contamination based on their topography. Climate conditions such as heavy rainfall or extensive irrigation can cause significant amounts of water to infiltrate the soil, potentially reaching the groundwater. Rainfall can also facilitate the transport of pesticides to nearby rivers, surface waters, lakes, and seas, leading to the contamination of these water bodies. Moreover, these chemicals can be carried over long distances to remote locations through various water channels and pathways. In terms of pesticide container handling, proper storage and disposal have an influence on environmental contamination (ANR, 2014).

 Pesticides that come into contact with non-target organisms can undergo biotransformation through various enzymatic reactions in the liver, such as hydrolysis, oxidation, reduction, or conjugation. Biotransformation is the organism's way of detoxifying and eliminating foreign substances, but it can also produce metabolites that are more harmful than the original compound, known as bioactivation. An example of bioactivation is the transformation of DDT, which is relatively non-toxic to birds, into DDE, a compound that disrupts calcium metabolism and leads to eggshell thinning (Schweitzer and Noblet, 2018).

 In a study conducted by Semalulu et al. (2005) in the Ugandan catchment of Lake Victoria, the presence of banned organochlorine pesticides (such as DDT, endosulfan, lindane, and dieldrin) was detected in the air, suggesting that these pesticides may still be used in the Lake Victoria basin. The United Kingdom aims to ensure pesticide sustainability by reducing the risks and impacts of pesticide use on human health and the environment. This involves promoting the development and implementation of alternative pest management methods and strategies (Ngowi et al., 2007).

**8. Effect of pesticides on Human health**

Employees and residents, especially those in rural areas, often have direct exposure to pesticides, which increases their risk of toxicity. Suicide by pesticides is popular in so many Latin American countries and Asian, as per World Health Organization (WHO) data (WHO, 2014). Pesticides are frequently largely uncontrollable and freely accessible, especially in low and middle-income nations (Sarchiapone et al., 2011). The first epidemiological observations of pesticide-related suicides emerged in the early 1990s. Many organizations and governments are currently concerned about pesticide-related homicides and suicides because suicide and depression clearly relate with high pesticide exposure. This issue has inspired and continues to encourage several more studies into when or where and why pesticide exposure occurs; researchers have also discovered ways to resolve this severe social problem (Freire and koifman, 2013).

Pesticides enter the human body either directly or indirectly. Humans can be exposed to pesticides when they are applied to crops, resulting in adverse effects on the mouth, respiratory tract, eyes, and skin. These effects can manifest as vomiting, headaches, sneezing, skin rashes, and irritation. The toxicity of pesticides to humans depends on the duration and concentration of exposure. The body typically eliminates pesticides through excretion, including biliary, urinary, and secretory gland excretion. Prolonged consumption of pesticide-contaminated fruits and vegetables can lead to an accumulation of toxins in the body organs, potentially causing chronic diseases such as neurotoxicity, necrosis, cancer, reproductive disorders, asthma, diabetes, cardiac disease, among others. Although quaternary nitrogen compounds like paraquat have been associated with neurodegenerative diseases like Parkinson's, the precise molecular mechanisms remain unknown. Similarly, the carbamate pesticide group inhibits the action of acetylcholinesterase (AChE), which serves as a biomarker for neurotoxicity. Pesticides, including organophosphorus compounds such as malathion and parathion, have been associated with various health issues, including cancer. Breast cancer is one of the most common types of cancer, and it has been linked to the effects of organophosphorus compounds on cellular growth and proliferation (Calaf, 2021). Similarly, organophosphorus compounds are implicated in asthma by affecting autoinhibitory M2 muscarinic receptors on parasympathetic neurons that regulate airway smooth muscle (Calaf, 2021). These compounds can also interfere with endocrine hormone action, disrupt hormone release patterns, and imitate hormones, leading to decreased fertility and the development of genital tract anomalies in both males and females. Studies have shown that organophosphorus compounds reduce paraoxonase activity and increase the risk of coronary artery disease (Kabir et al., 2015). Hunger and malnutrition remain significant challenges in several African countries.

The use of fertilizers and pesticides in agricultural lands can result in the transfer of these substances into crops, directly or indirectly impacting human health (Kumari and Sharma, 2008). Pesticides have been linked to endocrine disruption, chronic neurotoxicity, immune system disruption, carcinogenesis, genotoxicity, and mutagenicity, (Oluwole and Checke, 2019). Pesticide exposure has been linked to diabetes, asthma, Parkinson's disease, cancer, and leukaemia (SIDA, 2016). Kumari and Sharma (2008) and Damalas (2009) conducted research on farmers' perceptions of the effects on the environment of pesticide use as well as strategies used in the Himalaya western mountains.

**9. Bioremediation as Sustainable management**

Bioremediation is defined as the use of microorganisms for destroying or immobilize waste materials (Abatenh et al., 2017) without further disruption to the local environment. Bioremediation generally occurs due to microorganisms used the pollutants as a sole carbon and nitrogen source. So the degradation of pollutants is accompanied by microbial activities. The activity occurred by microbes in soil are affected by physico-chemical and environmental conditions such as pH value, temperature, moisture content, oxygen and so on. The degradation of pollutants is influenced by the availability of essential nutrients such as nitrogen, phosphorus, and carbon. Bioremediation, a process based on the activities of aerobic or anaerobic heterotrophic microorganisms, is commonly used to address soil contamination issues, particularly in industrialized areas worldwide. The control and optimization of bioremediation processes involve a complex system that takes into account various factors (Kensa, 2011). These factors include the viability of microbial populations capable of degrading pollutants, the accessibility of contaminants for microbial degradation, and environmental conditions that support microbial growth. Bioremediation process promotes the microbial metabolism of contaminants by adjusting the water; air and nutrient supply in the soil (Bhatt et al., 2021). If the bioremediation performed properly then it can be very cost effective technique. On-site remediation techniques are often favored due to their low cost and high level of public acceptance. These methods are generally considered cost-effective and can be implemented with relative ease. In this technique it involves utilization of naturally occurring microorganisms to detoxify or degrade persistent pollutants which are hazardous to environment as well as human health. In the bioremediation may use indigenous microorganisms to the polluted area or may isolate from elsewhere and brought to contaminated sites. Living microorganisms play a crucial role in the transformation of pollutants through various processes, including bioremediation, bioaccumulation, biomineralization, biodegradation, biotransformation, and co-metabolism (Zhang et al., 2020; Chugh et al., 2022). These reactions facilitate the breakdown and conversion of pollutants by microorganisms in the environment. By actions of various microorganisms, biodegradation of pesticides take place. In remediation of pesticide waste physico chemical methods are not sufficient and effective. many conventional methods for treating synthetic pyrethroids contaminated sites includes chemical treatment, recycling, incineration , pyrolysis and landfills are not effective ,efficient and costly which can lead to formation of toxic intermediates (Riser-Robert, 2020; Raheem et al., 2018). Thus bioremediation seems to be a reliable technique that utilizes microorganism for the removal of pesticides from contaminated area. Bioremediation is very cost effective and easy to use technique compare to other approaches. It does not pose any threaten of secondary pollution to the environment (Sharma, 2020; Medfu et al., 2020)

Bioremediation process is relatively slow process and requires weeks to months for effective clean up but on other hand it seems good alternative to conventional technologies (Medfu et al., 2020). It can be effective only when environmental conditions are favorable for microbial growth and microbial activities. It often involves manipulation of environmental parameters to allow microbial growth and degradation rate proceeds faster. Some essential factors which affect bioremediation process are pH, temperature, moisture content, organic matter, oxygen, microbe and Level of nutrients and co-substrates.

**10. Conclusion**

Pesticide use has increased dramatically in recent years, causing ecological harm, mainly soil and water contamination. Pesticides are available in a variety of forms, but the most commonly used pesticides are organophosphates, carbamate, organochlorine, and pyrethroids, which pose human and environmental concerns. Some pesticides, particularly organochlorides, are so persistent in the environment that they do not degrade. Consequently, these long-term environmental effects pose hazards to both non-target organisms and human beings. Pesticide misuse and management, as well as pesticide behavior in the environment, contribute to environmental pollution, which includes water pollution, soil pollution, air pollution, and food contamination. The scientific community has been dedicated to developing innovative approaches to reduce pesticide pollution. Numerous bioremediation approaches and servers are used in environmentally sustainable management strategies to fix pesticide issues or identify new green solutions. Bioremediation approaches are also inexpensive and environmentally friendly. Utilizing pesticide-degrading microorganisms in an environmentally friendly manner is an effective approach to manage pesticide pollutants. Further research is needed to screen and identify efficient enzymes and microbial strains to minimize the risks of pesticides to the environment and human health.

**11. Reference**

Abatenh E, Gizaw B, Tsegaye Z, Wassie M, 2017. The role of microorganisms in bioremediation-A review. Open Journal of Environmental Biology, 2(1):038-46.

Abhilash PC, Singh N, 2009. Pesticide use and application: an Indian scenario. Journal of hazardous materials, 15;165(1-3):1-2.

Agriculture and Natural Resources (ANR), 2014. Water quality: Controlling Nonpoint Source (NPS) Pollution. Pesticide Management to Protect Water Quality. Understanding Pesticides And How They Affect Water Quality 1999. Available from <http://www.aces.edu/pubs/docs/A/ANR-0790/WQ4.5.1.pdf>.

Aksakal O, Erturk FA, Sunar S, Bozari S, Agar G, 2013. Assessment of genotoxic effects of 2, 4-dichlorophenoxyacetic acid on maize by using RAPD analysis. Industrial Crops and Products. 1;42:552-7.

Aktar W, Sengupta D, Chowdhury A, 2009. Impact of pesticides use in agriculture: their benefits and hazards. Interdisciplinary toxicology, 2(1):1.

Aktar W, Sengupta D, Chowdhury A, 2009. Impact of pesticides use in agriculture: their benefits and hazards. Interdisciplinary toxicology. 1;2(1):1.

Baltazar MT, Dinis-Oliveira RJ, de Lourdes Bastos M, Tsatsakis AM, Duarte JA, Carvalho F. Pesticides exposure as etiological factors of Parkinson's disease and other neurodegenerative diseases—a mechanistic approach. Toxicology letters, 230(2):85-103.

Bhardwaj T, Sharma JP, 2013. Impact of pesticides application in agricultural industry: An Indian scenario. International Journal of Agriculture and Food Science Technology, 4(8):817-22.

Bhatt P, Verma A, Gangola S, Bhandari G, Chen S, 2021. Microbial glycoconjugates in organic pollutant bioremediation: recent advances and applications. Microbial Cell Factories, 20(1):1-8.

Boedeker W, Watts M, Clausing P, Marquez E, 2020. The global distribution of acute unintentional pesticide poisoning: estimations based on a systematic review. BMC public health, 20(1):1-9.

Boricha H, Fulekar MH, 2009. Pseudomonas plecoglossicida as a novel organism for the bioremediation of cypermethrin. Biology and medicine, 1(4):1-0.

Bowman MS, Zilberman D, 2013. Economic factors affecting diversified farming systems. Ecology and society, 18(1).

Calaf GM, 2021. Role of organophosphorous pesticides and acetylcholine in breast carcinogenesis. *Semin. Can. Biol.* 76, 206–217. doi: 10.1016/j.semcancer.2021.03.016

Carvalho FP, 2017. Pesticides, environment, and food safety. Food and energy security, 6(2):48-60.

Chugh M, Kumar L, Bhardwaj D, Bharadvaja N, 2022. Bioaccumulation and detoxification of heavy metals: an insight into the mechanism. InDevelopment in Wastewater Treatment Research and Processes. (pp. 243-264). Elsevier.

Damalas CA, 2009. Understanding benefits and risks of pesticides use. Sci Res Essay. 4(10):945-949.

Dubey NK, Ravindra Shukla RS, Ashok Kumar AK, Priyanka Singh PS, Bhanu Prakash BP, 2011. Global scenario on the application of natural products in integrated pest management programmes. InNatural products in plant pest managemen (pp. 1-20). Wallingford UK: CABI.

Freire C, Koifman S, 2013. Pesticides, depression and suicide: a systematic review of the epidemiological evidence. International Journal of Hygiene and Environmental Health; 216[4]:445-460.

Gangola S, Bhatt P, Kumar AJ, Bhandari G, Joshi S, Punetha A, Bhatt K, Rene ER. Biotechnological tools to elucidate the mechanism of pesticide degradation in the environment. Chemosphere, 133916.

Geetha M, Fulekar MH, 2008. Bioremediation of pesticides in surface soil treatment unit using microbial consortia. African Journal of Environmental Science and Technology. 2(2):036-45.

Ghorab MA, Khalil MS, 2015. Toxicological effects of organophosphates pesticides. International Journal of Environmental Monitoring and Analysis, 3(4):218-20.

Gill HK, Garg H, 2014. Pesticide: environmental impacts and management strategies. Pesticides-toxic aspects. 20;8(2014):187.

Grube A, Donaldson D, Kiely T, Wu L, 2011. Pesticides industry sales and usage. US EPA, Washington, DC.

Guo L, Fan XY, Qiao X, Montell C, Huang J, 2021. An octopamine receptor confers selective toxicity of amitraz on honeybees and Varroa mites. Elife. 12;10:e68268.

Gupta VK, Pathak A, Siddiqi NJ, Sharma B, 2016. Carbofuran modulating functions of acetylcholinesterase from rat brain in vitro. *Adv. Biol.* 2016:3760967. doi: 10.1155/2016/3760967.

Gyawali K. Pesticide uses and its effects on public health and environment. Journal of Health Promotion. 25;6:28-36.

Hashim M, 2015. Pesticides and drinking water. Journal of Advanced Botany and Zoology, 3(1):1-5.

Kabir ER, Rahman MS, Rahman I, 2015. A review on endocrine disruptors and their possible impacts on human health. *Environ. Toxicol. Pharmacol.* 40, 241–258. doi: 10.1016/j.etap.2015.06.009

Kalyabina VP, Esimbekova EN, Kopylova KV, Kratasyuk VA, 2021. Pesticides: formulants, distribution pathways and effects on human health–a review. *Toxicol. Rep.* 8, 1179–1192. doi: 10.1016/j.toxrep.2021.06.004

Kensa VM, 2011. Bioremediation-an overview. I Control Pollution, 27(2):161-8.

Kumar A, Thakur A, Sharma V, Koundal S, 2019. Pesticide residues in animal feed: Status, Safety, and Scope. J. Anim. Feed Sci. Technol, 7:73-80.

Kumar S, Kaushik G, Villarreal-Chiu JF, 2016. Scenario of organophosphate pollution and toxicity in India: A review. Environmental Science and Pollution Research, 23:9480-91.

Kumari S, Sharma HR, 2008. Farmer’s perception on environmental effects of pesticides use, climate change and strategies used in mountain of Western Himalaya. Int J Agric Sci Res. 1:57-68.

Lamichhane JR, 2017. Pesticide use and risk reduction in European farming systems with IPM: An introduction to the special issue. Crop Prot. 1;97:1-6.

Landrigan PJ, Stegeman JJ, Fleming LE, Allemand D, Anderson DM, Backer LC, Brucker-Davis F, Chevalier N, Corra L, Czerucka D, Bottein MY, 2020. Human health and ocean pollution. Annals of global health; 86(1).

Long EY, Krupke CH, 2016. Non-cultivated plants present a season-long route of pesticide exposure for honey bees. Nature communications, 7(1):11629.

Mahajan G, Chauhan BS, Gill MS, 2013 Dry-seeded rice culture in Punjab State of India: lessons learned from farmers. Field Crops Research, 20;144:89-99.

Mandal SK, 2019. Impact of Pest Control Chemicals on Biological Activity of Biocontrol Agents. InThe souvenir of Nafional Seminar on" Agro-Chemical Inputs and Its Extension Approaches Towards Food-Security and Bio-Safety: prospects and Chalanges (AEFS-2019), pp. 80-84.

Medfu Tarekegn M, Zewdu Salilih F, Ishetu AI, 2020. Microbes used as a tool for bioremediation of heavy metal from the environment. Cogent Food & Agriculture, 6(1):1783174.

Mrema EJ, Ngowi AV, Kishinhi SS, Mamuya SH, 2017. Pesticide exposure and health problems among female horticulture workers in Tanzania. Environmental health insights, 17;11:1178630217715237.

Ngowi AVF, Mbise TJ, Ijani ASM, London L, Ayayi OC, 2007. Pesticides use by small-holder farmers in vegetable production in Northern Tanzania. Crop Protection, 26(11):1617-1624.

Nieder R, Benbi DK, Reichl FX, Nieder R, Benbi DK, Reichl FX, 2018. Health risks associated with pesticides in soils. Soil components and human health, 503-73.

Oluwole O, Checke RA, 2019. Health and environmental impacts of pesticides use practices a case study of farmers in Ekiti State, Nigeria. Int J Agric Sustainability;7(3):153-163.

Osman KA, Al-Humaid AI, Al-Rehiayani SM, Al-Redhaiman KN, 2011. Estimated daily intake of pesticide residues exposure by vegetables grown in greenhouses in Al-Qassim region, Saudi Arabia. Food Control. 1;22(6):947-53.

Patel V, Ramasundarahettige C, Vijayakumar L, Thakur JS, Gajalakshmi V, Gururaj G, Suraweera W, Jha P, 2012. Suicide mortality in India: a nationally representative survey. The lancet. 23;379(9834):2343-51.

Pelfrène AF, 2010. Rodenticides. In Hayes' Handbook of Pesticide Toxicology (pp. 2153-2217). Academic Press.

Pérez-Lucas G, Vela N, El Aatik A, Navarro S, 2019. Environmental risk of groundwater pollution by pesticide leaching through the soil profile. Pesticides-use and misuse and their impact in the environment, 17:1-28.

Phillips PJ, Bode RW, 2004. Pesticides in surface water runoff in south‐eastern New York State, USA: seasonal and storm flow effects on concentrations. Pest Management Science: formerly Pesticide Science.60(6):531-43.

Raheem A, Sikarwar VS, He J, Dastyar W, Dionysiou DD, Wang W, Zhao M, 2018. Opportunities and challenges in sustainable treatment and resource reuse of sewage sludge: a review. Chemical Engineering Journal, 337:616-41.

Rathour SS, Kumar A, Maurya MK, Stephen AJ, Paul A, 2022. Study on consumer preference of fungicide with special reference to custodia (fungicide) in Bijnore district of Uttar Pradesh.

Riser-Roberts E, 2020. Remediation of petroleum contaminated soils: biological, physical, and chemical processes. CRC press.

Sachdeva S, 2007. Pesticides and Their Socio – Economic Impact on Agriculture, Southern Economist, 41 (38): 42- 53.

Sarchiapone M, Mandelli L, Iosue M, Andrisano C, Roy A, 2011. Controlling access to suicide means. International Journal of Environmental Research and Public Health. 8: 4550-4562.

Sarkar L, 2019. Emancipation of Effluent from Fertilizers and Chemical Pesticides Causing Water Contamination at Rishipur Village, West Bengal, India. International Journal of Research in Social Sciences. 9(8):62-8.

Schweitzer L, Noblet J, 2018. Water contamination and pollution. InGreen chemistry, (pp. 261-290). Elsevier.

Semalulu O, Hecky RE, Muir D, 2005. Agricultural chemicals and metal contaminants in the Ugandan catchment of Lake Victoria. Water quality and quantity synthesis final report, LVEMP, 162-77.

Sharma A, Kumar V, Shahzad B, Tanveer M, Sidhu GP, Handa N, Kohli SK, Yadav P, Bali AS, Parihar RD, Dar OI, 2019. Worldwide pesticide usage and its impacts on ecosystem. SN Applied Sciences. 1:1-6.

Sharma A, Kumar V, Shahzad B, Tanveer M, Sidhu GP, Handa N, Kohli SK, Yadav P, Bali AS, Parihar RD, Dar OI, 2019. Worldwide pesticide usage and its impacts on ecosystem. SN Applied Sciences. 1:1-6.

Sharma BM, Bharat GK, Tayal S, Nizzetto L, Čupr P, Larssen T, 2014. Environment and human exposure to persistent organic pollutants (POPs) in India: A systematic review of recent and historical data. Environment international. 66:48-64.

Sharma I. Bioremediation techniques for polluted environment: concept, advantages, limitations, and prospects. In Trace metals in the environment-new approaches and recent advances, IntechOpen.

SIDA. 2016. Pesticides in Agriculture. Department for International Organization and Policy Support.

Stehle S, Schulz R, 2015. Agricultural insecticides threaten surface waters at the global scale. Proceedings of the National Academy of Sciences. 5;112(18):5750-5.

Strassemeyer J, Daehmlow D, Dominic AR, Lorenz S, Golla B, 2017. SYNOPS-WEB, an online tool for environmental risk assessment to evaluate pesticide strategies on field level. *Crop protection*, *97*, 28-44.

Subramanyam B, Hagstrum DW, 2012. Alternatives to pesticides in stored-product IPM. Springer Science & Business Media.

Toda M, Beer KD, Kuivila KM, Chiller TM, Jackson BR, 2021. Trends in agricultural triazole fungicide use in the United States, 1992–2016 and possible implications for antifungal-resistant fungi in human disease. Environmental Health Perspectives.129(5):055001.

Tosh DG, McDonald RA, Bearhop S, Lllewellyn NR, Fee S, Sharp EA, Barnett EA, Shore RF, 2011. Does small mammal prey guild affect the exposure of predators to anticoagulant rodenticides?. Environmental Pollution. 1;159(10):3106-12.

Tudi M, Daniel Ruan H, Wang L, Lyu J, Sadler R, Connell D, Chu C, Phung DT, 2021. Agriculture Development, Pesticide Application and Its Impact on the Environment. *International Journal of Environmental Research and Public Health*. 18(3):1112. <https://doi.org/10.3390/ijerph18031112>

WHO - World Health Organization. Suicide prevention (SUPRE). http://www.who.int/mental\_health/prevention/suicide/suicideprevent/en/ (Accessed 16 August 2014).

Worldatlas, 2018. [https://www.worldatlas.com/articles/top-pesticide-consuming countries-of-the-world.html](https://www.worldatlas.com/articles/top-pesticide-consuming%20countries-of-the-world.html)

Yadav IC, Devi NL, Syed JH, Cheng Z, Li J, Zhang G, Jones KC, 2015. Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: a comprehensive review of India. Science of the Total Environment, 1;511:123-37.

Zhang C, Sun Y, Hu R, Huang J, Huang X, Li Y, Yin Y, Chen Z, 2018. A comparison of the effects of agricultural pesticide uses on peripheral nerve conduction in China. Scientific reports. 25;8(1):9621.

Zhang H, Yuan X, Xiong T, Wang H, Jiang L, 2020. Bioremediation of co-contaminated soil with heavy metals and pesticides: Influence factors, mechanisms and evaluation methods. Chemical Engineering Journal, 398:125657.

Zhang W, 2018. Global pesticide use: profile, trend, cost/benefit and more. Proc Int Acad Ecol Environ Sci 8(1):1–27