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Repercussion of Pesticide on Environment and Human Health

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Abstract: Pesticides are being utilized in different crops to satisfy the needs of an expanding population. In addition to agriculture, pesticides are used for a variety of other things including home gardening, control of disease-carrying insects, and other things. Though pesticides have positive effects on agriculture, they also have negative side effects and are getting worse day by day. Agrochemical runoff into streams and rivers can contaminate aquatic life, animals, and human beings through biomagnifications. Numerous theoretical and experimental studies show that pesticide residues can have long-term detrimental impacts on the health of people and animals as well as the stability of ecosystems, even if current formulations are relatively safe for non-target species. Any kind of human pesticide exposure can increase the likelihood of acquiring chronic conditions like diabetes, Parkinson's disease, cancer, asthma, reproductive problems, and Amyotrophic Lateral Sclerosis. Since everyone is exposed to pesticides in some way, an eco-friendly substitute must be developed. On the other side, bioactive nanoparticles have a limited lifespan, minimal environmental impact, and are biodegradable. Being in its initial stages, the use of bioactive nanomaterials to degrade synthetic pesticides is progressively gaining popularity and can be one of the promising degradation techniques in due course of time. The district of Bargarh in western Odisha is currently the unofficial cancer capital of the state. According to experts, the extensive use of pesticides in agriculture may be responsible for the high frequency of cancer. Bargarh has the highest rate of cancer cases out of the 30 districts of Odisha. 33 districts of three states (Odisha, West Bengal, and Chhattisgarh), Bargarh district of Odisha reported the most cancer cases between 2014 and 2017. Cancer prevalence in this district is up to 25.37% of the total population. This review focuses on exposure pathways of pesticides on people, the environment, and other creatures, as well as the pesticide degradation by different means.

Keywords: Pesticides, Human health, Diseases, Bioaccumulation, Environment, India, Odisha, Bargarh, Degradation

Highlights:

1. Increased pesticide residues in different environmental compartments can lead to several health hazards, which lead to disbalance in the ecosystem.
2. Pesticides cause deadly diseases like neurotoxicity, cancer, diabetes, reproductive disorder, and many more.
3. Bargarh is said to be the unofficial cancer capital of Odisha and scientists believe that the reason is due to the consumption of heavy amounts of pesticides in agricultural fields.
4. To combat the ongoing problems related to pesticides, various techniques including Photolysis and nanotechnology are used for the removal of intoxicants from the environment.

1. Introduction

The rising population of the globe has reached 8.2 billion in 2024 and feeding a population like this requires highly productive agriculture, which should be ideally sustainable. High-yield varieties are introduced to generate a large quantity of grains and increase crop output. To protect the crop from pest infestation, application of pesticides is initiated. Over time, pest species adapt and develop mechanisms to resist pesticide effects. As a result, pesticides are no longer efficient at protecting crops. The research and development process continues to create new pesticide formulations to kill resistant bug types. This is a simultaneous evolution of pests and pesticides. As a result, pesticides made from synthetic compounds are becoming more widely employed in agriculture. Some pesticides decompose and are released into the environment, but the majority are non-degradable and never go through the cycling process (Figure 1).

Heavy metals and pesticides are of major global concern since they are persistent in the natural environment, being particularly hazardous toxicants for humans, and wildlife (especially aquatic organisms) for their bioaccumulation in tissues (Cui et al., 2015). Because of their persistence, they may cause biological magnification (John and Prakash 2003).Nowadays it is extremely complicated to lower pesticide use. Using pesticides with caution appears to be one of the most significant barriers to intensive agriculture. To feed the rising global population, different technologies must be deployed to boost agricultural productivity while protecting environmental and human health (Storck et al., 2017).Pesticides enter the human body through a variety of ways, including the eyes, mouth, skin, and respiratory system (Kim et al., 2017). The oral route is the most essential method for determining pesticide toxicity. (Chedik et al., 2017). These problems disrupt cellular homeostasis, which is mostly caused by the action of pesticides, such as morphological alterations in mitochondria, disorders in ionic channels, and enzymes (Chen et al., 2017), and aggregation of DNA damage (Alleva et al., 2018). Pesticides in aquatic habitats are a global concern because they typically accumulate in aquatic organisms' bodies and soil sediment, harming human health (Syafrudin et al., 2021). Edible fishes are the most important source of omega-3 polyunsaturated fatty acids and proteins, which can protect humans from cardiovascular diseases (Hu et al.,2003). However, fish become contaminated as a result of pollution from various toxicants. Consuming these fishes can cause an accumulation of adulterants in the human body (Li et al., 2008). When fishes are exposed for a longer duration of time to pesticides then behavioral changes in fishes like avoiding predators and swimming ability are observed and also short-term exposure can kill salmon and some of the other aquatic organisms (Sabra and Mehana 2015). Chronic illnesses linked to pesticide accumulation include immunotoxicity, neurological disorders, asthma, cancer, dermatitis, reproductive dysfunction, birth abnormalities, endocrine difficulties, and many more (Kim et al., 2017).To achieve long-term sustainability in pest management, it is critical to evaluate the potential negative repercussions of pesticides, regardless of their effectiveness, price, or ease of use. Evaluating pesticide residues, their treatment, destiny, and application technologies is critical for reducing harmful health impacts.

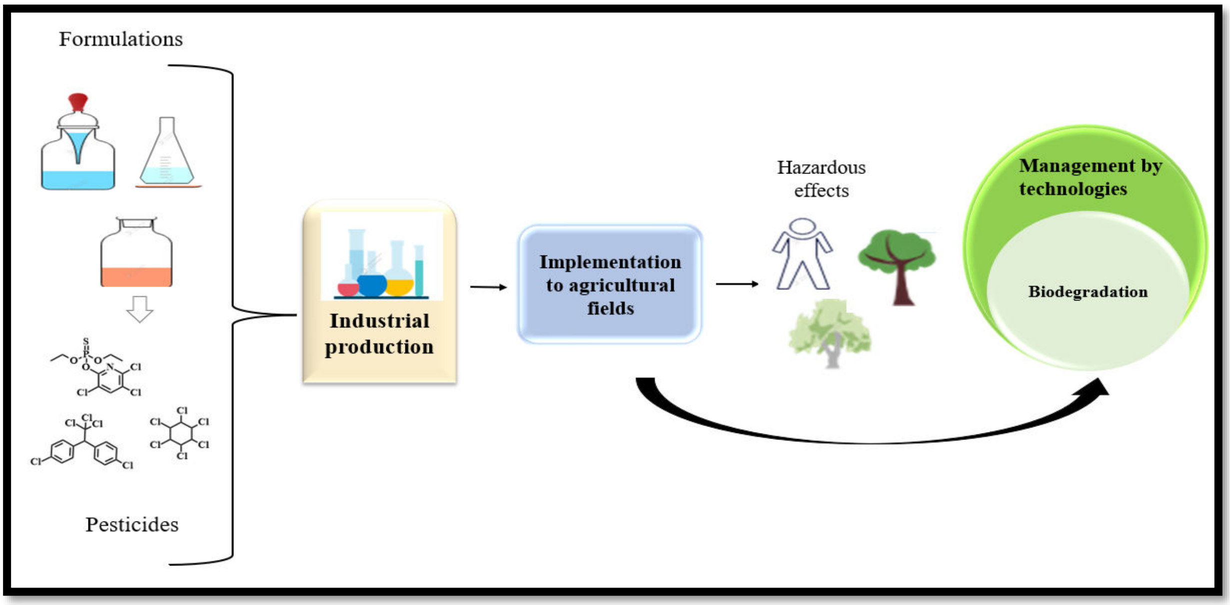


Figure 1: Thematic diagram illustrating the synthesis, production, usage, effects, and eco-friendly pesticide management (Pathak et al., 2022)

2. Methods

For classifying and determining the hazardous effect of pesticides a systematic electronic search of literature published in the English language was conducted using PubMed and Google Scholar (mainly from the year 2000 onwards). The following search terms were used: pesticides, disease, human health, environment, India, Odisha, Bargarh, degradation, and nanotechnology. The title and abstract of each result were first examined for relevance. Later on, focused on the items of our research interests. The results were grouped by the amount of pesticides used, their effect on humans as well as their exposure. The extraction of information was directly from the study's text, figures, or tables and incorporated them into different sections. After evaluating the full texts, only 87studies were included in the manuscript.

3. Background and Classification of Pesticides

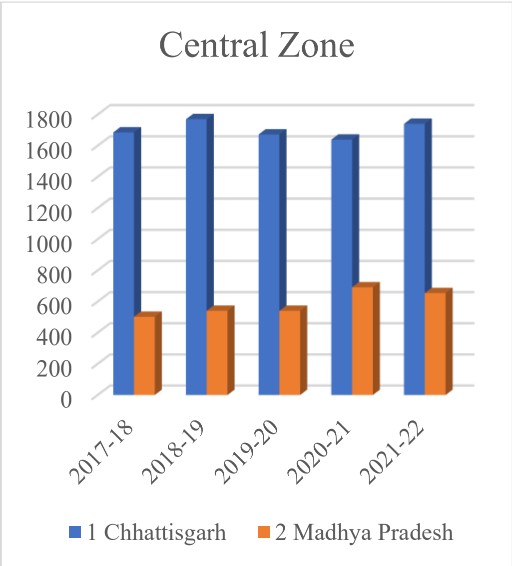
When Miller, a Swiss chemist who won the Nobel Prize in 1948, first showed the insecticidal characteristics of DDT (dichlorodiphenyltrichloroethane), it marked the starting of the genuine revolution in the use of synthesized chemicals to control pests. In addition to successfully reducing Colorado beetles and other plant pests. It also prevented insects from infecting humans with malaria and typhus during World War II, saving thousands of lives. DDT was inexpensive, simple to make, and effective in keeping pests out of the treated regions for several months. Aldrin, Dieldrin, Endrin, Chlordane, and Chlorinated Camphenes were among the various polychlorinated hydrocarbons that were synthesized in the 1940s. The Germans created the first phosphorus organic pesticide, parathion, in 1943 while working with military gases, concurrently with DDT research. In the Ciba-Geigy laboratories, carbaryl, the first carbamin insecticide, was synthesized in 1950. In 1967, the United Kingdom manufactured the first synthetic pyrethrin equivalent (resmethrine). DDT persists in the environment and accumulates in the food chains as a contact toxin, harming fish and bird fertility, and was discovered only after a few decades of its deployment. Subsequent studies demonstrated that DDT showed calcium management problems in birds, which lowered the thickness of eggshells and, as a result, caused it to crack before hatching. In addition, it builds up in adipose tissue and affects hormones, as demonstrated by laboratory studies on 13 mice and rats. (Banaszkiewicz and Tadeusz 2010).

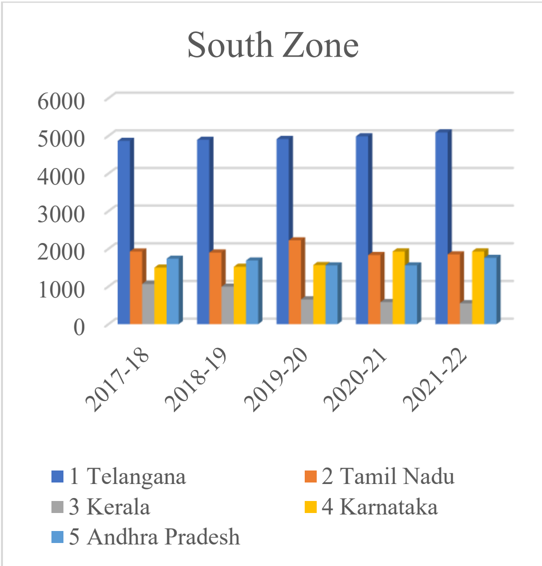
Pesticide classification can be done in various ways. The most prevalent classification method is according to the category of targeted pests (herbicides, insecticides, fungicides) (Tadeo et al., 2008); chemical structure (organophosphates, organochlorines, pyrethroids, carbamates etc.) (Kim et al., 2017; Tadeo et al., 2008); their toxicological risk (slightly hazardous, extremely, highly, moderately) (WHO Italy, 2010); persistence in environment (persistence, non-persistence, moderately persistence, permanently persistence) (Capoferri et al., 2018); or their mechanism of action (Lewis et al., 2016)

4. Pesticides use in India

In the agricultural field, using pesticides has been an essential part of various types of crops in several areas and the usage of these pesticides is at a very high level and in an unscientific manner (Atreya, 2007; Devi, 2010; Shetty *et al.,* 2010). It was found that in developing countries, around 8 lakhs people are dying due to pesticides after the arrival of the Green Revolution (Devi et al., 2017) and about 20,000 people die every year because of pesticide intake via food products (Bhardwaj and Sharma, 2013). In most of cases, the effect of pesticide exposure is mostly confined to the farmers or engaged in farm work (Nyakundi et al.,2012; Devi, 2012).India is dealing with the highest rate of pesticide consumption all over Asia and it ranks 12th position in the world. Also, India stood to be in the first position among the world's suppliers of agrochemicals following the USA, Japan, and China (Devi et al., 2017) and it is an export-oriented business in India. India's annual consumption of pesticides in tons was 45620 in 2013, 60280 in 2014, 56120 in 2015, 50410 in 2016, 52750 in 2017, and 58160 in 2018 (Source: www.fao.org) (Figure-2). In India for the period 2000-2003, the use of pesticidesis highest in Jammu and Kashmir followed by Punjab and Haryana (Devi et al., 2017). Pesticide use in India was recorded as 5000 metric tons in 1958 and increased to 102240 metric tons in 1998. In the year 1996-97 the rising demand for pesticides in terms of their value was approximately around Rs 22 billion, which was almost about 2% of the total world market, (Aktar et al., 2009).

It was found that northeastern states are mainly engaged in organic farming compared to the other parts of the country. Application of biopesticide to control pests in the crop field should be implemented to reduce the number of pesticides and chemical fertilizers. A high amount of pesticides are used in Maharashtra and Uttar Pradesh in the year 2017-22.





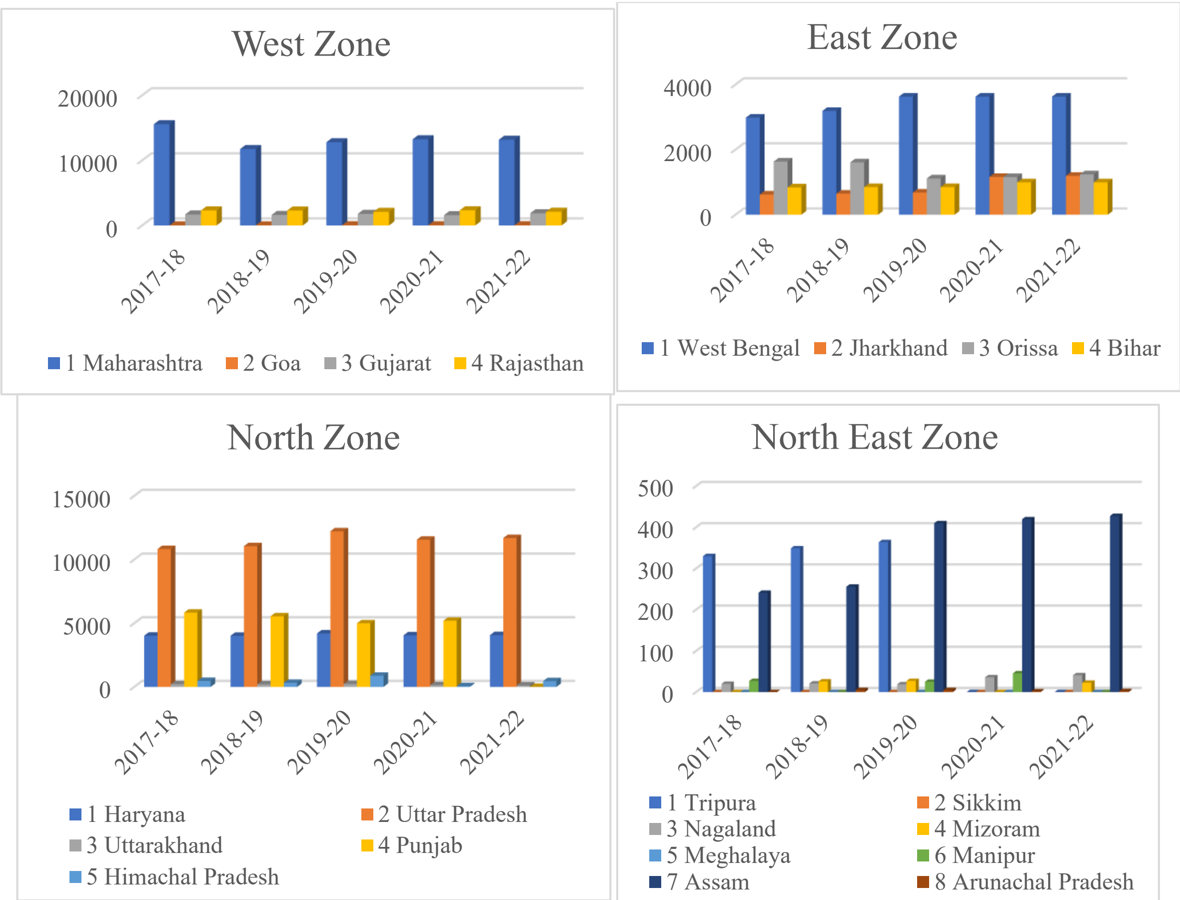


Figure 2. Pesticide consumption (in tons) rate state wise in respective years (Source: ppqs.gov.in)

One of India's leading states for rice production is Odisha. In Odisha, 76% of people are engaged in farm work. 187,000 hectares are irrigated out of the total 87,46,000 hectares that are planted with crops. As per available statistics for 2020-21, Odisha produces 9% of the total rice in India and 4.22% of the total food-grain production of the country. (www.thehindu.com) In last few years pesticide consumption (in tons) in this state was found to be 1633 during 2017-18, 1609 during 2018-19, 1115 during 2019-20, 1158 during 2020-21 and 1240 during 2021-22. (Source: ppqs.gov.in) (Figure-3). Bargarh is Odisha's highest rice-producing district, which means that the most pesticides were utilized in this area.

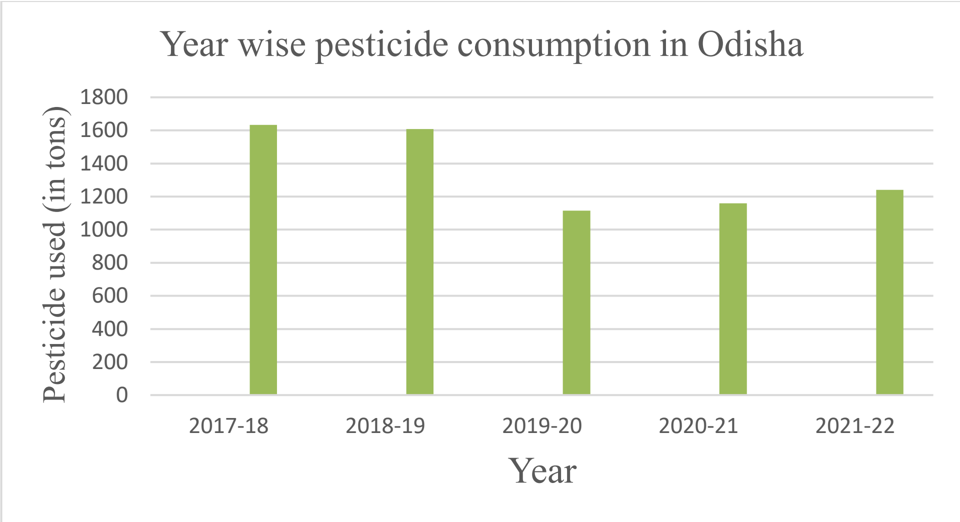


Figure 3.The graph represents year-wise pesticide consumption in Odisha

Bargarh district, located in the western part of Odisha is known as the Rice Bowl of Odisha because of intense agricultural activities since the commissioning of Hirakud Reservoir in the year 1953 over river Mahanadi. The farmers of Bargarh and its neighboring district (Sambalpur, Jharsuguda) sow paddy twice a year. After the induction of high-yielding hybrid rice varieties, cultivation practice changed to a mechanized farming system.High input of chemical fertilizers was used in crops for maximum yield that directly or indirectly imbalance the natural ecosystem. Higher susceptibility towards pest infestation, overall use of pesticides has been increased above the national average of pesticide application in paddy crops. The most common pesticide varieties used in this region are Chlorpyriphos, Profenofos, Thiamethoxam, Imidacloprid, Carbofuran, Fipronil, Tricyclazole, Hexaconazole, Buprofezin, etc. which are found to be toxic. As the farmers in this region belong to middle-class families, they always prefer the use of pesticides that are cost-effective. However, indiscriminate use of pesticides and chemical fertilizers to boost productivity has resulted in numerous community health issues headache and nausea to chronic impacts like cancer in the recent past (Seth et al., 2016). Recently, a stiff rise in the cases of cancer in Bargarh district has been reported which designated Bargarh as the unofficial cancer capital of the state (Majhi et al., 2017). Out of 30 districts in the state Bargarh is worst hit by cancer cases. Bargarh reported the highest number of cancer cases during 2014-17 among 33 districts of Odisha, West Bengal, and Chhattisgarh. As high as 25.37% people of in the Bargarh district are affected with cancer (Majhi et al., 2017). Several reports indicate the association of cancer incidence with the exposure of pesticide residues through various routes.

5. Effect on Humans

Acute impacts as well as chronic effects on humans can develop months or years after exposure to pesticides. Sting eyes, blisters, rashes, blindness, nausea, lightheadedness, diarrhea, and even death are examples of acute health impacts. Cancers, birth deformities, reproductive injury, immunotoxicity, neurological and developmental toxicity, and endocrine system disturbance are a few examples of documented chronic consequences (Shah, 2020). Some of the major human health effects caused by exposure to pesticides are as follows (Figure 4)

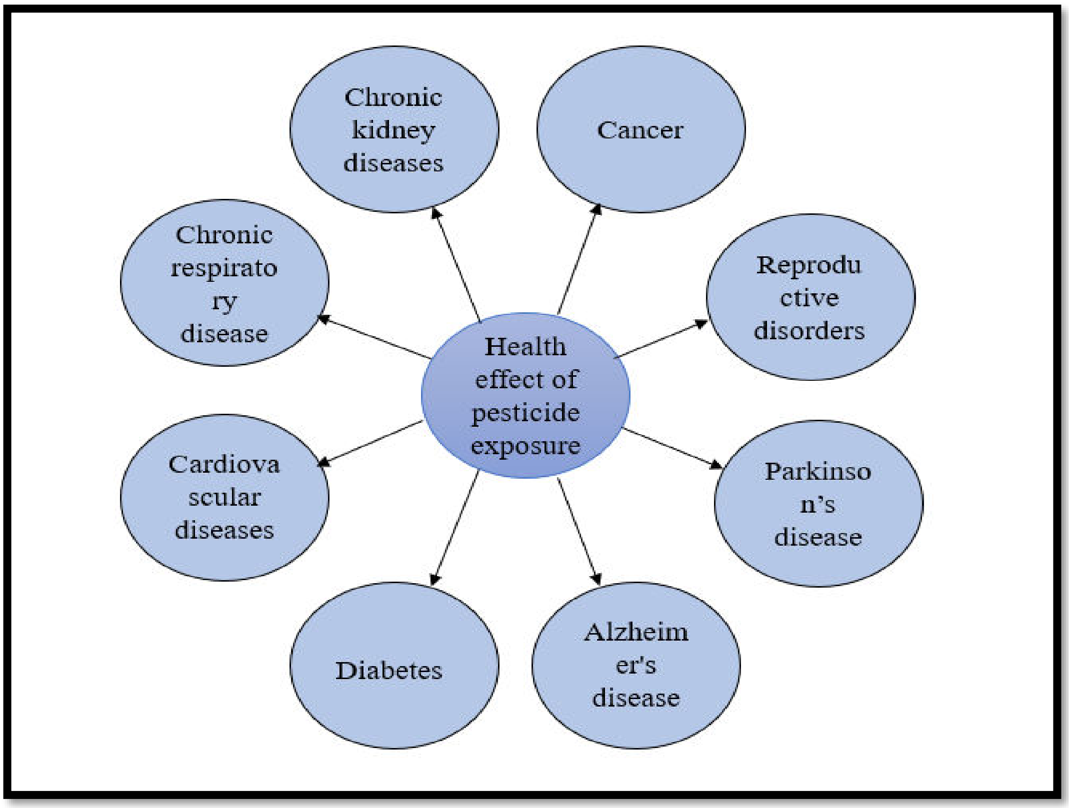


Figure 4. Effect of Pesticide exposure on human health

5.1. Cancer

Exposure to pesticides is one of the principal reasons for cancer across the world. The issue is one of the major concerns worldwide (Samanic et al., 2008). Before 50 years ago, the first report of cancer-related to pesticides was introduced where higher incidences of skin and lung cancer are diagnosed who are frequently exposed to insecticides in grape fields (Jungmann, 1966; Roth, 1958; Thiers et al., 1967). From a study, it is demonstrated that the pesticide Chlorpyrifos produces a redox imbalance which alters the antioxidant defense mechanism in breast carcinomas (Ventura et al., 2015). Growing evidence from molecular biology, toxicology, and epidemiology shows that exposure to several environmental contaminants, including pesticides, is linked to an increased risk of developing cancer. (Parrón et al., 2014). Several groups of insecticides like organochlorines, organophosphates, pyrethroids, and N-methylcarbamates have been proven to be carcinogenic in different models (Alavanja et al., 2013; George and Shukla, 2011). However, pesticidalagents can interact with several other chemicals and increase the cancer risk through several mechanisms including tumor promotion, genotoxicity, hormonal action, epigenetic factors, and immunotoxicity (Lyons and

Watterson, 2010). As reported by EPA (Environmental Protection Agency), almost every pesticide used in the US is specifically genotoxic (Collotta et al., 2013). Additionally, following the biomonitoring of people who had multiple exposures to pesticides, it was discovered that there were more signs of DNA damage, such as sister chromatid exchanges, chromosomal abnormalities, micronuclei, and single cell gel electrophoresis (Kapka-Skrzypczak et al., 2011).

5.2. Reproductive disorders

Thehigher risk of delayed abortion is linked with glyphosate and thiocarbamate type of pesticides (Jurewicz et al., 2008). A study conducted on a population of arbitrarily chosen couples that are engaged in farm work showed a higher risk of infertility as well as spontaneous abortion and incessant stillbirth (Neghab et al., 2014). Exposure to several pesticides either occupationally or environmentally could be related to reducing the quality of sperm (Martenies and Perry, 2013). People having contact with abamectin have been found to have decreased sperm motility and maturity (Celik-Ozenci et al., 2012). Organophosphorus pesticide affects the male reproductive system by reducing sperm activity (density, counts, motility, and viability), reducing testis weights, inhibiting spermatogenesis, DNA damage of sperm, and increasing abnormal sperm morphology (Mehrpour et al., 2014). Human exposure to organochlorine and organophosphate pesticides can be a possible risk for the induction of hypospadias (Michalakis et al. 2014).

5.3. Parkinson

Parkinson's disease is a motor progressive disorder of CNS that is characterized by degeneration of dopaminergic neurons in the substantia nigra. Herbicide rotenone is one of the major causes of degradation of nigrostriatal dopaminergic neurons by inhibiting mitochondrial complex-1 which leads to motor dysfunction (Tanner et al., 2011; Goldstein et al., 2015). Rotenone and paraquat develop toxin-based Parkinson's disease (PD) in animal models by inducing neuro-inflammation and loss of dopaminergic neurons. When rotenone was experimented with in Swiss albino mice it developed PD by degeneration of dopaminergic and dihydroxyphenylalenine-decarboxylase-rich neurons (Taetzsch and Block, 2013; Mitra et al., 2015). A higher risk of PD was linked with paraquat and rotating crops (Brouwer et al., 2017). The risk of PD increases when exposed to various types of herbicides, pesticides, and solvents but an approximate two-fold increase was seen when people were exposed to paraquat or maneb/mancozeb (Pezzoli and Cereda, 2013). Neurodegenerative disorders like Parkinsons disease are frequently studied in case of exposure to neurotoxic pesticides like organochlorines, pyrethroids, organophosphates, carbamates, and some insecticides because they cause interference with the function of ion channels and neurotransmission in nervous system (Costa et al., 2008).

5.4. Alzheimer

Alzheimer's disease is a type of dementia that impairs memory function and retentive ability as a result of cerebral cortex deterioration. Prenatal exposure to organophosphates is the cause of the alteration of mental function in school children (Mu~noz-Quezada et al., 2013; Gonz_alez-Alzaga et al., 2014). From an in vivo study in experimental animals, it was found that pesticides can alter the metabolic process involved in the homeostasis of amyloid β which increases the level of amyloid β in the hippocampus and cortex along with increased memory loss and reduced motor activity (Salazar *et al.* 2011). Evidence suggests that long-term and low-dose pesticide exposure can lead to neuronal loss in several regions of the brain which results in loss of motor function, a decrease in memory, attention, and cognitive impairment (Ullrich & Humpel 2009; Tartaglione et al., 2016).

5.5. Diabetes

Reports suggest that diabetes has become prevalent as 347 million people are said to be diabetic around the world. According to WHO, it is believed that deaths related to diabetes are likely to double in between 2005 to 2030 (www.who.int). Several studies indicate that exposure of pesticides to humans could be a possible risk factor for developing diabetes (Everett and Matheson, 2010; Montgomery et al., 2008; Saldana et al., 2007). Exposure of humans to pesticides especially organochlorines and metabolites is found to be responsible for the onset of type 2 diabetes and its comorbidities (Azandjeme et al., 2013). Researchers investigated the effects of pesticide exposure on glucose homeostasis in laboratory animals. From lots of reports, it was found that pesticides like organophosphates and organochlorines disrupt glucose metabolism with imbalanced secretion of insulin (Abdollahi et al., 2004a; Karami-Mohajeri and Abdollahi, 2011; Pournour mohammadi et al., 2007).

5.6. Cardiovascular diseases

Exposure to organophosphate pesticidesenhances the risk of coronary artery diseases through paraoxonase activity (Zamzila et al., 2011). In an experiment, when zebrafish were exposed to dieldrin (organochlorine pesticide), initiation of gene modification along with cardiovascular dysfunction was seen (Slade et al., 2017). Organophosphorus compounds and herbicides 2,3,7,8 TCDD are found to be toxic to heart muscles (Consonni et al., 2008; Hung et al., 2015). The organophosphorus compounds diazinon, malathion, coumaphos, chlorpyrifos (Dayton et al., 2010; Hung et al., 2015) organochlorine pesticide aldrin (Mills et al., 2009) and carbamate (Carbofuran) (Dayton et al., 2010) are linked with several serious diseases like arrhythmia (an irregular heartbeat), heart failure, coronary disease, SAH (Systemic Arterial Hypertension) and AMI (Acute Myocardial Infarction). Organophosphorus acts on CNS however central toxicity can be one of the causes of initiation of cardiovascular diseases either in condition of chronic exposure or interaction with different classes of chemicals (Crofton, 2008).

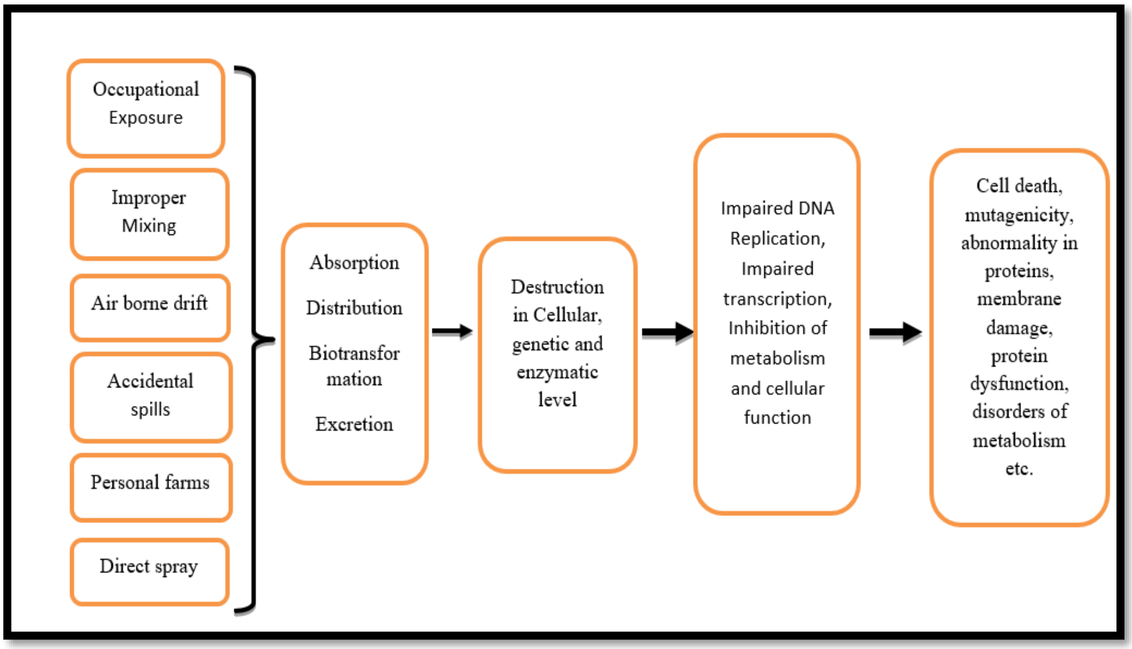


Figure 5. Impact of pesticide exposure in human (Singh et al., 2017, Kalyabina et al., 2021).

5.7. Chronic respiratory disease

Several reports indicate an increased risk of asthma in people being exposed to pesticides at the workplace (Hernandez et al., 2011). However, in an agricultural health study, it was found that exposure to pesticides can increase the risk of chronic obstructive pulmonary disease (COPD) in people engaged in farming (Hoppin et al., 2007). From an investigation carried out in northern India, it was found that pesticides can cause several different ailments like wheezing, blood in sputum, dry cough, and irritation of the respiratory system (Fareed et al., 2013). The use of pesticides can increase the risk of lung disorders along with morbidity and mortality problems (Buralli et al., 2018). An inspection of 926 pesticide applicators having active asthma revealed that the use of paraquat and glyphosate can lead to the worsening of asthma in individuals with allergies (Henneberger et al., 2014). Increased development of pulmonary symptoms along with lung dysfunction and the occurrence of enduring respiratory ailments was found in farmers exposed to several pesticides (Stoleski et al., 2019).

5.8. Chronic kidney diseases

Diabetes and hypertension are the two main global causes of chronic kidney disease (CKD), although epidemics of chronic kidney disease with unknown causes (CKDu) also occur in Central America, Sri Lanka, India, and other places (Valcke et al., 2017). Epidemiological studies suggest that environmental pollutants are involved, in causing CKD (Rajapurkar et al., 2012).A negative connection between blood levels of OCPs and estimated glomerular filtration rate (eGFR) in CKD patients was found, according to an interim report. (Siddharth et al., 2012). These findings are consistent with the fact that OCPs are well-known nephrotoxins and both occupational and unintentional exposure has been linked to reports of their toxicity. Experimental animals have shown histological changes in the kidney, including parenchymatous degeneration of the renal tubular and glomerular cells when exposed to OCP. (Uboh et al., 2011).

5.9. Other chronic diseases

Infrequent reports concerning pesticide exposure to several human chronic diseases like chronic fatigue syndrome (Behan and Haniffah, 1994), autoimmune diseases like rheumatoid arthritis and systemic lupus erythematous (Cooper et al., 2004; Gold et al., 2007; Parks et al., 2011) are reported due to pesticide exposure. Pesticides from the environment reachthe community causing numerous health hazards that can be noxious to humans as shown in Figure 4.

6. Effect on environment

Pesticides are specifically designed as toxic substances to some specific target organisms, but these can have several adverse effects on water, air, or soil along with other living creatures (Aktar et al., 2009). Pesticides are well known for their high levels of persistence and ubiquity in the environment, and depending on their nature, chemical composition, dosage, and intended targets, they may persist and interact with the environment and living things in a variety of ways. Globally pesticides can be found everywhere and these may persist in soil, water bodies, rain, fog, and air (Lushchak et al., 2018). A major supply of drinking water in many developing nations is surface water. (Mandl et al., 1994). Utilization of pesticides in the crop fields can contaminate surface water through various routes like draining, leaching, runoff, and drift (Rani et al., 2021). 2, 4-Dichlorophenoxyacetic acid is a water-soluble pesticide for which it is less persistent and quickly biodegradable in the environment. Due to this reason, they do not accumulate in the soil or sediments or bioconcentrate in organisms (Volodymyr et al., 2018).

The physicochemical constituents of pesticides determine how hazardous substances are absorbed and transported from the soil to plants (Pullagurala et al., 2018). On soil enzymes, pesticides have a variety of impacts. They affect the enzyme activity related to the Sulphur, nitrogen, carbon, and phosphorous cycle such as dehydrogenase, acid phosphatase, phosphatase, β glucosidase, urease, etc. (Riah et al., 2014; Md Meftaul et al., 2020). Heavy use of herbicides blocked the action of some specific fungal species (Chen et al., 2001; Harding and Raizada, 2015).

Pesticides can be carried downward with the flow of water after being sprayed on crops and also can adsorb, dissolve, and break down while passing through the soil. The elements of pesticides, the properties of the soil, and the existing environmental conditions influence how rapidly the pesticide passes through the soil (Katagi 2013). Due to soil fumigation, the proportion of pesticides leaching

into groundwater may significantly rise. (Huang et al., 2019). Accidental spills at chemical factories emit pollutants that are dangerous to humans and persist in nature. For example, during the 1960s, a pesticide factory accident in Wheat Hampstead, United Kingdom, led to TPs and DDT poisoning of the river Lee (Lea). (Jürgens et al., 2016). Controlled release systems (CRS) of pesticides are suggested to sustain a predefined concentration of pesticide for a long period. They make it possible to move an active component from trapped compartments to a surface that is targeted, minimizing the unwanted pesticide loss and obtaining the required effect on the target pests (Singh et al., 2020).
Emerging innovations are actively being researched to lower the percentage of harmful ingredients in pesticide products. Due to their increased affinity for the desired pest species, nanocarriers, decrease pesticide losses, avoid premature release, and improve the accuracy of active ingredient delivery. (Liang et al., 2020) (Kumar et al., 2019).

7. Effect on other organisms

Pesticide contamination in water creates serious risks to water bodies by lowering dissolved oxygen levels which can affect aquatic species at diverse trophic levels starting from algae to fish. Aquatic animals get exposed to pesticides in 3 modes. Those are orally (intake of contaminated water), breathing (by gills), and dermally (absorption through skin). Oxygen level in water decreases as a consequence of killing aquatic plants by the use of herbicides, which ultimately leads to suffocation in fish and a decrease in fish population (Rani et al., 2021). Fishes are highly sensitive to enzymatic and hormone disruption (Khan and Law, 2005). Doses of pesticides in the aquatic environment are not enough for the death of fishes but are related to indirect changes in physiology and behavior which has a deliberate effect on the reproduction and survival of fish population (Kegley, Neumeister et al., 1999). As a result of herbicide use, the reproductive capability of fish was also affected (Helfrich et al., 2009). Glyphosate increases the mortality rate of young frogs and tadpoles and carbaryl is found to affect many amphibian families (Relyea, 2005). Endosulfan and Chlorpyrifos have been found to produce severe damage in amphibians (Sparling and Feller, 2009).
Pesticide exposure also shows several effects on terrestrial nontargeted species. Extensive pesticide uses like organophosphates, pyrethroids, and carbamates decrease the population of valuable insects like beetles and bees. A higher insect population has been seen in organic farms as compared to non-organic farms (Rani et al., 2021). Neonicotinoid insecticides (clothianidin and Imidacloprid) were found harmful to bees (Yang et al., 2008). Neonicotinoids present in the soil have adverse effects like killing of earthworm species like *Eisenia fetida* (Goulson, 2013). Several organisms interact with each other in the food web but the migration and bioaccumulation of pesticides is necessary to evaluate their environmental effects.

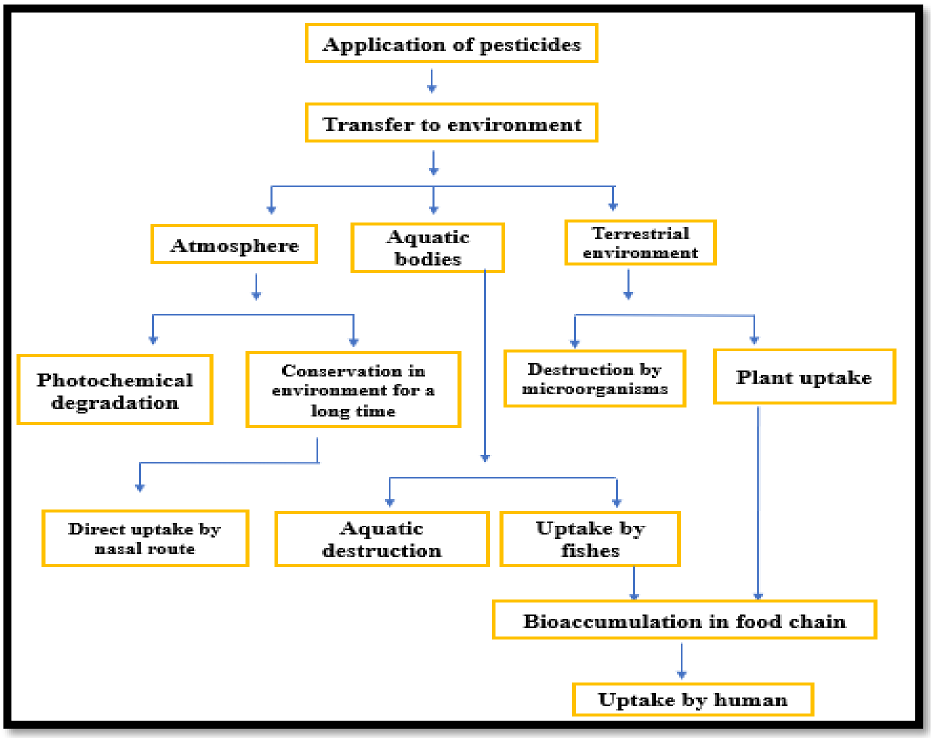


Figure 5. Flow pathway of pesticide in the environment

Mostly pesticides enter water bodies through runoff from adjoining fields and roads. Several other routes include contaminated groundwater, intentional dumping, airborne drift, improper mixing, and direct spray (Volodymyr et al., 2018). When pesticides enter the ecosystem, several environmental factors are affected. From various studies, it was demonstrated that chemicals interacting with the endocrine system have serious impacts on the growth, reproduction, and development of wildlife species (Figure-5).

8. Bioaccumulation of pesticides

Pesticides are persistent and non-biodegradable, leading to higher concentrations in species across the food chain. The process of biomagnification, is more harmful to the higher trophic levels as compared to lower trophic levels. Chemical pesticides are dual-purpose weapons that can be just as destructive to human health and ecosystems as they are to the target pests (Halwart and Gupta, 2004).Therefore, consumption of pesticides by non-targeted animals and their bioaccumulation in different compartments are a major concern.

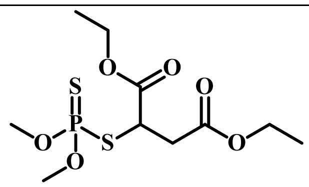
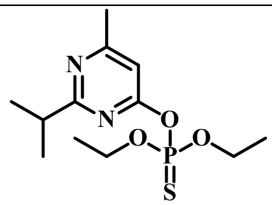
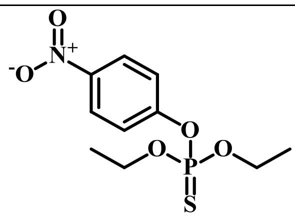
Cyprinus Carpio and *Puntius ticto,*were both fishes were exposed to aldrin, dieldrin, BHC (beta-Hexachlorocyclohexane), and DDT (Dichlorodiphenyltrichloroethane). All these pesticides belong to the group of organochlorines. When exposed to aldrin, the accumulation in *Cyprinus Carpio* was much greater as compared to *Puntius ticto.* But when these fishes were exposed to DDT, its accumulation was highest in *Puntius ticto* than in *Cyprinus Carpio.* In both these cases, the accumulation was greater in liver tissue

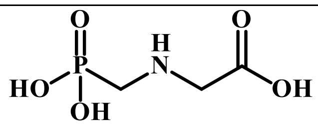
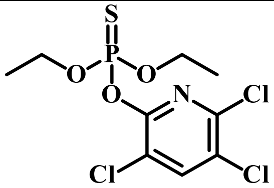
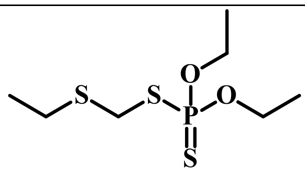
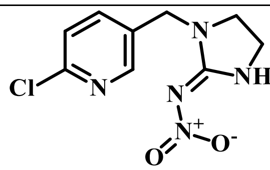
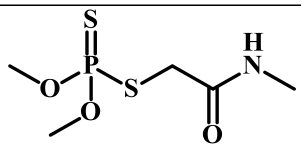
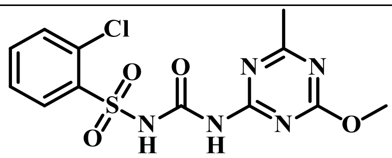
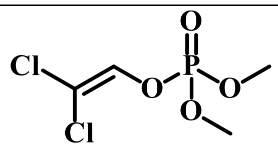
(Satyanarayan et al., 1999). The concentration of OCPs was found to be highest in *C.argus* and lowest in *C.caspio* (Zhang et al., 2014).
Mystus vittatus a teleost fish of freshwater belonging to the order Siluriformes and family Bagridae was exposed to Metasystox (an organophosphate) and Carbaryl (a carbamate) individually for 30 days with different concentrations (4ppm and 7ppm). After dissection, it was found that the bioaccumulation of Metasystox in the fish tissue was more in comparison to Carbaryl. The highest amount of pesticide residue was found in muscle tissue and the lowest residue in kidney tissues in both cases. The residues in other tissues like blood, gill and liver were found to be in between these two extremes that is muscle and kidney tissue (John et al., 2003).

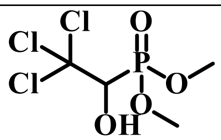
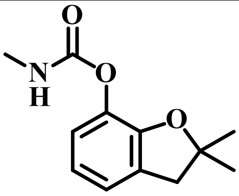
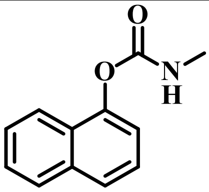
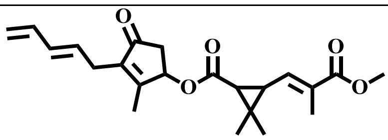
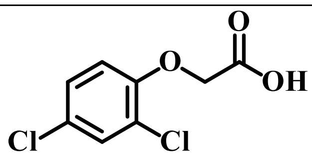
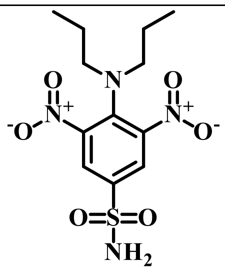
9. Degradation of pesticides

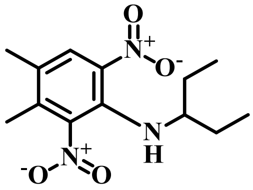
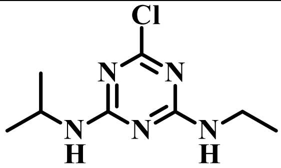
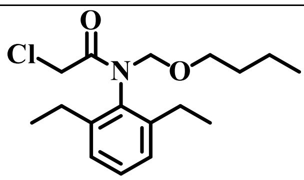
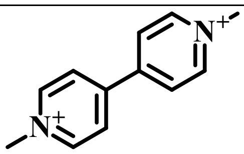
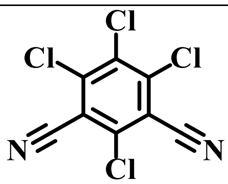
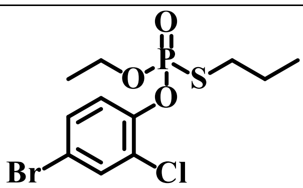
Pesticides can be degraded by various routes and the degradation of pesticides can be linked to their average half-life in different compartments. The average half-life of pesticides is depicted in table 1.

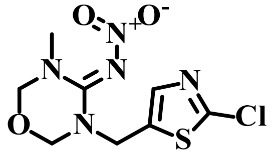
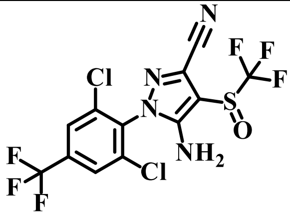
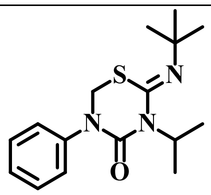
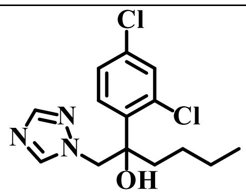
Table 1- Pesticides with their average half-life.

PESTICIDE	**STRUCTURE**	**GROUP**	**AVERAGE HALF-LIFE IN SOIL**	**REFERENC E**
Malathion		Organophosph ate insecticide	1 days	(Deer, 1999)
Diazinon		Organophosph ate insecticide	40 days	(Deer, 1999)
Parathion		Organophosph ate insecticide	<1 and 1.5 weeks	(Miles et al. (1979)

Glyphosate		Organophosphate herbicide	47 days	(Deer, 1999)
Chlorpyrifos		Organophosphate insecticide	30 days	(Deer, 1999)
Phorate		Organophosphate insecticide	60 days	(Deer, 1999)
Imidacloprid		Neonicotinoid insecticide	3 to 4 months to over 1 year	(Sarkar, M. A., et al. 2001)
Dimethoate		Organophosphate insecticide	7 days	(Deer, 1999)
Chlorsulfuron		Triazine herbicide	14 to 320 days	https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-118601_30-May-05.pdf
Dichlorovos		Organophosphate insecticide	1 week	Mirajkar and Pope, 2005

Trichlorfon		Organophosphate insecticide	<1-27 days	https://pubchem.ncbi.nlm.nih.gov/compound/Trichlorfon
Carbofuran		Carbamate insecticide	50 days	(Deer, 1999)
Carbaryl		Carbamate insecticide	10 days	(Deer, 1999)
Pyrethrin		Insecticide	12.9 hours	http://npic.orst.edu/factsheets/pyrethrins.html#:~:text=In%20the%20presence%20of%20sunlight,not%20readily%20spread%20within%20plants.
2,4,D		Phenoxy herbicide	10 days	(Deer, 1999)
Oryzalin		Dinitroaniline herbicide	20 days	(Deer, 1999)

Pendimethalin		Herbicide	42-101 days	(Zimdahl et al., 1984)
Atrazine		chlorotriazine herbicide.	60 days	(Deer, 1999)
Butachlor		Acetanilideherbicide	-	-
Paraquat		Bipyridyl herbicide	1000 days	(Deer, 1999)
Chlorothalonil		Benzonitriles fungicides	30 days	(Deer, 1999)
Profenofos		Organophosphate insecticide	-	-

Thiamethoxam		Neonicotinoid insecticide	46.3 to 301.0 days	(Gupta et al., 2008)
Fipronil		phenylpyrazole insecticide	122-128 days	*New Pesticide Fact Sheet - Fipronil*; EPA, 1996
Buprofezin		thiadiazine insecticide	16 days	(Oulkar et al., 2009)
Hexaconazole		triazole fungicide	18.1 days	(Liang et al., 2012)

9.1. Removal of pesticides using by photolysis method

Pesticides are degraded photolytically. This type of breakdown causes a chemical change by absorbing radiation. Pesticides produce hydroxyl, superoxide, and ozone radicals when light radiation is absorbed, and these radicals ultimately result in breakdown products. This usually happens when substances are subjected to radiation at or above 290 nm. (Vaya et al., 2020). An organophosphate insecticide named azinphos-methyl after photolytic degradation produces N-methyl anthranilic acid as the end product. (Yeasmin et al., 2009).Many technologies, such as photolysis, photo-Fenton, semiconductor-based photocatalysis, and photo electrocatalysis, are used to regulate the concentration of pesticides in nature. (Vaya et al., 2020). Among the various methods, photocatalytic treatment was found to be highly efficient, environmentally friendly, and a promising technique that has gained attention in recent years.

9.2. Removal of pesticides using microorganisms

Large-scale agricultural pesticide applications are frequently used in rural areas. Several microorganisms like *Flavobacterium, Rhodococcus, Alcaligenes,* *Trichoderma Gliocladium, Pseudomonas, and Penicillium* are found to use pesticides as their carbon source (Aislabie and Lloyd-jones, 1995). Microorganism-based pesticide biodegradation may be a practical and environmentally beneficial method of lowering environmental pollutants.

Under ideal circumstances, bacteria have been observed to exploit pesticides as a source of carbon, sulfur, and electron donor. Microbes, including bacteria, actinomycetes, and fungi, were discovered to help remove or detoxify chlorinated pesticides such as polychlorinated diphenyl, polycyclic aromatic hydrocarbons, and organophosphorus. The major bacterial genera are Bacillus, Pseudomonas, Flavobacterium, Moraxalla, Acinetobacter, Arthrobacter, Paracoccus, Aerobacter, Alkaligens, Burkholderia, and Sphingomonas (Parte et al., 2017)

Additionally, several fungi, including *Agrocybe semiorbicularis, Coriolus versicolor, Auricularia auricula, Dichomitus squalens, Hypholoma fasciculare, Flammulina velupites, Stereum hirsutum, Pleurotus ostreatus*, and *Avatha discolour*, can degrade different pesticide groups, including phenylurea, phenylamide, triazine, organochlorine and chlorinated pesticide (Bending et al. 2002).

A variety of microorganisms like *Bacilli, Pseudomonas*, and fungi can degrade malathion have been found from a wide range of natural environments (Kumar et al., 2019). Different groups of microbial species utilize malathion as the source of carbon. *Pseudomonas frederiksbergensis* degrades malathion 100% within 3 days of inoculation and uses it as a source of carbon (Abdel-Megeed and Al-Qurainy, 2009).

9.3. Removal of pesticides using nanotechnology

In the last decade, the applications of nanotechnology have emerged in present-day science specifically in the field of electronic devices, cosmetics, medicines, and many more (Mir et al., 2022). Along with these it also focuses on detection, degradation, and removal of pesticides (Figure-6). The chitosan-ZnO nanoparticles (CS-ZnONPs) composite beads show higher removal efficacy as compared to simple chitosan beads. The efficiency increased from 49% to 99% for 25 ml of permethrin solution (0.1mg/L). It can be an eco-friendly method for pesticide removal. (Dehaghi et al., 2014). It was observed that the adsorption capacity of CS–AgONPs (chitosan–AgO nanoparticles) beads were higher than chitosan beads. 0.5 g of CS– AgONPs nanocomposite beads removes 99% of permethrin in pH 7, shaking time 45 min and room temperature of 25 ml solution of pesticide (0.1 mg l-1) (Rahmanifar and Dehagh 2014). GO-MNPs (graphene oxide magnetic nanoparticles) were also found to be effective for removal of endrin and dieldrin from sample solution dependent on the pH, contact time, and dosage amount of NPs (Shrivas, Kamlesh, et al. 2017). Enzyme-loaded FeNPs (ENPs) and chitosan-coated FeNPs (CNPs) have been used for the degradation of Chlorpyrifos. It was found that CNPs degrade 68% whereas ENPs degrade more than 70% Chlorpyrifos (Das et al., 2017). To degrade profenofos Fe/Ni bimetallic nanoparticles was used as a catalyst (Mansouriieh et al., 2019). Pesticides like Parathion and methyl parathion in water samples were degraded by ZnO NPs as nano-photocatalyst. In optimum conditions it shows 93% of pesticide degradation (Sharma et al., 2016).

Adsorption is an effective method for water cleaning due to its low initial cost, flexibility, simplicity, ease of operation, and insensitivity to toxic pollutants. Nanostructures can be customized with different chemical groups to improve their effectiveness in removing desired target molecules. Graphitic carbons having one or multiple cylindrical tubules make up the new class of nanomaterials known as carbon nanotubes (CNTs). CNTs are distinct macromolecules with thermal stability, one-dimensional structure, and unique chemical characteristics. They are available as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs) These nanotubes have high potential to eliminate different kinds of pesticides. (Firozjaee et al., 2017; Ren et al., 2011, Firozjaee et al., 2018). Organic molecules may bind to CNTs by a variety of methods, including the covalent bonding, hydrophobic effect, hydrogen bonding, π-π interactions, and electrostatic interactions (Yang and Xing, 2010; Yu et al., 2014; Pyrzynska, 2011). Polycyclic aromatic hydrocarbons (PAHs), polar aromatic compounds, and other organic molecules containing C=C bonds or benzene rings can adsorb on CNT by π-π interaction. Adsorption can also occur when functional groups like COOH, OH, and NH2 form hydrogen bonds with organic molecules (Chen et al, 2007; Smith and Rodrigues, 2015; Yang et al., 2008). Two herbicides called dichlobenil and diuron were removed from contaminated water using MWCNTs was studied by Chen et al., 2011. Functional groups have the capacity to change the wettability of CNT surfaces, making them more hydrophilic and ideal for the sorption of molecules with low molecular weight and polarity (Cho et al., 2008).

Maliyekkal et al. 2012 investigated the pesticide adsorption by graphene. Graphene has excellent adsorption capabilities for pesticides (600–2000 mg/g) (Firozjaee et al., 2017). Through π– π interactions, graphene and other carbon-based nanomaterials can bind to pollutants containing aromatic rings. (Yang and Xing, 2010; Chen et al, 2007; Smith and Rodrigues, 2015; Bjork et al., 2010). For the removal of persistent organophosphorus pesticides from water, graphene-coated silica (GCS) was utilised as a highly effective sorbent. The process of OPP adsorption on GCS is based on the strong -bonding network of benzene rings and the electron-donating properties of P, S, and N atoms. (Liu et al., 2013).

Nanocrystalline metal oxides are extremely effective adsorbents for a broad range of pesticides. Under a wide variety of temperatures, nanocrystalline metal oxides not only adsorb but also remove many chemical dangers by transforming them into considerably safer by-products. (Fryxell and Cao, 2012). Magnetic core-shell nanoparticles with surface modifications have a high rate of pollutant removal and a high adsorption efficiency. (Kaur et al., 2014)

The CS-ZnONPs beads have a high adsorbent capacity and might be employed in the water treatment process to investigate new biocompatible and environmentally acceptable pesticide removal methods (Dehaghi et al., 2014).
Zero-valent iron (ZVI) has been used for contamination treatment on a large scale due to its accessibility, efficiency at degrading pollutants, and production of very little waste and secondary pollutants. (Joo and Cheng,2006: Thompson et al., 2010). It additionally employed successfully in dechlorination of extremely resistant herbicides and pesticides (Doong and Lai,2006;Sayles et al., 1997).
Metal nitrate precursors were used to create magnetically separable Fe-ZnO nanocomposites. The nanocomposites' structural, morphological, and optical characteristics were assessed using TEM, FE-SEM, XRD, FT-IR, UV-DRS, EDX, and VSM. FT-IR, Raman, and UV-Vis spectroscopy was used to test the photodegradation activity of a Fe-ZnO nanocomposite on the organophosphate insecticide chlorpyrifos at various doses. Using Fe-ZnO, up to 93.5% of degradation was seen in 60 minutes (Khan et al.,2018).
The presence of Al2O3 and MgO nanoparticles in activated carbon nanofibers increases the amount of destructively adsorbed Diazinon, and the reaction produces 2-isopropyl-6-methyl-4-pyrimidinol with less toxicity than Diazinon (Behnam et al., 2013).

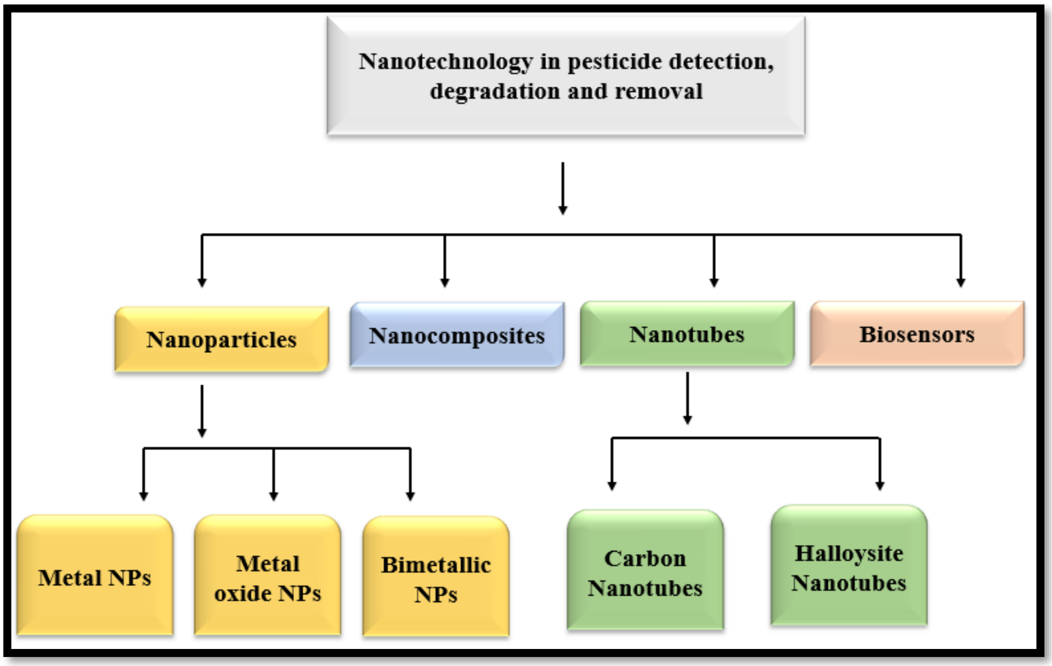


Figure 6. Nanotechnology based approaches for pesticide remediation (Rawtani et al., 2018)

10. Future perspective

The development of pest defence and pest resurgence by other means is necessary as the presence of pesticide residue in the air, water, and soil are the primary causes of human health risks and ecological imbalance. Implementing appropriate corrective actions helps to decrease instances of pesticide poisoning and other health problems related to pesticide use. Integrated pest management (IPM), Organic farming, Rational use of pesticides, Adsorption, Techniques for remediation of pesticides from environment, biological process, Advance oxidation processes etc. can be used to lower the amount of pesticide use (Rani et al., 2021). In order to have a minimal detrimental impact on the environment and people, pesticides should be created with the necessary accuracy and with a superior safety profile. Further in silico studies such as molecular dynamics simulations and in-vitro experiments could find out the highest stable molecules along with their inhibition efficacies.

11. Conclusion

Pesticides have several advantages like increasing crop yield and to control hazardous pests. But simultaneously they have deleterious effect in the environment as well as human beings. Direct or indirect exposure of pesticides can cause severe health effects like cancer, asthma, diabetes, reproductive disorders, neurological disorders etc. Damaging the quality of water and soil can lead to several hazardous effects to both aquatic as well as terrestrial animals. Now a day there is emerging need to reduce the use of pesticide and to encourage people about organic farming. People also should be aware about the safety measures during the application of pesticides.

Authors Contributions

AP contributes to conceptualisation, data curation, formal analysis and manuscript writing. SAM contributes to formal analysis, review, editing, manuscript preparation and supervision. AP contribution to structure preparation, review and formal analysis. IB contributes to manuscript preparation and formal analysis. BN contributes to editing, review and supervision. All authors read and accept the final version of manuscript for publication.

Conflict of Interest

All authors declare no conflict of interest.

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