Chapter

Pesticide Residues: Impacts on Fauna and the Environment

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Abstract

Pesticide residues are the traces of pesticide compounds that remain on or in the crop, water, soil and air after the application. Pesticide residues get into the environment as a result of application or by accident and can be found in the air, water and soil. Pesticide residues, if present in air, soil and water can pose a serious threat to biological diversity and human health. After depositing in the environment, the pesticides start to break down and forms metabolites that are more or less toxic. Pesticide residues decline as the pesticide breaks down over time, therefore the levels of residues are highest immediately after the application and diminish as the crops continue to grow. When exposed to sunlight or microorganisms in the soil, most pesticides degrade easily however, the utmost number of pesticides after application scatter into non-target areas or leach into groundwater or move in surface runoff by misuse and misapplication while handling or spraying. The impact of widespread usage of chemical pesticides has made an uncountable number of effects on human health, environment and other life forms and has turned into a serious issue across the globe. The present study aims to present an introduction to the environmental pesticide residues and various aspects highlighting their impact on nature and biodiversity.

Keywords: Pesticide, Residues, Environment, Contamination, Human Health

1. Introduction

To ensure food safety around the world, it is important to build up all necessary measures to boost crop production. A crop loss due to pests is the biggest challenge our agriculture sector faces today. A decrease in crop yield from pest damage is one of the significant errands to guarantee crop productivity. Pesticides assume an imperative job in boosting rural profitability. The advantages of pesticides involve increased crop yield, expanded benefits for agriculturists and the counteractive action to crop diseases. Pesticides help farmers to overcome work costs by diminishing the measure of time required to control weeds and pests from fields. Pesticides are the chemical compounds that are used to control various pests and disease-spreading vectors like mosquitoes, ticks and household pests such as rats and cockroaches. The majority of the pesticides are used in agriculture to control various types of insect pests as well as non-insect pests like ticks and mites, weeds and fungal infestations and other crop diseases. Pesticides assume a comparative job in control the pests and enhance the crop from notorious pests thereby boosting the economy of a country. However, with the rise in global population, the crops are being cultivated on a large scale resulted in unrestricted utilization of pesticides. Pesticides have been linked to various environmental contaminations like soil, water and air [1]. In addition to control insect pests, weeds, vectors and other household pests, there has been a great impact of pesticide use on beneficial insects like pollinators, birds, fishes, non-target plants and on human health as well [2]. While utilizing the pesticides, the residues can remain in the environment for a long period and can be dispersed over a long distance. While spraying these chemical pesticides, a series of reactions can undergo; plants can take up pesticides through leaves and roots, the atmosphere can take up pesticides as vapors carried off as drift, pesticides can get ingested by insects, worms and microorganisms [3]. Soil is one of the final destinations of pesticides after application. Depending on the physical–chemical characteristics of the pesticide and soil, the pesticides may be sorbed the particles or be leached and/or carried on the surface by the rains reaching subterranean waters and rivers [4]. Pesticide residues in soil and water can pose a threat to biological diversity and human health. After getting deposited in the environment, the pesticides start to break down and forms metabolites that are more or less toxic [5]. Abiotic and biotic transformations play an important role in removing the pesticide residues from the environment. Environmental degradation of pesticides involves biotic transformation processes facilitated by microorganisms or plants and by abiotic processes such as chemical and photochemical reactions [6]. When a pesticide is applied on the crops the pesticide residues remain in the environment even when a farmer follows all label instructions. Pesticides can cause both acute and chronic effects on human health and the farmers are the most susceptible to intoxication. The pesticides especially the insecticides which are designed to control the insect pests have caused an unaccountable damage among the non-target insect pests which include insect pollinators such as honey bees, bumblebees, syrphid flies and insect predators which check the insect pest populations in an ecosystem, therefore breaching the protocols of insect food chains and food webs [7]. The avian fauna including some of the top predatory birds has also threatened by the large-scale utilization of chemical pesticides including the DDT, which is banned in more than 40 countries, however, very persistent and its residues are found to this day [8]. Fish diversity and other aquatic creatures both animals and plants are also affected by pesticides. The entry of pesticides into water bodies is because of man-made or by natural activities, therefore, can pose a serious threat to aquatic life. Agriculture is the main source of food across the planet and to ensure crop productivity, pesticides are indispensable, however, contamination of the environment raises concerns. The impact of chemical pesticides including health ailments among farmers and environmental contaminations has been reported from all parts of the world from both developed nations to developing nations [9].

2. Pesticides residues

The term Pesticide includes all of the following; herbicide, insecticide, nematicides, acaracide, rodenticide, bactericide, fungicide, insect repellent, disinfectant and so on. The most commonly used pesticides are fungicides which account for 80% of all pesticides used. Most pesticides are intended to serve as plant protection products which in general protect plants from weeds, fungi or insects. Target pests can include insects, plant pathogens, weeds, mollusks, birds that destroy crops, cause nuisance or spread diseases. Although pesticides have benefits, most of the pesticides utilized in farm fields or in residential areas to control disease vectors have several drawbacks such as potential toxicity to humans and other organisms.

With the large-scale utilization, they still hold the potential to contaminate our ecosystems, pollute soil, water, air, impact wildlife, beneficial pollinators and human health. Pesticides have physical–chemical properties that will inflate their behavior in the environment. These are the properties of pesticides which after application can cause short-term or long-term effects on the environment and other organisms as well by either persisting at a long period or by drifting to places other than target sites [10].

a. Persistence: - How long the pesticide remains active in the environment.

b. Mobility: - How easily the pesticide can move from where it is applied.

c. Non-target toxicity: - How toxic is the pesticide to other organisms other than a pest.

d. Volume of use: - How much of that pesticide is used in the environment.

A number of properties of pesticides can affect their behavior in their environment and can cause multiple numbers of environmental contaminations which include Persistence, Degradation Bio-accumulation, Volatility, Adsorption and Absorption (**Figure 1**) [11]. Sooner or later, pesticides are broken down in the environment by a process called Degradation. Depending upon the nature of pesticide and environmental conditions of a particular area, the process of degradation can be rapid or deliberate. However, microorganisms present in the soil, chemical reactions and sunlight play a key role in the degradation of pesticides. On the other hand, Pesticide molecules can be a food source of microbes while taking the advantage of moist and warm soils; microbes can turn the pesticide molecules into carbon

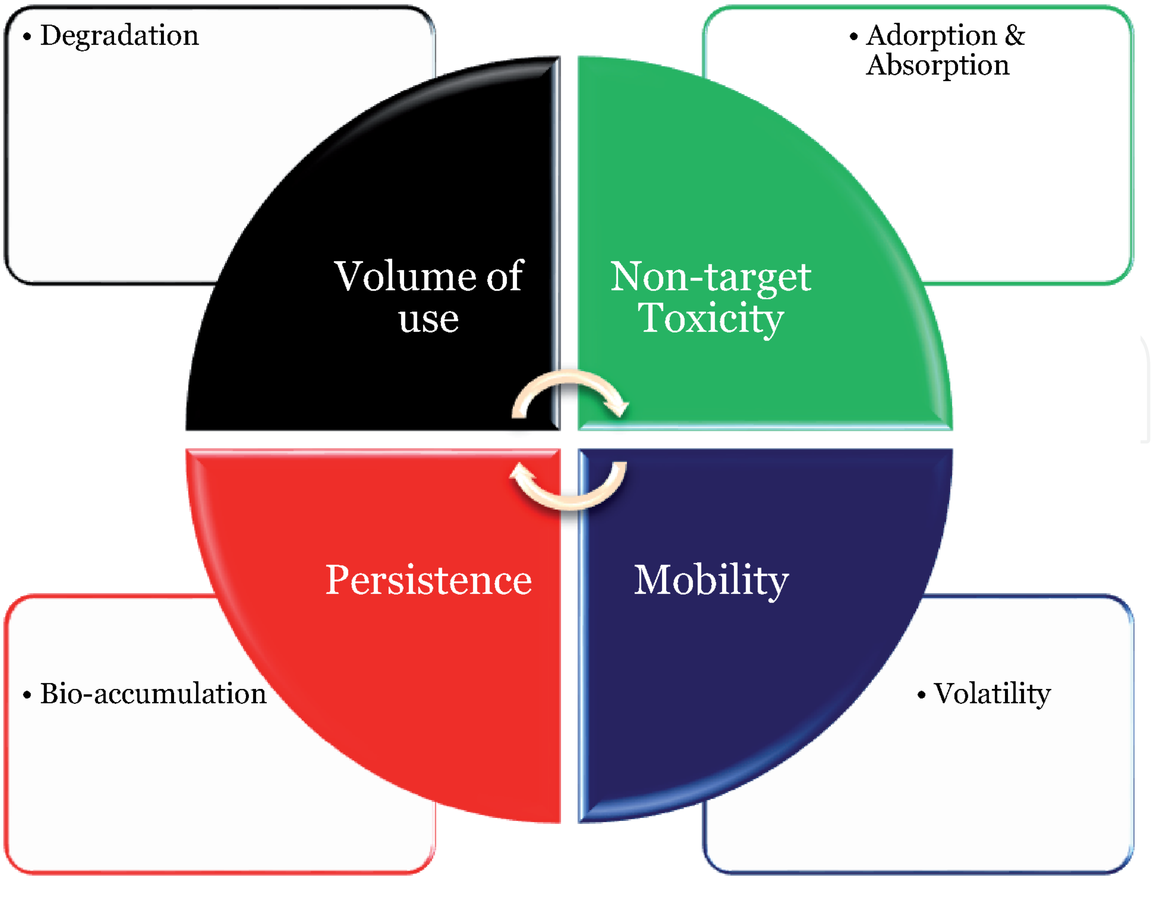

Figure 1.
Factors affecting pesticide and its degree of risk to the environment. (Designed in MS OFFICE POWERPOINT by Muzafar Riyaz).

dioxide and water. Some pesticides such as Chlordane and DDT do not break down quickly, this class of pesticides are called persistent pesticides [12]. Persistence can be greater in heavy clay or organic soil than in sandy soil. Some pesticides after intake through food, water or air may accumulate or build up in body tissues or body fat of humans and animals by a process called Bio-accumulation. These fat-soluble pesticides such as DDT are stores in the body's fat, and when the fatty tissues are used for energy, the compounds are released and cause acute poisoning [13]. If the organism cannot eliminate the pesticides from its body, there is a chance that more pesticide compounds will store in the fat cells, if the organism is exposed to the pesticides routinely. In the 1940s scientists found residues of the man-made chlorinated hydrocarbon pesticide, DDT in human fat which was an alarming issue back then, as many chlorinated hydrocarbon pesticides do not degrade readily and

Figure 2.
Drift can cause pesticides to travel away from the target site with vapors or dust particles while application. (Photo Muzafar Riyaz 2021).

because they accumulate in fat, they move from one organism to another upward in the food chain all the way to humans [14]. Small levels of these types of pesticides in water and soil can magnify into a significant hazard to predators at the top of the food chain. When exposed to air or evaporate, pesticides may change into a vapor by a process called volatility. Once a pesticide evaporates, it is carried for miles simultaneously with the dust particles in the air (**Figure 2**). Pesticides can bind onto soil particles and organic matter by a process called adsorption. In adsorption, A pesticide can bind to the surface of soil particle similarly to that of magnetic attraction. The most adsorptive soils are clay and soils which are having a high concentration of organic matter. Since these pesticides are bound tightly with the soils, there is a very low chance for pesticides to leach with water and therefore they cannot move downward through soil and will less likely to reach groundwater. Water or wind can be the cause of the erosion of pesticides tightly adsorbed to the soil and not be so readily degraded by soil microorganisms. Pesticides can be taken up by the flora and faunal species including insects by a process called absorption. The fate of the pesticides can be determined by a combination of properties and not by a single property. The crusade of pesticides in an environment is very complex as after the application the pesticides can move by some natural processes such as drift, surface runoff, leaching and soil erosion (**Figure 3**) [15].

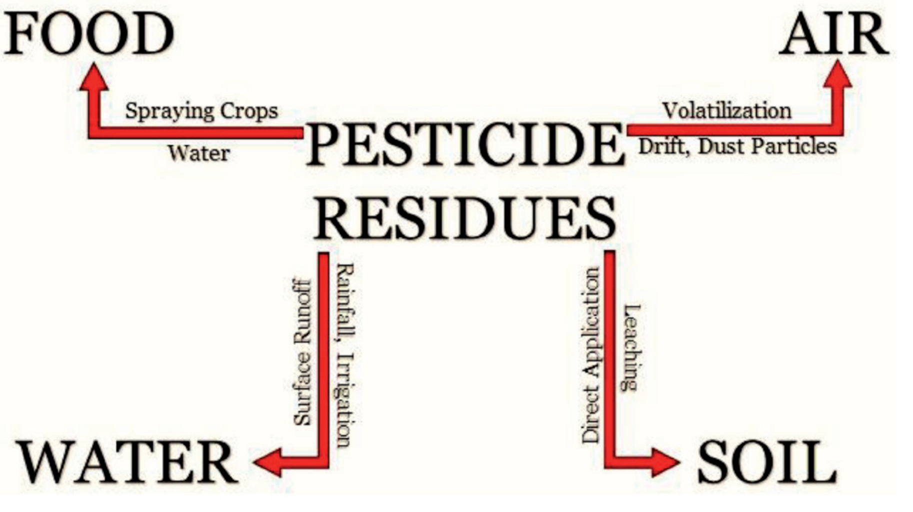

Figure 3.
Movement of pesticide residues in the environment. (Designed in MS OFFICE POWERPOINT by Muzafar Riyaz).

2.1 Air

For over 12 days, pesticides may thoroughly orbit the globe and particles will abide in the air for around seven days; at a height of 6 km, for 30 days; at a height of 30 km, for two years [16]. The purpose of pesticide application is to control a pest population. Ideally, pesticide application should impact only the target organism and have little or no impact on other organisms in the environment. However, many pesticide applications have the potential to affect non-target organisms and move beyond the application site. The potential for a pesticide to contaminate the environment depends in large part on the nature of the pesticide, its ability to break down in a given substrate, type of formulation, application rate, frequency of application and environmental conditions [17, 18]. A pesticide can change its nature from liquid form to a vapor by a process called Volatilization. Pesticides become airborne in many ways, including volatilization, drift or through movement as dust borne particles. Volatility increases with increase in temperature, wind speed and humidity. Applying pesticides in cooler temperatures (below 29°C), or above wind speeds of (10 m/hour) or when the humidity is less high, it's likely for pesticides to volatilize and move off the target sites. After application, volatilized pesticides such as Methyl-bromide drift off the application site and locomote into the atmosphere and taking advantage of air currents can relocate to longer distances as highly volatile compounds vaporize or evaporate at low temperatures [19]. On the other hand, volatility is a useful property in the application of pesticides which aids a pesticide to disperse across the farm field or application site or target area and therefore increase the exposure of pests to the pesticide however, it also can lead to exposure for non-target organisms. Environmental conditions such as air movement, relative humidity and temperature also influence volatilization. A number of pesticides, such as emulsifiable concentrate formulations and all of the fumigants, are classified as volatile organic compounds (VOCs) because they readily volatilize into the atmosphere. With the help of Sunlight, VOCs react with nitrogen oxides to produce ozone can which can contribute to smog and cause respiratory and plant injuries. Drift, on the other hand, refers to the airborne movement of pesticides away from the treatment site during application. Drift can damage plants away from the application site, reduce the effectiveness of a pesticide and cause environmental contamination such as water pollution. Drift is most serious when applications are made in windy conditions. Low relative humidity and high temperatures increase the potential for drift by causing spray droplets to evaporate faster [20]. Air temperature also contributes to pesticide drift by creating inversion layers near the soil surface; as a result of which warmer air layers trap cool air layers. At the time of pesticide application, fine spray droplets and pesticide vapors can be trapped by the inversion layers which can form a concentrated cloud with the ability to move from the treatment site. During pesticide application, droplet size also plays an important role in the movement of spray particles away from the application site. Small droplets fall through the air slowly and have a great potential to drift therefore while large droplets fall faster and are more likely to fall to the ground. Applications that release the pesticide as close to the target site as possible reduce drift. Spray pressure also affects drift by influencing the size of spray droplets; higher pressure decreases droplet size and increases drift. After application, fine particles of pesticides may drift off while splashing dust formulations and liquid droplets may stick to the soil particles and later be transported by the wind into the atmosphere [21].

2.2 Soil

Pesticide characteristics like water solubility, tendency to adsorb to the soil, pesticide persistence and soil characteristics like clay, sand and organic matter are important in determining the fate of the chemicals in the environment. Pesticides may be directly applied to the soil surface, incorporated into the top few inches of soil, or applied through chemigation (**Figure 4**). Once pesticides are present, the soil acts as a reservoir from which persistent pesticides can move into the bodies of invertebrates, be taken up by plants, pass into air or water or break down. After contact with the soil, pesticides are influenced by many factors, including adsorption rate, soil texture, organic matter content in the soil, microorganisms and the presence of water. The soil type influences pesticide persistence and leaching as the tendency for pesticides to be adsorbed vary with the proportion of clay and organic matter in the soil: the higher the percentage of clay and organic matter in the soil, the greater the number of adsorption sites as clay and inorganic matter increase the binding because they have more positive and negative charge sites. It also decreases the potential of a pesticide to move down through the soil, therefore the residues stay in the soil for longer periods of time without moving [22]. Pesticides tend to stay

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Figure 4.
Wet soil due to fresh pesticide application in a farm field. (Photo Muzafar Riyaz 2021).

longer in soils with high clay content and organic matter. The amount of water in the soil affects the persistence of pesticides, when more water is added there is a high chance of pesticide release from the soil particle as the water can and force it onto a solution. Usually, the half-life of the pesticide is a used parameter by which the persistence of a pesticide can be measured. A half-life of a pesticide is the period that takes 50% of the pesticide to break down in the environment; the longer the half-life, the greater the possibility for movement of a pesticide before it degrades [23]. On contrary, adsorption refers to the tendency of pesticides to become attached to soil particles. After their release into the environment, pesticides undergo a series of reactions that transform the original compound into various degradation products. Comparing the parent compound, the breakdown products of pesticides may be more toxic, less toxic or equally. Chemically induced transformations of pesticides occur through hydrolysis, photodegradation, microbial degradation and oxidation–reduction. The beneficial soil microorganisms and their associated biotransformation in the soils have been adversely affected by the pesticide residues. The pesticides have also resulted in inactivation of nitrogen-fixing and phosphorus-solubilizing microorganisms soils. A number of studies have shown that some pesticides disturb molecular interactions between plants and N-fixing rhizobacteria and consequently inhibit the vital process of biological nitrogen fixation. Pesticide residue can also reduce activities of soil enzymes that are key indicators of soil health [24–26].

2.3 Water

Water is the basis of life and only a tiny share of all the water on earth is fresh and renewed by the water cycle. Less than 1% of the water is left for drinking, agriculture, industry and nature. Another potential fate of the pesticide residues in the environment is moving into the water. The potential for movement is greater for pesticides that have a long persistence rate while other factors may include the tendency to adsorb to soil and high-water solubility. Lower adsorption can be a potential cause for pesticides to leach or move in the water. However, some pesticides that adsorb to soil particles, such as pyrethroid insecticides can be washed into surface water when soil and sediment erode. The water solubility of a pesticide affects the ease with which it leaches into soil or moves with surface runoff water [27]. Surface water and groundwater contamination can be closely connected and water-soluble pesticides by a problem in both. Surface water contamination occurs through a direct application (usually by accident) or through drift or runoff. Runoff is one of the most common ways that surface water can become contaminated. During pesticide application from a particular area, the movement of water and dissolved or suspended matter move into surface water or onto neighboring land. However, it's likely to occur when heavy rainfall or irrigation takes place after an application. Groundwater contamination can happen in several ways. Pesticides contaminate groundwater through direct entry and by leaching through the soil. Any opening in the soil will be the cause of direct entry of pesticides into groundwater, as it allows water (or contaminants) to detour the soil's natural filtration agents such as plant roots, burrows, abandoned wells etc. Spilling pesticides while mixing them near a well, pumping water into pesticide application equipment without using air gaps or backflow prevention devices and injecting pesticides into an irrigation system without a backflow prevention device can cause groundwater contamination [28]. Ground water has more possible chances to get contaminated than surface water by the pesticide residues as most surface waters (except deep lakes) have a rapid turnover rate, which means that fresh water dilutes the concentration of the contaminant quickly. On contrary, most surface waters contain free oxygen, which enhances the rate at which pesticides are broken down by microorganisms [29]. Another cause of the movement of pesticides is leaching, which makes a passage for a pesticide to move in water descending through the soil as a result of rainwater or irrigation water which percolates between the soil particles, carrying water-soluble pesticides with it. Nonpoint source pollution, as a result of normal applications on a farm field, orchard, or other wide areas over time, occurs when a small amount of pesticide enters groundwater from any location. Point source pollution, due to pesticide mishandling or from improperly constructed disposal sites or holding facilities, would include large quantities of contaminants entering groundwater at small defined locations. Pesticides that are more mobile in the soil and are resistant to degradation can easily settle down in the groundwater. Shallow water tables beneath treated areas are more susceptible to contamination because pesticides pass through less soil and therefore do not degrade much.

2.4 Food

Pesticides are considered important for protecting harvests and ensuring our food supply. All pesticides contain active substances which are essential ingredients that enable them to function. This can be a chemical or a microorganism such as a bacterium or a virus. In some cases, the chemical works by making the crop less palatable for pests. However, the pesticides work by simply killing or damaging the insect pests, weeds, fungi and so on. In some cases, small amounts called residues can find their way into food that humans eat [30]. These residues could be harmful if they exceed certain levels. There are many ways in which pesticide residues can get into our food [31]. Residues in treated crops can be carried from the field into the food by direct application of pesticides on crops till the time of harvest. Pesticide residues can get into the water supply or they can contaminate soil and animal feed, therefore, find their way into our food indirectly. The human food chain is also affected by the pesticide residues left in crops soil and water. Intake of pesticide residues in the body has been connected to birth imperfection, danger to the embryo, disease, hereditary deformities, neurotoxicity and endocrine disruption [32].

Pesticide residues can pose a risk to the heath of end consumers, if residue levels are too high. This is maintained by through Maximum residue levels (MRLs) which are the highest amounts of an individual pesticide that is permitted to be present. Pesticide residues are identified and quantified by comparing the sample extract to a calibration standard solution and analyzing them by liquid or gas chromatography coupled with mass spectroscopy. Once pesticides are demonstrated to be safe for the consumers, they have MRLs set for them which are determined based on rigorous evaluations. A maximum residue level is the maximum amount of residue that is legally permitted in food measured in milligrams of substance per kilogram of food based on good agricultural practices. MRLs are set far below levels that could possibly pose a risk to human health. Since MRLs are not safety limits but trading standards, these are not determined by the industry. However, MRLs are determined by independent government agencies which fully review each active substance present in pesticides. A number of reasons by which MRLs can surpass their limit of 3–5% which include; the incorrect way of pesticide application or exceptional climatic or crop conditions have occurred [33–35].

3. Impact of pesticide residues

The intemperate utilization of pesticides has made catastrophic concerns about the fatalistic consequences on human prosperity and a large number of pesticides are not degradable; they hold on in the soil, drain to ground and surface water and defile the more extensive environment [36]. Pesticide use around the world

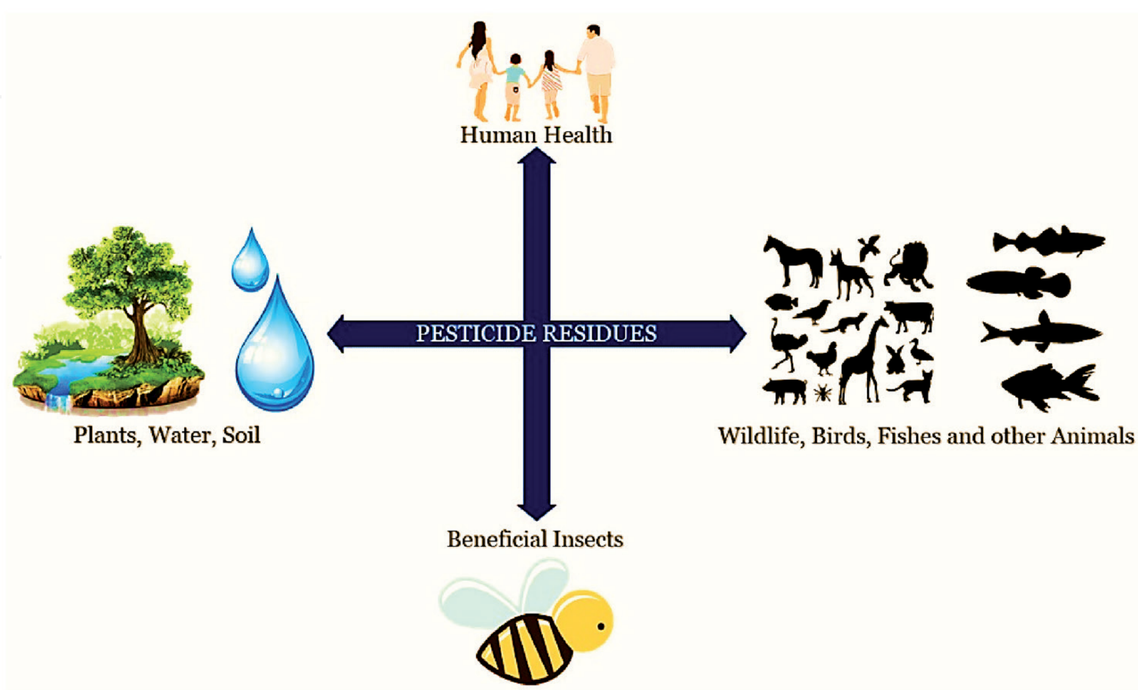

Figure 5.
Impact of pesticide residues on environment and different life forms. (Designed in MS OFFICE POWERPOINT by Muzafar Riyaz).

S. No	Name (Trade name)	Chemical Formula	Impacts on		References
			Human Health	**Other Animals**	
I	**Chlorinated Hydrocarbons**				
1	DDT	$C_{14}H_9Cl_5$	Cancer, Nervous system disorders, Respiratory damage, Reproductive organs, Immune system and endocrine disruptions, Birth defects	Central nervous system of Insects and other Animals, eggshell production in birds, Wildlife, Aquatic life including Fishes, sealions etc.	[52–55]
2	Methoxychlor	$C_6H_{15}Cl_3O_2$	Cancer, Central nervous depression, diarrhea, damage to liver, kidney, and heart	Physiological disruptions in animals, fishes and birds especially aquatic birds.	[56]
3	Chlorobenzilate	$C_{16}H_{14}Cl_2O_3$	Carcinogenic, Genotoxic, Eye damage	Toxic to Insects including honey bees, birds and fishes.	[57, 58]
4	BHC	$C_6H_6Cl_6$	Highly carcinogenic, dermatitis, psoriasis, burning, rashes,	Effects on domestic animals, wildlife and aquatic organisms.	[59, 60]
5	Toxaphene	$C_{10}H_{10}Cl_8$	Carcinogenic, Immune system failure, Reproductive organ damage, DNA damage,	Physiological disruptions in animals, adult reduction & egg shortening in birds, wildlife and fishes.	[61, 62]
6	Aldrin	$C_{12}H_8Cl_6$	Systemic, neurological, reproductive/developmental, immunological, genotoxic and tumorigenic.	Physiological disruption in Birds, toxic to aquatic animals, wildlife, domestic animals.	[63–65]
7	Dieldrin	$C_{12}H_8Cl_6O$	Carcinogenic, neurological, reproductive/developmental, immunological and genotoxic.	Carcinogenic, Highly toxic to birds, wildlife and other animals. Physiological disruptions in aquatic animals.	[66, 67]
8	Endosulfan	$C_9H_6Cl_6O_2\ S$	Cancer, Acute and chronic toxicity, respiratory failure, endocrine disruption, reproductive failure, DNA damage	Physiological, developmental, neurotoxic disruptions in birds, fishes, wildlife and other aquatic organisms.	[68–72]
II	**Organophosphates**				
9	Chlorfenvinphos	$C_{12}H_{14}O_4Cl_3P$	Developmental, reproductive, and immunologic effects	Physiological disruptions in animals, effects on the aquatic animals and birds.	[73, 74]
10	Methyl parathion	$C_8N_{10}NO_5PS$	Headaches, nausea, night-waking, diarrhea, difficulty breathing, mental confusion, nervous system, cardiovascular and reproductive system	Toxic to earthworms, fishes, insects, and other aquatic organisms. Physiological and metabolic disruptions in Fishes.	[75–77]
11	Diazinon	$C_{12}H_{21}N_2O_3PS$	Cancer, Reproductive system, Acute and chronic toxicity, respiratory failure, endocrine disruption	Highly toxic to birds and bees and other insects, birds and fishes.	[78–81]

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S. No	Name (Trade name)	Chemical Formula	Impacts on		References
			Human Health	**Other Animals**	
12	Ethion	$C_9H_{22}O_4P_2S_4$	Clinical toxicity, abdominal pain, diarrhea, vomiting, respiratory problems and undue secretions	Toxic to fishes, birds, aquatic organism, wildlife and domestic animals.	[82–84]
13	Malathion	$C_{10}H_{19}O_6PS_2$	Liver, kidney, testis, ovaries, lung, pancreas, blood, genotoxic and carcinogenic	Toxic to fishes, birds, aquatic creatures, domestic pets, and other animals.	[85–87]
III	**Carbamates**				
15	Carbaryl	$C_{12}H_{11}NO_2$	Neurological, Reproductive, Immunological disorders, possible carcinogen.	Moderate to high effect on birds, fishes and other animals.	[88, 89]
16	Aminocarb	$C_{11}H_{16}O_2N_2$	Cholinesterase inhibition, effects on the nervous system, sometimes death.	Toxic to birds, mammals and other animals including fishes and wildlife	[90, 91]
17	Carbofuran	$C_7H_{15}NO_3$	Body weakness, abdominal pain, blurred vision, nausea, sweating, muscle shuddering, coordination dysfunctions, respiratory and nervous system disorders.	Highly toxic to birds, Toxic to aquatic animals including fishes, other animals and non-target terrestrial creatures.	[92–94]
18	Aldicarb	$C_7H_{14}N_2O_2$ S	Headache, nausea, sweating, diarrhea, coordination system disruptions and sometimes death.	Toxic to aquatic organisms including fishes, toxic to birds and other organisms.	[95–97]
IV	**Pyrethroids**				
19	Cypermethrin	$C_{22}H_{19}Cl_2NO_3$	Neurotoxic, Hepatoxic, effects on behavior, molecular level and reproductive system.	Toxic to birds, aquatic organism including fishes and other creatures.	[98–100]
20	Deltamethrin	$C_{22}H_{19}Br_2NO_3$	Paranesthesia, Unwanted sensations, burning and partial numbness, "pins and needles", skin problems.	Toxic to domestic animals, aquatic organisms and terrestrial animals and plants.	[101–103]

Table 1.
Impact of some commonly used synthetic pesticides on human health and other animals.

has brought about various instances of acute and chronic poisoning, with impacts of proliferating peril on human wellbeing, from delicate effects to death [37]. Exposure to pesticides normally occurs while preparing the spray solutions and while showering the pesticides on crops. Proceeded with an introduction to sub-deadly amounts of pesticides for a protracted timeframe, may result in unending health-related issues among people [38]. Comparative health impacts are reliant upon the nature of the substance, the quantity received, course of the entrance, for example, intake by breath, ingestion or skin assimilation and individual perceptivity. Due to pesticides, there are possible incidences of several chronic diseases and disorders, such as cancer, diabetes, respiratory failures and fertility issues examined by several studies [39]. Different investigations have uncovered a connection between pesticide use and sarcomas, numerous myelomas, malignant growth of the prostate, pancreas, lungs, ovaries, the breast, gonads, liver, kidneys, alimentary tracts and brain [40–42]. As indicated by a 2017 European Food Safety Authority report, 44% of food samples conventionally produced contained one or more significant residues [43]. Pesticides have been linked to a wide range of human health hazards ranging from short-term impacts such as headache and nausea to chronic impacts like cancer, reproductive harm and endocrine disruption [44]. Chronic health effects may occur years after even minimal exposure to pesticides in the environment or result from the pesticide residues which gets transported to humans through the food and water. Pesticides have been linked to many types of cancers among humans. Some of the most prevalent forms include leukemia, non-Hodgkin's lymphoma, brain, bone and breast, ovarian, prostate, testicular and liver cancers [45]. Mounting evidence suggests that exposure to pesticides disrupts the endocrine system [46]. As the highest number of pesticides are synthetic chemicals, they can elicit a physiological reaction after getting an entry into a plant or animal body, which means if the pesticide can kill a creature; humans, domestic animals, pets, beneficial insect diversity such as pollinators and predators [47], birds, aquatic animals and plants, wildlife [48], non-target plants and our surrounding environment will also get affected by these chemical pesticides (**Figure 5**). Apart from all these consequences, pesticides can contaminate air, water and soil which in turn can be a cause of ailing human health across the globe [49–51]. The impact of various classes of pesticides on human beings and other animals have been listed in (**Table 1**).

4. Discussion and conclusion: strategies and alternatives

Pesticide movement can be reduced in these natural processes by developing strategic farming practices. To reduce pesticide drift, farmers can be provided with such spray nozzles that produce larger spray droplets or lowering the boom of a sprayer. Surface runoff of pesticides can be reduced by no-till or minimum tillage practices which can also reduce pesticide movement via soil erosion. Leaching is the movement of water down through the soil, potentially to tile lines and surface waters or groundwater. Adsorptive pesticides are less likely to leach because they stick to organic matter. Increasing the amount of organic matter in the soils, manures and crop residues can be a better alternative to farmers. Pesticides can also be prevented to enter the environment by handling pesticides with care. Farmers should be encouraged to store the pesticides properly so they do not contaminate organisms or the environment and when the pesticide application is done, one can dispose of the empty containers to pesticide container collection sites. An Integrated Pest Management (IPM) can help in control pests without pesticides. However, if the pesticide is being used, reading of pesticide label and checking environmental precautions should be made mandatory for farmers. The benefits of pesticide invention and application have saved our world from hunger and have caused direct adverse threats to nature as well. Considering the rich biodiversity of our planet it is impossible to assess the effect of pesticides on every organism and to conclude that any pesticide is completely safe. From the results of the recent studies, it is evident that we are yet to learn the unknown effects of pesticides on life forms and the physical world. The result of pesticide use for many decades has taught humans to search for a solution to the drastic impact it has created on nature. The remedy to the unintentional persistence of toxicity of pesticides in the environment came from nature itself with pesticide degrading microbes and also by the observation of abiotic degradation in the environment. The unexplored aspects of pesticide toxicity and their biotic and abiotic degradation in qualitative and quantitative aspects in air, water, soil and living beings need to be addressed. The identification of pesticide degrading microbes and intentional application of these organisms through bioremediation and comprehensive research using innovative technologies will create a revolution for a safer tomorrow. The present study aims to encourage people to the importance of alternative methods to solve the problem of the present and future generations. As proved by many, the remedy to the problem is the usage of alternative methods like biological control and biopesticides. The agents of biological control, as well as compounds for biopesticides, are to be comprehensively explored and utilized. The awareness of the people especially the farmers is the first step towards this movement. The easy and cheap access to biological pesticides and biological control measures are to be studied and made available to the public through government and non-governmental organizations. The present study thus finds an important place in the process of conservation and protection of nature and natural resources and of human health towards a bright future.

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Conflict of interest

The authors declare no conflict of interest.

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