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Environmental Impacts of Pesticides - A Review

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Abstract: Pesticides are applied in various sectors such as agriculture, domestic, material building, personal and public health for control of weeds, pests, rodents; household and garden spray, control of animals and birds; incorporation of paints, glues, plastic protection sheeting; for application of clothing and skincare; and for control of malaria, dengue fever and cholera. In agriculture, chemicals are purposefully discharged into the environment. Application of pesticides in agriculture is a subcategory of the largest group of manufactured compounds used in the present world. Excessive and inappropriate use of pesticides has resulted in contamination of environment. Pesticides are degraded into organic micro pollutants that have negative effects on the environment. By the mechanism of biomagnification and bioconcentration, they cause deleterious effects on the living organisms. Ecological impacts of pesticides are different but they are chronic and inter-related. During precipitation, pesticides from land, float to aquatic systems and become harmful to fishes, birds, non-target creatures, etc. They also interact with injurious algal blooms, which enhances the original poisonous nature of the pesticides. This review focuses on environmental impacts of pesticides on contamination of water, fate, effects and behaviour in the environment, effects of contamination on natural resources, food safety, non-target organisms and threats to biodiversity. This study recommends application of suitable amounts of less harmful formulation of pesticides, as and when required.

Keywords: Bioconcentration, Biomagnification, Environment, Pesticides, Toxicity, Contamination

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Introduction

Ghosh *et al*. (2015) documented that pesticides are wonderful creation of science which has become an integral part of modern intensive agriculture. Their role as saviours of mammalian food, feed and fiber has remained unchallenged, even though, they cause adverse impact like induction of pest resistance, pest resurgence, deleterious effects on the non-target flora and fauna, health hazard to human and environment.

Pesticides are widely used throughout the developing world, and their demand is increasing due to the priorities to high agricultural yields. Made up of chemicals that can control pests or regulate plant growth, pesticides have provided developing countries with one way to increase those yields. Many farmers in developing countries view pesticide use as the best means to protect their crops against pests and pesticides

can provide the only form of crop insurance available (EP, 2021).

Pesticides are widely used in agriculture and have considerable benefits by contributing to a sustainable production of food and feed. If used improperly or in an inappropriate manner, they also can present unacceptable risks to human and animal health and to the environment. Sustainable use of pesticides contributes to further risk reduction. Therefore, it is necessary to set high standards for the registration of new pesticides and re-evaluation of pesticides that are already on the market to ensure that they meet current health, environment and safety standards (OECD, 2022).

After application of the pesticides to a target plant, they enter the environment and can undergo transfer (or movement) and degradation. During pesticide degradation, new chemicals are produced, which are relocated from the target site to environment or non-target plants by transfer processes (adsorption, leaching, volatilization, spray drift, and runoff) (Tudi *et al*., 2021).

Overuse, misuse and abuse of agrochemicals causes health hazards to humans and long lasting adverse effects to the environment. As a result, the cost of pesticides imposed damage has to be borne by the society as a whole (Zhang, 2011; Padmajani *et al*., 2014). Indiscriminate application of pesticides in the agriculture and healthcare practices have contaminated the environment and has become a serious ecological and public health hazard. Properties of pesticides such as persistent nature, multifaceted toxicity, recalcitrance, long-range environment transport potential, bioaccumulation, and biomagnification are responsible for pesticide pollution in agricultural and non-agricultural settings (Assad *et al*., 2021).

Kumar *et al.* (2013) reported that pesticides are the chemicals, purposely applied to the environment to suppress the pests and to protect agricultural products. Negative impacts caused by pesticides on the environment include contamination of soil, water, turf and other vegetation; toxic to a host of other organisms (birds, fish and beneficial insects); affect non-target plants and animals; loss of biodiversity; leach to groundwater, surface water and contaminate the environment and bio-accumulate in food chains and influence the environment. The repeated use of persistent and non-biodegradable pesticides has polluted various components of water, air and soil ecosystem. Pesticides have also entered into the food chain and have bioaccumulated in the higher tropic level (Gill and Garg, 2014).

Tudi *et al.* (2021) described that pesticide contamination moves away from the target plants and results in environmental pollution. The chemical residues impact human health through environmental and food contamination. Extensive application and subsequent disposal of pesticides by farmers, institutions and the general public offer numerous possible sources of pesticides in the environment. Even when it is applied in a very small area, it spreads in the air, is absorbed in the soil or dissolves in the water and eventually reaches a much bigger area (Yadav and Devi, 2017).

According to Poudel *et al.* (2020), out of 2.5 million tons of pesticides applied to the crops, less than 0.1% acts on their target pests and remaining 99.9% are poured into the environment where they are bound to adversely affect public health and beneficial biota and contaminate soil, water and the ecosystem.

Review of literature suggests that though sufficient data is generated on impact of pesticides on the environment, there are still gaps in knowledge and information that need to be addressed (UNEP, 2022). To overcome the knowledge gaps and further research on innovative ideas on eco-friendly pesticides with minimum adverse effects on the environment, present study was undertaken.

Environmental Impacts of Pesticides:

Contamination of Surface and Ground water:

Pesticides enter the water by flowing (rundown) or filtering (leaching). Application of pesticides may lead to contamination of water by spray drift, runoff, and leaching and is harmful to terrestrial and aquatic ecosystems (Bansal and Gupta, 2000; Hassaan and Nemr, 2020). Pollution of groundwater by pesticides is more important because pesticides cannot be eliminated from groundwater and their concentration cannot be reduced as easily (Sjerps *et al*., 2019).

Gyawali (2018) reported that contamination of water resources by pesticides occur due to surface runoff and by bioconcentration and biomagnification.

- *Bioconcentration*: Movement of pesticide from the surrounding medium into an organism, especially into primary "sink", as fatty tissue (lipids). e.g. DDT.
- *Biomagnification*: Increasing concentration of pesticide as food energy is transformed within the food chain. Concentration of pesticides are increasingly magnified in tissue and other organs of top predators, including man.

Fate and effects of pesticides in aquatic ecosystems(*FAO, 1990; Hassaan and Nemr, 2020*):

Pesticides are involved in a wide range of organic micro pollutants that have negative environmental effects (Table 1). Excessive pesticides applied to agricultural land may lead to:

- Contamination of aquatic environment by spray drift, runoff, and leaching.
- Harmful to terrestrial and aquatic ecosystems.
- Affect fishes in a direct way, particularly small fishes are affected more.
- Indirect toxic effects on fishes: Decrease of food sources (algae and plankton), change in food habits, habitat and deterioration of the water quality.
- Reduction in abundance of primary producers by herbicides, thereby reducing the primary and secondary consumers.
- The primary consumers such as zooplankton are severely affected by some organochlorine pesticides.
- Insecticides may also adversely affect the micro-crustaceans.

Influence on Pesticide Behaviour in the Environment (*Poudel et al., 2020*):

According to Tudi *et al*. (2021), pesticide behaviour in the environment includes processes like transformation, degradation, movement, volatilization, runoff, and leaching processes, while pesticide degradation encompasses photolysis and chemical and microbial breakdown.

Many processes affect what happens to pesticides in the environment. These processes include adsorption, transfer, breakdown and degradation. Transfer includes processes that move the pesticide away from the target site. These include volatilization, spray drift, runoff, leaching, absorption and crop removal (British Columbia, 2017).

❖ *Volatilization*:

Increasing temperatures, higher soil moisture, and direct exposure to sunlight cause rapid volatilization of pesticides and is the main source of pesticide pollution in the atmosphere. After rainfall, there is a rapid volatilization with humid soil.

- *Runoff and Drift*:

Runoff and drift cause pesticide pollution in water. The parcel's slope, soil type, texture, and structure combined with crop growth, row directionality, and climatic factors are the main aspects that strongly affect the runoff rate. Increased precipitation and higher temperatures exacerbate runoff contaminated with pesticides.

- *Leaching*:

Transfer of pesticides to a depth via leaching and to surface water via drainage was influenced by interactions between climate and soil–pesticide combinations, enhancing

Table 1: Ecological effects of pesticides in the water (Source: FAO, 1990; Hassaan and Nemr, 2020)

Property	Ecological effects of pesticides
Toxicity	LD_{50} (Lethal Dose: Concentration of pesticide that will kill half of the tested organisms through a definite experiment time). The lower the LD_{50}, the greater the toxicity; (values of 0–10 are extremely toxic)
	Toxic response: Acute (death) or Chronic (doesn't lead to death but may causes tumors and cancers, teratogenic effects, growth inhibition, reproductive failure, etc.).
	Food guidelines and drinking water are measured by risk assessment. Risk = Exposure (amount and/or duration) X Toxicity.
Persistence	Determined as half-life (time necessary for the concentration to reduce by 50%). Persistence is measured by abiotic and biotic degradation processes. Photolysis, hydrolysis and oxidation are the non-biological processes, and the biological decomposition and metabolism are the biological processes. Current pesticides have short half-life times that reveal the time over which the pest needs to be regulated.
Degradation	Pesticide decomposition may produce degradation products that may have less, equivalent, or greater toxicity than the original pesticide. e.g. Breakdown of DDT (Dichlorodiphenyl trichloroethane) to DDD and DDE.
Environmental Fate	The environmental fate of a pesticide is influenced by the natural affinity of the chemical for biota, liquid (solubility in surface and soil water), solid state (particulate organic carbon and mineral matter) and gaseous form (volatilization). These factors of pesticides are used in the prediction of environmental fate of every pesticide.

the effect of precipitation volumes of variable duration, rainfall seasonality, intensity, and timing in relation with pesticide application. Temperature affects soil mineralogy and geochemistry and is consequently the main cause for leaching.

- *Degradation*:

  Degradation of pesticides occurs by photochemical, chemical and biological processes (microbiological reactions and pesticide metabolism). Global warming accelerates the degradation of chemical components due to accelerated microbial and chemical reaction rates and may reduce concentrations of pesticides in the environment. Also, increased soil moisture content and precipitation enhance pesticide degradation and persistence.

- *Degradation of pesticides in water*:

  Pesticides in water can degrade through UV photolysis, microbial degradation, hydrolysis or chemical oxidation. Concentration of pesticides from wastewater and drinking water can be reduced by treatments before human consumption or being discharged into the environment.

- *Metabolism of pesticides in animals*:

  Pesticide is converted to a less toxic form and excreted or retained in the organism. Enzymes from the liver play an important role in metabolism of pesticide.

- *Mineralization of pesticides in soil*:

- Mineralization results in conversion of pesticides into NH_3, H_2O, and CO_2 by photolysis and hydrolysis. It involves microbial metabolism and demolition. Soil micro-organisms consume pesticides as a source of

carbon or other nutrients. Mineralization of 2,4-dichloro-phenoxyacetic acid occur quickly in the soil, while 2,4,5-trichlorophenoxyacetic degrades very slowly whereas some compounds are very persistent and do not degrade gradually.

- *Persist for a long time period in the environment*:

  Pesticides contain 'persistent organic pollutants' (POPs), which are toxic organic compounds that resist degradation, persist for a long time period in the environment, migrate to long distances with high stability and mount up to levels harmful to the environmental and public health (Kumar and Kumar, 2019).

Adverse Effects of Pesticide Contamination on Natural Environment:

Population growth and climate change contribute mainly to the increasing use of pesticides. Increasing use of pesticides brings a number of negative effects to the environment and human health (Rajendran, 2003; Helfrich *et al*., 2009; Poudel *et al*., 2020). Pesticides are used to kill pests and control weeds, can also be toxic to other organisms, including birds, fish, beneficial insects, and non-target plants as well as environmental media like air, water, soil, and crops. The chemical residues of pesticides impact human health through the environment and food contamination. Pesticides move to the air, through wind currents, to water, through runoff or leaching, and to plants, animals, and humans (Tudi *et al*., 2021). The effects of pesticides on environmental system may range from minor deviation on the normal functioning of the ecosystem to the loss of species diversity (Yadav and Devi, 2017).

- *Impact on Water* (*Osten and Dzul-Caamal, 2017; Anderson et al., 2018*):

- *Entry of pesticides in the surface and groundwater*: By percolation and runoff from agricultural production fields, drift from agro-allied industrial wastewater, discharge from wastewater from clean-up equipment used for pesticide formulation and application atmospheric deposition, and air/water exchange (Pimentel, 1995).

The occurrence of pesticides in the water body is derived by the runoff from the agricultural field and industrial wastewater. Soluble pesticides were carried away by water molecules during precipitation by percolating downward into the soil layers and eventually reach surface waters and groundwater. It degrades water quality and reduces the supply of clean water for potable water (Syafrudin *et al*., 2021).

- *Pollution of groundwater*: By leaching of pesticides from the treated fields, mixing and washing sites, or waste disposal areas.
- *Accumulation of pesticides in surface water systems*: Rivers, lakes, streams, reservoirs, and estuaries get accumulated with pesticides and other chemicals.
- *Transfer of pesticides to groundwater*: From surface water, pesticides can be transferred to groundwater through seepage of the soil.
- *Transfer of pesticides to atmosphere*: Pesticides enter the atmosphere through evaporation and transpiration.
- *Pesticide contamination in water*: Impacts q drinking water quality in local areas and also transfer it to the next species (soil and food chain).
- *Human health impact*: Occurrence of pesticides in the water poses a deleterious effect on human health, where the effect magnitude depends on the solubility, half-life, adsorption capacity, biodegradability of the pesticide compounds (Syafrudin *et al*., 2021).
- *Impact on Soil* (*Gill and Garg, 2014; Wu et al., 2017; Gyawali, 2018*):
- Normal function of the soil is to filter, degrade, and detoxify pesticides.
- *Retention of pesticides in soil*: Retention refers to the ability of the soil to hold a pesticide in place and not allow it to be transported (USDA,

1998) Degradation of pesticides leads to formation of minute residues that are retained in the structures of the soil by adsorption, posing a threat to the environment.

- *Re-emit old organic pollutants*: As soil is the principal reservoir of environmental pesticides, it re-emit old organic pollutants into the atmosphere, groundwater, and living organisms as a secondary source.
- *Adverse impacts on quality of food and agricultural sustainability*: Because of principal reservoir of environmental pesticides, soil play an important role in the global distribution and fate of contamination of pesticides.
- *Alter microbial diversity and microbial biomass*: Disturbance in soil ecosystem and loss of soil fertility affect root-colonizing microbes in soil by influencing their growth, colonization and metabolic activities etc. Disturbed growth, microbial diversity or microbial biomass of the soil microflora inhibit or kill beneficial group of microorganisms. Increase in disturbances in the soil ecosystem alter/reduce the functional structure and diversity of microorganisms, but increase the microbial biomass.
- *Affect vital biochemical reactions of the soil*: Nitrogen fixation, nitrification, and ammonification were affected by activating/deactivating specific soil microorganisms and/or enzymes.
- *Mineralization of soil organic matter*: Key soil property which determines the soil quality and productivity. Application of herbicides (atrazine, primeextra, paraquat, and glyphosate) causes significant reduction in soil organic matter.
- *Alter the soil enzymatic activity*: Enzymatic pool of soil with free enzymes, immobilized extracellular enzymes and enzymes excreted by microorganisms are altered due to the action of pesticides. These enzymes act as indicator of biological equilibrium including soil fertility and quality.
- *Bio-accumulation of persistent pesticides*: Persistent and bio-accumulative pesticides such as organochlorine compounds (Aaldrin, Dieldrin, DDT, Hexacyclohexanes (HCH), Heptachlor, Chlordane, Endosulfan, Lindane) are strongly bound to soil particles due to their persistency and undergo bioaccumulation.
- *Threat to water and the food chain*: Soil contaminated by pesticides poses a widespread threat to water and the food chain.
- *Impact on Air* (*Gill and Garg, 2014; Gyawali, 2018; Yera et al., 2020*):
- *Hazardous impacts on flora, fauna and human health*: Pesticides applied as spray drift in the air for agricultural activities and the residues of pesticides in the air or by volatilization from the soil or plants cause adverse effects (Kim *et al*., 2017).
- *Air pollution*: All methods of spraying pesticides (subsurface application, surface application, aerial spraying, hand spraying) cause air pollution as well as to expose the general public to pesticides.
- *Negative impact on non-targeted fauna and flora*: Drift occurs during every application, and causes loss of 2 to 25% of the chemical being applied, which can spread over a distance of few yards to several miles. About 80–90% of an applied pesticide can be volatilized within a few days of application. This contamination will cause negative effect to non-targeted fauna and flora and disturb the ecosystem (Sanchez-Bayo, 2011).
- *Impact on Food Safety* (*Aktar et al., 2009; Fosu et al., 2017*):
- *Food contamination by pesticides*: Spraying pesticides for non-target plants and behaviour of pesticides in the environment (volatilization from the treated area to the air, soil, and non-

target plants) and transmission of residual pesticides from soil and water to crops, vegetables, and fruits results in occurrence of pesticides in food.

- *Negative health and environmental impacts*: The environmental behaviour of pesticides and their residues lead to food contamination and damage to plants.
- *Impact on Non-Target Organisms* (*Gyawali, 2018; Wanwimolruk et al., 2016*):
- *Negative influence on Non-Target Organisms*: Damage to wildlife, birds, aquatic ecosystems, honeybees, beneficial insects and natural enemies of insect pests.
- *Destruction of Natural enemies*: Pesticides are harmful to non-target organisms through direct contact and through pesticide residuals. Non-target organisms are disturbed when pesticides are applied to the target plants. Natural enemies regulate the pest population levels. Additional insecticide sprays are required to control the target pest. Natural enemies keep minor pests under check.
- *Disturbance to Soil invertebrates* (*arthropods*): Pesticide cause negative impact on soil invertebrates and several links in the food web. Soil animals such as Nematodes, Springtails, Mites, Micro-arthropods, Earthworms, Spiders, Insects etc. make up the soil food web and decompose organic compounds (leaves, manure, plant residues etc.). They are essential for the maintenance of soil structure, transformation and mineralization of organic matter.

Threats to Biodiversity (*Helfrich et al., 2009; Mahmood et al., 2016*):

Adverse impacts of fertilizers are mainly caused by their excessive and inefficient use resulting in nutrient losses to the environment, drinking water contamination and eutrophication of freshwater systems and coastal zones (Kopittke *et al*., 2019; UNEP, 2022). Accumulation of pesticides in the food chains directly affects the predators and raptors. Also, pesticides can reduce the quantity of weeds, shrubs and insects on which higher orders feed. Spraying of pesticides results in declines in the population of rare species of animals and birds. Long term and frequent usage of pesticides lead to bioaccumulation (Mahmood *et al*., 2016).

❖ *Threats to Aquatic Biodiversity* (*Helfrich et al., 2009, Scholz et al., 2012*):

- Pesticides enter the water via drift, runoff, leaching through the soil or applied directly into surface water for control of mosquitoes.
- Pesticide-contaminated water poses a great threat to aquatic form of life.
- It affect aquatic plants, decrease dissolved oxygen and cause physiological and behavioural changes in fish populations.
- Pesticides applied to land drift are toxic to fishes and non-target organisms.
- Pesticides interact with stressors such as harmful algal blooms.
- Overuse of pesticides causes decline in fish populations.
- Lack of oxygen to the fishes, decreases fish production.
- Aquatic animals are exposed to pesticides in three ways:

✓ Dermally - Direct absorption via skin

✓ Breathing - Uptake via gills during breathing

✓ Orally - Entry via drinking contaminated water

- Floating of pesticides into the lakes and streams influences the immune system of few amphibians and some fish species.
- Loss of habitat and overexploitation of amphibians due to contaminated surface water by pesticides.
- Carbaryl and herbicide glyphosate cause death of tadpoles and juvenile frogs.
- Pesticides chlorpyrifos and endosulfan cause

severe harm to amphibians.

- Adverse effects on bird population due to application of pesticides in pre- agricultural preparations.
- Death of bird species due to amassing of pesticide in their tissues.
- Glyphosate and chlorpyrifos have injurious impacts on earthworms at the cellular level triggering DNA destruction.

❖ *Threats to Terrestrial Biodiversity* (*Schreck et al., 2008; Lang and Cai, 2009*):

- Cause sub-lethal effects on terrestrial plants and killing non-target plants.
- Drifting or volatilization of phenoxy herbicides injure nearby trees and shrubs.
- Herbicide increases susceptibility of plants to diseases and reduces seed quality.
- Herbicides (sulfonylureas, sulphonamides and imidazolinones) affect productivity of non-target crops, natural plant communities and wildlife.
- *Effect of pesticides on Soil Fungi and Bacteria*:

✓ Indiscriminate use of pesticides in agriculture declines the population of beneficial soil microorganisms (Poudel *et al*., 2020).

✓ Herbicides cause considerable damage to fungal species in soil.

✓ Pesticides inhibit growth of symbiotic mycorrhizal fungi.

✓ Fungicides (Chlorothalonil and dinitrophenyl) disrupt nitrification and de-nitrification bacteria dependent processes.

✓ Herbicide (triclopyr) inhibits soil bacteria involved in the transformation of ammonia into nitrite.

- *Effect of pesticides on Insects* (*Kankam, 2021*):

✓ Insecticides (carbamates, organophosphates and pyrethroids) cause negative impact on bees and beetles.

✓ Fungicides (pyrethroids, triazole) exerts harmful effect on honey bees.

✓ Neonicotinoids insecticides (clothianidin and imidacloprid) are toxic to bees.

✓ Imidacloprid affects bee foraging behaviour and reduce learning capacity.

✓ Insecticides adversely affect the population of Bees, Butterflies, Damselflies, Dragonflies, Flying insects, Ground beetles, Hoverflies, Lady bird beetle etc.

- *Effect of pesticides on Birds and Mammals*:

✓ Accumulation of pesticide in the tissues of birds leads to death of birds.

✓ Fungicides reduce birds and mammal populations by killing earthworms on which they feed.

Conclusion

Injudicious and indiscriminate application of pesticides is a matter of grave-concerns in today's context. Suitable amounts of less harmful formulation pesticides should be applied, as and when required. Awareness among farmers, general public, students and pesticide producers should be created regarding fate of pesticides in the environment and its adverse effects on ecosystem. During application of pesticides, quote of Paracelsus should be followed i. e. "The right dose differentiates a poison from a remedy" (Kumar and Kumar, 2019).

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