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Pesticide Residues: Impact on Environment and Human Health, Risk Assessment and Safety Measures - A Review

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Abstract: Development, use, disposal, and storage of pesticides still remain a concern. Further, it is impossible to anticipate and prevent all potential negative effects of pesticide residues on human health and on whole ecosystems. This is a review of the latest literature data on the pesticide residues with respect to definition, reasons for formation, types, related terminologies and analysis. We address the issue of fate of pesticides after application, degradation, and impacts of pesticide residues on the environment, fauna and human health. In addition, the review also focus on human health risk assessment and safety measures for pesticide handlers or applicators. Present study recommends that, though pesticide residues are toxic to both human and environment, if suitable precautions are taken, they need not be hazardous to human and non-target fauna and flora. Special precautions must be taken during transport, storage and handling of pesticides. Also, suitable methods have to be used to reduce the pesticide residues from the food products. An important aspect of ensuring safety of agricultural products to consumers is government regulations.

Keywords: Contamination, Environmental issues, Health consequences, Pesticide residues, Risk assessment, Safety measures

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Introduction

To achieve the 'zero hunger' goal of the Sustainable Development Goals for reducing hunger to increasing world population, different strategies such as pest control, irrigation, and resistant crop varieties are being developed. Pesticide use, either in field or postharvest, has largely contributed to improved crop yield, with its attendant economic benefits (Vincent *et al.*, 2018). Pesticides have increased the agriculture productivity, reduced insect-borne, endemic diseases and protection as well as restoration of plantations, forests, harvested wood products,

homes and fiber (Ecobichon, 2000). Their use for food production has improved food quantity and quality, consequently improving nutrition and international trade (Maksymiv, 2015).

Grewal *et al*. (2017) stated that, increased use of pesticides results in contamination of the environment and the excess accumulation of pesticide residues in food products. Pesticide residues in food and crops are directly related to the irrational application of pesticides to the growing crops. Accumulated pesticide residues in food products have been associated with a broad variety of human health hazards, ranging from short-term effects to long-term toxic effects. Pesticide residues in agricultural products have always been a matter of serious concern, especially when they are consumed fresh such as lettuce, mustard, cabbage, and kale (Ngo *et al.*, 2022).

Pesticides are the substances used to control pests in agriculture, forestry, horticulture and on public lands to increase crop yields, improve the appearance of plant products, facilitate the care of open spaces and for public health purposes (Zhang *et al.*, 2011). Their use has increased over the years to effectively control a pest complex of vegetable crops due to rapid action and less human resources requirement. However, the exceeding prescribed maximum residue limits of pesticide residues in harvested produce are caused by injudicious use of these compounds, which may pose serious health risks (Mac Loughlin *et al.*, 2018).

Pesticides: *Definition and Concept*:

Pesticides are defined as any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies (FAO, 2002; Osman *et al.*, 2010).

Pesticides have been categorized into different classes depending on-- mode of action and/or mode of entry or the approach by which a pesticide controls or kills the target pest, chemical structure, the features of pesticides, and the character of the target pests (Hassaan and Nemr, 2020). Depending upon source, chemical pesticides are classified into four types such as carbamate, organophosphate, organochlorine, and pyrethroid pesticides. Pesticides derived from biological sources (plants, fungi, and bacteria) are referred as 'biopesticides'. Biopesticides are divided into biochemical pesticides, microbial pesticides, and plant incorporated protectants (Buchel, 1983). Pesticide covers a broad variety of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, plant growth regulators and others (Aktar *et al.*, 2009; Grewal *et al.*, 2017).

Chemical composition of pesticides with examples: Table 1 illustrates the chemical composition of pesticides and their examples (Nayak and Solanki, 2021; Syafrudin *et al.*, 2021; Anderson and Zagorski, 2022).

Some chemical pesticides contain carbamic and thiocarbamic derivatives, carboxylic acids and their derivatives, urea derivatives, heterocyclic compounds (benzimidazole and triazole derivatives), phenol and nitro phenol derivatives, hydrocarbons, ketones, aldehydes and their derivatives, fluorine containing compounds, copper-containing compounds, metal organic and inorganic compounds, and natural and synthetic pyrethroids (Maksymiv, 2015).

Many peer reviewed scientific studies, and the consolidated knowledge about the pesticide residues is available with respect to analytical scope; fact vs. fiction; introduced, dissipated, degraded, and affected by food processing techniques; monitoring studies on concentrations; pesticide usage and population exposure; toxicological consideration; and types of pesticides

Table 1: Chemical composition of pesticides with examples

Group	Examples	Chemical composition
Organochlorine	Aldrin, Chlordane, DDT, Endosulfan, Lindane, Hexachlorobenzene	Non-polar, lipophilic with carbon, chlorine, hydrogen atoms.
Organophosphate	Diazinon, Omethoate, Glyphosate, Malathion, Parathion,	Aliphatic, cyclic and heterocyclic with central phosphorus atom in molecule.
Pyrethroids	Pyrethrins	Alkaloid from petals of plant species, namely, *Chysanthemun cinerariefolium*.
Carbamates	Carbaryl	Chemical structure based on alkaloid of a plant namely *Physostigma venenosum.*
Biological	*Bacillus thuringiensis* (Bt) and its subspecies	Microorganism, viruses and their metabolic products.

used. But there are still gaps in knowledge and information that need to be addressed about the pesticide residues with respect to health and safety measures, health exposure risks, and risk assessment of hazard to human health and the environment (Inobeme *et al.*, 2020).

Pesticide residues remain in almost all the food commodities, as a result of pre-harvest or post-harvest application. The location of pesticides in different parts of food varies with the nature of molecule and type of food commodity and environmental conditions (Bajwa and Sandhu, 2014). Modern agrochemical companies are committed to developing safe formulations to avoid persistent and bioaccumulative properties of substances, it is impossible to anticipate and prevent all potential negative effects of pesticides on human health and on whole ecosystems (Valeriya *et al*., 2021).

According to CAST (2019), pesticide residues are often detected on our foods. Sufficient time between pesticide application and crop harvest allows the pesticides to degrade below detectable levels. Nevertheless, residues of pesticides on food crops commonly occur and their existence is often cause for consumer concern. Fussell *et al.* (2016) noted that, the application of pesticides can result in residues at detectable concentrations in food.

The present study aimed to assess the health hazards associated with the residual effect of pesticides to overcome the knowledge gaps and further research on innovative ideas on health and safety measures, and risk assessment of hazard to human health and the environment.

Literature Search Strategy:

Articles relevant on pesticide residues were searched in EMBASE, Google Scholar, Medline, NCBI, PubMed, Science Direct, Scopus, and Web of Science databases. Data and information was collected from the thorough study of the journal articles, research papers, reports and various literatures. The keywords used for reviewing the literature were the ones that refer to the issues concerning the 'pesticide residues'. For literature search, keyword "'pesticide residues" is combined with: fate, degradation, impacts, health and safety measures, risk assessment, hazard to human health and the environment.

Fate of Pesticides after Application:

Poudel *et al.* (2020) reported that, 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. After application of the pesticides to a target plant, they enter the environment and can undergo movement and degradation. During degradation, new chemicals

Table 2: Fates of pesticides after application

Method	Details of mechanism
Absorption	• Uptake of pesticide molecules into plant tissues. • Removes the pesticide from the environment. • Prevents the pesticide from becoming a water contaminant.
Adsorption	• Physical binding of pesticide molecules to soil particles. • Strength of binding depends on pesticide's chemical properties, its concentration in the soil water, soil pH, and composition of the soil. • Soil bound pesticide molecule is unlikely to leach or runoff. • Soluble pesticides bind strongly with soil. • Pesticides are adsorbed to soils with higher clay or organic matter. • They are not as strongly adsorbed to sandy soils. • Soil bound pesticide molecule undergoes microbiological degradation.
Erosion	• Movement of soil particles from the application site by heavy rains or excess irrigation. • Pesticides adsorbed to the soil particle, is also moved off-site.
Movement in runoff water	• Move from the application site across the soil surface, either dissolved or suspended in runoff waters. • Pesticides may quickly reach surface waters (lakes, streams and rivers). • Water solubility of a pesticide determines its movement in water. • Highly soluble pesticide show greater movement in runoff waters. • Amount of pesticide runoff depends on: slope, texture and moisture content of the soil, amount and timing of a rain, and type of pesticide used.
Leaching to groundwater	• Movement of pesticides in water through the soil. • Leaching occurs downward, upward, or sideways. • Soluble pesticides move downward through the soil to groundwater. • A highly soluble pesticide will tend to readily leach into groundwater.
Degradation	• Breakdown of pesticides into simpler compounds after application. • Rate depends on active ingredient and formulation of pesticide and environmental conditions. • Longer time break down control the insect, weed, or disease. • In extended degradation, pesticide leaches or runoff over a longer period of time.
Spray Drift	• Airborne movement of spray droplets away from a treatment site during application. • Spray drift is affected by spray droplet size, wind speed and distance between nozzle and target plant or ground.
Crop Removal	• Crop removal through harvest or grazing may remove pesticide residues.

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).

Based on the half-life, pesticides can be degraded by photolysis, hydrolysis, oxidation and reduction, metabolism (plants, animals or microbes), temperature, and pH (NPIC, 2011). Details on fates and degradation of pesticides after application are listed in Tables 2 and 3.

Pesticide residues:

Residue are the substances detected in any matrix resulting from the use derivatives, such as degradation and conversion products, metabolites, reaction products and impurities known to cause adverse effects on living organisms (Mondal *et al*., 2021). Pesticide residues includes any derivative of a pesticide, such as conversion products, metabolites, reaction products and impurities considered to amounts of residues primarily depend on nature of pesticides, environmental conditions, good agricultural practices, waiting periods and storage conditions. The amounts of pesticide residues primarily depend on nature of pesticides, environmental conditions, good agricultural practices, waiting periods and storage

Table 3: Methods of degradation of pesticides

Method	Details of mechanism
Photolysis/ Photocomposition	• Breakdown of pesticides by sunlight. • Occurs on the plant, soil, water, or any other surface where sunlight reaches.
Hydrolysis	• Degradation of pesticides by water. • Occur on the soil surface, in the root zone, or whenever a source of water is available. • Very active in warm water at or near the soil surface. • Rate of hydrolysis is inversely proportional to water temperature.
Microbiological Degradation	• Degradation of pesticides by microorganisms after application. • Examples: Bacteria, viruses, fungi, algae, and protozoa. • Occur at faster rate in soils having high organic matter. • Decreases when pesticide moves down below the root zone.
Chemical breakdown	• Breakdown of pesticides by chemical reactions in the soil. • Rate of breakdown is influenced by: binding of pesticides to the soil, soil temperatures and pH levels, and moisture.
Volatilization	• Process of solids or liquids converting into a gas, which can move away from the initial application site. • This movement is called vapour drift. • Vapour drift from some herbicides can damage nearby crops. • Pesticides volatize most readily from sandy and wet soils. • Hot, dry, windy weather and small spray drops increase volatilization. • Hazardous to plants, humans, and animals.

conditions (Racke, 2007).

According to Silva *et al.* (2019), pesticides are commonly used in agriculture to enhance crop production and control pests. After application of pesticides to soil or used to treat crops, they are capable of migrating within various environments and, ultimately, accumulate in food chains or persist as degradation products. Pesticide residues can persist in the environment and agricultural crops. It can produce long-term negative effects on the health of humans and animals and stability of ecosystems by molecular mechanisms that mediate the start of a cascade of adverse effects (Valeriya *et al*., 2021).

Pesticides not only accumulate in the crops but they can be transported through air, soil, and water over long distances, constituting a major pollution source in ecosystems (Fosu *et al*., 2017; Qu *et al*., 2019). Level of pesticide residues can be maintained by through maximum residue levels (MRLs) which are the highest amounts of an individual pesticide that is permitted to be present. They 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. While utilizing the pesticides, the residues can remain in the environment for a long period and can be dispersed over a long distance (Riyaz et al., 2021).

Definition of pesticide residues: Definition of pesticide residues has been illustrated in Table 4.

Reasons for pesticide residues (Source: Mondal *et al*., 2021):

The possible reasons for pesticide residues include:

- Effluents from pesticide manufacturing units.
- Indiscriminate use of chemical pesticides.
- Non-observance of prescribed waiting periods.
- Post harvest treatment of fruits and

Table 4: Definition of pesticide residues

Reference	Definition of pesticide residues
IUPAC (2006)	Pesticides that may remain on or in food after they are applied to food crops.
Encyclopaedia of Food and Health (2016)	Any substance or mixture of substances in food for man or animals resulting from the use of a pesticide and includes any specified derivatives, such as degradation and conversion products, metabolites, reaction products, and impurities that are considered to be of toxicological significance.
Mondal *et al.* (2021)	Bio-accumulated and bio-magnified through the food chain resulting in deleterious effects on human health. OR Any specified substance in food, agricultural commodities or animal feed resulting from the use of a pesticide.
Riyaz *et al*. (2021)	Traces of pesticide compounds that remain on or in the crop, water, soil and air after the application.

Table 5: Terminologies related to pesticide residues (Source: Mondal *et al*., 2021)

Type	Definition of pesticide residues
Aged residue	Residues that have diffused into intra-particulate regions of soil and is less accessible to mass transfer and bio-absorption processes.
Bound residues	Residue associated with endogenous macromolecules that cannot be disassociated by extraction or digestion without alteration.
Dislodgeable residues	Portion of the pesticide residue on treated vegetation which is readily removable.
Incurred residues	Residue resulting from specific use of a pesticide, consumption by an animal, or environmental contamination in the field.
Penetrated residue	The surface residue becomes penetrated residue by migration into the sub-strata.
Surface residue	The portion of pesticide left after sloughs off of the initial deposit, it is called surface or effective residue.
Terminal residue	Breakdown product of the pesticides, which are stable and create as many problems as the original compound.

vegetables.

- Pre-marketing pesticides.
- Use of DDT and other pesticides in Public Health Programmes.
- Use of sub-standard pesticides.
- Wrong advice and supply of pesticides to the farmers by pesticide dealers.
- Wrong disposal of left over pesticides and cleaning of plant protection equipments.

Types of pesticide residues: Various terminologies used for types of pesticide residues are given in Table 5 and 6.

Analysis of pesticide residues (Source: Tiryaki and Temur, 2010): Various steps for analysis of pesticide residues are given in Table 7.

Table 6: Terminologies related to pesticide residues (Source: Fussell *et al*., 2016)

Terminology	Definition or Concepts
Acceptable Daily Intake (ADI)	Maximum quantity of a substance which can be consumed every day for a lifetime without harm to the consumer. It is expressed in milligrams per kilogram of body weight (mg/kg of body weight).
Dissipation	Loss of pesticide residues from an environmental compartment due to degradation and transfer to another environmental compartment.
Half-life ($t_{1/2}$)	Time taken for the concentration of a pesticide in a compartment to decline by one-half.
Limit of Detection (LOD)	Minimum concentration of an analyte that can be distinguished from the assay background at a specified level of confidence.
Limit of Quantification (LOQ)	Minimum concentration that can be quantified at a specified level of a precision or accuracy (or both).
Maximum permissible intake (MPI)	The TMDI is compared with the ADI of the pesticide, calculated for a 50 kg average Indian as the maximum permissible intake (MPI) and expressed as a percentage of the ADI.
Maximum Residue Limit (MRL)	Maximum concentration of a pesticide residue resulting from the use of a pesticide according to Good Agricultural Practice (GAP). It is the limit that is legally permitted or recognized as acceptable in or on a food, agricultural commodity, or animal food.
Non Observed Adverse Effect Level (NOAEL)	The greatest concentration of a substance, found by experiment or observation, which causes no detectable adverse alteration of morphology, functional capacity, growth, development, or life span of the target organism under defined conditions of exposure.
Persistence	Residence time of a pesticide subjected to degradation or physical removal in a soil, crop, animal, or other defined environmental compartment.
Relative Standard Deviation (RSD)	Absolute value of the coefficient of variation and is expressed as a percentage (%).
Theoretical maximum daily intake (TMDI)	The exposure to pesticide residues, assessed using the internationally accepted approach of multiplying the supervised trial harvest residue by the estimated Indian daily per capita consumption of the crop.
Withholding period	Minimum permissible time between the final applications of a pesticide to the target items for human consumption.

Table 7: Steps for analysis of pesticide residues

Steps	Information of technique
Sample collection	• Process of taking portion(s) of a food or other substance for laboratory analysis. • The sample should be representative and sufficiently large. • Sample should be prepared for analysis. • Reduce the total sample to a manageable portion. • Original unprepared sample should be stored for future use.
Extraction	• Isolation of compounds having toxicological significance from surrounding biological environment. • Non-ionic residues are extracted with acetone. • Residues are partitioned from aqueous acetone to a suitable solvent in which the compound is highly soluble.
Clean-up	• Extracted pesticide residue was concentrated to near dryness. • The extract of pesticide residue contains different co-extractive. • Such co-extractives are removed by clean up. • Co-extractives are removed by passing through a glass column with materials like: activated florisil, activated charcoal, silica gel, Alumina etc. • Eluted solvent is evaporated to dryness. • Then the pesticide residues are used for detection.
Identification, Confirmation and Quantification	• Commonly used techniques are Chromatographic instrument like: ✓ Gas chromatography with different detectors (GC), ✓ High Performance Liquid chromatography (HPLC), ✓ Gas chromatography-mass spectrometry (GC-MS), ✓ Liquid Chromatography-mass spectrometry (LC-MS), ✓ Gas chromatography-mass spectrometry/mass spectrometry (GC-MS/MS), ✓ Liquid chromatography mass spectrometry/mass spectrometry (LC-MS/MS) etc.

Health Effects of pesticide residues:

Xu *et al.* (2003) and Tiryaki and Temur (2010) reported that, pregnant women, infants and children are among the most vulnerable population and are more susceptible to the adverse effects of the pesticide residues, because:

- children are much less able than adults to detoxify the pesticides.
- as they are growing and developing rapidly, processes that are vulnerable to disruption by toxic agents.
- because of their small body, they get greater doses of residues by consuming a given food, as compared to adults.
- since they eat more of a certain foods, which tend to be heavily contaminated with pesticides.

According to Valeriya *et al*. (2021), in human, routes of exposure to pesticides include occupational exposure, accidental spills, personal farms and local and imported food. The major groups of pesticide-related effects on humans suggest that chronic effects include hepatotoxic, carcinogenic, cytotoxic, teratogenic, neurotoxic, reproductive, and endocrine disorders.

Toxicity of pesticide residues:

Pesticides can cause negative health effects in human and damage ecosystem. Pesticide residues absorbed by inhalation, ingestion, and dermal contact can lead to acute and chronic toxicity. Such toxicity depend on types of pesticides, port of entry, dose, metabolism, accumulation, etc (Aktar *et al*., 2009).

❖ *Acute toxicity*:

- It is due to short-term exposure.
- It happens within a relatively short period of time.
- Affects the neurological function and also the immune and endocrine systems.

❖ *Chronic toxicity*:

- Chronic toxicity is due to repeated or long-term exposure.
- It happens over a longer period.
- It interrupts the metabolic and systemic functions of the human body.
- Pesticide disrupts the neurological function.
- Injurious to the immune and endocrine systems.

Impacts of pesticide residues on human health (Nicolopoulou-Stamati *et al*., 2016):

❖ *General symptoms* (Riyaz *et al*., 2021):

- Headache, nausea, sweating, diarrhoea, coordination system disruptions, and sometimes death.
- Body weakness, abdominal pain, blurred vision, muscle shuddering, respiratory and nervous system disorders.
- Paranesthesia, unwanted sensations, burning and partial numbness, “pins and needles”, skin problems.
- Night-waking, mental confusion, cancer, respiratory damage, reproductive organs, immune system and endocrine disruptions, birth defects, etc.

❖ *Birth defects*:

- Higher rates of birth defects in children born in pesticide applicators region.
- Limb reduction defects in children born to mothers living and working in agricultural areas with high pesticide use.
- Child with a 'cleft plate' born to a pregnant women exposed to multiple pesticide residues.

❖ *Neurological effects*:

- Reduced IQ, learning disability, and permanent brain damage.
- Children with less stamina, poor eye-hand coordination, poorer memory, poor skilled in figure drawing.

- More risk of developing Parkinson's disease.
- Risk of dementia and neurological diseases.

❖ *Cancer* (Young-Ho *et al*., 2013):

- More risk of leukaemia, lymphoma, brain, kidney, breast, prostrate, pancreas, liver, lung and skin cancer.
- Childhood cancers: neuroblastoma, soft-tissue sarcoma, and cancer of brain and testes.

❖ *Fertility*:

- Impaired fertility in males.

❖ Disorders (Riyaz *et al*., 2021):

- Threat to the developing human brain and nervous system.
- Disorders: diabetes, respiratory failures, thyroid disorders, Attention Deficit Hyperactivity Disorder (ADHD), autism, behavioural and emotional problems, delays in development etc.

- Pesticide poisoning: dyslipidemia, diabetes, liver, kidney and cardiovascular diseases (Aramjoo *et al*., 2021).

Impacts of pesticide residues on the Fauna:

Gavrilescu (2005) described that, with the large-scale utilization, pesticides hold the potential to contaminate the ecosystems, pollute soil, water, air, impact wildlife, pollinators and human health. They have physical–chemical properties that will inflate their behaviour 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 (Table 8).

Impacts of pesticide residues on the Environment:

Many properties of pesticides such as, persistence, degradation, bio-accumulation, volatility, adsorption and absorption can affect the behaviour of pesticide residues in the environment and can cause multiple numbers of environmental contaminations (Table 9) (Pereira *et al*., 2016). According to Riyaz *et al*. (2021), properties of the pesticides that determines their effect on the environment include:

- Mobility: Easy movement of the pesticide from the site of application.
- Non-target toxicity: Toxicity to other organisms other than a pest.
- Persistence: Longevity of the pesticide to remain active in the environment.
- Volume of use: Amount of the pesticide used in the environment.

Risk Assessment of pesticide residues:

Sivaperumal *et al*. (2022) stated that, though studies have been performed throughout the world for pesticide residue analysis, but no detailed studies have been performed with regards to health risk assessment of pesticide residues. The risk assessment supports that one can make a safety finding.

Risk and Exposure:

- Risk is calculated by combining toxicity information and exposure information.

  Risk = Hazard (Toxicology) X Exposure (Chemistry)

- Exposure is calculated by combining reported consumption values of foods with pesticide residues on those foods.

Exposure (mg/kg bw/day) = Residue (mg/kg food) X Consumption (kg food/kg bw per day)

Dietary Assessments: *Acute, Chronic, and Cancer*: Table 10 illustrates the dietary assessments of pesticide residues.

Human Health Risk Assessments:

Damalas and Eleftherohorinos (2011) reported that risk assessment of pesticide impact on human health is not an easy and accurate process because of differences in the periods and the levels of exposure, type of pesticides (regarding toxicity),

Table 8: Impacts of pesticide residues on the fauna (Source: Riyaz *et al*., 2021)

Fauna	Impacts of pesticide residues	Reference
Insects	• Affects central nervous system.	Lewis *et al*. (2016)
Fishes	• Affects eggshell production. • Carcinogenic and toxic. • Metabolic disruptions.Physiological, developmental, and neurotoxic disruptions.	Edwards and Tchounwou (2005)
Birds	• Affects eggshell production. • Carcinogenic and highly toxic. • Developmental and neurotoxic disruptions. • Physiological disruptions in aquatic birds. • Shortening of egg.	Sutherland *et al*. (2004)
Wildlife	• Adult shortening. • Affects central nervous system. • Affects eggshell production. • Developmental and neurotoxic disruptions. • Metabolic and physiological disruptions.	Jongbloed *et al*. (2000)

Table 9: Impacts of pesticide residues on the environment (Source: Riyaz *et al*., 2021)

Environmental component	Impacts of pesticide residues	Reference
Air	• Air pollution. • Hazardous impacts on flora, fauna and human health. • Negative impact on non-targeted fauna and flora.	Yera *et al*. (2020)
Food	• Food contamination by pesticides. • Negative health and environmental impacts.	Fosu *et al*. (2017)
Soil	• Adverse impacts on quality of food and agricultural sustainability: • Affect vital biochemical reactions of the soil. • Alter microbial diversity and microbial biomass. • Alter the soil enzymatic activity. • Bio-accumulation of persistent pesticides. • Mineralization of soil organic matter. • Re-emit old organic pollutants. • Retention of pesticides in soil. • Threat to water and the food chain.	Poudel *et al*. (2020)
Water	• Accumulation of pesticides in surface water. • Adversely affect the micro-crustaceans. • Decrease of food sources, change in food habits, habitat and deterioration of the water quality. • Human health impact. • Pollution of water due to surface runoff and by bioconcentration and biomagnification. • Reduction in primary and secondary consumers. • Transfer of pesticides to atmosphere. • Transfer of pesticides to groundwater.	Syafrudin *et al*. (2021)

Table 10: Dietary Assessments of pesticide residues

Type of Assessment	Details
Acute	• Risk resulting from 1-day exposure. • Residue level, food consumption, and endpoint all must represent 1-day exposure or dosing.
Chronic	• Risk resulting from 6 months to lifetime exposure. • Residue level, food consumption, and endpoint all represent long term exposure or dosing.
Cancer	• Assess the risk from a chemical using the cancer potency factor.

mixtures or cocktails used in the field, and the geographic and meteorological characteristics of the agricultural areas where pesticides are applied. Human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future (EPA, 2022; Meng *et al*., 2022).

According to Whitford *et al*. (2016), the risk of pesticide exposure to human health is a function of both exposure and toxicity. Since both measurements involve a degree of uncertainty, risk assessments generally use very conservative assumptions to assure adequate margins of safety. The risk assessment process generally proceeds in a tiered manner from assessments based on very limited data with very conservative assumptions through assessments. Human risk assessment is best described as a 3-step process:

- Toxicity assessment: an evaluation of intrinsic toxicity or hazard potential of the chemical.
- Exposure assessment: an estimation of potential human exposure to the chemical.
- Risk characterization: an evaluation of potential risk to humans

❖ *Hazard Identification*:

- Process of determining whether exposure to a pesticide residue can cause an increase in the incidence of specific adverse health effects (e.g., cancer, birth defects).
- It is also whether the adverse health effect is likely to occur in humans.
- For chemical pesticides, the process examines the available scientific data for a given chemical and develops evidence to characterize the link between the negative effects and the chemical agent.
- Exposure to a pesticide may generate different adverse effects in a human: diseases, formation of tumours, reproductive defects, death, or other effects.

❖ *Dose-Response Assessment*:

- Describes the numerical relationship between likelihood and severity of adverse health effects to the amount and condition of exposure to an agent.
- The term "exposure-response" relationship is used to describe either a dose-response or a concentration-response, or other specific exposure conditions.
- The risk assessor gather information to determine the numerical relationship between exposure and effects.

❖ *Exposure Assessment*:

- Process of measuring the magnitude, frequency, and duration of human exposure to the pesticide in the environment, or estimating future exposures for pesticide that has not yet been released.
- Includes discussion of the size, nature, and

types of human populations exposed to the pesticide, and discussion of the uncertainties.

- Exposure can be measured directly through consideration of measured concentrations in the environment, models of chemical transport and fate in the environment, and estimates of human intake over time.

- *Different Kinds of Doses*:

✓ Considers the exposure pathway (the course an agent takes from its source to the person(s) being contacted) as well as the exposure route (means of entry of the agent into the body).

✓ The exposure route is described as intake (taken in through a body opening, e.g. as eating, drinking, or inhaling) or uptake (absorption through tissues, e.g. through the skin or eye).

❖ *Risk Characterization*:

- Conveys the risk assessor's judgment as to the nature and presence or absence of risks, along with information about how the risk was assessed, where assumptions and uncertainties still exist, and where policy choices will need to be made.

- Risk characterization takes place in both human health risk assessments and ecological risk assessments.

- Each component of the risk assessment as an individual risk characterization written to carry forward the key findings, assumptions, limitations, and uncertainties.

- Individual risk characterizations provide the information basis to write an integrative risk characterization analysis.

- Overall risk characterization consists of the individual risk characterizations plus an integrative analysis.

Safety Measures for pesticide residues (Damalas and Eleftherohorinos, 2011; Verma, 2020) **:**

Safety is always an issue when using pesticides. Applicators, bystanders, and the environment can be harmed by exposure to pesticide concentrates or vapour drift. Those who work with pesticides must know and follow safe practices to reduce risk. Pesticide safety begins with choosing the correct product. Safety is important in pesticide storage, transportation, mixing, and loading. Equipment cleanup and maintenance must be done safely. Unwanted pesticides and empty pesticide containers must be properly disposed.

Safety procedures for pesticide handlers or applicators:

- Selection of the most suitable pesticide available.

- Selection and use of proper personal protective equipment (PPE).

- Proper cleaning and maintenance of application equipment.

- Proper transport, storage, mixing, loading, and application.

- Proper disposal of excess pesticides and empty pesticide containers.

Selection of a pesticide according to:

- The pest to be controlled.

- Application equipment available.

- Personal protective equipment needed.

- Compatibility with integrated pest management.

- Environmental conditions.

Personal Protective Equipment (*PPE*):

- Selection of the PPE as per the type and formulation of pesticide.

- Protection of all routes of exposure (skin, eyes, and airways).

- Absorption of pesticides via skin can be minimized with the use of coveralls, gloves, boots, and hats.

- Use of goggles or face shields to protect the eyes.

- Airways can be protected by cartridge

respirators, canister respirators, air-powered purifying respirators, or self-contained breathing equipment.

- Selection of PPE by:

✓ type of pesticide being used.

✓ time required to complete the pesticide application.

✓ other hazards associated with the application.

- PPE must be correctly worn, kept in good order, and replaced regularly.
- Good personal hygiene is important to pesticide safety.
- Proper care and cleaning of PPE and application equipment is a must.
- All PPE must be cleaned after each job or at the end of the day.

Safe Transport of pesticides (Verma, 2020):

- Safe transport of pesticides can reduce spills.
- Containers that are in good order can only be transported.
- Caps and plugs of containers must be tightly closed.
- Containers should be secured to prevent spills.
- Vehicles should be locked to prevent theft.
- Pesticides should be transported separate from non-pesticides.
- Transport in the passenger compartment of a vehicle must be avoided.

Safe Storage of pesticides (Verma, 2020):

- Pesticides must be stored safely.
- Storage area must be restricted for general public and animals.
- A good storage facility will:

✓ Be made of fire-resistant materials.

✓ Prevent entry by unauthorized persons.

✓ Be well ventilated.

✓ Have emergency and spill clean-up equipment nearby.

Conclusion

Despite the public desire for zero risk, worldwide, the human being is not risk free and encounters with the risks associated with pesticide use. An important aspect of ensuring safety of agricultural products to consumers is government regulations. The developed countries have established complex systems for pesticide approval and controlling pesticide sale and use, but other countries do not always follow the same strict rules. Preventive measures include testing of the safety of formulants for non-target species, based on complete and reliable data on their effects, and performing mandatory assessment of chronic effects of adjuvants. The main preventive measure is, correct and justified application of chemicals in cultivation of crops: in the context of the increasing environmental awareness and decreasing impact on the ecosystems.

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