NEW PERSPECTIVES INTO HEALTH RISKS AND ENVIRONMENTAL HAZARDS CAUSED BY AGRICULTURAL PESTICIDES AND HEAVY METALS

Surayya Farouk Durumin Iya[1], Musa Ibrahim Mohammed[2], Isa Baba Koki[3],

Abdullahi Rabiu Abubakar[4*]

[1,3] Department of Chemistry, Yusuf Maitama Sule University, Kano, 700235 Nigeria.

[2]Department of Pure and Industrial Chemistry, Bayero University, Kano.

[4*]Department of Pharmacology and Therapeutics, Faculty of Pharmaceutical Sciences, Bayero University, Kano 700233 BUK Road, Kano, Nigeria.

Corresponding Author: Surayya Farouk Durumin Iya Email: faroukSurayyaiya@gmail.com

Received: February 14, 2025, Accepted: April 28, 2025

Abstract: Agricultural pesticides and heavy metals continuous deposition on the environment have overtime caused soil, water, and air pollution. They also lead to the serious health risk among humans, animals, and plants. The purpose of this article was to appraise various the health risks and environmental pollution caused by agricultural pesticides and heavy metals. Literature search was carried out using six electronic databases, including PubMed, ScienceDirect, SpringerLink, MedlinePlus, HerbMed, and Agricola, using Google Scholar, HotBot, and FreeFullPdf as search engines. A number of health risks identified includes cancer, asthma, cardiac arrest, liver damage, kidney failure, reproductive diseases, endocrine, gastrointestinal, and mental disorders. Environmental pollutions reported include damages to crops, aquatic animals, and air contamination. These continue to escalate overtime due to the agricultural, building construction, industrial, and mining activities that release large amounts of pesticides and heavy metals into the surroundings. In conclusion, pesticides and heavy metals pollute cities and villages causing remarkable health risks and environmental pollution. Unfortunately, children and neonates are the most vulnerable group of humans affected by these chemicals. This literature suggests that authorities should take urgent measures to protect the humans and environment from hazards caused by pesticides and heavy metals.

Keywords: Agriculture, Environment, Health, Heavy-metals, Pesticides, Pollution.

Introduction

Agricultural pesticides and heavy metals incessant deposition on the environment cause various health risks and environmental contamination, and they are considered one the major environmental health challenges faced by modern societies. Typical examples include soil, water, and air pollution which in turn affect the wellbeing of humans, aquatic animals and even crops (Mitra et al., 2022; Mesnage et al., 2021). These are as a result of agricultural, building construction, industrial, and mining activities. It was estimated that 3 million cases of pesticide and heavy metals toxicities occur annually. Unfortunately, 95% of these toxicities are fatal and occur mostly in the low- and middle-income countries (LMIC) especially in Africa (Alengebawy et al., 2021; Oyugi et al., 2021; Rai et al., 2019).

Pesticides comprised of various classes of chemicals use in farmlands, home gardens, houses and offices to kill pest. They include insecticides, fungicides, herbicides, rodenticides, and household disinfectants. Pesticides are generally categorized according to their chemical structures. They include organophosphates, organochlorines, carbamates, pyrethrins and pyrethroids (El Nemr et al., 2016; El Nemr & El-Sadaawy, 2016; Yadav & Kumar, 2015). Pesticides are generally used in agriculture to repel pest and safeguard crops from diseases. However, improper application and the use of toxic pesticides can lead to pollution of soil, air, and water bodies. Some pesticide residues may accumulate in the food chain, causing substantial health risks to the farmers and consumers (WHO, 2019; Yadav & Devi, 2017).

Heavy metals are elements with atomic weight above 20 and density more than 5.0 g/cm^3. Typical examples of heavy metals are arsenic (As), copper (Cu), cadmium (Cd), lead (Pb), chromium (Cr), mercury (Mg), zinc (Zn), etc (Sharma et al., 2019; Koller & Saleh, 2018; Al-Qodah et al., 2017). Heavy metals are released into the environment via agricultural runoff, industrial waste, mining activities, and natural processes. Experiment conducted on ground water revealed that high concentration of heavy metals from soil contaminate natural water, making it unfit for human, animal, and even crop consumption. As a result, presence of heavy metals in water and soil may produce adverse effects on plants, animals and even human health (Triassi et al., 2023; Sharma et al., 2019; Sako et al., 2018).

Pesticides and heavy metals deposit on air and soil are washed by heavy rainfall into ponds, streams, and rivers. This significantly affects the integrity of both underground and surface water. Pollution of natural water bodies will directly affect domestic water use, agriculture and other commercial activities making it one of the major public health concerns (Ghosh et al., 2024; Alengebawy et al., 2021; Liu et al., 2016). Rapid increase in population around the globe has led to the concurrent increase in the demand for food supply. Hence, there is need to increase the use of pesticides by farmers in order to increase crop production to meet up with the global demands. However, this may result in indiscriminate use of pesticides and couple with continuous discharge of heavy metals from industries this will led to various health risks and environmental contamination (Ghosh et al., 2024; Rai et al., 2019; Olatunji et al., 2015). In addition, a number of reports have indicated that pesticides are commonly used to commit suicide with a total of 110,000 deaths per annum between 2010 and 2014. Generally, poisoning involving pesticides constitutes 13.7% of total global suicides (Khetre et al., 2023; Peter & Mampilly, 2023; Mew et al., 2017).

African countries especially Nigeria is also facing challenges related to health risk and environmental pollution caused by pesticides and heavy metal. This is linked to rapid population growth accompanied by an indiscriminate waste disposal (Kolawole et al., 2024; Balogun et al., 2020; Ngene et al., 2020). Many farmers in Nigeria use large quantity of pesticides to protect crops and boost agriculture. As such, there is gradual deposition of pesticide residue on the soil and water bodies causing environmental pollution. In the same manner, gradual deposition of heavy metals through mining and industrial activities, cause substantial water and soil contamination (Kolawole et al., 2024; Obiora & Chukwu, 2019; Mijinyawa et al., 2016). In order to address these issues, the Nigerian government introduced policies to control the use of pesticides and discharge of heavy metals into the environment. However, implementation of these regulations remains a very big challenge (Kolawole et al., 2024; Balogun et al., 2020; Ngene et al., 2020). The goal of this review was to appraise the various health and environmental hazard caused by pesticides and heavy metals and to suggest ways to protect the environment and maintain healthy living.

Health And Environmental Risks Caused By Pesticides

Pesticides

Pesticides are wide range of chemicals used in agriculture and forestry for the obliteration of insects, weeds, fungi, bacteria, etc. They include insecticides, herbicides, fungicides, bactericides, and rodenticides. The prime target of pesticides is to boost crop harvest and meet up the demands of rapidly growing population (Ahamad et al., 2023; Rajmohan et al., 2020; Arias-Este´vez et al., 2008). The application of pesticides in crop production has several advantages. These include increase in crops yield, protection against damage by insects and vector borne diseases. Ideally, pesticide should be highly selective in action; while having fatal effect on the targeted organisms it should be friendly to people and the environment. Nonetheless, frequent and inappropriate use of pesticides may contaminate soil, water and air causing significant health hazard to humans, animals, and even plants (Ahamad et al., 2023; Rajmohan et al., 2020; Arias-Este´vez et al., 2008).

A number of fast acting pesticides have been produced and marketed to revolutionize agriculture productivity and meet up with the global demands. Unfortunately, a number of them are harmful to human and the ecosystem (Singh & Kumar, 2024; Sharma et al., 2019; Mostafalou & Abdollahi, 2013). The global distribution of pesticides production and sales across the continents include America (50%), Asia (28%), Europe (14%), Africa (6%), and Oceania (2%). In general, pesticides used worldwide include herbicides (48%), insecticides (30%), fungicides (17%) and others (5%) (Huang & Li, 2024; Mesnage et al., 2021; Usman, 2021). Worldwide, the use of pesticide has significantly increased to 3.5 billion kilogram of pesticide active ingredients per year. This is equivalent to 45 billion US dollars in the world market (Tian et al., 2024; Wang et al., 2024).

In Africa, the pesticides consumption and distribution data includes insecticides (80%), herbicide (15%), fungicides (2%), and others (3%) (Wisnujati, 2023; Shattuck et al., 2023; FAO, 2022. Tolera, 2021; Sarkar et al. 2021) [36-39]. In Nigeria, a recent report indicated that the country consumes herbicides (75%), insecticides (14%), fungicides (5%), soil fumigant (5%) and mosquito repellant coils (1%). This translates to about 244 million US dollars annually (Yadav et al., 2024; Omohwovo *et al.*, 2024; Usman, 2021). In 1991, a fungicide was the highest imported pesticide (65%), followed by insecticides (35%), and cocoa pesticides (31%). Later in 1998, there was an increase in pesticide importation with about 125,000-130,000 metric tons supply every year (FAO, 2022; Usman, 2021; Ojo, 2016).

Classification of Pesticides

Pesticides are classified into 2 main groups which include natural and synthetic. Natural pesticides are called biopesticides that are obtained from plants, fungi, bacteria and other organic compounds having significant pest repellants properties (WHO, 2019; Yadav & Devi, 2017). A synthetic pesticide is man-made chemical obtained through distillation of petrochemicals. They are divided into four groups according to their chemical structure, mode of entry into the target organism, and intensity of activity. These include organophosphate, organochlorines, carbamates, and pyrethroids pesticides (WHO, 2019; Yadav & Devi, 2017).

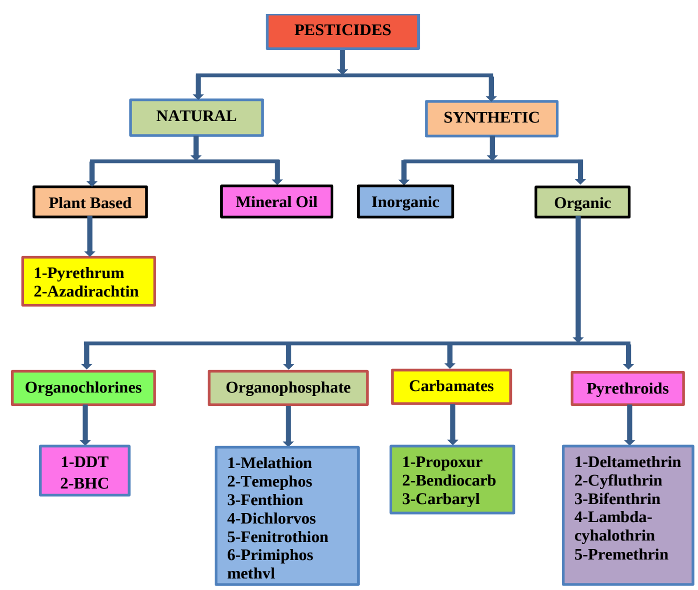

Figure 1. Classification of Pesticides (Yadav & Devi, 2017).

Organochlorine pesticides (OCPs)

Organochlorine pesticides can be described as synthetic chlorinated hydrocarbons that are broadly used in agriculture, forestry and mosquito control. Structurally, organochlorines are categorized into five classes. (1) Dichloro-diphenyl-trichloroethane (DDT): example Dichloro-diphenyl-dichloroethylene (DDE) and Dichloro-diphenyl-dichloroethane (DDD). (2) Hexachloro-cyclohexane (HCH): example lindane (3) Cyclodienes: examples aldrin, dieldrin, endrin, heptachlor, chlordane, and endosulfan. (4) Toxaphene; (5) Mirex and chlordecone (Ibukun et al., 2024; Hassaan & El Nemr, 2020). Their chemical structure is shown in figure 2.2 below (Figure 1.2). One of key features of OCPs is that they have long filed half-life. As such, toxaphene has 9 days, and aldrin has 365 days, while DDT, DDE and DDD have an average field half-life of 15 years respectively (Ibukun et al., 2024; Hassaan & El Nemr, 2020).

Mechanism of toxicity of DDT is via its potential to store in adipose tissues of animals and humans. Through this way, DDT can persist in the people's body for 50 years or more. Later the DDT maybe release from adipose tissue into the systemic circulation during stress or harsh weather condition and cause various type of illnesses (El Nemr et al., 2016; Ibukun et al., 2024; Mrema et al., 2013). Specifically, this causes changes action potential and enzymes activities leading to the acute poisoning, seizures, and even death (Ibukun et al., 2024; Mrema et al., 2013; Singh et al., 2016).

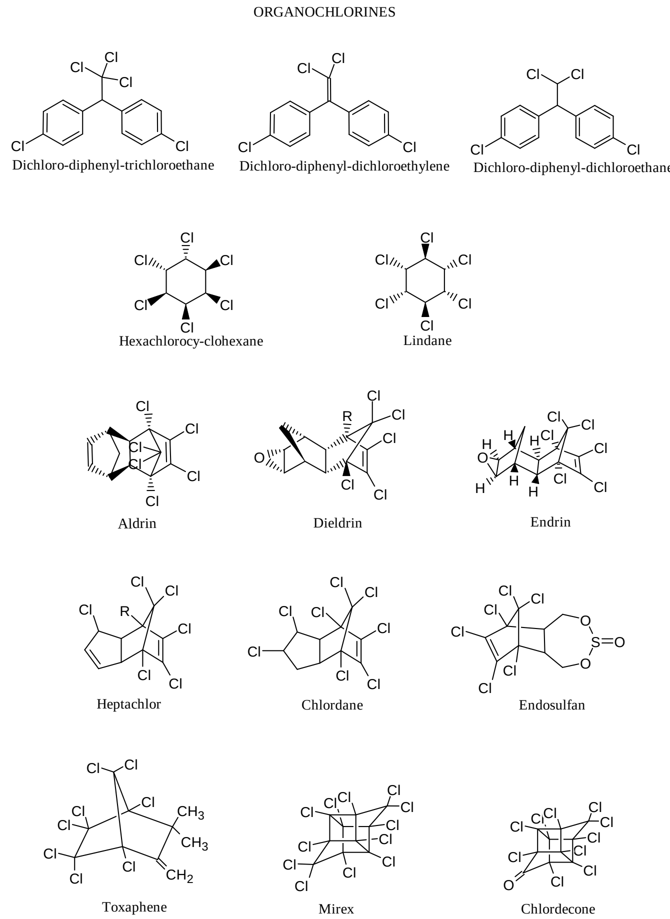

Figure 2.1: Structure of some organochlorines (Ibukun et al., 2024).

Organophosphate pesticides (OPPs)

Organophosphates pesticides are chemicals obtained from esterification of phosphoric acid and alcohol. They are used as pesticides, herbicides, insecticides and nerve gas. Chemically they comprised of amides, thiols, esters of phosphonic, phosphinic, or phosphoric acids with two organic side chains of the cyanide, thiocyanate or phenoxy group (Kiran et al., 2024; Kumar et al., 2016; Gupta et al., 2011). Typical examples of OPPs include Acephate (Orthene), Malathion, Azinphos-methyl (Guthion), Mevinphos (Phosdrin), Chlorpyrifos (Dursban). Others include Diazinon, Parathion (Penncap), Fenamiphos (Nemacur), and Trichlorfon (Figure 1.3) (Kiran et al., 2024; Gupta et al., 2011; Kolodiazhnyi & Kolodiazhna, 2024). Mechanism of action involve the inhibition of the enzyme acetylcholinesterase (AChE), leading to buildup of acetylcholine (ACh) that is cholinergic toxidrome (Kiran et al., 2024; Blanco-Muñoz et al., 2024; Costa, 2018).

The mechanism of toxicity is similar to mechanism of action. Sign and symptoms of OPPs toxicity include gastrointestinal disorder, dizziness, hyperactivity, convulsion, fever, muscle and body weakness. In severe cases they cause respiratory depression, bradycardia, bronchospasm and even death. The OPPs toxicity can be treated by identifying the toxidrome and administering atropine (muscarinic receptor antagonist) (Blanco-Muñoz et al., 2024; Costa, 2018; Syed et al. 2015).

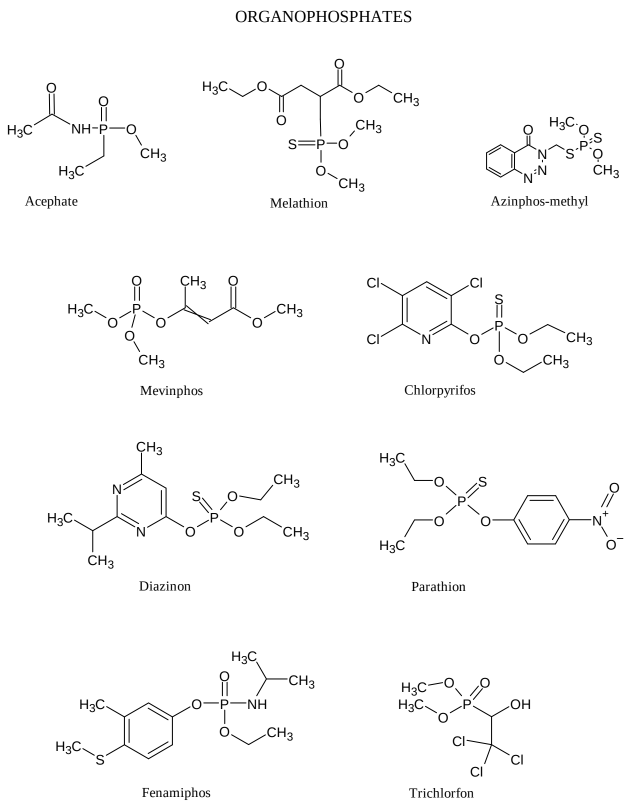

Figure 2.2: Chemical structure of some pesticides (a) Carbaryl and (b) Carbofuran (Kiran et al., 2024).

Carbamate Pesticides

Carbamates are organic ester substances obtained from dimethyl-N-methyl carbamic acid. They are used as pesticides, insecticides, nematicides, herbicides, and fungicides. Examples of carbamates pesticides include aldicarb, disulfiram, pyridostigmine, thiobencarb, methiocarb, propoxur, and molinate (Figure 2.4) (Pampalakis, 2024; Ripley & Chau 2020; Kaur et al., 2019). Carbamates are used as agricultural pesticides especially among animals such as cats and dogs. They cause wide range of toxicity; however, they have shorter duration than that of organochlorines and organophosphates pesticides. Carbamates toxicity include acute poisoning, anticholinergic side effects, respiratory depression, sweating, bradycardia, and hypotension, restlessness, ataxia, convulsion, and coma (Pampalakis, 2024; Espinoza & da Silva, 2024; Patel & Sangeeta, 2019). The mechanism of action and toxicity is via inhibition of acetylcholinesterase leading to the accretion of acetylcholine. This will causes hyperactivity and various signs and symptoms of pesticides toxicities. Treatment of carbamtes toxicity involves the use of atropine, a muscanic antagonist (Pampalakis, 2024; Espinoza & da Silva, 2024; Patel & Sangeeta, 2019).

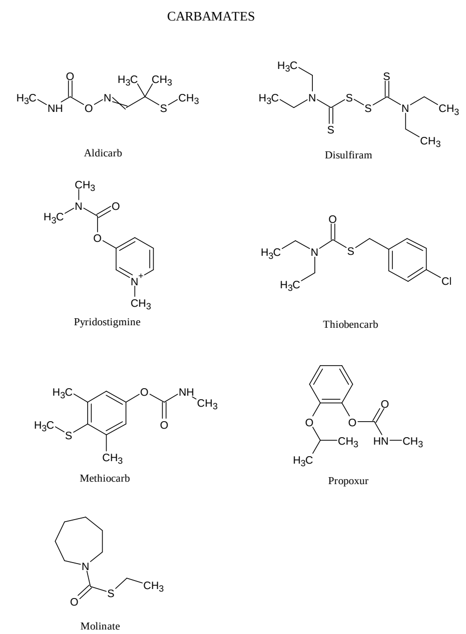

Figure 2.3: Chemical structure of some carbamate and thiocarbamates pesticides (Pampalakis, 2024).

Pyrethrins and Pyrethroids Pesticides

Pyrethrins pesticide is a naturally occurring chemicals obtained from flower of a plant called chrysanthemum (pyrethrum). This plant byproduct is named pyrethrum which contains pyrethrin I and pyrethrin II. It was first used as insecticide in Asia in the 1800 to kill tick, bugs, and mosquitos (Hodoşan et al., 2023; Sun et al., 2020; Chrustek et al., 2018). Examples of pyrethrin pesticides include bifenthrin (Talstar), cis-cyfluthrin (Tempo 2), permethrin (Ambush), esfenvalerate (Asana), phenothrin (Sumithrin) (Figure 2.4) (Hodoşan et al., 2023; Sun et al., 2020; Chen et al. 2022). Pyrethroids are synthetic forms of pyrethrins and they are of two forms. Example of Type I pyrethroids include allethrin, resmethrin, tetramethrin, d-phenothrin, bioresmethrin, and permethrin (Figure 2.5). Type II pyrethroids include cypermethrin, deltamethrin, trans-cyfluthrin, fenvalerate, and fluvalinate (Figure 2.6) (Hodoşan et al., 2023; Ahamad et al., 2023; Bao et al., 2020). The mild symptoms of pyrethrins and pyrethroids toxicity include numbness, itching, and burning sensation. Ingestion of large quantities of these pesticides may cause dizziness, gastrointestinal symptoms, muscle jerking, and convulsions (Chrustek et al., 2018; Ahamad et al., 2023; Thatheyus & Selvam, 2013).

Mechanisms of action and cellular toxicity of pyrethrin and pyrethroid pesticides involve inhibition of GABA binding to its receptor causing central nervous system hyperactivity . Pyrethroids pesticides resemble pyrethrins in chemical structure, but are more toxic and may remain in the environment for a prolonged duration. This is because Pyrethrins disintegrate rapidly when exposed to sunlight or degraded by microorganism (Bao et al., 2020; Soderlund, 2010; Wolansky & Harrill 2008). Rainfall removes the remaining of pyrethroids from air, combines with those from farmlands and washed them down the ponds, lakes, streams and rivers. Pyrethrins and pyrethroids are directly sprayed onto crops hence the residue maybe found on leaves vegetables, flowers and fruits (Chrustek et al., 2018; Thatheyus & Selvam, 2013).

PYRETHRINS

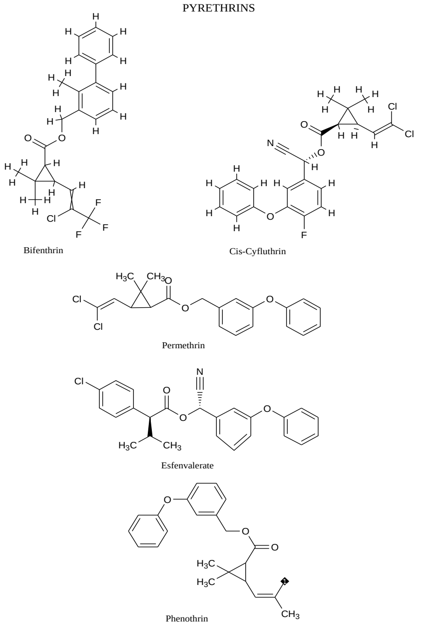

Figure 6. Pyrethrin Chemical Structures (Hodoșan et al., 2023; Sun et al., 2020).

TYPE I PYRETHROIDS

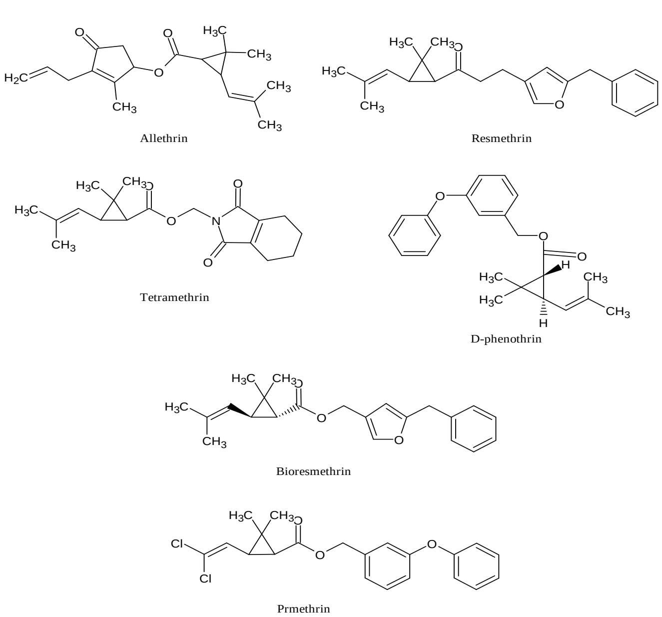

Figure 6. Chemical Structures of Type I Pyrethroids (Hodoșan et al., 2023; Ahamad et al., 2023).

TYPE II PYRETHROIDS

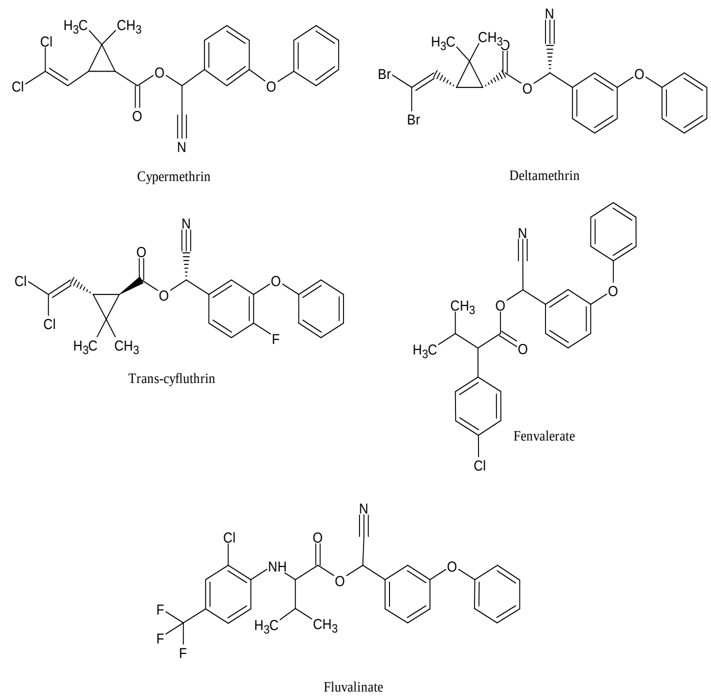

Figure 6. Chemical Structures of Type II Pyrethroids (Hodoșan et al., 2023; Ahamad et al., 2023).

Routes of Exposure to Pesticides

The primary method of ingestion of pesticides by humans includes inhalation, contact with skin, eye, or ingestion of pesticides contaminated food. A plant when sprayed with pesticides will absorb it from air into its various parts of the body including the leaves, flower, fruits, stem, and roots there by protecting the plant from pest and infections (Hassaan & El Nemr, 2020; Seppo-Saari et al., 2019). Through this process, most of the plant byproducts contain trace amount of the pesticide which when consumed by an individual may cause acute or chronic poisoning. Glyphosate and 2,4-dichlorophenoxyacetic acid are insecticides used in animals to kill lice and bugs. These pesticides enter the animals' body through lesion or wounds which when later consumed by human beings cause poisoning (Hassaan and El Nemr, 2020; Seppo-Saari et al., 2019). Furthermore, majority of the pesticides are vapors meant to be sprayed directly onto the plants or infected animals. As such, substantial amount sprayed is inhaled by farmers causing acute or chronic poisoning (Yadav & Devi, 2017; Mrema et al., 2013).

Use of Pesticides in Agriculture

Pesticides are employed by farmers to prevent damage to their crops by insects, birds, and weeds during farming. Also, it is used to preserve farm harvest during long storage period and for short term stay in the market before final purchase by the end users (FAO, 2022; Pretty & Bharucha, 2015). However, there is substantial evidence of lack of awareness on dangers of pesticide among farmers leading to misuse, environmental pollution and even health hazard. For instance, there is general misconception that higher quantity of pesticides caused faster killing of the pests. This causes regular cases of over-dosage, environmental pollution and poisoning (Usman, 2021; Ozkara et al., 2016). Also, spraying beans or cocoa with Gamalin 20 to prevent the growth of mold is another misuse of pesticide. Other major challenges during the use of pesticide are poor disposal of expired and unused products. These include disposal of pesticides into the water bodies especially Gammalin – Lindane that kills and or contaminate crops and fishes meant for human consumption. Many people have been poisoned through the consumption of Gamalin contaminated products. Furthermore, some farmers mixed two or more pesticides that may not be compatible. Unfortunately, this type of practice may worsen the environmental pollution and health hazards (Usman, 2021; Ozkara et al., 2016).

Pesticides Residues in Soil

Continuous use of pesticide for farming and in the house hold has increasingly contaminated soil overtime. The intensity of the pollution depends on the properties of the pesticide including soil adsorption, water solubility, and presence of organic matter (Riyaz et al., 2022; Yeung et al., 2017). Generally, pesticides are adsorbed more into the soil with higher proportion of organic matter and clay because this combination produces both negative and positive charge binding sites. This makes the pesticide to stick firmly onto the surface of clay soil and significantly reduces its downward permeation into underground water (Manjarres-López et al., 2021; Copaja & Gatica-Jeria, 2021). Pesticides may degrade on its own over time, however, the higher the half-life, the more likely for the pesticide to permeate the soil before it finally degrades (Manjarres-López et al., 2021; Copaja & Gatica-Jeria, 2021).

Once pesticide is released into the environment, it undergoes chemical reactions such as hydrolysis, oxidation, reduction, photo-degradation, and microbial degradation. These convert the pesticides into many byproducts that maybe more toxic than the parent compound (Riyaz et al., 2022; Tudi et al., 2021). The entire processes destabilize phosphorus-solubilizing and nitrogen-fixing bacteria in the soils thereby obstructing natural nitrogen fixation process. In addition, pesticide presence in soil may destroy soil enzymes activities which are necessary for existence of healthy soil (Ataikiru et al., 2019; Hussain et al., 2009). Once pesticides are applied, it may be taken up by crops, invertebrate animals, or inhale by human beings. The end result of soil contamination is health hazard that could manifest as various diseases including cancer, asthma, gastrointestinal and mental disorders (Manjarres-López et al., 2021; Copaja and Gatica-Jeria, 2021).

Pesticides Residues in Water

Water is essential in life and only a small percentage of the inland water is fresh and recycled by the water cycle. As a result, only small amount of the inland water is left for drinking, agriculture, industry and; while the majority is contaminated by the human activities (Ganaie et al., 2023; Pérez-Lucas et al., 2018). Pesticides and other chemicals are discharged into the water bodies causing significant water pollution. This contaminates or kills fishes and other aquatic animals. In addition, when contaminated water is used for irrigation it contaminates the farm produces and cause poisoning among the end users which may manifest as cancers, asthma, cardiac arrest, liver damage, and kidney failure (Yadav & Devi, 2017; Li et al., 2008). A report published by the Environmental Protection Agency (EPA) in 1990 reveal that, 50% of water contamination from ponds, streams, and rivers are caused by the discharge of chemicals from agriculture. Pesticides released into the aquatic ecosystems may cause soil erosion, aerial sprinkling or landslide (Gonçalves & da Silva, 2022; WHO, 2020).

The higher the pesticides water-solubility the faster it contaminate both surface water and groundwater. Heavy rainfall or large volume of water from irrigation dissolves large quantity pesticides and drain them into the rivers through leaching (Pérez-Lucas et al., 2018; Sankhla et al., 2018).

Generally, pesticides contaminates underground water more than the surface water. This is because surface water contains abundant oxygen and microorganism which brake down the pesticides to less toxic compounds (Riyaz et al., 2022; Manjarres-López et al., 2021). In order to control water pollution by pesticides, various techniques have been applied such as leaching, cleaning and landfilling. However, water and soil decontamination methods are expensive and time-consuming (Li et al., 2008; Gonçalves & da Silva, 2022). Water and soil contamination by pesticides can be treated with organic wastes, compost dung or earthworm techniques. The aim is to change the water or soil taste and decrease the concentration of toxic chemicals. Furthermore, decontamination may be achieved through the application of various bacterial species to produce biosurfactants (Tarla et al., 2020; Yañez-Ocampo et al., 2016). This procedure is known as Bioremediation techniques. It involves the use of microorganisms to produce enzymes that degrade and convert pesticides into less poisonous products (Mishra et al., 2022; Sanchez-Hernandez, 2019).

Pesticides Residue in Plants

Pesticides are regularly used in agriculture and forestry to kill pests and improve crop production. Pesticides when applied to fruits and vegetables they directly increase their yield significantly. Also, they improved the quality and their nutritional values (Ssemugabo et al., 2022; Damalas & Koutroubas, 2016). Therefore, pesticides are considered necessary to boost agriculture and meet up with the global food demands. However, regular use of pesticides may lead to their buildup in plants. When these plants are consumed by people they may cause health risk to the famers and the consumers (Ansari et al., 2024; Stanton et al., 2018. The negative health effect of pesticides may occur immediately or overtime due to gradual accumulation of the chemicals. A number of reports have revealed that exposure to pesticides may cause cancers, birth defects, hormonal abnormality, reproductive disorders, neurological illnesses and mental disorders. In addition to this, pesticides may trigger environmental pollution and degradation (WHO, 2022, EFSA, 2022).

In an attempt to control the negative effect of pesticides, farmers must ensure that the limit of pesticide residues in their farm do not exceeded the maximum threshold called as Maximum Residue Limits (MRL) (Leskovac & Petrović, 2023; Khatun, 2023). The MRLs is defined as the maximum quantity of a pesticide residue permitted in food or animal feeds, expressed as mg/kg of the food. The presence of pesticide deposits in vegetables and fruits is harmful to people's health once it exceeds the MRL. Worldwide, good agricultural practices (GAP) are measured in terms of pesticide regulations (MRLs) among others. The primary focus of MRLs is to evade potential health hazard due to exposure to high concentration pesticide (Leskovac & Petrović, 2023; Khatun 2023).

Pesticides Residue in Fish and Other Aquatic Animals

Pesticides from farmland usually drain into the rivers or water bodies. As such, large quantity may gradually accumulate in the body of fishes and other aquatic animals. Later, this will be transfer into the human body whenever they consume fish and other sea foods (Ahmad et al., 2024; Pathak et al., 2022). This suggests the need to periodically determine the level of pesticides residue in aquatic animals before consumption in order to prevent potential health hazards. Recently, a number of pesticides that are still in use such as chlorpyrifos, pendimethalin, or trifluralin have been found in fish. Notably, fish has moderate ability to metabolize the organochlorine pesticides (OCPs) placing it at a high risk of contamination b(Abbassy et al., 2021; Magna et al., 2022). Interestingly, the amounts of OCPs found in fish gills can be used to suggest level of OCPs concentration in that water. The majority of the pesticides taken by fishes are usually stored in the liver. Henceforth, the amount of pesticides that kill fishes can be used to measure the level of water pollution. A number of health effects have been identified caused by consumption of contaminated aquatic animals. The most common ones include blood diseases, reproduction defects, cancers and endocrine diseases (Boedeker et al., 2020; Islam et al. 2022).

Pesticides Use in Africa

The economy of African countries essentially relies on agriculture. It was estimated that about 59% of the peoples' source of income is through agriculture. Despite this, there is poor supply of pesticides. The total supply of pesticides to Africa is only about 2-4% of the global distribution. The population of Africa is growing very fast with a reciprocal increase in the demands for food and the need for pesticide for agriculture (Adebisi et al., 2023; Manyilizu et al., 2019)[102-103]. The primary goal for the use of pesticide is to increase yields and maximize in profits. Despite these advantages, generally there is lack of awareness on the safe use of pesticides among farmers causing significant health risks and environmental pollution. In Western Africa, pesticides were registered and controlled by Comité Sahélien des Pesticides (CSP) (Sheahan 2017; Williamson et al., 2008).

In Africa, importation and use of pesticides is marred with series of anomalies such as lack of proper regulation, corruption, and lack of awareness on the risks associated with pesticides. A report by Pesticide Risk Reduction Program revealed that 53% of the registered pesticides were classified as WHO-Class II chemicals (moderately hazardous) (Anaduaka et al. 2023; Haggblade et al., 2021). Also, in another report 50% of farmers in Botswana use malathion and cypermethrin pesticides that were WHO-Class II chemicals (moderately hazardous). Also, in the same country, 7.1% of farmers use methomyl, 1.8% use dichlorvos, and 2.7% use demeton-S-methyl. These pesticides fall under WHO-Class Ib chemicals (highly hazardous) (Ojo, 2016; Oluwole & Cheke, 2019). In Nigeria, 78% of farmers use monocrotophos that falls under WHO-Class Ib chemicals. There was also report of the use of other pesticides such atrazine and metolachlor that belongs WHO-Class III chemicals (slightly hazardous). Others include lindane, paraquat and copper sulfate that are categorized as WHO class II chemicals (moderately hazardous) (Ojo, 2016; Oluwole & Cheke, 2019). In Zambia, 41% farmers apply monocrotophos that is WHO class Ib. Also in Malawi, 25% of farmers use parathion that falls under WHO-Class Ia pesticide (extremely hazardous). Other African countries such as Ghana, Benin, Senegal and Ethiopia use pesticides that fall under different WHO pesticides risk classification such as malathion (III), glyphosate (III), cypermethrin (II), chlorpyrifos (II), dimethoate (II), deltamethrin (II), fenitrothion (II), endosulfan (II), and profenofos (II). These classes pesticides are also used frequently in Ethiopia, Senegal, Benin, and Ghana (Williamson et al., 2008; Snyder et al, 2015).

Health and Environmental Risks Caused by Heavy Metals

Heavy Metals

Heavy metals are described as substance with atomic weight above 20 and density greater than 5.0 g/cm^3. Examples of heavy metals include arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), mercury (Mg), chromium (Cr), cobalt (Co), copper (Cu), and zinc (Zn) (Jadaa & Mohammed, 2023; Gutiérrez-Ravelo et al., 2020). Heavy metals are primarily divided into essential and non-essential metals based on the body requirements for trace micronutrients. Essential heavy metals include iron, zinc and nickel that are needed by the human, animals, and plants as cellular building materials. Non-essential heavy metals include lead, cadmium, and mercury that are not needed because they are toxic to the biological system (Jadaa & Mohammed, 2023; Gutiérrez-Ravelo et al., 2020). In general, heavy metals are natural and essential components of humans, animals, plants and microorganisms and they play vital roles during physiological activities. Despite these advantages, they cause dose-dependent toxicities in human bodies and the environment. Therefore, toxicity occurs mostly when their amount in the body exceeded the required threshold level (Abd Elnabi et al., 2023; Engwa et al., 2019). The primary manifestation of heavy metals toxicity include cancers, heart diseases, reproductive diseases, endocrine and mental disorders. They also pollute environment and cause disruption of microbial balance, destabilization of ecosystem, and significantly reduce soil fertility (Abd Elnabi et al., 2023; Engwa et al., 2019).

Cadmium Health Risks and Environmental Hazards

Cadmium is a heavy metal that gets into the ecosystem through the process of metal refining and other industrial activities. Industrial wastes such as paints, metal traces and battery wastes release substantial quantities of cadmium into the environment (Du et al., 2020; Järup & Åkesson, 2009). Heavy rainfall and storm wash cadmium from metallic alloys and phosphate fertilizers into ponds, streams and rivers. As such, irrigation with contaminated water transfers a larger amount of cadmium into vegetables. Consequently, consumption of cadmium contaminated vegetables will lead to deposition of significant amount of cadmium into the humans and animals bodies over time (Du et al., 2020; Järup & Åkesson, 2009).

Cadmium toxicity occurs mainly through the exposure to cadmium via inhalation or ingestion over a long period. Precisely, exposure by humans happens through inhalation of gas containing cadmium particles, ingesting of cadmium contaminated food or drinking water. Substances like fertilizers, metal alloys, metal coatings, cigarettes, paintings, and batteries contain substantial quantities of cadmium. As such, cigarette smokers have twice risks of getting cadmium toxicity than non-smokers (Doccioli et al., 2024; Yimthiang et al., 2022). The primary signs and symptoms of cadmium toxicities include gastrointestinal disorders, fragile bones, kidney failure, and death at very high doses. Inhalation of cadmium may cause respiratory depression, nose inflammation, and flu-like symptoms (Liu et al., 2022; Wu et al., 2016). Cadmium toxicities can be minimized by using personal protective equipment at work place and adhering to safety guidelines. Environmental safety can be enhanced through a reduction in the use of phosphate fertilizers. In general, government can protect both human and environment by ensuring adequate treatment of industrial and municipal wastes before discharging them into the river (Doccioli et al., 2024; Yimthiang et al., 2022).

Chromium Health Risks and Environmental Hazards

Chromium is a heavy metal that is presence in abundance but does not occur as free element. It is always found as a mixture of mineral known as chromite. Chemically, chromium ions exist in two main forms, the chromium (III) and chromium (VI) ions. Chromium (III) is harmless to the human body and it is an essential element necessary for metabolism. However, chromium (VI) is very harmful and has lower threshold of toxicity (Zulfiqar et al., 2023; Prasad et al., 2021). Notably, chromium has various uses in an industry; it is used for making of metallic alloys, hardening of steel, and dye production. Typical example includes the use of 18% of chromium for hardening and sterilizing stainless steel `to prevent corrosion. Chromium is also used in paint for high quality painting of metallic objects. As a result, chromium painted alloy is the primary source of chromium contamination affecting environment and water bodies (Iyer et al., 2023; Shin et al., 2023).

Chromium from ponds and rivers is taken up by fishes and other sea foods leading to its accumulation in their bodies. During dry season farming using chromium-contaminated water for irrigation leads to the absorption of chromium by the crops. It is through this way chromium accumulates gradually in the human body. In addition, consumption of chromium-contaminated fish may raise the concentration above normal threshold causing chromium toxicity (Georgaki et al., 2023; Fatnani et al., 2023). The primary route of exposure to chromium is via inhalation or direct ingestion of chromium-containing substances. The primary symptom of chromium toxicity is its ability to trigger various oxidation reactions that will cause hemolysis, liver, and kidney damage. Furthermore, high quantity chromium (VI) modifies the genetic composition of human body causing cancers and malignancies. Others symptoms include gastrointestinal, dermatitis, ulcers, disturbances, fever, neurological disorder, respiratory depression, and even death (Iyer et al., 2023; Shin et al., 2023).

Copper Health Risks and Environmental Hazards

Copper is a heavy metal that has wide applications, it is very soft and highly elastic that can be molded to various forms and shapes without breaking. Copper is used as the number one metal conductor for generating electricity (Charkiewicz et al., 2024; Fan, 2023). As a result most electrical connections within buildings are made using copper metal. It has other specialized function, for instance brass is made up of combination of copper and zinc. Also, cupronickel is made up of copper and nickel and it is used for printing currencies (Charkiewicz et al., 2024; Fan, 2023). Notably, copper is used as vital plant macronutrient responsible for chlorophyll formation, seed production, and enzymatic activities. Hence copper sulfate is suitable component during crop production. The versatile nature of copper and its varieties of applications may lead to its gradual deposition and accumulation in the environment. Also, discharge of untreated industrial waste increases the deposition and contamination of environment by copper (Domingo, 2024; Taylor et al., 2023).

Physiologically, copper is responsible for bone formation, nerve functions, red blood cells production, and maintenance of immune system. As such, there is need for daily intake to prevent deficiency. Examples of copper deficiency include Menkes disease, Wilson's disease, and Alzheimer's disease (Zhao et al., 2024; EFSA Scientific Committee et al., 2023). Despite this the maximum quantity of copper metal a human body can accommodate is 10 mg per day and any increase above this may cause toxicity. The sign and symptoms of copper toxicity include dizziness, headaches, nausea, vomiting and diarrhea (Domingo, 2024; Taylor et al., 2023).

Lead Health Risks and Environmental Hazards

Lead is a heavy metal with various applications in the industries. It is used in production of paint, battery making, building ship and other machines. Lead tetraethyl was used earlier to minimize wear and tear of engine valves and to prevent the engine from knocking (Raj and Das, 2023; Sonne et al., 2023). Leaded-fuel was used in the fast to clean engine and improve the efficiency of motor vehicle. Also, lead pipes were also used for municipal water supply in the past. However, people get expose to a large quantity of lead through water supply. In addition, batteries made from lead harbor a substantial amount of lead into the environment (Raj and Das, 2023; Sonne et al., 2023). Furthermore, lead residue from motor exhaust, traces of lead from wall paints, worn out lead water pipe gradually get deposited on the environment and cause pollution. Overall, traces of lead particles when it gets into the human body through any of the above processes will causes serious toxicities. Unfortunately, children are more vulnerable to lead poisoning. This is due to the possibility of ingesting paint scratched from wall and having low level of body immunity (WHO, 2023; Ghosh, 2023).

Lead from air or soil is washed by the rainfall into the ponds, seas and rivers. Fishes and other aquatic animals absorbed lead causing its significant accumulation in their body. Whenever lead-contaminated fishes are eaten by humans different signs and symptoms of lead poisoning could manifest. Similar, episode may occur when lead contaminated water is used for irrigation (WHO, 2023; Ghosh, 2023). Substantial quantity of lead may be absorbed by the vegetables causing toxicities among people who consume it. The sign and symptoms of lead toxicity in adults include abdominal pain, anemia, high blood pressure, seizures, kidney failure, and even death. In children major symptoms include mental illness, attention deficit hyperactivity disorder, and stunted growth (WHO, 2023; Ghosh, 2023).

Zinc Health Risks and Environmental Hazards

Zinc metal is another heavy metal with wide industrial and medical application. Major uses of zinc include battery production, galvanization, zinc-metal alloys, and production of radiation protector. Other functions of zinc include production of paints, pigments, fertilizer, and for construction of explosion protector equipment. Medically zinc is a trace element taken by an individual daily as recommended by health personnel (Schoofs et al., 2024; Vuong et al., 2023). The recommended daily dose of zinc is and 11 milligrams for people aged 14 years and above, 8mg for children aged 9-13 years, and 5mg for children below 8 years. This is to maintain healthy body cells, tissues and organs. However, excessive intake of zinc above the daily recommended dose may lead to zinc toxicity (Schoofs et al., 2024; Vuong et al., 2023).

Several industrial applications of zinc and its uses in house hold made zinc prone to health risk and environmental hazard. The major sources come from fertilizer used in agriculture, paint and zinc metal from industrial waste. When large industrial effluent or zinc containing fertilizers are discharged into the ponds, seas and rivers it may lead to a consumption of a substantial amount of zinc by the fishes and other aquatic animals (El-Agawany & Kaamoush, 2023; Chasapis et al, 2020). This load of zinc will later transferred to humans who consumed those fishes and may accumulate over time through a process called bio magnification. In addition, during irrigation zinc contaminated water used will be absorbed by vegetables and other crops. People who consume vegetables regularly especially vegetarians may experience zinc toxicity over timer. This happens whenever the amount of zinc the body surpassed the daily recommended dose (El-Agawany & Kaamoush, 2023; Chasapis et al, 2020).

The signs and symptoms of acute zinc poisoning include mild gastrointestinal disturbances including nausea, vomiting, diarrhea, and fever. Chronic zinc poisoning may occur due to continuous accumulation over time. An elevated amount of zinc in the tissues can disrupt the balance of other metals in the body and normal body metabolism (Du et al, 2023; Boreiko, 2010). Typical examples include inhibition of the absorption of copper into the systemic circulation causing copper deficiency. It also interferes with iron metabolism in the body causing hematological disorders such as anemia and eosinophilia. High amount of zinc may lower concentration of high-density lipoprotein and body immune mechanism. Symptoms of chronic zinc toxicity include gastrointestinal disorders, respiratory depression and neurological disorders (Du et al, 2023; Boreiko, 2010).

Table 2.1: Summary of the Sources of Heavy Metals, their Health Risks, and Environment Hazards (Afzaal et al., 2022).

Heavy Metals	**Sources**	**Effects**
Pb (Lead)	➲ Acid batteries ➲ Old plumbing system ➲ Lead shots used for hunting ➲ Combustion of leaded gasoline ➲ Lead smelters ➲ Waste incinerations ➲ Ore and metals processing ➲ Utilities	➲ Effects air quality ➲ Effects freshwater ➲ Effects drinking water ➲ Food items ➲ Various health problems in human beings ➲ (Cardiovascular) ➲ Bioaccumulation ➲ Disturb soil function ➲ Effects the global balance ➲ Effect aquatic insect community
Hg (Mercury)	➲ Mining	➲ Contaminate the fish, sea food and wild life ➲ Cause various disorders in human health and

	ↄ Urban discharge ↄ Agricultural materials ↄ Atmospheric deposition ↄ Combustion and industrial discharge ↄ Cosmetic materials ↄ Religious materials	different organs (Immunological, neurological, reproductive & embryonic toxicological effects ↄ Effects on plants and soil health ↄ Accumulation into food, plants, water and soil
Zn (Zinc)	ↄ Microplastic pollution in marine ecosystem adsorb ↄ Heavy metals ↄ Traffic emissions ↄ Industrial emissions ↄ Hazardous waste sites ↄ Mining ↄ Smelting	ↄ Contaminate surface water ↄ Bio-accumulated in fishes ↄ Increase acidity of water ecosystem ↄ Effects aquatic insect community ↄ Soil contamination ↄ CO_2 release by Zn production ↄ Hazardous for unborn/newborn
Cu (Copper)	› Industrialization › Moto oils › Paints › Copper IUDs › Agricultural activities › Mining › Metal and electrical manufacturing › Domestic use of pesticides › Leather processing › Automotive brake pads	ↄ Ocean acidification ↄ Bioaccumulation ↄ Effects aquatic creature health (by damaging kidneys, nervous systems, and livers) ↄ Effects on human health ↄ Effects aquatic species ↄ Liver cirrhosis in children ↄ Multiple problems in human health (nausea, diarrhea, chest pain, irritation in respiratory tract)
Cadmium (Cd)	ↄ Excessive fertilization ↄ Incineration of municipal waste & sewage sludge ↄ Incineration ↄ Metal mining ↄ Processing to ores ↄ Burning of fossils fuels	ↄ Cause various types of cancer ↄ Bioaccumulation in foods ↄ Air pollution ↄ Groundwater pollution ↄ Different health impacts (Bristling of bones)
Ni (Nickel)	ↄ Coal combustion ↄ Incineration of waste ↄ Mining activities ↄ Smelters ↄ Traffic oil combustion for heat and electricity ↄ Non-ferrous metal production ↄ Metallurgical, chemical and food processing industries ↄ Tobacco smoking ↄ Kitchen utensils ↄ Stainless steel products ↄ Dental and orthopedic implants ↄ Wind-blown dust by weathered rocks and soil, ↄ Volcanic emissions, forest fires ↄ Vegetation	ↄ Toxic to plants ↄ Toxic to living organisms ↄ Effects the ocean and fresh water ecosystem ↄ Effects phytoplankton ↄ Carcinogenic ↄ Effects soil fertility by altering mineral nutrition
Cr (Chromium)	ↄ Electroplating industries ↄ Leather tanneries ↄ Textile industries ↄ Steel ↄ Industrial combustion ↄ Wood burning ↄ Reuse incineration ↄ Fertilizers	ↄ Effects soil fertility ↄ Effects plants growth ↄ Effects germination ↄ Effects yield ↄ Effects physiological processes in plants ↄ Bioaccumulation ↄ Effects human health ↄ Carcinogenic ↄ Effects surface water
As (Arsenic)	› Timber treatment › Agricultural chemicals › Glass production › Metal alloys	ↄ Air pollution ↄ Soil contamination ↄ Water pollution ↄ Inhibition of growth, photosynthesis and ↄ reproduction

➢ Pharmaceutical ➢ Mining ➢ Metal smelting ➢ Burning of fossil fuels ➢ Microplastic particles	➢ Lethality ➢ Behavioral changes in individuals ➢ Toxicity to rice seedling/growth

Conclusion

As human population increases economic activities such as agriculture, building construction, industrial, and mining activities continue to expand to meet up with the needs of the emerging communities. Despite the economic importance of these, they cause significant health and environmental risks through discharging pesticides from farmlands, toxic industrials waste, and heavy metal from industrial and mining sites. Agricultural pesticides and heavy metals pollute cities and villages, causing diseases such as cancer, asthma, cardiac arrest, liver damage, kidney failure, reproductive diseases, endocrine, gastrointestinal and mental disorders. They also cause environmental contamination that damages crops, kill fish and other aquatic animals, and pollutes the atmosphere. Children and neonates are the most vulnerable group of humans affected by these chemicals. Overall, pesticides and heavy metals cause health risks and environmental hazards that directly affect quality of life, domestic and commercial activities.

Recommendation

i. Farmers should be studied to assess the level of health and environmental risks posed by agricultural pesticides and heavy metals.

ii. The use of fertilizer containing heavy metals should be substituted with organic fertilizers in order to protect the environment.

iii. There is need for government to enforce policies to ensure treatment of industrial waste and control of their discharge into the environment.

iv. Government and business owners should supply and enforce the use of personal protective equipment on farmlands, industries and hospitals.

v. Authorities should take urgent measures to protect aquatic and humans and environment from further damages caused by pesticides and heavy metals.

Conflict of Interest

The authors declared that they have no conflict of interest.

Funding

No funding for this article.

References

1. Mitra, S., Chakraborty, A.J., Tareq, A.M., Emran, T.B., Nainu, F., Khusro, A., Idris, A.M., Khandaker, M.U., Osman, H., Alhumaydhi, F.A. and Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University-Science, 34(3), 101865.
2. Mesnage, R., Straw, E.A., Antoniou, M.N., Benbrook, C., Brown, M.J., Chauzat, M.P., Finger, R., Goulson, D., Leadbeater, E., López-Ballesteros, A. and Möhring, N. (2021). Improving pesticide-use data for the EU. Nature ecology & evolution, 5(12), 1560-1560.
3. Alengebawy, A., Abdelkhalek, S.T., Qureshi, S.R., Metals, M.Q. (2021). Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications, Toxics, 9(42), 1-33.
4. Oyugi, A.M., Kibet, J.K., Adongo, J.O. (2021). A review of the health implications of heavy metals and pesticide residues on khat users. Bulletin of the National Research Centre, 45,158.
5. Rai, P.K., Lee, S.S., Zhang, M., Tsang, Y.F., & Kim, K. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International, 125, 365-385.
6. El Nemr, A., El-Said, G.F., Ragab, S., Khaled, A., El-Sikaily, A. (2016). The distribution, contamination and risk assessment of heavy metals in sediment and shellfish from the Red Sea coast, Egypt. Chemosphere, 1(165), 369-380.
7. El Nemr, A., El-Sadaawy, M.M. (2016). Polychlorinated biphenyl and organochlorine pesticide residues in surface sediments from the Mediterranean Sea (Egypt). International Journal of Sediment Research, 31(1), 44-52.
8. Yadav, U., Kumar, D. (2015). Role of Pesticide in Agriculture, Environment and Also in Human Being. International Journal of Research in Science and Technology, 5(1), 74-84.
9. World Health Organization. (2019). The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 2019. https://iris.who.int/bitstream/handle/10665/332193/9789240005662-eng.pdf
10. Yadav, I. C., & Devi, N. L. (2017). Pesticides classification and its impact on human and environment. Environmental science and engineering, 6(7), 140-158
11. Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., ... & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, *1*, 1446.
12. Koller, M., Saleh, H.M. (2018). Introductory chapter: Introducing heavy metals. Heavy metals, 1:3-11.
13. Al-Qodah, Z., Yahya, M. A., & Al-Shannag, M. (2017). On the performance of bioadsorption processes for heavy metal ions removal by low-cost agricultural and natural by-products bioadsorbent: a review. Desalination and Water Treatment, *85*(August), 339-357.
14. Triassi, M., Cerino, P., Montuori, P., Pizzolante, A., Trama, U., Nicodemo, F., D'Auria, J.L., De Vita, S., De Rosa, E. and Limone, A. (2023). Heavy metals in groundwater of southern Italy: Occurrence and potential adverse effects on the environment and human health. International Journal of Environmental Research and Public Health, *20*(3), 1693.
15. Sako, A., Yaro, J. M., & Bamba, O. (2018). Impacts of hydrogeochemical processes and anthropogenic activities on groundwater quality in the Upper Precambrian

sedimentary aquifer of northwestern Burkina Faso. *Applied Water Science*, *8*(3),88.

16. Ghosh, D., Chaudhary, S., Sarkar, S., Singh, P. (2024). Water pollution in rural areas: Primary sources, associated health issues, and remedies. Water Resources Management for Rural Development, 1, 15-28.
17. Liu, W., Li, Y., Shen, L., & Wang, X. (2016). Heavy metal contamination and ecological risk in the surface sediments of Liaohe River, China. Environmental Monitoring and Assessment, 188(12), 665.
18. Olatunji, J.A, Odediran, O.A., Obaro, R.I. and Olasehinde, P.I. (2015). Assessment of Groundwater Quality of Ilorin Metropolis using Water Quality Index Approach. Nigerian Journal of Technological Development, 12(1), 18-21.
19. Khetre, R., Harbade, A., Chaudhari, K., Maske, D., Zine, K., Zine, K. and Shelake, M. (2023). Profile of Agricultural Pesticide Compound Suicidal Poisoning Deaths: An Autopsy Based Study. Research Journal of Medical Sciences, 17(12), 478-481.
20. Peter, J.V. and Mampilly, A.P. (2023). Approach to reducing the burden of pesticide poisoning and improving outcomes in patients with deliberate self-harm. Current Medical Issues, 21(2),79-82.
21. Mew, E. J., Padmanathan, P., Konradsen, F., Eddleston, M., Chang, S. S., Phillips, M. R., & Gunnell, D. (2017). The global burden of fatal self-poisoning with pesticides 2006-15: systematic review. Journal of affective disorders, 219, 93-104.
22. Kolawole, I. D., Kolawole, G. O., Sanni-manuel, B. A., Kolawole, S. K., Ewansiha, J. U., Kolawole, V. A., & Kolawole, F. O. (2024). Economic impact of waste from food, water, and agriculture in Nigeria: challenges, implications, and applications—a review. Discover Environment, *2*(1), 51.
23. Balogun, D.O., Abe, G.O., Ibrahim, A., Ibrahim, B.K., Auta, U.S., and Adgidzi, J.A. (2020). Spatial Distribution of Groundwater Quality Using GIS in Kano Metropolis, Kano State, Nigeria. World Wide Journal of Multidisciplinary Research and Development; 6(5): 51-58.
24. Ngene, B. U., Nwafor, C. O., Bamigboye, G. O., Ogbiye, A. S., Ogundare, J. O., & Akpan, V. E. (2020). Assessment of water resources development and exploitation in Nigeria: A review of integrated water resources management approach. Heliyon, 7(1), e05955.
25. Obiora, S. C., & Chukwu, A. (2019). Assessment of heavy metals in topsoil and street dust from the city of Kano, Nigeria. Environmental Monitoring and Assessment, 191(1), 4.
26. Mijinyawa, Y., Abdullahi, A., & Abdullahi, I. (2016). Pesticide use and occupational health effects among commercial farmers in Kano, Northern Nigeria. Toxicology Reports, 3, 849-854.
27. Ahamad, A., Ahamad, J., & Javed N.M. (2023). Current Perspective on Pesticides: Their Classification, Behaviour, Potential Use and Toxic Effects. Journal of Angiotherapy, 7(1), 9360.
28. Rajmohan, K. S., Chandrasekaran, R., & Varjani, S. (2020). A review on occurrence of pesticides in environment and current technologies for their remediation and management. Indian journal of microbiology, 60(2), 125-138.
29. Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., Mejuto, J. C., & García-Río, L. (2008). The mobility and degradation of pesticides in soils and the pollution of groundwater resources. Agriculture, ecosystems & environment, 123(4), 247-260.
30.
31. Singh, M., Kumar, A. (2024). Pesticide Pressure on Insect and Human Population: A Review. Archives of Current Research International, 24(4),188-202.
32. Mostafalou, S., & Abdollahi, M. (2013). Pesticides and human chronic diseases: evidences, mechanisms, and perspectives. Toxicology and applied pharmacology, 268(2), 157-177.
33. Huang, Y., Li, Z. (2024). Assessing pesticides in the atmosphere: A global study on pollution, human health effects, monitoring network and regulatory performance. Environment International, 187, 108653.
34. Usman, H.I. (2021). Nigeria pesticides consumption profile. Journal of Research in Weed Sciences, 4(4), 257-263.
35. Tian, T., Liu, F., Fu, Y., Ao, J., Lin, S., Cheng, Q., ... & Qiao, J. (2024). Environmental exposure patterns to 94 current-use pesticides in women of reproductive age who are preparing for pregnancy. Science of The Total Environment, 948, 174624.
36. Wang, M., Zhang, X., Chen, H., Li, H., Zhang, Z., Zhang, D., & Cao, X. (2024). Determination of multi-pesticide residues in agricultural products with a modified QuEChERS process based on magnetic biochar from coconut clothing. Food Chemistry, 464, 141617.
37. Wisnujati, N.S. (2023). Unveiling the epoch: exploring pesticide utilization and trade trends globally and regionally from 1990 to 2020. SCIENTIA: Journal of MultiDisciplinary Science, 2(2):108-121.
38. Shattuck, A., Werner, M., Mempel, F., Dunivin, Z., & Galt, R. (2023). Global pesticide use and trade database (GloPUT): New estimates show pesticide use trends in low-income countries substantially underestimated. Global Environmental Change, 81, 102693.
39. Food and Agricultural Organization of the United Nations (FAO). (2022). Pesticides use, pesticides trade and pesticides indicators – Global, regional and country trends, 1990–2020. FAOSTAT Analytical Briefs, no. 46. Rome.
40. Tolera, S.T. (2021). Adverse Effect of Pesticide on Top Ten Importers of African Countries: Systematic Review. EC Pharmacology and Toxicology, 9.2, 61-79.
41. Yadav, D.K., Rathee, S., Sharma, V., Patil, U.K. (2024). A Comprehensive Review on Insect Repellent Agents: Medicinal Plants and Synthetic Compounds. Anti-Inflammatory & Anti-Allergy Agents in Medicinal Chemistry, doi: 10.2174/0118715230322355240903072704. Epub ahead of print. PMID: 39415571.
42. Omohwovo, E. J., Lucero-Prisno III, D. E., & Jibril, H. L. (2024). Towards sustainable pesticide management in Nigeria: A call for improved regulatory standards and laboratory testing. Public Health and Toxicology, 4(1), 2
43. Ojo, J. (2016). Pesticides use and health in Nigeria. Ife Journal of science, 18(4), 981-991.
44. Ibukun, A. E., Abd Hamid, M. A. B., Mohamed, A. H., Zain, N. N. M., Kamaruddin, M. A., Loh, S. H., ... & Yahaya, N. (2024). A review on the toxicity and properties of organochlorine pesticides, and their adsorption/removal

studies from aqueous media using graphene-based sorbents. Journal of Chemical Reviews, 6, 237-303.
45. Hassaan, M.A., & El Nemr, A. (2020). Pesticides pollution: Classifications, human health impact, extraction and treatment techniques. The Egyptian Journal of Aquatic Research. 46(3), 207-220.
46. Mrema, E. J., Rubino, F. M., Brambilla, G., Moretto, A., Tsatsakis, A. M., & Colosio, C. (2013). Persistent organochlorinated pesticides and mechanisms of their toxicity. Toxicology, 307, 74-88.
47. Singh, Z., Kaur, J., Kaur, R., & Hundal, S. S. (2016). Toxic effects of organochlorine pesticides: a review. American Journal of BioScience, 12(3), 11-18.
48. Kiran, P. S., Mandal, P., Jain, M., Ghosal, P. S., & Gupta, A. K. (2024). A comprehensive review on the treatment of pesticide-contaminated wastewater with special emphasis on organophosphate pesticides using constructed wetlands. Journal of Environmental Management, 368, 122163.
49.
50. Kumar, S., Kaushik, G., Villarreal-Chiu, J. F. (2016). Scenario of organophosphate pollution and toxicity in India: a review. Environmental Science and Pollution Research, 23(10), 9480–9491.
51. Gupta, R.C., Malik, J.K., Milatovic, D. (2011). Organophosphate and carbamate pesticides. Reproductive and developmental toxicology, 471-486.
52. Kolodiazhnyi, O.I., Kolodiazhna, A.O. (2024). Stereoselective Syntheses of Organophosphorus Compounds. Symmetry, 16(3), 342.
53. Blanco-Muñoz, J., Escamilla-Núñez, C., Lagunas-Martínez, A., Aguilar-Garduño, C., Burguete-García, A. I., Cebrian, M., & Lacasaña, M. (2024). Association between exposure to organophosphate pesticides and cytokine levels in a population of flower workers in Mexico. Environmental Toxicology and Pharmacology, 110, 104521.
54. Costa, L.G. (2018). Organophosphorus compounds at 80: some old and new issues. Toxicological Sciences, 162(1), 24-35.
55. Syed, S., Gurcoo, S. A., Farooqui, A. K., Nisa, W., Sofi, K., & Wani, T. M. (2015). Is the World Health Organization-recommended dose of pralidoxime effective in the treatment of organophosphorus poisoning? A randomized, double-blinded and placebo-controlled trial. Saudi journal of anaesthesia, 9(1), 49-54.
56. Pampalakis, G. (2024). Classification, Chemical, and Toxicological Properties of Carbamate Nerve Agents. Journal of Xenobiotics, 14(4), 1729-1756.
57. Ripley, B.D., Chau, A.S. (2020). Carbamate pesticides. In Anal Of Pesticides In Water Anal Nitrogen Containing Pesticides. Edition 1st Edition. First Published 1982. Imprint CRC Press. Pages 182. eBook ISBN 9780429292774.
58. Kaur, R., Mavi, G. K., Raghav, S., & Khan, I. (2019). Pesticides classification and its impact on environment. International Journal of Current Microbial and Applied Sciences, 8(3), 1889-1897.
59. Espinoza, L., & da Silva, J. (2024). 31 Acetylcholine Overload: Organophosphate and Carbamate Exposures. Medical Toxicology, 352.
60. Patel, S., & Sangeeta, S. (2019). Pesticides as the drivers of neuropsychotic diseases, cancers, and teratogenicity among agro-workers as well as general public. Environmental Science and Pollution Research, 26 (1), 91-100.
61. Hodoşan, C., Gîrd, C. E., Ghica, M. V., Dinu-Pîrvu, C. E., Nistor, L., Bărbuică, I. S., ... & Popa, L. (2023). Pyrethrins and pyrethroids: a comprehensive review of natural occurring compounds and their synthetic derivatives. Plants, 12(23), 4022.
62. Sun, W., Shahrajabian, M. H., & Cheng, Q. (2020). Pyrethrum an organic and natural pesticide. Journal of biology and Environmemntal Science, 14(40), 41-44.
63. Chrustek, A., Hołyńska-Iwan, I., Dziembowska, I., Bogusiewicz, J., Wróblewski, M., Cwynar, A., Olszewska-Słonina, D. (2018). Current research on the safety of pyrethroids used as insecticides. Medicina, 54, 61.
64. Chen, S., Xiao, X., Qi, Z., Chen, L., Chen, Y., Xu, L., Zhang, L., Song, X., Li, Y. (2022). Effects of prenatal and infant daily exposure to pyrethroid pesticides on the language development of 2-year-old toddlers: A prospective cohort study in rural Yunnan, China. Neurotoxicology, 92,180-190.
65. Ahamad, A., Kumar, J. (2023). Pyrethroid pesticides: An overview on classification, toxicological assessment and monitoring. Journal of Hazardous Materials Advances, 1(10), 100284.
66. Bao, W., Liu, B., Simonsen, D.W., Lehmler, H.J. (2020). Association Between Exposure to Pyrethroid Insecticides and Risk of All-Cause and Cause-Specific Mortality in the General US Adult Population. JAMA Interneal Medicine, 180, 367-374.
67. Thatheyus, A. J., & Selvam, A. G. (2013). Synthetic pyrethroids: toxicity and biodegradation. Applied Ecology and Environmental Sciences, 1(3), 33-36.
68. Soderlund, DM. (2010). Toxicology and mode of action of pyrethroid insecticides. InHayes' handbook of pesticide toxicology. Academic Press, 1665-1686.
69. Wolansky, M. J., & Harrill, J. A. (2008). Neurobehavioral toxicology of pyrethroid insecticides in adult animals: a critical review. Neurotoxicology and teratology, 30(2), 55-78.
70. Seppo Saari, D.V.M., Anu Näreaho, D.V.M., Sven Nikander, D.V.M. (2019). Chapter 12 Therapy and Control. In Canine Parasites and Parasitic Diseases. Academic Press, An imprint of Elsevier, 247-254. ISBN: 9780128141137.
71. Pretty, J., Pervez, Bharucha, Z. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. Insects, 6(1), 152-182.
72. Özkara, A., Akyıl, D., & Konuk, M. (2016). Pesticides, environmental pollution, and health. In Environmental health risk-hazardous factors to living species. IntechOpen, .
73. Riyaz, M., Ahmad Shah, R., & Sivasankaran, K. (2022). Pesticide Residues: Impacts on Fauna and the Environment. IntechOpen, DOI: 10.5772/63094.
74. Yeung, M. T., Kerr, W. A., Coomber, B., Lantz, M., McConnell, A., Yeung, M. T., & McConnell, A. (2017). Why maximum residue limits for pesticides are an important international issue. Declining International Cooperation on Pesticide Regulation: Frittering Away Food Security. Palgrave Macmillan, Cham, 1-9. https://doi.org/10.1007/978-3-319-60552-4_1.

75. Manjarres-López, D.P., Andrades, M. S., Sánchez-González, S., Rodríguez-Cruz, M.S., Sánchez-Martín, M.J., & Herrero-Hernández, E. (2021). Assessment of pesticide residues in waters and soils of a vineyard region and its temporal evolution. Environmental Pollution, 284, 117463.
76. Copaja, S.V., Gatica-Jeria, P. (2021). Effects of clay content in soil on pesticides sorption process. Journal of the Chilean Chemical Society, 66(1), 5086-5092.
77. Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., & Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. International journal of environmental research and public health, 18(3), 1112.
78. Ataikiru, T.L., Okpokwasili, G.S.C., & Okerentugba, P.O. (2019). Impact of pesticides on microbial diversity and enzymes in soil. South Asian Journal of Research in Microbiology, 4(2), 1-16.
79. Hussain, S., Siddique, T., Saleem, M., Arshad, M., Khalid, A. (2009). Impact of pesticides on soil microbial diversity, enzymes, and biochemical reactions. Advances in agronomy, 102, 159-200.
80. Ganaie, M. I., Jan, I., Mayer, A. N., Dar, A. A., Mayer, I. A., Ahmed, P., & Sofi, J. A. (2023). Health risk assessment of pesticide residues in drinking water of upper Jhelum region in Kashmir Valley-India by GC-MS/MS. International Journal of Analytical Chemistry, 2023(1), 6802782.
81. Pérez-Lucas, G., Vela, N., El Aatik, A., Navarro, S. (2018). Environmental risk of groundwater pollution by pesticide leaching through the soil profile. In Pesticides-use and misuse and their impact in the environment. IntechOpen, 19. https://doi.org/10.5772/intechopen.82418.
82. Li, X. H., Wang, W., Wang, J., Cao, X. L., Wang, X. F., Liu, J. C., ... & Jiang, X. N. (2008). Contamination of soils with organochlorine pesticides in urban parks in Beijing, China. Chemosphere, 70(9), 1660-1668.
83. Gonçalves, C. R., & da Silva Delabona, P. (2022). Strategies for bioremediation of pesticides: challenges and perspectives of the Brazilian scenario for global application–a review. Environmental Advances, 8, 100220.
84. World Health Organization (2020). Chemical safety: Pesticides. World Health Organization. https://www.who.int/news-room/questions-and-answers/item/chemical-safety-pesticides
85. Sankhla, M. S., Kumari, M., Sharma, K., Kushwah, R. S., & Kumar, R. (2018). Water contamination through pesticide & their toxic effect on human health. International journal for research in applied science and engineering technology, 6(1), 967-970.
86. Tarla, D. N., Erickson, L. E., Hettiarachchi, G. M., Amadi, S. I., Galkaduwa, M., Davis, L. C., ... & Pidlisnyuk, V. (2020). Phytoremediation and bioremediation of pesticide-contaminated soil. Applied Sciences, 10(4), 1217.
87. Yañez-Ocampo, G., Wong-Villarreal, A., Del Aguila-Juarez, P., Lugo-de la Fuente, J., & Vaca-Paulin, R. (2016). Composting of soils polluted with pesticides: A microbial approach and methods for monitoring. JSM Environmental Science and Ecology, 4(1032), 1010-1016.
88. Mishra, C. S. K., Samal, S., & Samal, R. R. (2022). Evaluating earthworms as candidates for remediating pesticide contaminated agricultural soil: A review. Frontiers in Environmental Science, 10, 924480.
89. Sanchez-Hernandez, J. C. (2019). Bioremediation of pesticide-contaminated soils by using earthworms. In Bioremediation of agricultural soils (pp. 165-192). CRC Press. ISBN 9781315205137.
90. Ssemugabo, C., Bradman, A., Ssempebwa, J. C., Sillé, F., & Guwatudde, D. (2022). Pesticide Residues in Fresh Fruit and Vegetables from Farm to Fork in the Kampala Metropolitan Area, Uganda. Environmental Health Insights, 16. https://doi.org/10.1177/11786302221111866
91. Damalas, C.A., Koutroubas, S.D. (2016). Farmers' exposure to pesticides: toxicity types and ways of prevention. Toxics. 4(1), 1.
92. Ansari, I., El-Kady, M. M., Mahmoud, A. E. D., Arora, C., Verma, A., Rajarathinam, R. K., ... & Mittal, J. (2024). Persistent pesticides: Accumulation, health risk assessment, management and remediation: an overview. Desalination and Water Treatment, 317, 100274.
93. Stanton, R. L., Morrissey, C. A., & Clark, R. G. (2018). Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. Agriculture, Ecosystems & Environment, 254, 244-254.
94. World Health Organization (WHO). (2022): Pesticide residues in food. WHO headquarters in Geneva Avenue Appia 20, 1211 Geneva, Switzerland https://www.who.int/news-room/fact-sheets/detail/pesticide-residues-in-food
95. European Food Safety Authority (EFSA), Carrasco Cabrera L, Medina Pastor P. (2022). The 2020 European Union report on pesticide residues in food. EFSA Journal, . 20(3), e07215.
96. Leskovac, A., Petrović, S. (2023). Pesticide use and degradation strategies: food safety, challenges and perspectives. Foods, 12(14), 2709.
97. Khatun, P., Islam, A., Sachi, S., Islam, M. Z., & Islam, P. (2023). Pesticides in vegetable production in Bangladesh: A systemic review of contamination levels and associated health risks in the last decade. Toxicology Reports, 11, 199-211.
98. Ahmad, M. F., Ahmad, F. A., Alsayegh, A. A., Zeyaullah, M., AlShahrani, A. M., Muzammil, K., ... & Hussain, S. (2024). Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. Heliyon, 10 (7), e29128.
99. Pathak, V.M., Verma, V.K., Rawat, B.S., Kaur, B., Babu, N., Sharma, A., Dewali, S., Yadav, M., Kumari, R., Singh, S., Mohapatra, A. (2022). Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. Frontiers in microbiology, 13, 962619.
100. Abbassy, M. A., Khalifa, M. A., Nassar, A. M., El-Deen, E. E. N., & Salim, Y. M. (2021). Analysis of organochlorine pesticides residues in fish from Edko Lake (North of Egypt) using eco-friendly method and their health implications for humans. Toxicological Research, 37(4), 495-503.
101. Magna, E.K., Koranteng S.S., Donkor, A., Gordon, C. (2022). Levels of persistent organochlorine compounds in nile Tilapia (Oreochromis niloticus) from three cage aquaculture farms on the volta basin of Ghana: implications for human health. Environmental Processes, 9(3), 52.
102. Boedeker, W., Watts, M., Clausing, P., & Marquez, E. (2020). The global distribution of acute unintentional

pesticide poisoning: estimations based on a systematic review. BMC public health, 20(1), 1-19. https://doi.org/10.1186/s12889-020-09939-0
103. Islam, M. A., Amin, S. N., Rahman, M. A., Juraimi, A. S., Uddin, M. K., Brown, C. L., & Arshad, A. (2022). Chronic effects of organic pesticides on the aquatic environment and human health: A review. Environmental Nanotechnology, Monitoring & Management, 18, 100740.
104. Adebisi, F., Dauda, M., & Anjorin, T. (2023). A Review on Global Pesticide Use and Food Contamination: African Perspective. Pollution, 9(4), 1706-1730.
105. Manyilizu, W.B. (2019). Pesticides, anthropogenic activities, history and the health of our environment: lessons from Africa. Pesticides-use and misuse and their impact in the environment. Intechopen, 111-120. DOI: 10.5772/intechopen.82600.
106. Sheahan, M., Barrett, C. B., & Goldvale, C. (2017). The unintended consequences of agricultural input intensification: human health implications of pesticide use in Sub-Saharan Africa. Vice Presidency for Economic Governance and Kowledge Management, BR, 8(4), 8.
107. Williamson, S., Ball, A., & Pretty, J. (2008). Trends in pesticide use and drivers for safer pest management in four African countries. Crop protection, 27(10), 1327-1334.
108. Anaduaka, E. G., Uchendu, N. O., Asomadu, R. O., Ezugwu, A. L., Okeke, E. S., & Ezeorba, T. P. C. (2023). Widespread use of toxic agrochemicals and pesticides for agricultural products storage in Africa and developing countries: Possible panacea for ecotoxicology and health implications, Heliyon, 9(4), e15173.
109. Haggblade, S., Diarra, A., Jiang, W., Assima, A., Keita, N., Traore, A., & Traore, M. (2021). Fraudulent pesticides in West Africa: a quality assessment of glyphosate products in Mali. International Journal of Pest Management, 67(1), 32-45.
110. Oluwole, O., & Cheke, R. A. (2009). Health and environmental impacts of pesticide use practices: a case study of farmers in Ekiti State, Nigeria. International journal of agricultural sustainability, 7(3), 153-163.
111. Snyder, J., Smart, J., Goeb, J., Tschirley, D. Pesticide use in Sub-Saharan Africa: Estimates, projections, and implications in the context of food system transformation. Context of Food System Transformation. 2015. IIAM Research Report No. 8E. https://doi.org/10.22004/ag.econ.230980
112. Jadaa, W., Mohammed, H. (2023). Heavy metals–definition, natural and anthropogenic sources of releasing into ecosystems, toxicity, and removal methods–an overview study. Journal of Ecological Engineering 2023, 24(6), 249-271.
113. Gutiérrez-Ravelo, A., Gutiérrez, Á. J., Paz, S., Carrascosa-Iruzubieta, C., González-Weller, D., Caballero, J. M., ... & Hardisson, A. (2020). Toxic metals (Al, cd, pb) and trace element (b, ba, co, cu, cr, fe, li, mn, mo, ni, sr, v, zn) levels in sarpa salpa from the north-eastern atlantic ocean region. International Journal of Environmental Research and Public Health, 17(19), 7212.
114. Abd Elnabi, M. K., Elkaliny, N. E., Elyazied, M. M., Azab, S. H., Elkhalifa, S. A., Elmasry, S., & Mahmoud, Y. A. G. (2023). Toxicity of heavy metals and recent advances in their removal: a review. Toxics, 11(7), 580.
115. Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanism and health effects of heavy metal toxicity in humans. Poisoning in the modern world-new tricks for an old dog. Intechopen, 10, 70-90.
116. Du, B., Zhou, J., Lu, B., Zhang, C., Li, D., Zhou, J., & Zhang, H. (2020). Environmental and human health risks from cadmium exposure near an active lead-zinc mine and a copper smelter, China. Science of the Total Environment, 720, 137585.
117. Järup, L., & Åkesson, A. (2009). Current status of cadmium as an environmental health problem. Toxicology and applied pharmacology, 238(3), 201-208.
118. Doccioli, C., Sera, F., Francavilla, A., Cupisti, A., & Biggeri, A. (2024). Association of cadmium environmental exposure with chronic kidney disease: A systematic review and meta-analysis. Science of The Total Environment, 906, 167165.
119. Yimthiang, S., Pouyfung, P., Khamphaya, T., Kuraeiad, S., Wongrith, P., Vesey, D. A., & Satarug, S. (2022). Effects of environmental exposure to cadmium and lead on the risks of diabetes and kidney dysfunction. International journal of environmental research and public health, 19(4), 2259.
120. Liu, Y., Chen, Q., Li, Y., Bi, L., Jin, L., & Peng, R. (2022). Toxic effects of cadmium on fish. Toxics, 10(10), 622.
121. Wu, H., Liao, Q., Chillrud, S. N., Yang, Q., Huang, L., Bi, J., & Yan, B. (2016). Environmental exposure to cadmium: health risk assessment and its associations with hypertension and impaired kidney function. Scientific reports, 6(1), 29989.
122. Zulfiqar, U., Haider, F. U., Ahmad, M., Hussain, S., Maqsood, M. F., Ishfaq, M., & Eldin, S. M. (2023). Chromium toxicity, speciation, and remediation strategies in soil-plant interface: A critical review. Frontiers in Plant Science, 13, 1081624.
123. Prasad, S., Yadav, K. K., Kumar, S., Gupta, N., Cabral-Pinto, M. M., Rezania, S., & Alam, J. (2021). Chromium contamination and effect on environmental health and its remediation: A sustainable approaches. Journal of Environmental Management, 285, 112174.
124. Iyer, M., Anand, U., Thiruvenkataswamy, S., Babu, H. W. S., Narayanasamy, A., Prajapati, V. K., & Vellingiri, B. (2023). A review of chromium (Cr) epigenetic toxicity and health hazards. Science of the Total Environment, 882, 163483.
125. Shin, D. Y., Lee, S. M., Jang, Y., Lee, J., Lee, C. M., Cho, E. M., & Seo, Y. R. (2023). Adverse human health effects of chromium by exposure route: a comprehensive review based on toxicogenomic approach. International Journal of Molecular Sciences, 24(4), 3410.
126. Georgaki, M.N., & Charalambous, M. (2023). Toxic chromium in water and the effects on the human body: a systematic review. Journal of Water and Health, 21(2), 205-223.
127. Fatnani, D., Patel, M., Parida, A.K. (2023). Regulation of chromium translocation to shoot and physiological, metabolomic, and ionomic adjustments confer chromium stress tolerance in the halophyte Suaeda maritima. Environmental Pollution, 320, 121046.
128. Charkiewicz, A.E. (2024). Is Copper Still Safe for Us? What Do We Know and What Are the Latest Literature

Statements?. Current Issues in Molecular Biology, 46(8), 8441-8463.
129. Fan, A. M. (2023). Assessment of metals in drinking water with specific references to lead, copper, arsenic, and selenium. In Toxicology of Metals. CRC Press, I, 39-53.
130. Domingo, J.L. A Literature Review of the Environmental and Health Risks of Copper Foil Manufacturing Plants in Relation to a New Facility Planned in Catalonia, Spain. Journal of Environmental & Earth Sciences, 6(2), 29-41.
131. Taylor, A. A., Tsuji, J. S., McArdle, M. E., Adams, W. J., & Goodfellow Jr, W. L. (2023). Recommended reference values for risk assessment of oral exposure to copper. Risk Analysis, 43(2), 211-218.
132. Zhao, J., Xu, Z., Wang, X., Wan, S., Chen, W., Huang, W., & Zhang, H. (2024). Environmental copper exposure, placental cuproptosis, and miscarriage. Environmental Pollution, 348, 123847.
133. EFSA Scientific Committee, More, S. J., Bampidis, V., Benford, D., Bragard, C., Halldorsson, T. I., & Leblanc, J. C. (2023). Re-evaluation of the existing health-based guidance values for copper and exposure assessment from all sources. EFSA Journal, 21(1), e07728.
134. Raj, K., & Das, A.P. (2023). Lead pollution: Impact on environment and human health and approach for a sustainable solution. Environmental Chemistry and Ecotoxicology, 5.79-85.
135. Sonne, C., Lam, S.S., Kanstrup, N. (2023). The environmental threats from lead ammunition. Eco-Environment & Health, 2(1),16.
136. World Health Organization.(2023). Exposure to lead: a major public health concern. Preventing disease through healthy environments. World Health Organization. Geneva. 2023 Aug 16.
137. Ghosh, J. R. (2023). Effects of Lead on Growth of Children. Anthropological Research in India: Retrospect and Prospects. Lexiton Books 4501 Forbes, Boulevard Suite 200, Maryland, 20706, 209.
138. Schoofs, H., Schmit, J., Rink, L. (2024). Zinc toxicity: understanding the limits. Molecules, 29(13), 3130.
139. Vuong, X. T., Vu, L. D., Duong, A. T. T., Duong, H. T., Hoang, T. H. T., Luu, M. N. T., ... & Minh, T. B. (2023). Speciation and environmental risk assessment of heavy metals in soil from a lead/zinc mining site in Vietnam. International Journal of Environmental Science and Technology, 20(5), 5295-5310.
140. El-Agawany, N. I., & Kaamoush, M. I. (2023). Role of zinc as an essential microelement for algal growth and concerns about its potential environmental risks. Environmental Science and Pollution Research, 30(28), 71900-71911.
141. Chasapis, C. T., Ntoupa, P. S. A., Spiliopoulou, C. A., & Stefanidou, M. E. (2020). Recent aspects of the effects of zinc on human health. Archives of toxicology, 94, 1443-1460.
142. Du, B., Zhang, H., Ji, D., Huang, Z., Fangqun, G., & Zhou, J. (2023). Environmental contamination and health risk assessment to toxic elements in an active lead–zinc mining area. Exposure and Health, 15(3), 687-698.
143. Boreiko, C.J. (2010). Overview of health risk assessments for zinc. Journal of Toxicology and Environmental Health, Part A, 73(2-3), 166-174.
144. Afzaal, M., Hameed, S., Liaqat, I., Ali Khan, A. A., abdul Manan, H., Shahid, R., & Altaf, M. (2022). Heavy metals contamination in water, sediments and fish of freshwater ecosystems in Pakistan. Water Practice & Technology, 17(5), 1253-1272.