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Ecological Risk Assessment of Inorganic Arsenic and Mercuric Fungicides Through Biological Tools

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ABSTRACT

This review discusses the use, mode of action, biomarkers, and bioindicators of inorganic arsenic and mercuric fungicides, as well as their effects on the environment and human health. The most prevalent indicator of exposure to arsenic is the measurement of total arsenic in urine. Biomarkers of exposure for arsenic and inorganic fungicides incudes the analysis of hair, urine, blooda and nails. Bio indicators are species or group of species that are used to indicate adverse effect of contamination. Freshwater fish species act as a very good bio indicator for inorganic arsenic. Tree bark, rice fields and sea birds could be a valuable indicator of inorganic arsenic contamination. Black Piranha, fish and earthworms are an ideal bio indicator of inorganic mercury. Inorganic arsenic compounds are known to be highly carcinogenic and toxic compounds. Mercuric fungicide is very toxic when inhaled by humans or animals it causes severe health issues and when absorbed by plants it retards their growth. To estimate the daily dose of arsenic exposure to humans through absorption, ingestion and other pathways, Average daily dose is implemented by using two equations from the US EPA. To determine the ecological risk assessment a simplified equation was proposed by FDA i.e. HQ = E/RfD. Overall, the review emphasizes the need for heightened awareness, regulation, and alternative approaches to fungicide use, with a focus on minimizing the use of inorganic arsenic and mercuric fungicides to safeguard the environment and promote sustainable agricultural practices.

INTRODUCTION

Fungicide is defined as a poisonous substance that is used to inhibit the growth of fungi and to kill fungi. It is a type of pesticide. Generally, to control parasitic fungi that either cause damage to crops or ornamental plants or can be harmful to the health of humans or domestic animals fungicides are used. The majority of the fungicides are applied to plants in the form of dusts or sprays (Carisse O, 2010). Some of them are applied to seeds as a cover for protection before germination. Fungicides also known as antimitotic Fungicides work by disrupting the critical cellular process of parasitic fungi. It binds with specific enzymes to intersperse the metabolic pathways that are associated with cellular respiration (Colbourn P et al., 1975).

Numerous anthropogenic and natural activities exculpate arsenic into the environment in both organic and inorganic forms. Even at relatively low concentrations arsenic is a major threat to human health (Wightwick A et al., 2010). According to the United States Environmental Protection Agency, inorganic arsenic is a Group-A human carcinogen. Natural sources of arsenic in the soil are the weathering of the arsenic-rich parent material and volcanic eruptions and anthropogenic sources include activities like the combustion of fossil fuel, smelting, mining, wood preservatives, arsenic-containing pesticides, insecticides, herbicides, and fungicides (Wighrwick AM et al., 2012 & Amyot M et al., 1997). Arsenic is widely distributed throughout the crustal plate mostly in the form of arsenic sulfide or metal arsenates or arsenide. Igneous and sedimentary rocks are enriched with arsenic (De Flora et al., 1994 & Mathew C et al., 1976). Weathering of these rocks increases the

amount of arsenic in the soil. Arsenic exists in the form of arsenate in water, if the water is oxygenated. It is present in the form of arsenite if the water in under reducing conditions. Arsenic is naturally present in soil from 0.1- 40 ppm but it may vary among different areas (Kennedy C & Frias-Espericueta M et al., 2019).

When an inorganic form of arsenic is absorbed in the body it is metabolized in organic form which is easier to be excreted out of the body through urine (Frias-Espericueta M et al., 2019). There are two basic processes that are involved in the metabolism of inorganic arsenic fungicides (Abbas G et al., 2018). The first process which we are going to discuss is the reduction and oxidation process. In it arsenate (As^{+5}) is reduced to arsenite (As^{+3}) (Khalid S et al., 2017 & Mombo S et al., 2016). The second process is known as the methylation process in which arsenite in converted into monomethyarsonic acid and dimethyarsisnic acid also abbreviated as MMA and DMA respectively (Xiong T et al., 2016). The excretion of inorganic arsenic from the body then occurs in the form of MMA and DMA as both of these acids are readily excreted in urine (Shahid M et al., 2015 & Ottesen RT et al., 2013).

When a farmer is applying fungicides to an agricultural crop or plant, unavoidably some of the quantity of the chemical spray will not come up to scratch and miss the target. The chemical will penetrate into the surface of the soil and will persist there for some time (Maluqi H et al., 2018). Eventually, it will migrate off-site because of leaching or rum off. Moreover, some of these chemicals will migrate off-site due to aerial drift and will eventually enter nearby water bodies or groundwater resources and will cause adverse impacts on aquatic organisms. The metabolism of inorganic arsenic fungicide in the environment is affected by the properties of the chemical such as its ability to bind the soil, and ecological factors such as type of soil, topography, rainfall, and agricultural management practices (Bernhoft RA, 2012 & Branco V et al., 2012). The key to understanding the metabolism of arsenic in the environment is its adsorption-desorption onto the soil. When farmers apply arsenic fungicides to the agricultural area some of the arsenic is left on the topsoil (Chehmi L et al., 2012). This arsenic will not be washed out or dissolved by rainwater or flood in oxidized condition because of its affinity to manganese, aluminum, iron, and other minerals in the soil. As a result, surface soil will be accumulated with arsenic (Falluel Morel et al., 2012 & Chandrakar V et al., 2016). The increased concentration of arsenic in the topsoil and in irrigation the main cause of the increased concentration of arsenic in plants and food grains is water (Niazi NK et al., 2017).

Mercuric fungicide is a harmful and toxic chemical that affects humans, plants, and the environment in numerous ways (Mehmood T et al., 2017). It is categorized as a toxic pollutant that can transpose into many states by oxidation and reduction reactions. Earlier in the 20th century Mercuric fungicides were used in seed treatments (Abid M et al., 2016). Mercury toxicity has increased with time due to soil contamination by heavy metals and a significant amount of mercury is used as a fungicide in agricultural fields. The absorption of mercury is specific to lichens, mycorrhizae, wetland plants, bryophytes plants, and crop vegetation. Mercury accumulates in plants' roots and shoots which results in soil contamination (Esdaile L et al., 2018). The growth of plants and evolution of lichens and mosses is inhibited by the Metallic mercury and mercury compounds that are present in the soil. By observations of experiments the growth of toadstools on turf and the activity of ascomycetes is also retarded by mercury (Astani E et al., 2011). No fungicidal action of mercury is being observed in vitro but the rate of growth of hyphae is affected by mercury vapors (Zheng N et al., 2011). The lack of fungicidal properties of mercury and its good performance in controlling certain soil-borne diseases are adapted by assuming that differential retardation disturbs the links that are crucial for infection (Anzai K et al., 2012 & Rahman MA et al., 2014). Mercury fungicides include mercurous chloride, phenyl mercury acetate, ethyl mercury chloride, methoxyethyl mercury chloride, etc.

The metabolism of all forms of inorganic mercury in laboratory mammals and humans is the same according to recent observations. Inorganic mercury perforates in an oxidation–reduction cycle when it is absorbed (Rahman MA et al., 2014). Elemental mercury is oxidized to the divalent inorganic cation in the lungs and red blood cells. Absorbed divalent cation from exposure to mercuric mercury compounds can, in turn, be reduced to the

metallic or monovalent form and released as exhaled elemental mercury vapor (Muhammad A et al., 2013 & Singh AP et al., 2017). Elemental mercury vapors enter rapidly in the bloodstream when inhaled. The dissolved vapor undergoes rapid oxidation in the red blood cells, to its inorganic divalent form by the hydrogen peroxide–catalase pathway (Pandey C et al., 2017 & Fenendez Martinez et al., 2019). It is also believed that the rate of oxidation is influenced by the following: (1) Concentration of catalase in the tissue; (2) Autogenous production of hydrogen peroxide; (3) Availableness of mercury vapor at the oxidation site.

According to some research, there are chances of oxidation of elemental mercury in the brain, lungs, liver, and in all other tissues to some extent (Hosseini M et al., 2013). Un-oxidized elemental mercury can be oxidized and become trapped in the brain because it is more strenuous for the divalent form to exit the brain via the blood-brain barrier (Lu L et al., 2017 & Van den Toren et al., 2019).

METHODS

The Method of reviewing the ecological risk assessment of inorganic arsenic and mercuric fungicides through biological tools involved secondary data collection including:

Table 1. Methodology

Evaluation of existing studies	Assessing the available scientific literature to gather information on the ecological risks associated with inorganic arsenic and mercuric fungicides. This includes reviewing studies on the effects of these substances on various organisms, ecosystems, and ecological processes.
Identification of exposure pathways	Investigating the pathways through which inorganic arsenic and mercuric fungicides enter the environment and potentially impact different organisms. This involves identifying sources of contamination, such as agricultural practices or industrial activities, and understanding how these substances can be transferred through different trophic levels in ecosystems.
Assessment of toxicological effects	Examining the toxicological effects of inorganic arsenic and mercuric fungicides on different organisms, including plants, animals, and microorganisms. This involves evaluating the toxicity thresholds, dose-response relationships, and potential sub-lethal and chronic effects on various ecological receptors.
Application of biological tools	Investigating the use of biological tools, such as biomarkers, bioindicators, and ecological modeling, in assessing the ecological risks posed by inorganic arsenic and mercuric fungicides. This includes exploring their applicability, sensitivity, and reliability in detecting and quantifying the impacts of these substances on different ecological components.

RESULTS AND DISCUSSION

A biomarker is a trait in an organism that is measurable and it responds to a toxicant. It is actually a disturbance in the normal functioning of an organism (Raissy M et al., 2014). The potential application of biomarkers is in impact assessment and in monitoring the condition of living organisms as they provide evidence of exposure to any chemical, stressor, or any ecological impact. The properties of a good biomarker are given below:

1. It can be measured easily
2. The measurements are cheap and fast
3. They are specific to the type of toxicant
4. They show a dose-response relationship

Biomarkers are of three types which are biomarkers of exposure, susceptibility, and effect. The biomarkers of exposure for inorganic arsenic fungicides are of the greatest attention. The most prevalent indicator of exposure to arsenic is the measurement of total arsenic in urine. Another biomarker of exposure for arsenic is urinary porphyrins (Pobi KK et al., 2019). An example of a susceptibility biomarker of arsenic is variability in the metabolism of arsenic which results in

polymorphism in the genes that code for the enzyme that metabolizes arsenic.

Biomarkers of exposure for arsenic include the analysis of nails, urine, hair, and blood. Urine: When inorganic arsenic is absorbed in the body it is primarily excreted in the form of urine. It has a half-life of approximately 4 days in humans. If exposure of inorganic arsenic is excessive in drinking water than it will lead to urinary arsenic levels > 700 µg/L (Manavi PN et al., 2018). Blood: Only in the scenario of acute arsenic poisoning blood arsenic is a useful biomarker because arsenic in the blood is cleared in few hours after it is absorbed. Hair and nails: For analysis of past arsenic exposure hair and nails can be a good biomarker. When arsenic is absorbed it is accumulated in hair and nails because arsenic[3] binds with sulfhydryl groups in keratin. A group of people who are exposed to more inorganic arsenic in drinking water and soil have increased concentrations of arsenic in nails and hair (Nogara PA et al., 2019).

For analysis of the exposure of inorganic mercuric fungicides in humans, the following biological media can be used as biomarkers;

Blood: If inorganic mercury is present in blood then it indicates recent exposure to it. Inorganic mercury in the diet is readily absorbed through the gastrointestinal tract and then blood distributes it throughout the body. Usually, the concentration of inorganic mercury in the blood reaches to a maximum within 4 to 14 hours and after 20 to 30 hours it undergoes clearance from the blood to other body tissues. According to WHO the normal mean concentration of mercury in the blood is to be between 5 to 10 µg/L in the individuals who do not consume any contaminated fish (Natasha M et al., 2020).

Hair: For estimation of long-term average exposure of inorganic mercury hair is a preferred choice because it provides an integrative, simple, and non-invasive sampling. Incorporating inorganic mercury into the hair prevents it from returning to the blood, making it a useful long-term biomarker for inorganic mercury Ruggeiri F et al., 2017). Urine: occurrence of acute inorganic mercury poisoning urine is considered a good biomarker (Singh S et al., 2020).

Bioindicators are species or groups of species that are used to indicate adverse effects of contamination. Plants, microbes, animals, and planktons are used to screen the health of the natural ecosystem in the environment. Through their chemical, physiological, and behavioral changes, they convey information on changes in the environment (Sysalova J et al., 2013).

Characteristics of a good bioindicator are given below;

1. It can be easily raised in the lab.
2. Its sampling is easy
3. It can accumulate high levels of pollutants without dying
4. The dose-response relationship can be observed easily

Bioindicators for inorganic arsenic fungicides include:

Freshwater fish species act as a very good bioindicator for inorganic arsenic. Fish are continually exposed to arsenic contamination because of the uptake of contaminated food and through their gills. Inorganic arsenic swells the kidney cells of the fish. It also increases the mucus production in fish which can cause suffocation or detrimental effects on gill epithelium. It can also interfere with the immune system of the fish by suppressing the antibodies. Arsenites are absorbed quickly in fish and are more harmful than arsenate compounds (Zamani Hargalani F et al., 2014).

Tree bark could be a valuable indicator of inorganic arsenic contamination. 32 tree species including *M. indica, P. sylvestris, E. globulus*, contain high amounts of heavy metals in their soil. At high levels of arsenic in the soil, the nodule bacteria lose the amount of leghemoglobin, therefore bacteria destroy and it can be used as a bioindicator in soil toxicity assessment (Zang T et al., 2020). Rice fields are also a good bioindicator of inorganic arsenic as they show stunt growth, brown spots, and scorching on leaves when they are grown on soil contaminated with inorganic arsenic. Sea birds are also a good bioindicator for inorganic arsenic in marine environments because of their diet. They can provide evidence of bioaccumulation by sampling feathers and eggs (Duncan EG et al., 2017).

Bio indicators for inorganic mercuric fungicides:

According to many studies, carnivorous fish accumulates more amount of fish than any other species. Black Piranha is an ideal bioindicator of inorganic mercury as 80% of its diet is fish based, it

lives in quite waters and do not make long migrations.

Earthworms act as a good alternative of bioindicators other than traditionally used organisms i.e. fish because they are simple, well-studied organisms and can accumulate inorganic mercury for polluted soil and other media. A few studies have also documented inorganic mercury concentration in the tissues of earthworms (Clemens S et al., 2016).

Effects of Inorganic Arsenic Fungicides

Inorganic arsenic compounds are known to be highly carcinogenic and toxic compounds. Chronic exposure to inorganic arsenic compounds in any form has more effects on health than any other toxicants. Poisoning of arsenic takes 8 to 14 years to show its effects on health (Sytar O et al., 2013). It also depends upon the amount of arsenic ingested and the immunity of the affected person. Some toxic actions of inorganic arsenic are listed below;

The persistence and presence of inorganic arsenic fungicides in agricultural soils may have negative effects on soil organisms such as earthworms and soil microorganisms. These organisms are responsible for crucial functions of soil such breakdown of organic matter and in facilitating the nutrient cycle. When these organisms are affected by the toxicity of arsenic these crucial functions of soil are also affected (Faita F et al., 2013).

Likewise, when these fungicide residues make their way into ground and surface water they have a potential to harm the biodiversity and aquatic ecosystem. Arsenic has been shown to induce apoptosis of fin cells in the fish taxa. It also causes gallbladder inflammation, edema, kidney fibrosis, and liver inflammation (Faita F et al., 2013). Arsenic in the soil can disrupt the normal metabolism of plants, resulting in stunted growth, decreased crop yields, low fruit production, reduced leaf numbers, and reduction in biomass.

In birds toxic effects of arsenic includes depression, tremors, gasping, watery diarrhea, etc. Birds can get in contact with arsenic when they drink water from contaminated water surfaces or when they eat plants or grains affected by inorganic arsenic fungicides (Tofan-Lazer et al., 2012).

In humans, the toxicity of arsenic includes denaturing of cellular enzymes, altering gene regulation, disturbing the DNA binding capabilities, disrupting cell division, inhibiting DNA repair, a complication of nervous systems, digestive difficulties, liver diseases, cancer, and diabetes. Many cardiovascular diseases are caused by long-term exposure to inorganic arsenic such as hypertension, atherosclerosis, etc.

Those environments which are affected by inorganic arsenic are characterized by limited species diversity and abundance. If the level of arsenate is very high than only those species will be present which have developed resistance to it.

Studies have shown that approximately 72 million birds are killed annually in America because of the application of inorganic arsenic fungicides. Women farmers who are pregnant and are working in the fields spraying inorganic arsenic fungicides to the crops have more miscarriages and abnormalities in the babies. Studies have shown that prolonged exposure to inorganic arsenic fungicide exposure can contribute to depression among its applicators (Srivastava S et al., 2014).

Pollinators such as honey bees, fruit flies, beetles, etc are highly affected by inorganic arsenic fungicides as its application affects their various activities such as colony mortality, the efficiency of collecting pollens, and foraging behavior. Overuse of inorganic arsenic fungicides in the agricultural field affects the plant communities as they retard the growth of plants and cause the death of some plants and crops (Tiwari S et al., 2017).

Effects of inorganic mercuric fungicides

Mercuric fungicide is very toxic when inhaled by humans or animals it causes severe health issues and when absorbed by plants it retards their growth. It has numerous toxic actions that harm the humans and environment which include:

Mercuric fungicide is inhaled or ingested in humans which results in severe problems like cognitive, sensory, personality, and motor disturbances. Other Prominent symptoms include tremors emotional lability, lack of sleep, memory loss, neuromuscular changes, and headaches. Deficits in motor function, attention, and possibly the visual system may persist for years after occupational exposure has ended, according to a recent study of 75 formerly exposed workers examined using a comprehensive neuropsychological test battery (Gupta P et al., 2018).

Respiratory side effects are exceptionally constant because of short-term and significant level openness to basic mercury vapors. The most common side effects are burning pains, chest tightness, and cough. Chronic cough has been proclaimed in subjects exposed to mercury vapor for numerous weeks (Gupta P et al., 2018).

Side effects of inhalation or absorption of mercuric fungicides and its particles resulted in elevated blood pressure and palpitations. Increased blood pressure and heart rate have been reported due to prolonged exposure due to spills or occupational exposure. Livestock, wild birds that consumed the treated seeds showed toxic symptoms and laid eggs with thin shells and the chick after birth couldn't survive properly and it effected the population size of the bird. Mercuric fungicide retards the growth of plants. The development of lichens and mosses is also constrained. Mercuric ions present in Mercuric fungicide disrupts the antioxidant defense mechanism by changing the modulation of non-protein thiols, ascorbate peroxidase, and glutathione reductase (Padmavathi S).

Exposure to mercury results in an increase in the mortality rate of birds and animals which results in a decrease in the population size of the species. Wildlife and livestock is also being effected due to exposure to mercuric ions. Mercuric ions present in the soil and atmosphere are accountable for the reduction in microbiological activities that are vital to the terrestrial food chain in soil. Mercuric fungicide causes soil contamination and soil pollution. Mercuric ions that are present in freshwater effects the marine ecosystem by altering their population size. In aquatic ecosystems, fish at the upmost of the food chain such as pike contain 3000 times more mercury than the water. Most of the mercury reaches into the atmosphere through evaporation by soil and water which results in air pollution and also disrupts the atmospheric cycles. Overuse of mercuric fungicides in agricultural field effect the plant communities as they retard the growth of plants and cause the death of some plants and crops (Pavithra KG et al., 2023).

Testing for inorganic arsenic fungicides

Unusual concentration of arsenic in blood indicates considerable exposure of arsenic. Arsenic that is absorbed distributes speedily in the storage sites of tissues. Arsenic will not be detected in the specimen of blood except for when the blood specimen is not taken within two days of exposure. The method used for arsenic detection in the blood is called Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) in which the analytic time is of one day (Mohammadnnia E et al., 2019).

Urine 'spot' tests are used to diagnose the presence of arsenic of high amounts in the body still this test does not distinguish between the organic and in organic arsenic form. On the other hand, a specimen test is also done that helps to determine the type of arsenic whether it is organic or in organic. Hydride generation atomic absorption spectrometry and graphic furnace atomic absorption spectrometry is also used for testing of inorganic arsenic in urine. In GFAAS the sample preparation is done by passing the urine specimen through a 0.45 μm Millipore membrane filter and then microwave digestion of the sample is done after adding nitric and hydrochloric acids. In HGAAS the sample preparation of urine specimen is done by reducing it with sodium borohydride to arsine (Martin Yega D et al., 2013).

To find the concentration of arsenic over the past six to twelve months in the body tests on nails and hair are also been carried out. For the detection of inorganic arsenic in nails and hair ICP-MS is used. Tests carried out on nails and hair cannot anticipate whether the level of arsenic in the body will affect human health or not but inorganic arsenic has toxic effects on the human body (Ma Y et al., 2022).

Testing for inorganic mercuric fungicides

Exposure to mercury and its other compounds can be analyzed or determined by using urine, hair or blood samples in the laboratory. The concentration of mercury found in blood or urine is directly proportional to its toxicity. In the laboratory, the samples are collected in trace-metal-free containers. Mercury levels of urine are usually less than 10 to 20 μg/24 hours. Higher level of mercury concentration in urine is harmful and is associated with death (Ma Y et al., 2022).

Hair is also useful to find out the presence of methyl mercury in the body. If the length of hair is long and testing is done carefully it can easily reveal or show the exposure to mercury that occurred months or years ago. Hair sampling is done by cutting approximately 100-150 strands of hair which are about 3 centimeters long. The most

common methods used to measure the amount of inorganic mercury in hair are inductively coupled plasma mass spectrometry (ICP-MS), cold vapor atomic absorption spectrometry (CVAAS), and cold vapor atomic absorption spectrometry (CVAAS) (Ma F et al., 2015).

ERA entails six fundamental processes		
Preparation	Step 1	Describe the background of ERA
	Step 2	Determine and describe the main environmental pressures
	Step 3	Provide examples of environmental metrics and values for ERA.
Assessment	Step 4	Establish risk groups, describe environmental trends, and analyze indicator linkages.
	Step 5	Analyze changes to risks and indicators.
Result	Step 6	Report findings and create risk mitigation plans

Blood testing is the most approved method to detect mercury as it is present in red blood cells. One when recently exposed, have higher levels of mercury in the blood e.g. a large seafood meal may raise blood mercury level, and it declines gradually with time and over weeks. The half-life of inorganic mercury after exposure is 3-4 weeks. The most common technique used for determining the amount of inorganic mercury in blood is CVAAS as it has adequate sensitivity to measure the total amount of inorganic mercury at low ppb levels in blood and also it is comparatively easy to perform in a standard lab. ICP-MS can also be used in the testing of blood for the detection of inorganic mercury but it involves expensive instrumentation and higher per-sample cost (Luo Z et al., 2021).

Environmental Risk Assessment (ERA)

Environmental Risk Assessment is defined as a method that comprises the evaluation of the probability of the adverse impacts of environmental values that occur due to human activities. Environmental risk assessment consists of the following stages:

1. Setting the focus for the assessment with the pertinent background information and preparing for the assessment, which includes gathering and analyzing the material.
2. Organizing or conducting the assessment
3. Interpretation, reporting of the assessment, and application of the results (Liu Z et al., 2022).

Environmental risk assessment helps us to have a greater and better understanding of the environment. An environmental risk assessment plays a vital role as it is used to conclude the risks to the health of humans. It is a lithe tool or approach that can be functional at any scale and is used for numerous environmental problems. It helps to propose important decisions when there is any environmental hazard or danger that can affect human health, ecosystem, and sustainability (Wu Q et al., 2022). The steps involved in the process of Risk assessment for the environment are given in the table above table.

Risk assessments depend on scientific data which is not easy to interpret and is complex or incomplete. Data analysis for risk assessment depends upon the professional judgment that is formed on scientific expertise. To estimate the daily dose of arsenic exposure to humans through absorption, ingestion, and other pathways, the Average daily dose is implemented by using two equations from the US EPA. The assessment was conducted on children and adults (Mandal D et al., 2022).

$$ADD_{ing} = (C \times IRd \times EF \times ED)/BW \times AT \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$ADD_{dermal} = (C \times SA \times SL \times ABS \times EF \times ED)/BW \times AT \ldots.. (2)$$

ADD is known as an average daily dose of elements through ingestion pathways (ADDing)
ADDderm is dermal absorption
C is the Heavy metals concentration
BW is the body weight
EF is exposure frequency
SA stands for skin surface area
AT is an average exposure time
ABS is a dermal absorption factor
SL is a skin adherence factor
ED is exposure duration

Non-Carcinogenic Risks

The following equations are used to analyze the non-carcinogenic risks. THQ refers to the ratio between the reference dose and ADD of each

element. The reference dose of each element is taken from the screening levels of the US EPA.

$$THQ=CDI/RfD$$

$$\text{Total THQ (HI)}= \sum THQ$$

Carcinogenic Risks

Cancer risks are also known as carcinogenic risks (CR) according to EPA they are defined as "the incremental possibility of an individual to get cancer, over a lifetime, as a result of exposure to a potential carcinogen". The following equation was used to find out the carcinogenic risks. CSF is a risk factor for cancer. (Banik G et al., 2021).

$$CR=CDI\times CSF$$

Walkers and his colleagues developed this model of inorganic arsenic carcinogenesis. This is also known as a two-generation model. In this model drinking water accumulated with inorganic arsenic at concentrations of 42.5 and 85 mg/L is given to pregnant mice and then they are monitored for a lifetime. It was observed that there was an increased incidence in lung and liver tumors in mice (Garrai P et al., 2021).

The dose-response model is generally used for arsenic risk assessment, it is then further adjusted according to the situation e.g. Adjustments for Water Intake, assumptions about water consumption in both the study group and the U.S. population must be made to calculate the cancer risks associated with a specific arsenic content in drinking water. According to EPA estimates, Americans use an average amount of water each day per person. Include age, sex, and weight when calculating risk rather than just utilizing a point estimate. Rice and sweet potatoes are the mainstay foods when making adjustments for dietary intake of arsenic (Banik G et al., 2021 & Garai P et al., 2021). When cooked, those foods absorb a lot of water. EPA (2001) modified its lower-bound estimates to take exposure to arsenic in drinking water into consideration as part of its risk assessment.

Inorganic mercuric fungicides have the potential to get biomagnified along the food chain when they enter the aquatic food web. In this context, sharks can accrue substantial mercury concentrations in their tissues and organs. To determine the ecological risk assessment a simplified equation was proposed by FDA i.e.

$$HQ = E/RfD$$

Where E = level of exposure and RfD = reference dose of inorganic mercury

To determine the human health risk assessment USEPA proposed the following equations:

$$ADD_{ing}= (C\times IRd\times EF\times ED)/BW\times AT\ldots (1)$$

$$ADD_{inh} = (C\times IR_{inh}\times EF\times ED)/PEF\times BW\times ED\ldots (2)$$

$$ADD_{dermal}= (C\times SA\times SL\times ABS\times EF\times ED)/BW\times AT\ldots (3)$$

ADD is known as an average daily dose of elements through ingestion pathways (ADD_{ing})

ADD_{dermal} is dermal absorption

ADD_{inh} is the inhalation dose through the mouth and nose

C is the concentration of the heavy metals

BW is the body weight

EF is exposure frequency

SA stands for skin surface area

PEF is a practical emission factor

AT is an average exposure time

ABS is a dermal absorption factor

SL is a skin adherence factor

ED is exposure duration

Geochemical tools can be useful for all the risks explained above. The geochemical model HP1 was developed in the work model. This model can be used as a tool in both ecological risk assessment and human health risk evaluations (Ahmed SF et al., 2022).

CONCLUSION

In conclusion, inorganic arsenic and mercuric fungicides pose significant risks to the environment and human health. Monitoring and assessing exposure to these fungicides through biomarkers and utilizing bioindicators can provide valuable information about contamination levels. Understanding their mode of action and effects on various organisms is crucial for implementing effective measures to minimize their adverse impacts and protect ecosystems and human well-being.

Based on the issues highlighted in the review, the following recommendations can be made:

Regulation and Monitoring: Governments and regulatory bodies should implement strict regulations on the use of inorganic arsenic and mercuric fungicides in agriculture. Regular monitoring programs should be established to assess contamination levels in soil, water, and food products.

Alternatives to Inorganic Fungicides: Encourage the development and adoption of safer and more environmentally friendly alternatives to inorganic fungicides. This could include promoting the use of organic fungicides, biological control methods, crop rotation, and integrated pest management practices.

Education and Awareness: Increase awareness among farmers, agricultural workers, and consumers about the risks associated with inorganic arsenic and mercuric fungicides. Provide information on the safe handling, storage, and disposal of these chemicals, as well as the potential health effects.

Research and Innovation: Support research efforts aimed at understanding the ecological impacts of inorganic fungicides and developing innovative solutions. This could involve studying the mechanisms of toxicity, identifying alternative fungicides, and exploring sustainable agricultural practices that minimize the need for fungicide use.

Risk Communication: Improve communication channels between scientists, policymakers, farmers, and consumers to effectively communicate the risks associated with inorganic fungicides. Transparent information sharing will enable informed decision-making and promote responsible use.

International Collaboration: Foster collaboration among different countries to address the global issue of inorganic fungicide contamination. Sharing knowledge, best practices and research findings can help develop effective strategies for mitigating the risks.

Support for Affected Communities: Provide support and resources to communities that are heavily affected by inorganic fungicide contamination. This could include access to clean drinking water, healthcare facilities, and education on reducing exposure risks.

REFERENCES

1. Abbas, G., Murtaza, B., Bibi, I., Shahid, M., Niazi, N. K., Khan, M. I., Amjad, M., Hussain, M., & Natasha. (2018). Arsenic uptake, toxicity, detoxification, and speciation in plants: Physiological, biochemical, and molecular aspects. *International Journal of Environmental Research and Public Health*, 15(1).
2. Abid, M., Niazi, N. K., Bibi, I., Farooqi, A., Ok, Y. S., Kunhikrishnan, A., Ali, F., Ali, S., Igalavithana, A. D., & Arshad, M. (2016, May 3). Arsenic (V). *International Journal of Phytoremediation*, *18*(5), 442–449.
3. Ahmed, S. F., Kumar, P. S., Rozbu, M. R., Chowdhury, A. T., Nuzhat, S., Rafa, N., Mahlia, T. M. I., Ong, H. C., & Mofijur, M. (2022, February 1). Heavy metal toxicity, sources, and remediation techniques for contaminated water and soil. *Environmental Technology and Innovation*, *25*, 102114.
4. Amyot, M., Mierle, G., Lean, D., & Mc Queen, D. J.. (1997). Effect of solar radiation on the formation of dissolved gaseous mercury in temperate lakes. *Geochimica et Cosmochimica Acta*, 61(5), 975–987.
5. Anzai, K., Ban, N., Ozawa, T., & Tokonami, S. (2012):1112080130-. Fukushima Daiichi Nuclear Power Plant accident: Facts, environmental contamination, possible biological effects, and countermeasures. *Journal of Clinical Biochemistry and Nutrition*, 50(1), 2–8.
6. Astani, E., Vahedpour, M., Babaei, H., & Karimipour, M. (2011), Determination of the total mercury concentration in the Anzali International Wetland, Iran and effect of environmental parameters on its concentration. *Research Journal of Chemistry and Environment*, (June 1), 15:2.
7. Banik, G. C., Deb, S., Khalko, S., Chaudhury, A., Panda, P., & Hogue, A. Arsenic toxicity in water-soil-plant system an alarming scenario and possibility of bioremediation. *Inbioremediation science from theory to practice*. (2021, May 20) (pp. 240–251). CRC Press.
8. Bernhoft, R. A. (2012, October). Mercury toxicity and treatment: A review of the

literature. *Journal of Environmental and Public Health*, *2012*, 460508.

9. Branco, V., Canário, J., Lu, J., Holmgren, A., & Carvalho, C. (2012, February 15). Mercury and selenium interaction in vivo: Effects on thioredoxin reductase and glutathione peroxidase. *Free Radical Biology and Medicine*, *52*(4), 781–793.
10. Carisse, O. (Ed.). (2010, December 14). *Fungicides. BoD–books on demand*.
11. Chandrakar, V., Naithani, S. C., & Keshavkant, S. (2016, May 1). Arsenic-induced metabolic disturbances and their mitigation mechanisms in crop plants: A review. *Biologia*, *71*(4), 367–377.
12. Chehimi, L., Roy, V., Jeljeli, M., & Sakly, M. (2012, September 1). Chronic exposure to mercuric chloride during gestation affects sensorimotor development and later behaviour in rats. *Behavioural Brain Research*, *234*(1), 43–50.
13. Clemens, S., & Ma, J. F. (2016, January 21). Toxic heavy metal and metalloid accumulation in crop plants and foods. *Annual Review of Plant Biology*, *67*(1), 489–512.
14. Colbourn, P., Alloway, B. J., & Thornton, I. (1975). Arsenic and heavy metals in soils associated with regional geochemical anomalies in south-west England. *Science of the Total Environment*, 4(4), 359–363.
15. De Flora, S., Bennicelli, C., & Bagnasco, M.. (1994). Genotoxicity of mercury compounds. A review. *Mutation Research*, 317(1), 57–79.
16. Duncan, E. G., Maher, W. A., Foster, S. D., Krikowa, F., O'Sullivan, C. A., & Roper, M. M. (2017, August 1). Dimethylarsenate (DMA) exposure influences germination rates, arsenic uptake and arsenic species formation in wheat. *Chemosphere*, *181*, 44–54.
17. Esdaile, L. J., & Chalker, J. M. (2018, May 11). The mercury problem in artisanal and small-scale gold mining. *Chemistry*, *24*(27), 6905–6916.
18. Faita, F., Cori, L., Bianchi, F., & Andreassi, M. G. (2013, April). Arsenic-induced genotoxicity and genetic susceptibility to arsenic-related pathologies. *International Journal of Environmental Research and Public Health*, *10*(4), 1527–1546.
19. Falluel‐Morel, A., Lin, L., Sokolowski, K., McCandlish, E., Buckley, B., & DiCicco‐Bloom, E. (2012, April). N‐acetyl cysteine treatment reduces mercury‐induced neurotoxicity in the developing rat hippocampus. *Journal of Neuroscience Research*, *90*(4), 743–750.
20. Fernández-Martínez, R., Esbrí, J. M., Higueras, P., & Rucandio, I. (2019, June 25). Comparison of mercury distribution and mobility in soils affected by anthropogenic pollution around chloralkali plants and ancient mining sites. *Science of the Total Environment*, *671*, 1066–1076.
21. Frías-Espericueta, M. G., Ruelas-Inzunza, J., Benítez-Lizárraga, R., Escobar-Sánchez, O., Osuna-Martínez, C. C., Delgado-Alvarez, C. G., Aguilar-Juárez, M., Osuna-López, J. I., & Voltolina, D. (2019). Risk assessment of mercury in sharks (Rhizoprionodon longurio) caught in the coastal zone of Northwest Mexico. *Journal of Consumer Protection and Food Safety*, 14(4), 349–354.
22. Frías-Espericueta, M. G., Ruelas-Inzunza, J., Benítez-Lizárraga, R., Escobar-Sánchez, O., Osuna-Martínez, C. C., Delgado-Alvarez, C. G., Aguilar-Juárez, M., Osuna-López, J. I., & Voltolina, D. (2019). Risk assessment of mercury in sharks (Rhizoprionodon longurio) caught in the coastal zone of Northwest Mexico. *Journal of Consumer Protection and Food Safety*, 14(4), 349–354.
23. Garai, P., Banerjee, P., Mondal, P., & Saha, N. C. (2021). *Effect of heavy metals on fishes: Toxicity and bioaccumulation. J Clin Toxicol*. S, *18*.
24. Gupta, P. K. (2018, September);4:37-43. Herbicides and fungicides. *InReproductive and Developmental Toxicology* 2017 Jan 1. Academic Press, Saturday A. Mercury and its associated impacts on environment and human health: A review. J. Environ. Health Sci., (657–679).
25. Hosseini, M., Nabavi, S. M., & Parsa, Y. (2013, December). Bioaccumulation of trace mercury in trophic levels of benthic, benthopelagic, pelagic fish species, and sea birds from Arvand River, Iran. *Biological Trace Element Research*, *156*(1–3), 175–180.

26. Kennedy, C. J. *Toxicoloy: The toxicology of metals in fishes, encyclopedia of fish physiology*.
27. Khalid, S., Shahid, M., Niazi, N. K., Rafiq, M., Bakhat, H. F., Imran, M., Abbas, T., Bibi, I., & Dumat, C. Arsenic behaviour in soil-plant system: Biogeochemical reactions and chemical speciation influences. *Inenhancing cleanup of environmental pollutants*. (2017) (pp. 97–140). Springer.
28. Liu, Z., Zhen, F., Zhang, Q., Qian, X., Li, W., Sun, Y., Zhang, L., & Qu, B. (2022, September 1). Nanoporous biochar with high specific surface area based on rice straw digestion residue for efficient adsorption of mercury ion from water. *Bioresource Technology*, *359*, 127471.
29. Lu, L., Liu, G., Wang, J., & Liu, Y. (2017, September). Accumulation and health risk assessment of trace elements in Carassius auratus gibelio from subsidence pools in the Huainan coalfield in China. *Environmental Monitoring and Assessment*, *189*(9), 479.
30. Luo, Z., Jia, T., Liu, Q., Song, Y., Zhou, M., Ma, X., Wu, J., Qin, Z., & Wu, X. (2021, December 15). Development of CuInS2/g-C3N4 nanolayer for efficient adsorption of elemental mercury from coal combustion flue gas. *Chemical Engineering Journal*, *426*, 131905.
31. Ma, F., Peng, C., Hou, D., Wu, B., Zhang, Q., Li, F., & Gu, Q. (2015, December 30). Citric acid facilitated thermal treatment: An innovative method for the remediation of mercury contaminated soil. *Journal of Hazardous Materials*, *300*, 546–552.
32. Ma, Y., Xu, T., Zhang, X., Wang, J., Xu, H., Huang, W., & Zhang, H. (2022, February 5). Excellent adsorption performance and capacity of modified layered ITQ-2 zeolites for elemental mercury removal and recycling from flue gas. *Journal of Hazardous Materials*, *423*(A), 127118.
33. Malqui, H., Anarghou, H., Ouardi, F. Z., Ouasmi, N., Najimi, M., & Chigr, F. (2018, October). Continuous exposure to inorganic mercury affects neurobehavioral and physiological parameters in mice. *Journal of Molecular Neuroscience*, *66*(2), 291–305.
34. Manavi, P. N., & Mazumder, A. (2018, May 1). Potential risk of mercury to human health in three species of fish from the southern Caspian Sea. *Marine Pollution Bulletin*, *130*, 1–5.
35. Mandal, D., Sonar, R., Saha, I., Ahmed, S., & Basu, A. (2022, October). Isolation and identification of arsenic resistant bacteria: A tool for bioremediation of arsenic toxicity. *International Journal of Environmental Science and Technology*, *19*(10), 9883–9900.
36. Martín-Yerga, D., González-García, M. B., & Costa-García, A. (2013, November 15). Electrochemical determination of mercury: A review. *Talanta*, *116*, 1091–1104.
37. Mathew, C., & Al-Doori, Z.. (1976). The mutagenic effect of the mercury fungicide Ceresan M in Drosophila melanogaster. *Mutation Research*, 40(1), 31–36.
38. Mehmood, T., Bibi, I., Shahid, M., Niazi, N. K., Murtaza, B., Wang, H., Ok, Y. S., Sarkar, B., Javed, M. T., & Murtaza, G. (2017, July 1). Effect of compost addition on arsenic uptake, morphological and physiological attributes of maize plants grown in contrasting soils. *Journal of Geochemical Exploration*, *178*, 83–91.
39. Mohammadnia, E., Hadavifar, M., & Veisi, H. (2019, November 15). Kinetics and thermodynamics of mercury adsorption onto thiolated graphene oxide nanoparticles. *Polyhedron*, *173*, 114139.
40. Mombo, S., Foucault, Y., Deola, F., Gaillard, I., Goix, S., Shahid, M., Schreck, E., Pierart, A., & Dumat, C. (2016). Management of human health risk in the context of kitchen gardens polluted by lead and cadmium near a lead recycling company. *Journal of Soils and Sediments*, 16(4), 1214–1224.
41. Muhammad, A. I., Muhammad, N. C., Rass, M. K., Zulfiqar, A., & Tariq, M. (2013, May 9). Toxicity of arsenic (As) on seed germination of sunflower (Helianthus annuus L.). *International Journal of Physical Sciences*, *8*(17), 840–847.
42. Natasha, M., Shahid, M., Khalid, S., Bibi, I., Bundschuh, J., Khan Niazi, N., & Dumat, C. (2020, April 1). A critical review of mercury speciation, bioavailability, toxicity and detoxification in soil-plant environment: Ecotoxicology and health risk assessment. *Science of the Total Environment*, *711*, 134749.

43. Niazi, N. K., Bibi, I., Fatimah, A., Shahid, M., Javed, M. T., Wang, H., Ok, Y. S., Bashir, S., Murtaza, B., Saqib, Z. A., & Shakoor, M. B. (2017, July 3). Phosphate-assisted phytoremediation of arsenic by Brassica napus and Brassica juncea: Morphological and physiological response. *International Journal of Phytoremediation*, *19*(7), 670–678.
44. Nogara, P. A., Oliveira, C. S., Schmitz, G. L., Piquini, P. C., Farina, M., Aschner, M., & Rocha, J. B. T. (2019, December 1). Methylmercury's chemistry: From the environment to the mammalian brain. *Biochimica et Biophysica Acta. General Subjects*, 1863(12), 129284.
45. Ottesen, R. T., Birke, M., Finne, T. E., Gosar, M., Locutura, J., Reimann, C., & Tarvainen, T. (2013, June 1). Mercury in European agricultural and grazing land soils. *Applied Geochemistry*, *33*, 1–12.
46. Padmavathi, S., & Sujatha, B. *Assessment of mercury toxicity on seed germination, shoot and root growth of Cajanus cajan (L.) MILLSP*.
47. Pandey, C., Augustine, R., Panthri, M., Zia, I., Bisht, N. C., & Gupta, M. (2017, February 1). Arsenic affects the production of glucosinolate, thiol and phytochemical compounds: A comparison of two Brassica cultivars. *Plant Physiology and Biochemistry*, *111*, 144–154.
48. Pavithra, K. G., SundarRajan, P., Kumar, P. S., & Rangasamy, G. (2023). Mercury sources, contaminations, mercury cycle, detection and treatment techniques: A review. *Chemosphere*, 312(1), 137314.
49. Pobi, K. K., Satpati, S., Dutta, S., Nayek, S., Saha, R. N., & Gupta, S. (2019, April). Sources evaluation and ecological risk assessment of heavy metals accumulated within a natural stream of Durgapur industrial zone, India, by using multivariate analysis and pollution indices. *Applied Water Science*, *9*(3), 1–6.
50. Rahman, M. A., Hogan, B., Duncan, E., Doyle, C., Krassoi, R., Rahman, M. M., Naidu, R., Lim, R. P., Maher, W., & Hassler, C. (2014, August 1). Toxicity of arsenic species to three freshwater organisms and biotransformation of inorganic arsenic by freshwater phytoplankton (Chlorella sp. CE-35). *Ecotoxicology and Environmental Safety*, *106*, 126–135.
51. Raissy, M., Rahimi, E., Nadeali, V., Ansari, M., & Shakerian, A. (2014, April). Mercury and arsenic in green tiger shrimp from the Persian Gulf. *Toxicology and Industrial Health*, *30*(3), 206–210.
52. Ruggieri, F., Majorani, C., Domanico, F., & Alimonti, A. (2017, May). Mercury in children: Current state on exposure through human biomonitoring studies. *International Journal of Environmental Research and Public Health*, *14*(5), 519.
53. Shahid, M., Khalid, S., Abbas, G., Shahid, N., Nadeem, M., Sabir, M., Aslam, M., & Dumat, C. Heavy metal stress and crop productivity. *InCrop production and global environmental issues*. (2015) (pp. 1–25). Springer.
54. Singh, A. P., Dixit, G., Kumar, A., Mishra, S., Kumar, N., Dixit, S., Singh, P. K., Dwivedi, S., Trivedi, P. K., Pandey, V., Dhankher, O. P., Norton, G. J., Chakrabarty, D., & Tripathi, R. D. (2017, June 1). A protective role for nitric oxide and salicylic acid for arsenite phytotoxicity in rice (Oryza sativa L.). *Plant Physiology and Biochemistry*, *115*, 163–173.
55. Singh, S., & Kumar, V. (2020, August). Mercury detoxification by absorption, mercuric ion reductase, and exopolysaccharides: A comprehensive study. *Environmental Science and Pollution Research International*, *27*(22), 27181–27201.
56. Srivastava, S., & Singh, N. (2014, September 1). Mitigation approach of arsenic toxicity in chickpea grown in arsenic amended soil with arsenic tolerant plant growth promoting Acinetobacter sp. *Ecological Engineering*, *70*, 146–153.
57. Sysalová, J., Kucera, J., Fikrle, M., & Drtinová, B. (2013, September 1). Determination of the total mercury in contaminated soils by direct solid sampling atomic absorption spectrometry using an AMA-254 device and radiochemical neutron activation analysis. *Microchemical Journal*, *110*, 691–694.
58. Sytar, O., Kumar, A., Latowski, D., Kuczynska, P., Strzałka, K., & Prasad, M. N. V. (2013, April). Heavy metal-induced oxidative damage, defense reactions, and detoxification mechanisms in plants. *Acta Physiologiae Plantarum*, *35*(4), 985–999.

59. Tiwari, S., & Sarangi, B. K. (2017, March 1). Comparative analysis of antioxidant response by Pteris vittata and Vetiveria zizanioides towards arsenic stress. *Ecological Engineering*, *100*, 211–218.
60. Tofan-Lazar, J., & Al-Abadleh, H. A. (2012, February 16). ATR-FTIR studies on the adsorption/desorption kinetics of dimethyl arsinic acid on iron–(oxyhydr) oxides. *Journal of Physical Chemistry. A*, *116*(6), 1596–1604.
61. van den Toren, S. J., van Grieken, A., Mulder, W. C., Vanneste, Y. T., Lugtenberg, M., de Kroon, M. L. A., Tan, S. S., & Raat, H. (2019, September). School absenteeism, Health-Related Quality of Life [HRQOL] and happiness among young adults aged 16–26 years. *International Journal of Environmental Research and Public Health*, *16*(18), 3321.
62. Wightwick, A. M., Bui, A. D., Zhang, P., Rose, G., Allinson, M., Myers, J. H., Reichman, S. M., Menzies, N. W., Pettigrove, V., & Allinson, G. (2012). Environmental fate of fungicides in surface waters of a horticultural-production catchment in southeastern Australia. *Archives of Environmental Contamination and Toxicology*, 62(3), 380–390.
63. Wightwick, A., Walters, R., Allinson, G., Reichman, S., & Menzies, N. (2010). Environmental risks of fungicides used in horticultural production systems. *Fungicides*.
64. Wu, Q., Jiang, X., Wu, H., Zou, L., Wang, L., & Shi, J. (2022, June 2). Effects and mechanisms of copper oxide nanoparticles with regard to arsenic availability in soil–rice systems: Adsorption behavior and microbial response. *Environmental Science and Technology*, 56(12), 8142–8154.
65. Xiong, T., Dumat, C., Pierart, A., Shahid, M., Kang, Y., Li, N., Bertoni, G., & Laplanche, C. (2016). Measurement of metal bioaccessibility in vegetables to improve human exposure assessments: Field study of soil–plant–atmosphere transfers in urban areas, South China. *Environmental Geochemistry and Health*, 38(6), 1283–1301.
66. Zamani Hargalani, F., Karbassi, A., Monavari, S. M., & Abroomand Azar, P. (2014, April). A novel pollution index based on the bioavailability of elements: A study on Anzali wetland bed sediments. *Environmental Monitoring and Assessment*, *186*(4), 2329–2348.
67. Zhang, Y., Chen, J., Zheng, W., Sun, R., Yuan, S., Cai, H., Yang, D. A., Yuan, W., Meng, M., Wang, Z., Liu, Y., & Liu, J. (2020, March 15). Mercury isotope compositions in large anthropogenically impacted Pearl River, South China. *Ecotoxicology and Environmental Safety*, *191*, 110229.
68. Zheng, N., Liu, J., Wang, Q., & Liang, Z. (2011, February 1). Mercury contamination due to zinc smelting and chlor-alkali production in NE China. *Applied Geochemistry*, *26*(2), 188–193.
69. Zheng, N., Liu, J., Wang, Q., & Liang, Z. (2011, February 1). Mercury contamination due to zinc smelting and chlor-alkali production in NE China. *Applied Geochemistry*, *26*(2), 188–193.