



Impact of Environmental Pollution on Food Safety and Human Health

Iqra Aslam

Department of Geography, Government College University, Lahore.

Corresponding author iqraaslam270@gmail.com

Aurangzaib

Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan

aurangzaib7052@gmail.com

Sumiya Younas

Institute of food science and Nutrition, University of Sargodha

sumiyayounas56@yahoo.com

Aghsania kainat

Institute of Food Science and Nutrition, University of Sargodha

aghsaniakainat16@gmail.com

Wajeaha Fatima

Institute of Food science and Nutrition, University of sargodha.

wajihafatima686@gmail.com

Maryam

Institute of Food Sciences and Nutrition, University of Sargodha

maryamamjad.22345@gmail.com

Amir Arshad

Riphah International University Faisalabad campus

amir.arshad@riphahfsd.edu.pk

Asifa Naz

Soil and Water Testing laboratory for Research Sargodha

asifanaz.64@gmail.com

Abstract: *Environmental pollution poses significant risks to food safety and human health in Pakistan. Industrial effluents, excessive agrochemical use, and unsafe irrigation practices introduce heavy metals, pesticide residues, and microbial contaminants into the food chain. These pollutants compromise food quality, lower nutritional value, and trigger both acute and chronic health problems, including foodborne diseases, organ damage, developmental disorders, and cancer. Vulnerable groups such as children and pregnant women face heightened risks due to physiological susceptibility and exposure levels. Weak regulatory enforcement, inadequate surveillance, and limited public awareness further exacerbate these threats. This review*



highlights the sources and impacts of environmental contaminants on food safety, assesses their associated health risks, and emphasizes the urgent need for policy reforms, sustainable agricultural practices, and effective regulatory systems. Strengthening food safety infrastructure, adopting integrated pest management, improving water treatment, and enhancing food safety education are essential steps to safeguard human health and ensure sustainable food systems in Pakistan.

Keywords: *Food safety, Human health risks, Heavy metals, Pesticide residues, Microbial contamination, Pakistan, Public health, Sustainable agriculture, Water pollution*

1.1. Introduction

The analysis of the problem of environmental pollution and its adverse effect on food safety and human health in Pakistan is important because the country badly faces pollution, which poses serious threats to human health and economic disorder. Such as, water pollution is spreading due to industrial and agricultural effluents resulting in epidemic waterborne diseases and huge impact on health grounds (Jabeen *et al.*, 2015; Nabeela *et al.*, 2014). There is also a widely-uses of wastewater in the irrigation process, therefore, exposing the population to heavy metals in food products, such as raw milk, which poses carcinogenic risks (Iqbal *et al.*, 2020). Poor surveillance, and limited public health infrastructure further fuel these dangers, and efforts must be made to implement the stronger enforcement of the laws controlling the environment and creating mitigation measures, it is necessary to identify and discuss these issues to protect the health of the population and guarantee sustainable use of the national resources (Akhtar, 2014).

1.1.1. Sources of Pollution

Industrial wastes and emissions have a lot to do with food safety and human health in Pakistan. Impact of industrial emissions and wastes is multidimensional. Dumping of heavy metals in the water bodies by industrialists causes their incorporation in the food products with build-up of toxins in agricultural products with the time. The levels of lead (Pb) and arsenic (As) are high in industrial regions and have found their way into the food chain therefore causing significant health effects to man (Rehman *et al.*, 2007). There is also evidence of contamination with potentially toxic elements (PTEs) including nickel (Ni) in wheat, particularly in industrial areas in Pakistan, such as Faisalabad, and long-term exposure carries some carcinogenic and non-carcinogenic risks (Abbas *et al.*, 2017). Additionally, pollution by industrial waste and agricultural drainage have caused accumulation of heavy metals in fishes that addition to the dangers of individuals who consume contaminated fishes (Chatha *et al.*, 2023). These contaminants affect food safety not only but also pose a serious threat to environmental pollution and making it much more difficult to address this issue to improve the spread of disease-health in the region (Abbass *et al.*, 2021; Jabeen *et al.*, 2015).

The agricultural chemicals especially the pesticides and fertilizers affect the food safety and human health adversely. Pesticides are commonly applied in the crop protection against diseases and pests in order to achieve crop protection and benefits. Its residues in foods contribute to the development of health hazards likely to neurotoxicity, endocrine disruption and predisposition to cancer. These dangers are aggravated by unsatisfactory pesticide uses and insufficient control system (Beyuo *et al.*, 2024; Lazarevi *et al.*, 2025). Moreover, the legacy of certain agrochemicals on soil health and groundwater have long-term risks, including reproductive changes and hormonal ailments

(Baweja *et al.*, 2020; Hossain *et al.*, 2022). This has raised an urgent demand of sustainable agricultural systems including integrated pest management (IPM) and organic farming as an intervention measure to counter these negative effects, thereby promoting safer production of food (Carvalho, 2017; Grewal *et al.*, 2017).

The contamination of water presents great risks to food safety and human health due to the presence of pathogenic, heavy metals and chemical contaminants. Polluted water is the habitat of pathogenic bacteria and viruses that cause diseases such as diarrhea, gastroenteritis and other diseases that can be more pronounced in vulnerable groups of people as shown in (Figure-1) (Krishan *et al.*, 2023). Pb, As, and cadmium (Cd) are heavy metals that can impact the crop plant and consequently lead to bioaccumulation of the toxins throughout the food supply chain, which is very dangerous (Guerrieri *et al.*, 2024). Besides, irrigation water can be contaminated with pathogens that persist in fruits and vegetables and can further endanger food safety and health of the population (Iwu and Okoh, 2019). It is important to ensure that water treatment and management practices are safe to reduce such risks and safeguard human wellbeing (Lanrewaju *et al.*, 2022).

Degradation of land and air pollution introduce tremendous health hazards that negatively affect food safety and human health. Agricultural and industrial sources of air pollution have been shown to cause poor air quality, which leads to increments in morbidity and death associated with respiratory and cardiovascular diseases (Domingo *et al.*, 2021; Santos *et al.*, 2021). The usage of fertilizers and pesticides in the agricultural sector not only contributes to the discharge of hazardous particles to the air but the volatilization of chemicals used in the agricultural sector as well (Rizwan *et al.*, 2024). The contamination of soils by heavy metals and the excess of agrochemicals damages food security in its production as well as its safety. The toxicants like heavy metals may be inherited in crops thus exposing the people to health issues when they migrate into the food chain, creating immediate health effects such as organ damages or chronic long-term diseases (Lazarevi *et al.*, 2025). In addition, the soil degradation process decreases the soil fertility level, increasing investments in the use of crop production and causing the risk to abandon the land, which eventually leads to food security in the long term (Gomiero, 2016).

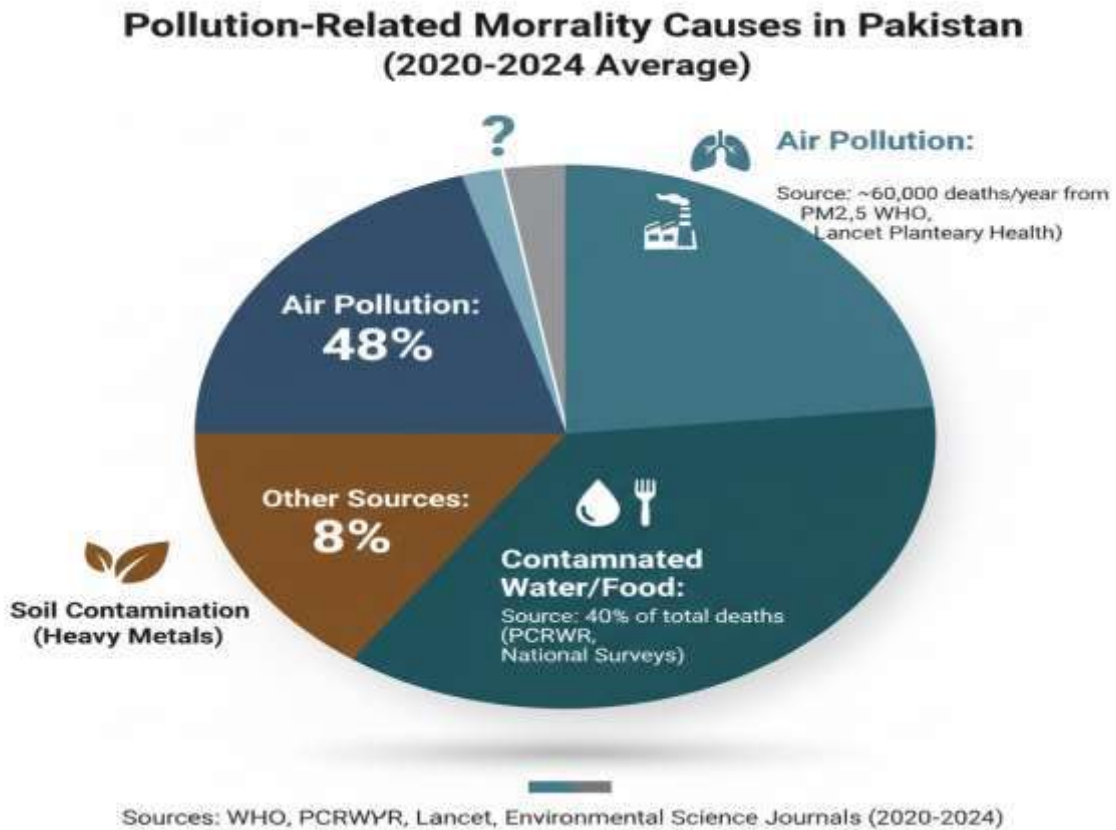


Figure 1. Pollution related morality causes in Pakistan (2020-2024)

1.1.2. Effect on Food Safety

Food safety is posing a big threat in Pakistan due to presence of heavy metals in crops and vegetables. Causes of heavy metal pollution to food chain owing to industrial activities, application of chemical fertilizers and irrigation using untreated waste- materials hence contaminating soil, water and air (Manwani *et al.*, 2022). In Pakistan, agricultural activities that applied sewage and industrial effluents have long been suspected of soil and water pollution and promoting the enrichment of edible crops with high-level heavy metals (Munir *et al.*, 2021). The resulting effect of such contamination may result in the development of adverse health conditions when ingesting the contaminated food such as cancer, developmental problems and immuno-suppression (Manwani *et al.*, 2022). Poor regulation is compounded by the health risks, monitoring and strategic interventions are much needed to resolve these matters and achieve food safety (Akhtar, 2014).

The horrors of pesticide residues in food products can be as immense a risk to food safety and to human health. The consumption of food containing the pesticide residues may have various health effects such as neurotoxicity, endocrine disruption and high risks of cancer (Beyuo *et al.*, 2024; Sajad *et al.*, 2024; Stachniuk and Fornal, 2015). The accumulation of such residues is often a result of improper or indiscriminate use of pesticides when they end up in the produce (Beyuo *et al.*, 2024; Grewal *et al.*, 2017). Investigations indicate that though there are food samples that have not reached

the maximum residue limits (MRLs), these foodstuffs still create issues of acute and chronic toxicity especially when they are consumed by susceptible groups such as children (El-Sheikh *et al.*, 2022; Nisha *et al.*, 2021). In order to deal effectively with these risks, strict regulatory systems, sustainable farming, and alternative methods like IPM have to be put in place (Lazarević-Pašti *et al.*, 2025). The realization that there are few measures available to prevent the problem in certain areas of developing world, both financially and legally faced by these regions, a constant surveillance of the problem and creation of awareness can also help in alleviating this health risk related to pesticide residue (Grewal *et al.*, 2017).

Contaminated water also is used in irrigation and production processes which are likely to contaminate the dietary chain with different pathogens and pollutants presenting major threats to food security. Irrigation with water that contains a hazardous microorganism, especially in areas where the lack of good quality water as given in (Figure-2) (Iwu and Okoh, 2019). Besides, viral pathogens such as Norovirus and Human Papillomavirus have been also found in fresh water sources which is directly related to food borne diseases (Itarte *et al.*, 2021). In food processing, use of water contaminated with microbial or chemical substances to wash or clean products may further jeopardize food safety and result in development of foodborne illness (Kyaw *et al.*, 2022). The risk is especially high in food, such as vegetables, and thus rigorous monitoring and use of safer farming practices such as, drip irrigation of water to minimize exposure or direct contact with contaminated water and plant parts that are edible needs to be practiced (Allende and Monaghan, 2015; Cao *et al.*, 2023).

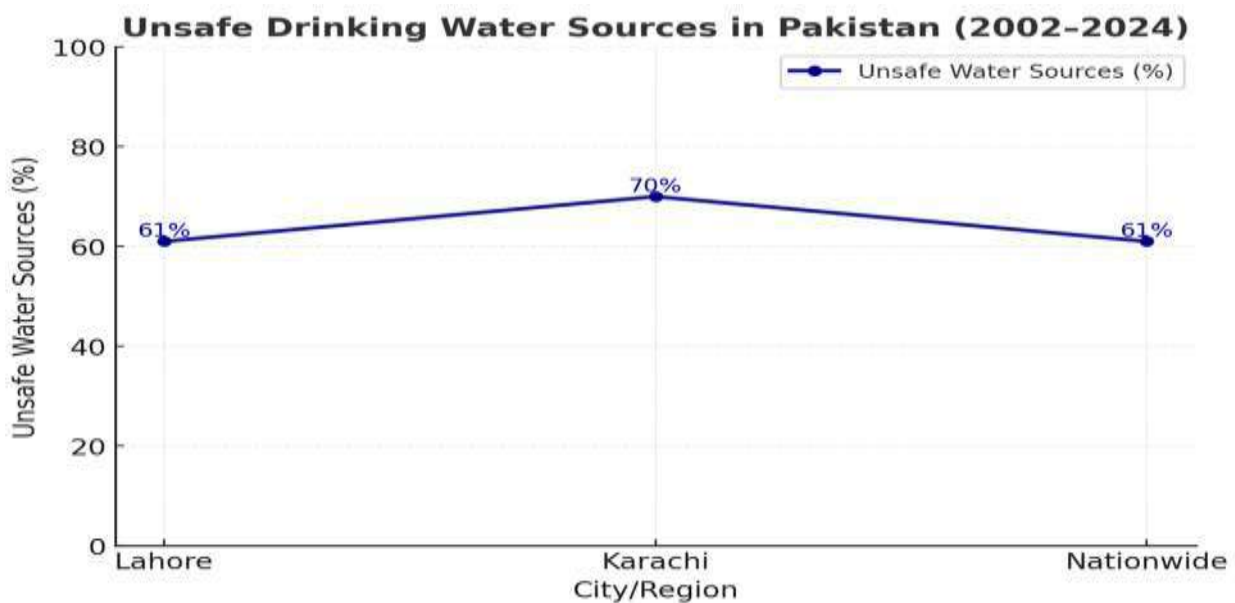


Figure 2. Unsafe drinking water sources in Pakistan (2002-2024)

The presence of microbial contamination of polluted environments presents great challenges to the food safety and general health of the population through the increase in the incidence of foodborne diseases. Pathogenic microorganisms that may be found in foodstuffs include bacteria, viruses, and protozoa, and they may enter the food chain through the polluted water sources, in agricultural activities, or direct contact with contaminated areas (Bintsis, 2018). They have the potential of compromising the food chain at various points such as in the agricultural field and also in

food handling and processing, which can result in the occurrence of foodborne problems (Doddabematti Prakash *et al.*, 2024; Garvey, 2019). Microplastics in the food chain could also be as a source of infection of these pathogens, and this aspect increases the difficulty of determining the safety of food as shown in (Figure-3) (Tavelli *et al.*, 2022). The occurrence of antimicrobial-resistant in the pool of foodborne pathogens should be addressed by urging preventive actions and forming efficient hygiene policies to reduce microbial contamination and its effects (Bumunang *et al.*, 2023).

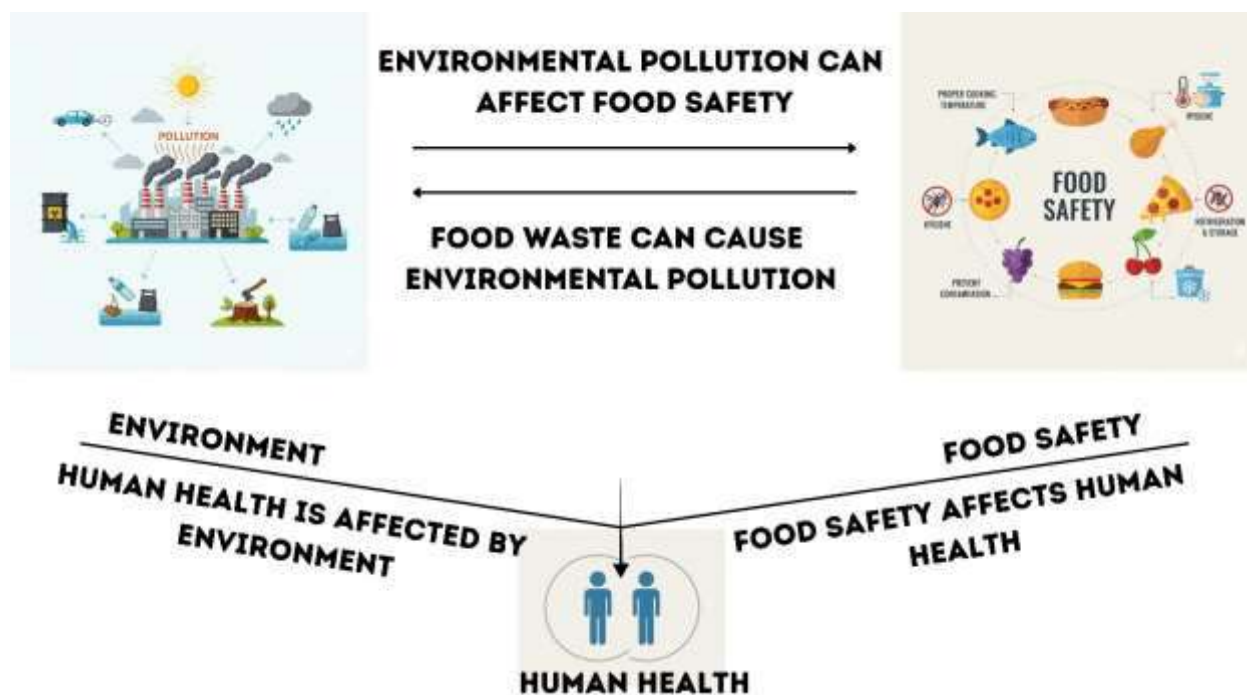


Figure 3. Effect of environmental pollution on food safety

1.1.3. Possible Health Risks to Source-Grave Challenges with Human Health

Environmental pollution leads to food safety risks due to which there are several acute and chronic diseases associated. Acute diseases tend to be primarily associated with microbial contamination, and food-poisoning organisms including *Clostridium perfringens*, *Escherichia coli* and *Salmonella* spp. Result in infectious diseases after ingestion of contaminated vegetables or animal products (Bintsis, 2018). In case of chronic exposure, heavy metals such as Pb, Cd, and mercury may give rise to chronic health issues such as heart diseases, kidney disease, and cancer (Mititelu *et al.*, 2025). The potential consequence of persistent organic pollutants (POPs) in food will have endocrine disruptions, diabetes and the eventual occurrence of cancers (Guo *et al.*, 2019). Ni builds up in agricultural soils is also a major health hazard of chronic exposure through food chain (Rizwan *et al.*, 2024). These concerns raise the need to implement adequate measures to address this pollution-related food safety risk.

Food safety has been deteriorated by environmental pollution to a significant extent that has resulted in malnutrition and food poisoning. The presence of pollutants such as chemical compounds and residues left behind due to pesticides, as well as heavy metals, and microbial contamination because of the unclean water supply, affect the food quality at different points along the food chain as mentioned in (Table-1) (Bintsis, 2018; Santos *et al.*, 2023). Besides lowering the nutritional value of

food thereby causing malnutrition, such contaminants have serious health effects by causing transmission of food borne pathogens like *Salmonella* and *Escherichia coli*. Due to low regulatory control, however, such risks are severer in developing countries where the food safety system is unable to keep up with the pollution levels. This is the main cause of rampant food-related diseases, which, in turn, compromise the status of general health (Bintsis, 2018; Subedi *et al.*, 2024). It is important that comprehensive food safety measures and regulations are integrated to reduce these risks and enhance nutritional security and the outcome of the public health (Santos *et al.*, 2023; Subedi *et al.*, 2024).

Children and pregnant women are at a high risk of food safety issues brought upon by pollution given their stoichiometric vulnerability coupled with greater exposure levels as compared to their body masses. In the case of children, typically their metabolic pathways are not that mature, and this makes them less able to detoxify bad substances such as pesticides and heavy metals, which can pose developmental and health hazards (Li *et al.*, 2025). Pregnant women are, however, more vulnerable to food contaminants as those contaminants may pass through the placental barrier and cause fetal development malformations, which may result in poor developmental effects and prematurity (Bank-Nielsen *et al.*, 2019; Padula *et al.*, 2018). Also, the relation to fish consumption could result in elevated levels of contaminants such as mercury and polyfluoroalkyl substances and thus careful dietary choices before and after pregnancy and beyond toddlerhood should be considered (Papadopoulou *et al.*, 2019).

In Pakistan, there are a couple of case studies whose complexity relates to the interconnection between environmental pollution solutions and the food safety of human beings. Among them, one common problem is water pollution, due to untreated sewage, industrial wastes, and runoff in the agricultural activities, which degrade the quality of drinking water and human health to an immense extent. The literature points out that water contamination, especially that with pathogenic microorganisms and heavy metals, causes severe health risks, including mass water-associated diseases that take up quite a large portion of diseases in the country (Jabeen *et al.*, 2015; Nabeela *et al.*, 2014). Moreover, heavy metal pollution on land severely affects food safety since crops such as rice are affected which in turn finds its way in the human food chain causing health hazards. The mitigation of these risks through efforts in remediation with engineered nanomaterials and new regulatory policies is under consideration. Moreover, the rapidly surging population, which also contributes to the booming urbanization, has resulted in the enhancement of food adulteration, especially the dairy products, which also complicates the food safety issues in Pakistan. The suggested strategies to overcome these issues should be multipronged and entail effective implementation of environmental and food safety laws and development of novel remedial technologies (Akhtar, 2014).

Table 1. Health Impacts from Pollution-Contaminated Food in Pakistan

Pollutant Type	Associated Diseases	Prevalence/Impact in Pakistan	Vulnerable Groups	Annual Deaths/Cases
Heavy Metals (e.g., Pb, As)	Cancer, Kidney Disease, Cardiovascular	11-22,000 deaths from air/soil pollution links	Children, Pregnant Women	~60,000 from related diseases

Pesticides	Neurotoxicity, Endocrine Disruption	High in agricultural workers; 40% of foodborne illnesses	Farmers, Children	40% of total deaths linked to poor water/food
Microbial (from Water)	Diarrhea, Gastroenteritis	50% diseases due to contaminated water	Rural Populations	153 million premature deaths globally (Pakistan ranks 3rd)
Air Pollutants (PM2.5)	Respiratory/Cardiovascular	Shortens life by 3.9 years avg.	Urban Dwellers (e.g., Lahore)	28,000 indoor + 22,000 outdoor

1.1.4. Procedures and Issues

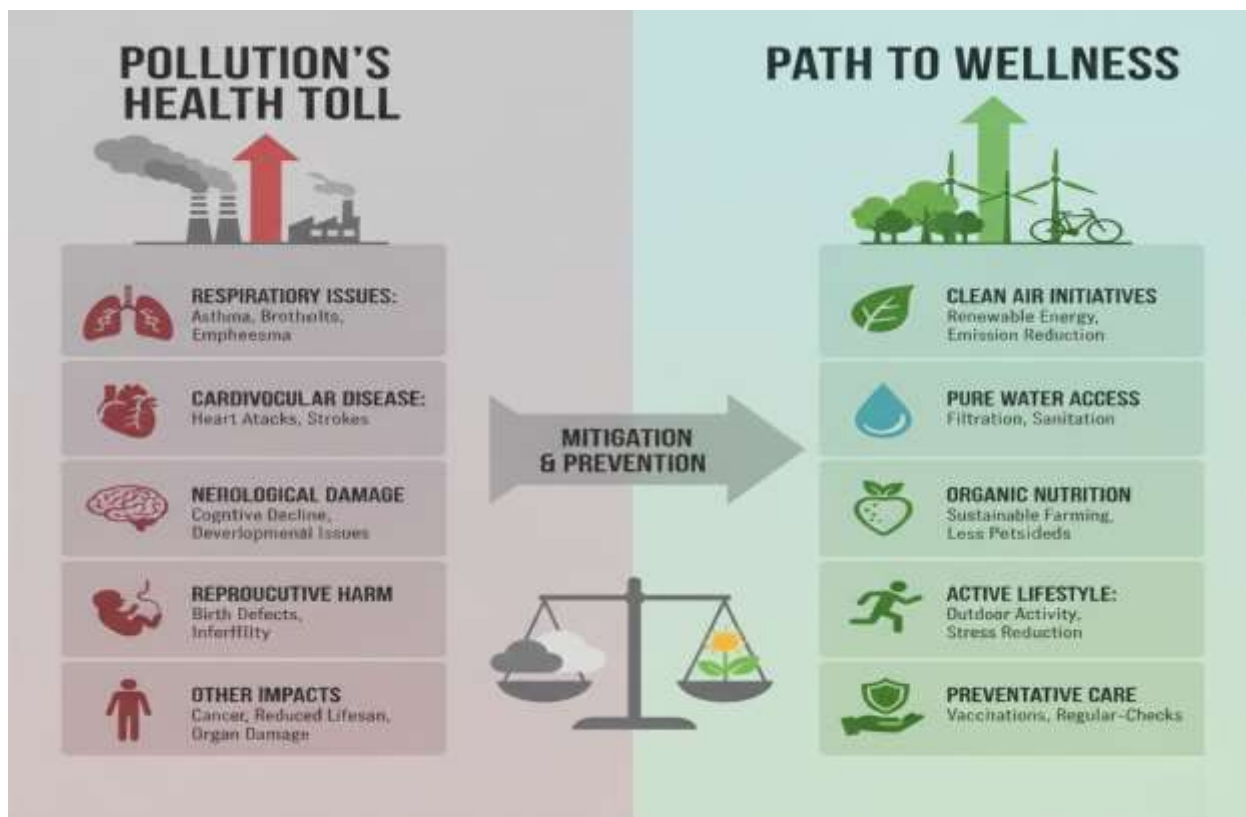
The present food safety regulations in Pakistan are not very effective in dealing with health hazards caused by environmental contamination. Food safety legislation may have reached a level of development, although most of those developed are not essentially implemented, one of the challenges facing food safety which leads to persistent pollution crises (Jabeen *et al.*, 2015). The industrialization and urbanization processes have induced hazardous substances (e.g. manganese and nickel) into soil and food chains that have developed non-carcinogenic and carcinogenic effects on the health of the local communities (Abbas *et al.*, 2017). The problem is further aggravated by water pollution, mostly as a result of poor waste disposal and deterioration of infrastructure, with a considerable proportion of drinking water samples having been founded contaminated causing numerous water-borne diseases (Nabeela *et al.*, 2014). Although some of these issues are being addressed with regulation and monitoring policies, it is restricted by limited resources, ineffective coverage, and the absence of public awareness, and more infrastructural, regulatory, and educational interventions are required (Ashiq, 2014).

Gaps in food safety policies monitoring and enforcement can be exhibited in different ways as far as pollution is concerned. The focus on the paper lacks the substance of reality on the ground, as Nigeria case suggest that the resources designated towards addressing the issue of plastic pollution are not sufficient, monitoring, and enforcement of the policies (Aare *et al.*, 2024). Similarly, in the case of microbial contamination, food safety is undermined by the presence of contamination sources such as, livestock and wildlife, which indicates the inadequacies of pre-harvest prevention despite the existence of good agricultural practice systems (Bintsis, 2018). This is coupled with the fact that in the developing world, the lack of consumer awareness and resources to enforce the law results in the adulteration of foods and the intransigence of unsafe practices (Singh and Puniya, 2024). To mitigate these concerns, it is highly significant to consider the collaboration of various services, higher quality of infrastructure, and implement technological solutions to traceability, such as, the idea of block chain (Oriekhoe *et al.*, 2024).

Among agricultural practices that can increase food safety and human health, even under environmental pollution stress through the agro-ecological practices of crop rotation, organic farming, and agroforestry as shown in (Figure-4) (Saikanth *et al.*, 2023). These practices have the potential of lower the dependency on synthetic pesticides thereby limiting the entry of potentially spurious chemicals into food chain due to their known effects of causing ailments (Mititelu *et al.*, 2025). Other methods such as, nano remediation may also be important in alleviating soil pollution and fostering biodiversity. The use of plant growth-promoting bacteria (PGPB) can increase yield and stress resistance in plants, also making the agricultural process sustainable by bettering their nutrient extraction and the effects of pollutants (Kumari *et al.*, 2023). Moreover, the natural preservatives use in food preservation can be integrated, thus ensuring safety in foods without having a chemical-based preservative to ensure the maintenance of clean labeling and ensuring good health of the population (Lisboa *et al.*, 2024).

Food safety surveillance and food safety education is a key element in minimizing health complications due to pollutants and contaminated food. Workable food safety laws maintain that food items contain no harmful microorganisms, chemicals and physical hazards that are catalyzed by pollution (Singh and Puniya, 2024). Educational campaigns to the population enable risk reduction by increasing knowledge on food handling, storage, and food preparation to reduce the risk of foodborne diseases (Eruaga, 2024). Such efforts, together with a strong regulatory framework and local community engagement, can help adoptive a more informed approach to food safety and can help consumers formulate better food choices in decreasing food-borne diseases (Madilo *et al.*, 2024). A proper collaboration between stakeholders including government agencies and non-governmental organizations also contribute to the creation of awareness on the people and the proper execution of food safety standards hence protecting the health of the people against the negative health effects of pollution (Houghton *et al.*, 2006).

In order to enhance food safety and human health in Pakistan, it is imperative that substantial policy reforms and research activities that are aimed at the area need to be conducted. First, they require a well-built and comprehensive food safety system that boosts surveillance, and control of food disease-causing organisms all through the human-animal and environment interface (Akhtar, 2014). This would be through forming laboratory networks like those done in India, where real-time



data is generated and updated in the policy (Das *et al.*, 2024). Enforcement of existing laws with stricter measures are also essential to mitigate pollution of the water by industrial, agricultural, and sewage pollution that is a major form of drinking water as the epicenter of foodborne diseases and improved general health (Jabeen *et al.*, 2015). Also, the food safety policies should consider improving adulteration and contamination in the food supply chain through enhanced foods processing and storage procedures (Akhtar, 2014). Collaborative work to assess water-saving methods in the agricultural sector could give an idea about sustainable techniques to guarantee long-term food security even when the water source is scarce (Muzammil *et al.*, 2020).

Figure 4. Mitigation strategies

1.2. Conclusion

Pakistan can improve food safety besides safeguarding human health against environmental contamination by undertaking a number of strategic initiatives. Second, it is important to reinforce the food safety infrastructure, which assumes planning and implementation of extensive regulations to control and prevent food contamination. Targeting drinking water microbial pollution and mitigation of further pollution by enhancing water filtration and disinfection plants, in addition to the enforcement of regulations including water quality regulations, are the ways to reduce waterborne

diseases. Moreover, the utilization and degradation of pesticides in farming may reduce the negative outcomes in the health sector which are linked to the presence of chemical pollutants in the food chain (Leskovac and Petrović, 2023). Training of food handlers to enhance their food safety knowledge can help to create better food handling habits that will minimize risk of food poisoning (Ahmed *et al.*, 2021). In addition, participation and involvement of the population can contribute to the successful implementation process of environmental policies (Ittefaq and Kamboh, 2023). Pakistan will be in a position to reduce the risk of food safety and general health to the environment by taking up these broad measures.

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