REVIEW ARTICLE

Environmental and Health Effects of Emerging Contaminants – A Critical Review

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ABSTRACT: Emerging contaminants, including pharmaceutical drug molecules, personal care products, and microplastics, are frequently present in the environmental samples. These are derived from various sources of municipal wastewater discharges, domestic solid waste dumped on land, disposal from farmlands, and industrial discharges. These may cause innumerous hazardous effects, particularly endocrine disruption to all the organisms exposed to such contaminants. The treated sewage sludge is applied to the agricultural field without screening for emerging contaminants. As a result of the toxicity exposed to the organisms, antibiotic-resistant bacteria disseminated in the environment due to the occurrence of antibacterial drugs in the environmental samples. It is reported that more than 200 different kinds of pharmaceutical drugs were found in the river water, and the ciprofloxacin concentration was up to 6.5 mg/l. Global water scarcity has a major impact on agriculture, leading to the use of treated wastewater for farmland. The United States Environmental Protection Agency (EPA) recognizes pharmaceutical and personal care products (PPCPs) as carcinogens and endocrine disruptors. Many scientists have recently reported that these kinds of novel contaminants are toxic and can affect the environment and health. This paper critically analyzes emerging contaminants and their impact on the environment and health. Further, it presents viable solutions to manage and control them through various analytical techniques, artificial intelligence, and machine learning methods.

KEYWORDS: Agro-biodiversity, Antibiotics, Artificial Intelligence and Machine Learning, Industrial pollutants, Pharmaceuticals and personal care products, Wastewater.

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INTRODUCTION

Pollutants are defined as synthetic or chemical substances that are not normally observed in the environment but have the potential to enter the environment, cause known or suspected pollution, and have ecological and/or human-health impacts. The United States Geological Survey defines organic matter as “any synthetic or naturally occurring chemical or biological substance that persists in the environment and has known or suspected ecological and/or human health effects” [1]. Emerging pollutants are defined as: (i) new compounds or molecules that have emerged recently; (ii) current air pollutants with unprecedented levels of air pollution; and (iii) new environmental pollution with new information.

Emerging contaminants (ECs) originate from natural and man-made activities and have been potentially affecting the environment for the last few decades. Figure 1 depicts the sources and flow of emerging contaminants which cause damage the soil and water and thereby polluting the ground water. The chemicals that are present in the range of micrograms to nanograms per litre in aquatic systems are generally considered to be emerging contaminants [2]. The adverse effects caused by these contaminants are of current interest to many researchers across the globe to ensure environmental sustainability. The ECs include pharmaceutical and personal care products (PPCPs), endocrine disturbing compounds (EDC), antibiotic preparations, analgesic compounds, hormonal products, and pesticides, chemical discharges from industries, surfactants, and many other products that are

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commonly observed in soil, surface, and

and effects of these compounds on the environment and living beings are not well studied. The novel techniques to analyze and remove emerging contaminants are important to prevent potential hazards generated by these tiny pollutants. Even though there have been many analytical techniques available in recent years, there is a knowledge gap. It is reported that the presence of 203 pharmaceutical drugs disposed of in river water is observed in 41 countries, and these are extremely contaminated pollutants [3]. Anthropogenic activities resulted in the generation and dissemination of antibiotic resistance and the rise of antibiotic-resistant genes in the aquatic

groundwater samples. The toxicological impact

environment [4]. The contaminants are easily passed through the drinking water and irrigation water resources and reach the biological system [5]. The chemical properties and their pathways are not well understood, thus creating a channel for the experts to find a significant and favourable solution for the problem. This is the main concern for the current situation, which encouraged the authors to prepare this critical review to create proper awareness related to the potential hazards of emerging contaminants present in the soil, water, agricultural, environmental, and health-related accessories, and offer probable solutions to manage and control them.

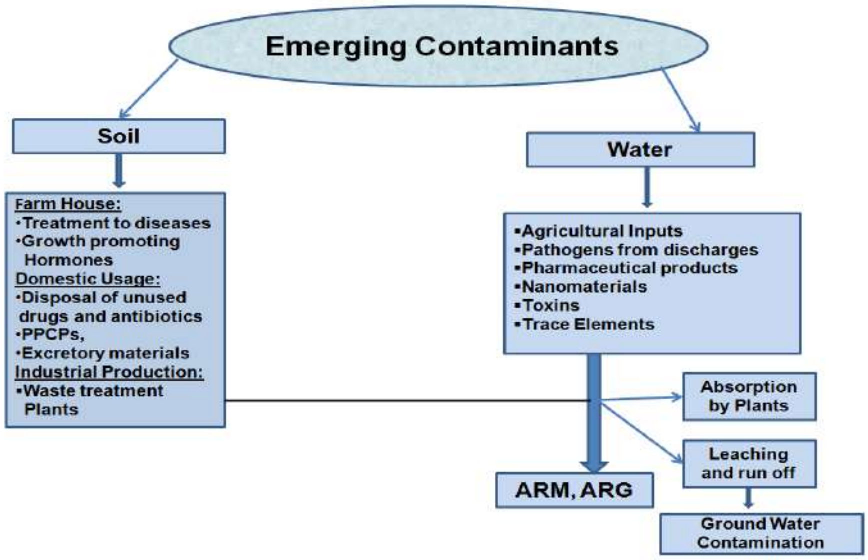

Figure 1 Sources and flow of emerging contaminants

PPCPs - Pharmaceutical and Personal Care Products; ARM - Antibiotic Resistant Microbes
ARG - Antibiotic Resistant Genomes

Emerging Contaminants in Soil

Healthy and fertile soil is the key factor for food security and sustainability. The soil is capable of producing food crops, mitigating and adapting to climatic change, infiltration of water, flooding, and drought resilience. Soil pollution leads to a loss of biodiversity and an uncontrolled reduction in organic matter, which is used to nourish crops. FAO warned that soil pollution greatly affects the infiltration capacity of soil to restore groundwater [6].

A better understanding of emerging contaminants and their impact on irrigation water and soil may prevent the degradation of soil and its productivity. The challenge is the need for simple and accurate measurement tools to effectively measure and control emerging contaminants. Treated waste water usage for crop cultivation and other allied agricultural activities increases the amount of contaminants in the soil and, consequently, the agro-products. An experimental study conducted in Saudi Arabia revealed that the presence of 64 emerging contaminants in treated waste water. Amidst these, six pharmaceutical compounds and seven pesticide residues were recorded in plants obtained from soil [7]. Gas chromatography and mass spectrometry studies of samples from agricultural environments resulted in the occurrence of steroid hormones. These hormones include beta-estradiol, alpha-estradiol, estriol, and estrone, and their derivatives, sulfate and glucuronide [8]. A recent health risk alert call was made for the existence of micro- and nano-sized plastic materials that are entering the food chain due to the mismanagement of these types of waste materials. It was evidently announced that only 10% of plastic wastes flow through bodies of water to the ocean, and the rest of the portions are dumped in the soil [9]. It is reported that microplastics are accumulated in the food chain, from earthworms and soil biota to chickens and even human beings [10]. Harmful substances entering food products through various contact routes, consumption of such products, and absorption from food plants through the soil threaten human health. The knowledge of different kinds of emerging contaminants and their impact on health is lacking [11].

Emerging contaminants are given importance as they have shown their potential threat to human health and that of other living organisms. As these contaminants are enter into the human system or other living beings through contaminated air, soil, and water [12]. These major contaminants include different substances such as agricultural runoff, microplastics, nanomaterials, persistent organic pollutants like industrial chemicals, dioxins, etc., personal care products, pesticides, pharmaceuticals, rare earth metals, etc. [13]. Currently, research is going on in the evaluation of the toxicity or bioaccumulation of these contaminants in the environment or in living organisms.

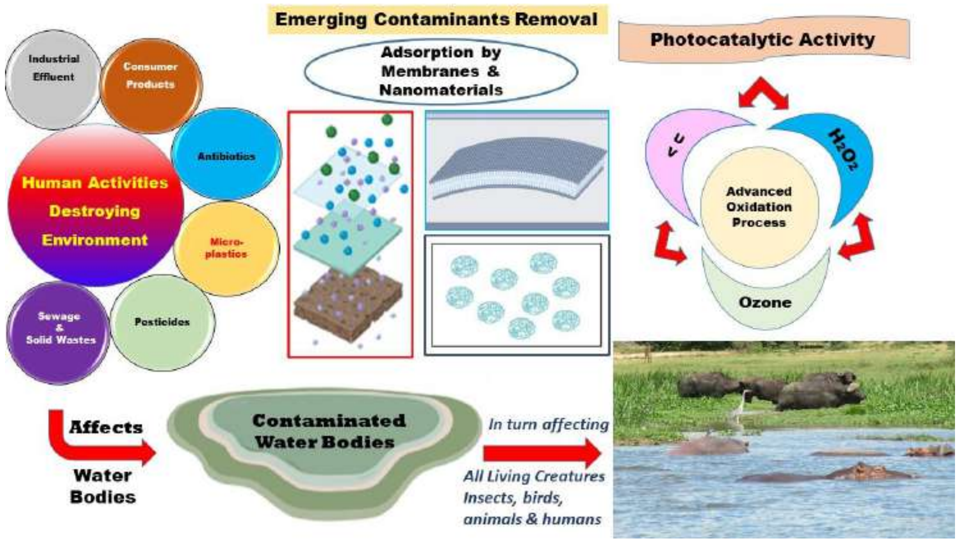

Figure 2 Schematic representations of emerging contaminants affecting the human system and environment along with various remediation or techniques available to remove the emerging contaminants

Exposure Pathways

There are several ways that people might become exposed to newly emerged pollutants. Some common exposure to emerging contaminants occurs through contact with contaminated soil, consumer products, drinking water, ground water, the food chain, healthcare products, polluted air, medical exposures, and workplace contaminants. Inadequate disposal practices lead to the release of pollutants into the environment, especially those associated with medications and healthcare items from medical facilities [14, 15]. Emerging contaminants pathways connecting the sources and various techniques available for elimination is given in the Figure 2.

Direct contact with polluted soil, water or sediment might expose people to newly emerged pollutants. This can happen at work, in leisure spaces, or in homes where there are pollutants. A percentage of the nutrients used in urban and agricultural settings end up in runoff and eroding water, which supplies nutrients to lakes, rivers, streams, groundwater, etc. The degradation of soil and water quality brought on by these excessive nutrient loadings may have serious repercussions for aquatic ecosystems, human health, and environmental sustainability. Emerging pollutants including heavy metals are exhibiting a growing tendency in soil and freshwater bodies, to cause pollution by chemicals and nutrients [16]. In addition to degrading freshwater supplies and soil quality, these newly emerged pollutants have the potential to enter the food chain and harm both human and animal health [12, 14]. Further, a clear idea required about various wastewater treatment techniques to remove pollutants and/or their derivatives from the wastewater influent. Therefore, it is imperative to create regulations and policy recommendations pertaining to the upper limits of these emerging pollutant concentrations in soil and water.

Food chain

Humans and other living things are at greater risk from eating plants and seafood that have been polluted by contaminated soil or water. Crop contamination occurs when toxins are absorbed by the roots of the plants from the soil and water [17]. On the other hand, aquatic organisms were bio-accumulated with contaminants from polluted water and through their food. Humans are at risk when these bio-accumulated aquatic animals [18].

Further, food contamination happens with the addition of chemical substances in order to increase the shelf life of the food materials. Also, the lack of hygienic conditions of kitchen and poor sanitation were found to be responsible to cause the food contamination. Chemical contaminants enter the food products naturally, whereas pathogens (microbes) enter the environment due to these poor hygienic conditions.

Water Quality Parameters and Emerging Contaminants

Emerging contaminants occur both in drinking water and groundwater. Drinking water sources can be contaminated by runoff from agricultural fields, wastewater treatment plants, industrial effluents, or unintentional spills [14]. The agricultural products are consumed by people and intern the contaminants were noted in the aquatic system used as a drinking water. Emerging pollutants may enter the groundwater directly by discharge of contaminants into the ground or may enter through polluted surface water [14,19]. From the wells, human beings are exposed to the contaminants.

The aquatic environment is under severe threat caused by a number of emerging contaminants originating from the disposal and diffusion of pollutants. Most of the chemicals are not monitored by regulatory authorities, which adversely affect the environment and public health. Water pollution is a global problem that needs urgent attention and the implementation of a better plan to find a solution. Environmental quality and sustainability are indicated and monitored by resource utilization, selected technology, the performance criterion, removal and minimizing waste constituents including BOD, ammonia forms of nitrogen, phosphorous and the presence of pathogenic organisms [20]. It is reported that two million tons of waste including sewage, industrial effluents, and waste from the agriculture sector, are discharged every day to the water-bodies in the world [21]. The estimation reported by the UN is that the annual production of waste-water is about 1500 kilo m3, which accounts for six times the amount of water available in all rivers flowing around the world [21]. Nearly 2.5 billion people residing world-wide are facing a lack of sanitation [22]. Among these, 1.8 billion people are in Asia, who lacks sanitation, and accounts for 70% of the world's population. A list of 700 pollutants and their transformed products are considered emerging pollutants as reported in the European aquatic environment. Secondary water-treatment processes involving the activation of microbial organisms on emerging contaminants are reported [23]. Biodegradation of these emerging contaminants plays a prominent role during waste-water treatment [24].

Table 1 Pharmaceuticals observed in the treated waste-water

S.No.	Nature of Pharmaceutical items	Concentration (Nano g/l)	References
1	Esterone	4.3-12	[25]
2	Propranolol	9.3 – 388	[25-27; 30]
3	Carbamazepine	826-3117	[26-27]

4	Diclofenac	58-599	[25-27; 28-29]
5	Ranitidine	9-425	[26-27]
6	Bezafibrate	177-418	[26-27]
7	Venlafamine	95-188	[28]
8	Dosulepin	57	[28]
9	Oxycocodone	7-12	[28]
10	Oxymorphone	1.7-8.4	[28]
11	Morphine	59-131	[28]
12	Sidenafil	14-28	[28]
13	Amoxicillin	31	[26]
14	Erythromycin	109-1385	[26-27]
15	Metronidazole	265-373	[26-27]
16	Tamoxifen	10-369	29-30
17	Benzophenone	22-4309	[26-27]
18	Paraben	4-63	[26-27]

It is estimated that there will be a 60% increase in agricultural production by the year 2050 to sustain food security [31]. The exploitation of water resources and contamination of these resources by man-made activities such as the usage of pesticides in agricultural fields, the discharge of pharmaceuticals and drugs, and many other contaminants of emerging concern will severely spoil food crops, either directly or indirectly. Traces of different chemicals have been found in treated waste water that can be used for agricultural activities, as shown in Table 1. In developing countries, nearly 80–90% of waste water is discharged without proper treatment. A significant impact on the quality of the soil resulted from the irrigation of polluted water from industrial, agricultural, and municipal sources [32]. Fresh water sources, like surface-water and ground-water sources, record the presence of pharmaceutical and personal care products (PPCPs) in considerable quantity [33]. Non-steroidal anti-inflammatory drugs (NSAIDs), beta-blockers used to treat psychiatric ailments, anti-hypersensitivities, antibiotics, and antidiuretics are some of the pharmaceutical products observed in the sewage. Pharmaceutical products present in treated waste-water, used to irrigate crops, pose the problem of uptake of contaminants by the crop-plants [34].

Emerging Contaminants from Industries

Major industries such as textiles, leather, rubber, cement, etc, result in the generation of emerging contaminants. Waste-water with chemicals and dyes from the textile and leather industries is a major environmental concern in many parts of the world. Textile industries produce useful goods and products but also damage the environment through the discharge of waste-water, solid waste, air pollutants, and noise pollution [35]. A large amount of water is used in the textile industry to wash raw materials, finished products, and for many flushing treatments in the entire production process. Water is used in several chemical and physical processes, namely sizing, de-sizing, scouring, bleaching, mercerizing, dyeing, finishing, printing, washing, etc. [36]. The outlet of all these processes has a huge quantity of waste-water. According to the World Bank report [37] that the waste-water generated by dyeing and finishing processes accounts for around 17%–20% of total industrial effluents. The waste-water discharged from textile industries contains harmful contaminants such as dyes, chromium, NaOH, starch, acid, etc. It is reported that around 300,000 tonnes of synthetic dyes are reportedly discharged annually into treatment facilities world-wide [38]. In addition, the waste-water has harmful pollutants that impact the clean water [39]. The excessive dye-laden waste-water has a great impact on photosynthetic activity in plants, animals, and aquatic life. It also affects human health due to the presence of compounds such as heavy metals and chlorine in man-made dyes. So, it is of paramount importance to treat such waste-water to produce clean and harmless water for use in other sectors such as agriculture, electricity, environment, etc. Teshale et al., [40] reported that textile industries release a huge amount of highly polluted water into the environment. Hence, effluent and waste-water from the textile industry must be treated before they are discharged into the water bodies. They observed several treatment techniques, which include biological treatment methods using fungi, algae, bacteria, and microbial fuel cells, chemical treatment methods like photocatalytic oxidation, ozone, and Fenton's process, and physicochemical treatment methods, viz., adsorption, ion exchange, coagulation, and filtration. They also studied the hybrid treatment methods and their cost per cubic metre of treated waste-water.

By addressing these concerns with sustainable treatment options, one can prevent the flow of wastewater into local watersheds, thus safeguarding public health and the ecosystem. Thus, by treating and reusing textile wastewater, it is possible to save and increase existing water resources and reduce environmental pollution [41-44].

Li et al., [45] reported that the contamination due to industry-derived antimony (Sb) is of great concern. The authors conducted a detailed study to identify the source of Sb together with other Potential Toxic Elements (PTEs) in and around an industrial area in China and emphasized the contribution of Sb to ecological risk in the local aquatic environment. By investigating the distribution of nine PTEs in surface water in Wujiang County in dry and wet seasons, they revealed that textile waste-water was the main source of Sb. The distribution of Sb (0.48~21.4 μg/L) showed the least seasonal variation among the nine elements. Factor analysis revealed that the factor that controls Sb distribution is unique. They found that Sb was more concentrated in the area where there were a large number of textile industries, and it was affected by the specific conductivity and total dissolved solids in water ($p < 0.01$). The Sb concentration in 35.71% of samples collected from the drainage outlet exceeded the standard limit of 10μg/L. The results from three pollution assessment methods suggested that >5% of the sampling sites were too heavily polluted, and Sb contributed the most. Hence, it is necessary to strengthen the administrative control and supervision of local textile industries in order to raise the quality standard of local textile waste-water emissions.

It is pertinent to mention here that there is a growing interest in cleaner technologies [46], which might be applied in various textile waste-water treatment and reuse processes. Hence, the researchers have to ponder over new ideas, which may lead to the development of innovative approaches in the future. So there is a continuous need for research and innovation to develop newer hypotheses and better approaches in the field of textile waste-water treatment.

Emerging Contaminants from Hospital and Medical Sectors

Antibiotics are widely used to treat diseases in humans and animals. The production and usage of antibiotics are continuously increasing from 100,000 to 200,000 tonnes globally to combat diseases and increase meat production [47]. Table 2 shows the presence of antibiotics in different kinds of samples. In 2010, the consumption of antibiotics by livestock was 63,151 tons, and it is expected to increase by about 67% by the year 2030 [56]. The tremendous increase in antibiotic usage for therapeutic operations, aquaculture, and animal culture has resulted in the generation of antibiotic-resistant pathogenic microorganisms. Antibiotic resistance is one of several threats faced by health, food security, and safety, as reported by the World Health Organization (WHO). For preventing and controlling antibiotic resistance, WHO has given suggestions to individuals, policy makers, health-care professionals, health-care industries, and the agricultural sector [57].

Table 2 Antibiotics observed in different kinds of samples

Nature of the Antibiotic observed	Type of Sample	Concentration µg/kg	References
Fluroquinolones	Manure	1420 - 225000	[48-49]
Macrolides		7000-8100	[50]
Tetracyclins	Sewage sludge	8326	[51]
	Bio-solids	743	[52]
	Soil	2683	[53]
Ionophores		0.0004	[54]
Sulphonamide		0.9 – 1.83	[55]

Estimation carried out by the European Centre for Disease Prevention and Control reported that every year, 25,000 people from Europe lost their lives due to the infection caused by drug-resistant bacteria [58]. The onset of resistance was observed with *Staphylococcus aureus* strains, and it is reported that 70% of these strains achieved resistance within six months [59]. The molecular techniques like PCR and other multi-omics methods used to detect resistant genes in environmental samples are well documented [60]. The majorities of the antibiotics, around 70%, simply passes through the digestive tract of humans and are excreted as urine without any alteration. Antibiotic-resistant genomes and bacterial strains were observed in sewage discharged from hospitals [61].

Effect of emerging contaminants on health care Products

Consumer and healthcare products

The products like toothpaste, cosmetics, skincare products, antibiotics, medicines, fragrances, medications used in the agro-industry etc. are daily used and fall under consumer and healthcare products [62]. Pharmaceutical and healthcare products are one of the important classes of newly emerged pollutants in healthcare and they are known to be endocrine disruptors. Water sources may become contaminated as a result of the disposal of leftover or expired drugs and their presence in wastewater. The potential health effects of prolonged exposure to traces of medications in drinking water are still being investigated, although they might be mild [62]. Consumer and healthcare products observed in the environment is shown in the Figure 3.

Table 3 Representing consumer and healthcare products with their chemical formula and utilization

S.No	Emerging contaminants/ Class	Compounds	Formula	General use
Pharmaceuticals				
1	Antibiotics	Penicillin	$C_{16}H_{18}N_2O_4S$	Infection by bacteria
2		Erythromycin	$C_{37}H_{67}NO_{13}$	
3	NSAIDS	Diclofenac	$C_{14}H_{11}Cl_2NO_2$	Analgesic, antipyretic and anti inflammatory
4		Ibuprofen	$C_{13}H_{18}O_2$	
5	Hormones	17-beta-Estradiol	$C_{18}H_{24}O_2$	Reproduction and

6		Estriol	$C_{18}H_{24}O_3$	growth related issues and cancer
7	Stimulant	Caffeine	$C_8H_{10}N_4O_2$	Treatment for obesity and migrane
Personal care products				
1	Insect repellents	N,N-diethyl m – toluamide	$C_{12}H_8O_3$	To remove Insect pest and vector
2	UV filters used in skin cream	Methyl paraben	$C_8H_{17}NO$	Preservation of food and cosmetics
3	Fragrances	Galaxolide	$C_{18}H_{26}O$	Improve the surrounding odour
4		Toxallide	$C_{18}H_{26}O$	

Through water, these endocrine disruptors enter into the human system, causing severe health problems such as cancer, mutagenesis, reproductive problems, genotoxicity and physiological disorders including diabetes, respiratory problems etc., [62-63]. The widespread utilization of antibiotics in healthcare is another key problem. It leads to the emergence of antibiotic-resistant bacteria, or multi-resistant bacteria, which are going to exhibit resistance to multiple drugs. These resistant bacteria have the probability to spread across water systems and impact the health of aquatic life as well as humans, making them a problem for both the environment and healthcare system. Consumer and healthcare products with their chemical formula and utilization is listed in the Table 3.

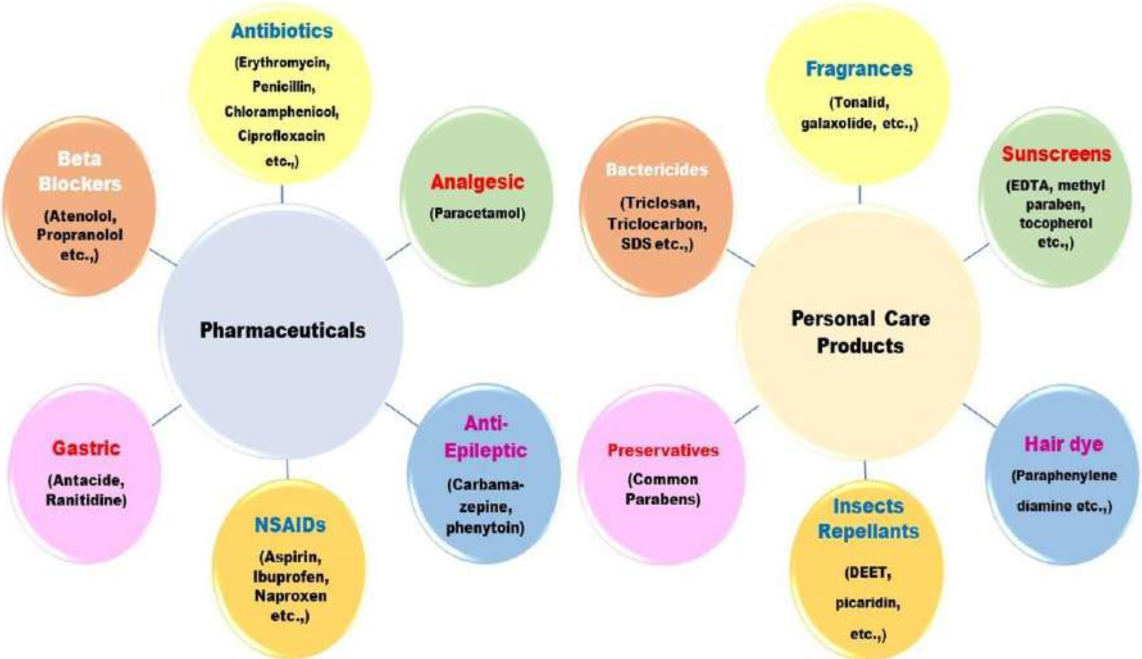

Figure 3 Pictorial representation of consumer and healthcare products detected in the environment

Medical and workplace exposure

Certain pollutant in the environment is observed due to the use of medications and personal care items. Another way to cause contamination is through the disposal of leftover medicines [64]. Workers in various sectors that utilize or create emerging toxins run the risk of exposure by ingestion, skin contact, or inhalation. For several pollutants utilized in industrial processes, working exposure is a serious problem. It's crucial to remember that the pathways of emerging contaminants might be complex and interlinked. Especially so much concern was raised about the potential impact of contaminants in the context of healthcare [14]. In this part, several important aspects of the possible consequences of emerging pollutants on health are discussed.

Limited Research

Research on the health effects of emerging contaminants is ongoing, and the long-term consequences of exposure to low levels of these substances are not fully understood. Furthermore, variables including the contaminant's concentration, the length of exposure, and a person's sensitivity may affect the level of exposure and its possible health implications. To comprehend and reduce the dangers related to emerging pollutants, research and monitoring projects are still in progress. Therefore, caution is warranted, and monitoring and risk assessment are crucial in healthcare settings.

Regulatory Response

Regulatory agencies are working to address the issues caused by emerging contaminants. They are developing guidelines and standards for testing and regulating these substances in the environment and in products used in healthcare settings to avoid the achievement of the SDGs (Sustainable Development Goals) by UNO. Also, this is imposing limitations or prohibitions on the production and application of specific pollutants, particularly if they provide serious dangers to the environment and public health. In order to maintain good health in humans and to protect the environment from emerging contaminants, the below approaches are recommended, considering low-income countries [65].

- The precautionary principle is being adopted
- Financing research subjects that support development in low-income countries
- Fortifying the research-policy link
- Refining and execution of the framing by scientists

A broad and cooperative strategy combining governmental organizations, businesses, academic institutions, and the general public is needed to address new pollutants. A thorough plan is needed to minimize and prevent the effects of emerging pollutants, which must include regular changes to regulation, continuing research, and the implementation of sustainable practices.

Mitigation and Prevention

Healthcare institutions have the ability to reduce the amount of emerging contaminants. Reducing contamination may be achieved by investing in cutting-edge water treatment technology, following best practices for managing hazardous chemicals, and disposing of medications properly. In summary, new pollutants may have an impact on health both within and outside of healthcare environments. To reduce these compounds' negative effects on human health and the environment, it is crucial to keep studying and keeping an eye on them, to establish suitable legislation, and to put best practices into practice [66-67].

Effects of Emerging Contaminants on Agriculture

The Prithvi Sutra of the Artharva Veda has given importance through the prayer to Goddess Prithvi: 'O Mother! With your ocean, rivers, and other bodies of water, you give us land to grow grains on which our survival depends' and 'May You, our Mother, land on which are born five races of mankind, be nourished by the cloud, loved by the rain' [68]. The Father of our Nation, Mahtma Gandhiji, also insisted on this concept with his statement, 'Earth has plenty for every man's need but not for greed' [69]. The target is to feed 9.5 billion people during 2050 and achieve the second goal of sustainable development, which pledges to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. By 2030, we have to end hunger and ensure access to food for all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious, and sufficient food throughout the year [70].

Agriculture requires a major workforce in India, and it is considered a primordial socio-economic activity of our country, which accommodates a larger population for their survival and is considered the backbone of our economy. Soil quality is an important criterion for maximum productivity in the agro-sector. Crop cultivation and production depend mainly on the presence of available soil and water reserves [71]. Human activity severely affected around 89% of the land area [72]. The United

Nations Environment Programme (UNEP) has recorded that India is one of the 17 most diverse countries based on the availability of the earth's major species and the number of endemic varieties. The biodiversity of India is due to the observation of climatic variation, topography of landscapes, and many soil varieties. Biologically rich soil originates naturally to organize many ecosystem-based services like reservoirs of water, providers of nutrients to plants, and shelter for many organisms by supporting the existence of biodiversity. Urbanization and industrialization resulted in 1% of every state in our country losing its agro-geographic area in a consistent manner [73]. Organic agriculture is the best option for current agricultural practices, and it has proven to be the solution for deleterious effects on the current agricultural system caused by the application of chemical fertilizers to enrich the soil and herbicides and pesticides to protect the crops [74]. In the soil environment, organic matter plays a vital role, making it dynamic in nature. It continuously changed in terms of quantity and quality [75].Contaminants like agro-nutrients, pesticide compounds, and sediments deposited in water resources are strongly affecting the agricultural environment. The ECs, which include antibiotics, surfactants, and steroids, are the least known contaminants noted in agricultural land. The agricultural land observed around the Ratlam industrial area was drastically affected by the use of contaminated groundwater, resulting in low yields, a reduction in the rate of irrigation, and the deterioration of its infrastructure [76]. Remote sensing data studies by the researchers revealed that the ground water and land area of Bathinda district of Punjab were polluted dramatically [77].

Impact of Emerging Contaminants on Agro-Biodiversity

Maintenance of crop-land improves the production of food in terms of quality and quantity. It helps water resource management and provides habitat for wild species, which is beneficial for agricultural practices and human health. It is essential to improve agriculture by means of area and production to meet the demand in the future for providing food to several billion people. The contamination of water, soil pollution, erosion, and reduction in biodiversity are initiated by modern agricultural practices [78].

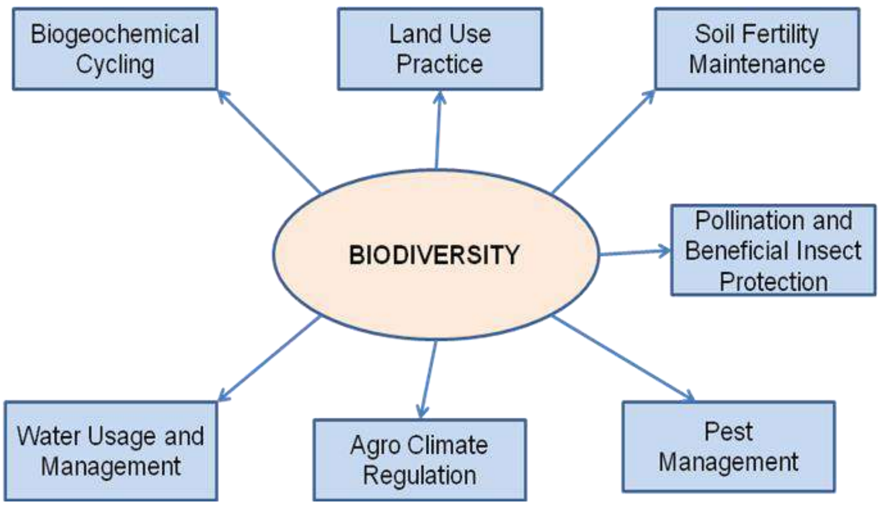

Figure 4 Role of biodiversity on agricultural activities

Soil organisms such as microorganisms and insects play an important role in preserving biodiversity and producing agricultural products. The important role played in the agricultural ecosystem is illustrated in Figure 4. Soil biodiversity is often affected by mechanical factors such as soil due to inappropriate agricultural practices, constant use of chemical fertilizers, crop rotation, and many chemical products on the land [79]. Reduced biodiversity reduces food and health food production [80]. The impact of biodiversity loss on agriculture is leading to the release of excess nutrients into the water. This exposes it to the harmful effects of eutrophication, leading to soil pollution and ammonia evaporation [81]. For sustainable food production, agricultural biodiversity needs to be protected to ensure food security and the balance of cooperation between members such as pollinators and predators. Water and air quality controls are designed to protect the supply chain.

Control and Treatment Measures of Novel Emerging Contaminants (NEC)

Removal of emerging contaminants from water resources is not easy because of the high complexity of the waste materials, which consist of recalcitrant molecules. They are mixed with organic materials, and mineral mixtures include metal and metal-based waste materials. The complex mixture of contaminants comprises the pollutant with chemically mixed materials with functional elements. The diverse quantity of pollutants present in the waste water can be treated with advanced methods that are effective, technologically viable, and should have a feasible cost.

Oxidoreductase enzymes, laccase, and peroxidases are involved in the bioremediation of waste water contaminants. The enzymes are effectively useful in the removal of contaminants through their oxidation reduction potential in bioremediation. The enzymes are capable of removing contaminants including PPCPs, dioxins, dyes used in the textile industry, pesticides, herbicides used in agricultural fields, phenolic compounds, oxidases, peroxidases, oxygenases, and dehydrogenases, collectively known as oxido reductase enzymes. Laccases observed in bacteria, fungi, insects, and plants are grouped as multi-copper reductase enzymes. Laccases have substrate specificity available in microbial cells like fungi, which are decomposing lignin, cellulose, and hemicelluloses from wooden logs and are capable of degrading a wide range of environmental contaminants. Laccases can degrade many kinds of emerging contaminants. Aromatic compounds consist of hormones, viz., alpha-ethinylestrdiol, estrone, and beta-estradiol.

Role of Machine Learning and Artificial Intelligence in NEC

Over the past decade, Artificial Intelligence (AI) has contributed too many applications. Artificial intelligence plays an important role in facing the current problems of diseases arising from various sources. AI caters crucial steps in environmental monitoring, waste water treatment and public health. It includes dynamic, non-linear and highly challenging tasks like mathematical modeling, simulation, optimization and prediction accurately at unexpected speed [82,83]. Chemometric analysis of environmental data seeded with AI is used for quantitative analysis, environmental impact assessment, toxicity analysis, and modeling [84]. Principal component analysis (PCA) can also be employed as a multivariate analysis to find statistical significance [82]. PCA and cluster analysis (CA) are unsupervised statistical models involved to determine multivariable data. PCA used to find out the correlation between the variables, whereas CA is used for grouping samples among the variables.

Chemometric tools can be applied to analyze environmental samples like soil and water, which reduces the cost of sample collection and analysis [85]. The heavy metals present in the environmental sample, including the metal source, metal concentration, size of the particle, and total organic carbon content, were analyzed by using PCA [86].

Environmental Monitoring

AI based environmental monitoring employed to assess quality of the environment, finding limits and predict the potential level of pollutants. Variables and its related time-interval can be measured using the algorithms. Environmental and public health monitored using the modern AI based algorithms and tools. Human activity created global environmental problems climatic change and natural calamities. To solve all these problems, AI through artificial neural networks (ANN) and machine learning are used [87].

Sensor Networks: AI algorithms created to measure the data from sensor networks to find emerging contaminants in real-time. These sensors may be deployed in water treatment plants, flow and water quality of rivers, and other environmental parameters.

Satellite Imagery: AI can analyze satellite images captured by Geographical Information Systems (GIS) and other remote sensing tools to monitor the change of land use practices, sources of contamination and find the impact of emerging contaminants on environment in large scale. Analysis and observation of images captured by satellite, data obtained from remote sensing, data interpretation can be performed through AI tools. This is possible by the

development of machine learning and data mining and it is used to monitor the geological and environmental sources [88]. Machine learning models and big data analysis are used to track the contaminants like nitrate, arsenic and PFAS present in the drinking water [89].
AI is used to regulate the water treatment processes through the prediction of contaminants, adjustment of chemicals in real-time, and to improve the efficiency of treatment plants. For smart water distribution, AI can help to manage water distribution systems, minimize the risk of contaminants and ensure the quality of water.

Machine Learning Models

AI based analysis especially machine learning models, can perform prediction of large datasets to understand patterns and trends related to the occurrence and distribution of emerging contaminants. This helps to predict the sources of contamination and understand the nature of contaminants. Predictive modeling can find the probability of contamination based on data already available, environmental conditions, and other relevant factors. Risk Prediction tools assist for the prediction of risks factors associated with exposure of emerging contaminants to help the experts to prioritize in monitoring and mitigation strategies. Decision Support Systems provide valuable insights for policymakers, water quality managers, and officials of public health to monitor the issues caused by emerging contaminants. Health Surveillance carried out to analyze electronic health data to infer the relationship between exposure to emerging contaminants and health effects, facilitating early detection of health related issues. Epidemiological Studies performed by using epidemiological data to understand the long-term health impacts of exposure to emerging contaminants. Virtual Screening is used to measure new emerging contaminants and assess their environmental impact [90].

Chemoinformatics

Chemical data used to understand the structure-activity relationships of emerging contaminants, aiding in the development of targeted monitoring and treatment strategies. Overall, the integration of AI in addressing emerging contaminants enhances the ability to monitor, analyze, and mitigate the impact of these pollutants on the environment and public health. Jaffari et al [91] used ten different machine learning tools comprises CatBoost, bagging, Hist Gradient Boosting, Extra Trees, Gradient Boosting, XG Boost , Random Forest, Decision Tree and K Nearest Neighbors for predicting the capacity of emerging contaminants absorption through biochar materials. Chemometric method used to find the trace elements includes Zn, Cu, Fe, Mn, Ca, K, Mg, Ba,B and Al. Chemometric analytical methods are used to analyze chemical analysis quantification, environmental assessment, monitoring, toxicological prediction and modeling [92].

The quantitative structure–retention relationship (QSRR) model is used to find the behavior of the chemical compounds. Molecular descriptors utilized for the prediction using QSRR model includes multiple linear regression (MLR), deep neural network (DNN) and support vector machine. Mean absolute deviation (MAE) mentioned in the equation 1 and Mean squared error (MSE) given in the equation 2 are calculated by using the following formula.

$$MAE = \frac{\sum_{i=1}^{n}(y_a - y_b)^2}{n} \quad \text{-------1}$$

$$MSE = \frac{\sum_{i=1}^{n}(y_a - y_b)}{n} \quad \text{------- 2}$$

Where y_a = experimental value

y_b = predicted value

They found that MAE and MSE values of 0.0860 and 0.0143 respectively. It is proved model useful for the screening and identification of emerging pollutants [93].

Analytical Methods to identify major contaminants

The analysis of major contaminants in water and soil is crucial for environmental monitoring, assessment, and remediation efforts. Various analytical methods are employed to detect and quantify these contaminants. Here are some commonly used analytical methods like pH measurement, Conductivity and Total Dissolved Solids (TDS), Temperature, Nitrate and Phosphate Analysis, Microbial Analysis, Voltammetry, Gas Chromatography-Mass Spectrometry (GC-MS) and Liquid Chromatography-Mass Spectrometry (LC-MS), High-Performance Liquid Chromatography (HPLC), FT-IR, NIR, Raman, NMR and so on for identifying water contaminants. The applications of some analytical methods are discussed in depth.

Atomic Absorption Spectroscopy (AAS)

Atomic Absorption Spectroscopy is used for the detection of heavy metals like lead, cadmium, and mercury in both water and soil. It measures the absorption of specific wavelengths of light by metal atoms in a sample. Many studies on water pollution have been conducted in the literature. This review highlights some of the most important results published worldwide. The metal content such as Pb, Ni, Cd, As, Cu and Zn were studied in the water collected from Daura gypsum mining area of Nigeria [94]. The results show that the concentration of the metals determined decreases in the order of Cd>As>Ni>Pd>Zn. The authors concluded that the drinking water is heavily contaminated with Cd, As, and Ni. This may cause a kidney-related risk to people over a long period of time. Assessment of heavy metals in water and fish samples of abandoned mining ponds in Barkin Ladi, Plateau State, Nigeria, was reported by Nangbes Jacob Gungsat et al. [95]. The results reveal that the metal concentration of water samples decreases in the following sequence: Hg > Ni > Cr> Pb > As > Cd. Moreover, Hg has the highest concentration, followed by Ni and Cd. The elemental concentrations in the catfish samples decreased in sequence for the flesh, as Ni > Cr >Pb > Hg > As > Cd, and for the gills. Ni > Hg > Cr > Pb > As > Cd, for kidney Ni > Pb > Hg > Cr > As > Cd; for liver, Ni > Cr > Cd > Pb > Hg > As. The authors concluded that the pond water is not suitable for drinking and agricultural purposes. Afrasiab Khan Tareen et al. [96] studied heavy metals (Pb, Sb, Al, and As) through atomic absorption spectroscopy from drinking water in District Pishin, Balochistan, Pakistan. The results reveal that the percentage of antimony and aluminum was found to be higher than the standard recommended values. In addition, the concentrations of arsenic and lead were found to be lower than the recommended values for all the samples. The present results showed that even the groundwater is contaminated by the use of fertilizers and insecticides. Sirajudeen and Pravinkumar [97] studied the heavy metals analysis of the groundwater of Thirukoviloor, Villuppuram, Tamil Nadu, India. They analyzed heavy metals such as zinc, chromium, copper, and iron using an atomic absorption spectrophotometer (AAS). They compared their results with the WHO guidelines and showed that the water quality in these areas is good and suitable for drinking purposes.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

ICP-MS is a highly sensitive technique for the quantification of trace metals and metalloids, including arsenic, selenium, and rare earth elements, in water and soil samples. Recently, Balaram et al., [98] reported an excellent review on the pollution of water resources and the application of ICP-MS for monitoring. This review focuses on the use of different ICP-MS technologies, such as classical ICP-MS, ICP-MS/MS, ICP-TOF-MS, HR-ICP-MS, MH-ICP-MS, and MC-ICP-MS. Quality detection and determination of metals, isotopes, and metal species, as well as quality control of various pollutants in drinking water, groundwater, underground water, wastewater, domestic water, water supply, and various industries, constitute the main topics covered in this study. Sasan Rabieh et al., [99] reported the MH-ICP-MS analysis of the freshwater and saltwater environmental resources of Upolu Island, Samoa. The authors analyzed 69 elements ranging from Li (3) to U(92) measured in each sample by Mattauch-Herzog inductively coupled plasma mass spectrometry (MH-ICP-MS). Human activities, such as the use of pesticides and herbicides, which can be linked to many chemicals in pharmaceuticals known to cause obesity, can also affect coral reefs to collapse. Moreover, some saltwater samples tested contained high levels of salt, possibly due to climate change, which could further harm the health and biodiversity observed in the coral reefs. Devika Vashisht et al., [100] reported a case study on groundwater and drinking water in Chandigarh, India. The authors analyzed novel contaminants (endosulfan (ES) and hexachlorohexane (HCH)) in water samples using gas chromatography mass spectrometry (GC-MS). In the study, it was determined that the levels of HCH and ES were below the detection limits in all water samples. They concluded that some water impurities, such as TDS, EC, DO, and total hardness, exceeded the limit set by the Bureau of Indian Standards (BIS). The parameters pH, EC, DO, BOD, COD, total and faecal coliforms were monitored in the post summer season. The EC and pH values showed increasing trend from dam source towards the mixing site. The calcium, magnesium and bicarbonate ions were found to be increased and the counts of

Enterobacteriaceae and pathogens at the sites of crammed population [101].

UV-Visible Spectroscopy

UV-Vis spectroscopy can be used to analyze organic compounds, such as aromatic hydrocarbons and some pesticides, by measuring their absorption of UV or visible light. Yuchen Guo et al [102] reviewed the principles and applications of UV-visible spectroscopy in water quality detection. Various UV-visible technologies helps to measure water quality affected by on contaminants such as toxic oxygen demand, heavy metal ions, nitrate nitrogen and dissolved carbon monoxide. Finally, future developments of UV-visible spectroscopic methods used to identify water quality parameters.

NMR Spectroscopy

Nuclear Magnetic Resonance (NMR) Spectroscopy is a sensitive tool used to determine the structural, functional, dynamical, and stereochemical characteristics of molecules of various scientific interests. The use of this technology has spread to almost every branch of science, including environmental science. Analysis of various NMR parameters, such as chemical shifts and relaxation times, can provide important information about the nature of molecular interactions in liquid and liquid mixtures [103-106]. Diffusion NMR can be used to study the translational motion of molecules, providing insights into their size, shape, and interactions. The diffusion NMR is a valuable tool used in various scientific disciplines for studying the dynamics and spatial distribution of molecules. This method is highly useful to identify different contaminants present in pharmaceutical and environmental samples without any sample preparation [107-108]. The potential of this method should be further investigated by creating new pulse sequences. Maryam Tabatabaei Anaraki [109] reports on the use and future potential of wastewater analysis using NMR spectroscopy. The authors review data on various heteronuclear nuclei (^{13}C, ^{15}N, ^{19}F, ^{31}P, and ^{29}Si) and other nuclei and metals (e.g., ^{27}Al, ^{51}V, ^{207}Pb, and ^{113}Cd). Additionally, a combination of NMR methods such as multiphase NMR, NMR microscopy, and hyphenated methods (e.g., LC-SPE-NMR-MS) are discussed to contribute to the current understanding of wastewater. Elenilson et al. [110] reviewed the advances in wastewater analysis by NMR spectroscopy. This review article introduces the application of NMR spectroscopy in wastewater treatment research, conducts a literature review, and provides guidance to interested readers. NMR is also widely used in the analysis of different wastewaters, such as organic matter (fulvic and humic acids) and sludge.

Liquid Chromatography (LC)

LC, particularly High-Performance Liquid Chromatography (HPLC), is used for the analysis of a wide range of organic compounds, including pesticides, herbicides, and pharmaceuticals, in water and soil samples. Kasiske et al [111] reported the Application of high-performance liquid chromatography to water pollution analysis. The authors identified very low concentrations of trace organic compounds in water. Moreover, HPLC plays a major role in the identification of contaminants like heavy metals, pesticides an organic compounds and this method is generally used for high precision quality controls. Xiaodan Chen and Liang Wang [112] discussed the Application of High Performance Liquid Chromatography in food controls, drug inspection and environmental monitoring.

Liquid Chromatography-Mass Spectrometry (LC-MS)

LC-MS is used to analyze a wide range of organic compounds, including pharmaceuticals, pesticides, and environmental contaminants. Instrumentation sensitivity, resolution, reproducibility, efficiency, selectivity, speed, column lifetime, sensitivity and reproducibility are negatively affected by the presence of contaminants. Simon J. Hird et al. [113] reported the usefulness of LC-MS for the determination of chemical contaminants in food. Zoraida Sosa-Ferrera et al. [114] analyzed the different classes of micropollutants in aqueous and solid environmental samples using the combination of liquid chromatography (LC) with mass spectrometry (MS). The authors discussed different aspects of methodologies based on these techniques, including sample preparation (extraction or pre-concentration) and matrix effects. Zhang et al. [115] studied the multi-residue determination of 244 chemical contaminants in chicken eggs using Liquid Chromatography-Tandem Mass Spectrometry after effective lipid clean-up. This method was successfully applied to the quality control of eggs. This method detects nearly 244 compounds in the egg samples, which include the presence of some banned compounds. Sun et al [116] reviewed the usefulness of mass spectrometry to detect harmful contaminants in food materials. This method is more rapid, sensitive and accurate for the determination of contaminants in food and food packing materials.

FT-IR Spectroscopy

Fourier Transform Infrared Spectroscopy (FT-IR) is another powerful analytical technique used to identify and quantify the chemical composition based on the absorption of infrared radiation. This method can be used to identify and quantify pollutants such as nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOCs), and other gases. Several research works have been reported in the literature on the chemical analysis of organic and inorganic compounds found in water samples [117-120]. Additionally, this method is useful to analyze soil samples for pollutants and contaminants. It helps to understand the impact of economic activity on soil quality and health services [119]. Śliwińska et al. reported the simultaneous detection of heavy metals (i.e., Cr, Zn, Ba, Hg, Ni, and Pb) in soil samples using the FT-IR method (far, mid, and near-infrared) [121]. The structure of the PLS model based on Fourier transform infrared (FT-IR) spectroscopy allows FT-IR spectroscopy to be considered as an additional method to predict and monitor soil pollution. Generally, FT-IR method is a fast, non-destructive method that can be used to identify many compounds. However, it is worth noting that FT-IR can identify many compounds but may not be as accurate as other methods such as gas chromatography-mass spectrometry (GC-MS) used for some applications. For this reason, it is often used in conjunction with other analytical methods for a more comprehensive analysis.

CONCLUSION

` The present effort is to aggregate widely distributed information in a single window to enable understanding of the potential threats caused by emerging contaminants and to protect our environment to pave the way for food security and human health. There are many types of nano-scale contaminants that deliberately escape from diagnostic techniques. In this review, special attention is given to collecting all the diagnostic tools comprising Artificial Intelligence and Machine Learning, Mass Spectroscopy, Liquid Chromatography-Mass Spectroscopy (LC-MS), Atomic Absorption Spectroscopy (AAS), NMR Spectroscopy, UV-visible spectroscopy and FT-IR Spectroscopy. It is essential to develop fast and appropriate analytical techniques to record accurate data on such contaminants, which is the first step in providing solutions to the present calamities. Disseminating information to diverse membership groups and raising awareness among experts, policymakers, and the public by organizing workshops, seminars, and discussions is an important effort in dealing with the threats posed by today's viruses.

Agriculture is playing a prominent role in the food chain, and the presence of ECs poses bioaccumulation hazards. Industrial discharges and disposal from all the source of utilization increase the risk to the environment and health. Innumerous amount of unnoticed contaminants arise from health care industries also highlighted in this review to attract researchers to find solution for the calamities. This is the right time to address all the problems generated by nano- and pico-scale contaminants. At present, people are deliberately ignoring the environmental contamination caused by these pollutants in the midst of their busy mechanical lives. Truly, it is a wakeup call to the entire human population to enable them join our hands and stand against the giant contaminants to provide a clean and green environment to our generations without any pollutants, thus providing a healthy and happy life to all living beings.

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