5 Emerging Contaminants in Wastewater: Sources of Contamination, Toxicity, and Removal Approaches

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5.1 Introduction

We are moving very fast on the roads of development, innovating in the desire of becoming more and more efficient with resources. Day by day mankind is developing complex methods and chemicals for simplifying life. However, several incidents have been recorded in the history of, chemical compounds that were developed to improve the standard of living left a hazardous impact on the environment and human health. Contamination of air, water, and soil is not a problem that developed in recent years, contaminants like arsenic and lead are age-old contaminants, with the advancement in research we can identify new problems associated with their increasing concentrations. Like aggravation of arsenic pollution problem in recent years in South East Asian region (Fendorf et al. 2010). The insatiable quest for economic growth led to the quantitative expansion of manufacturing. Every industrial setup generates wastewater, composed of chemicals developed and used as part of technological advancement in manufacturing. Variety of organic hydrocarbons, heavy metals, nutrient enrichment by human waste, and microbes that are pathogenic for human health are primary constituents of wastewater. These compounds are difficult or impossible to be degraded by natural processes or their insertion is so huge that it persists in significant quantity for a long time and adversely affects human health and the environment. Pollutants that are present in trace amounts in the environment are micropollutants, these can be synthetic in origin such as strongly halogenated molecules (fluorinated surfactants, etc.) or can be natural compounds

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like antibiotics (penicillin) or estrogens. Their presence in trace amounts made it difficult to identify their effects; however, with advancements in research there possible negative impacts have been highlighted which raised the concern of stakeholders towards these trace compounds.

Emerging contaminant reaches the environment via many anthropogenic sources and spread in environmental matrices. Most of the emerging contaminants (ECs) present in the aquatic system originate from direct and diffused pollution sources, posing a challenge to the environment and society (Haq and Raj 2018). ECs are synthetic or natural chemical compounds, molecules of which have the potential to disturb the ecological cycle and cause a threat to the sanctity of the environment and human health. These contaminants are mobile but persistent in air, water, and soil sediments.

Table of DDT usage in agriculture is a horrendous example of how devastating impact a contaminant can pose on ecology and the environment. DDT was developed as an insecticide and was used for medicinal purposes during World War II. Its usage as a pesticide was started in 1945, as food demand was increased after the world war and the chemical proved itself effective during a crisis. It was in 1962 when negative impacts of DDT were highlighted (Carson 2002). This whole situation raised concern about bringing synthetic drugs for general public use without prior investigation of their effects on the environment, biodiversity, and human health. With growing innovations in manufacturing, humans are bringing out innumerable contaminants in nature. Most of these emerging contaminants can be categorized as flame retardants, surfactants, pharmaceuticals, personal care products, gasoline additives, and their degradation products, biocides, polar pesticides, and their degradation products, and various proven or suspected endocrine-disrupting chemicals (EDCs). In recent years problem of nanomaterials, plastics, and microplastics has become the center of attention for researchers. Along with these man-made complex compounds, well-known traditional trouble of heavy metal ions like mercury, cadmium, thallium, arsenic, lead, etc. has aggravated with time. Advances in epidemiological and toxicological studies have discovered emerging problems regarding these old pollutants.

Studies suggest that a significant amount of contaminants remains in treated water via sewage treatment plants, this treated water when discharged in natural resources of water like rivers and lakes (Stasinakis et al. 2013). These unfiltered contaminants cause severe damage to the natural aquatic ecosystem and biodiversity. When contaminated water or partially treated water is used for agricultural and for other secondary uses. Studies suggest their acute hazards effect on soil and agricultural produce (Boots et al. 2019).

5.2 Emerging Contaminants

Chemicals of synthetic or natural origin, which cause known or suspected adverse ecological or human health effects, are contaminants. Contaminants from a chemical class that so far has not been studied extensively, where there is either a concern from stakeholders (scientists, regulators, NGOs, etc.), that the contaminant class may be having an impact on the environment or human health are emerging contaminants; also, where there is a concern that existing environmental assessment paradigms are not appropriate for the contaminant class are contaminants of emerging concern (CEC). The ecotoxicological perspectives typically used to characterize environmental contaminants have fallen short when attempting to classify the complex network of emerging contaminants. The typical approach taken by toxicologists of characterizing a compound by its persistence, lipophilicity (preference for fat-tissue), and toxicity (both acute and chronic) has proven to be inadequate with regard to emerging contaminants. An emerging contaminant can exhibit what is known as "pseudo-persistence" whereby a contaminant is continually present in the environment because it is continually being released by sewage treatment plants. Lipophilicity, typically used to determine how easily a contaminant will cross cell membranes or enter tissues, is an incomplete characterization tool because many emerging contaminants are pharmaceutically engineered to be actively transported into cells and tissues. There are even more characteristics of emerging contaminants that limit our reliable characterization of their risk to humans and the environment. Our power to detect and measure these compounds currently surpasses our knowledge of their toxic effects on humans or wildlife. Besides, to establish a cause–effect relationship, toxicologists cannot simply cite the co-occurrence of contaminant and adverse effects. Rather, the uptake, mode of action, and biological endpoints of each emerging contaminant must be researched and documented to establish a correlation between contaminant and consequence.

These contaminants have been incorporated by anthropogenic activities in almost all spheres, i.e. biosphere, hydrosphere, lithosphere, atmosphere, and cryosphere, all spheres are affected and contaminated by these compounds. Emerging contaminants are not only ones whose existence is recently noticed by the scientific community, but it is also about new concerns raised about old contaminants due to advancement in research (Sauve and Desrosiers 2014). It is important to note that the majority of emerging contaminants are no pollutants that are new or have just gained entry into the environment. Rather, most emerging contaminants are well-established pollutants with a newly demonstrated toxic effect or mode of action. Thus, the word "emerging" refers not only to the contaminant itself but also to an emerging concern about the contaminant. As such, emerging contaminants are often referred to as "chemicals of emerging concern" or "contaminants of emerging concern." Since there is little toxicological information for the vast majority of the chemicals we use, particularly with regard to long-term, low-level exposure, it is possible that many chemicals with a long history of use (such as MTBE) could contribute to the future burden of emerging contaminants.

Bioaccumulation, toxicity, and resistance to degradation are key properties that can make any contaminant disastrous. With increasing knowledge of the negative impacts of naturally available chemical compounds, we are adding contaminants to the list of emerging contaminants. Environmental concerns can be sorted into three classes of contaminants. (1) a new compound, a molecule which is recently appeared to scientific research or not studied yet fully, (2) the contaminant is common or known to exist but the research of contaminant still going on, (3) old contaminant such as mercury, arsenic, DDT where new research is pushing our understanding of environmental and human health risk of such contaminant.

Proper knowledge of the type, source, and effects of any contaminant is a must to monitor and mitigate their harmful effects. In recent times, wastewater is loaded with emerging micro-contaminants, these contaminants are present in trace quantities in natural waters, it is because of advancement in research technology that quantitative analysis of these compounds is possible.

5.2.1 Pesticides

Any substance or mixture of substances that are intended for preventing, destroying, repelling, or mitigating any pest is pesticides. Pesticides are classified into different classes according to their applications such as herbicides, insecticides, fungicides, rodenticides, nematicides, and microbicides. Excessive use of pesticides in agricultural fields will result into leach out of chemicals in soil/sediments or through runoff it will infuse with streams can be a potential concern to aquatic life and ecosystem, as well as human health if they affect the drinking water source and recreational uses areas. There has been a steady growth in the production of technical-grade pesticides in India, from 5000 metric tons in 1958 to 102,240 metric tons in 1998. In 1996–1997 the demand for pesticides in terms of value was estimated to be around Rs. 22 billion (USD 0.5 billion), which is about 2% of the total world market (Aktar et al. 2009). Globally, around three million tons of pesticide is used equivalent to a market value of USD 40 million. Regardless of the benefits of pesticides in the crop field and their significance for the economy, overexploitation of pesticides is raising a serious threat to the environment and humans. The most widely used conventional pesticides are herbicide 2,4-dichloro phenoxy acid, herbicide glyphosate, the herbicide atrazine, fumigant metam sodium, herbicide acetochlor, inorganic chemical insecticides such as calcium arsenate, lead arsenate, and fluoro-organic compounds. Most conventional inorganic pesticides are permanently banned or for other pesticides countries have developed their standard concentration guidelines.

Around the world an enormous number of persistent organic contaminants are present in wastewater effluent, surface water, and drinking water. The pesticides alachlor, dieldrin, and DBCP are each classified under the USEPA designation "probable human carcinogen." Perhaps the greatest threat posed by pesticides, however, is their endocrine-disrupting potential. Pesticides such as atrazine, malathion, methoxychlor, and many others have been shown to disrupt endocrine systems, even at very low concentrations. Exposures can cause reproductive system damage including sterility, decreased fertility, and birth defects, as well as impaired development, immuno-suppression, and metabolic disorders. It represents the ineffectiveness of present and conventional technologies. In US EPA rainbow report $>$1000 pesticide is listed such as borax, nitrogen, warfarin, phorate, zinc phosphide. Pesticides are used in the excess amount in agricultural fields, golf courses, and residential areas to prevent insects, mosquitoes, and other pests (Ikehata et al. 2008). Surface water in the urban and agricultural areas is more prone to pesticide contamination which can pose threat to the aquatic ecosystem even present in low concentrations (ng/L) (Moschet et al. 2014). Pesticide can develop hemopoietic tissue of anterior kidney and immune-depressive effects in fishes, mammals (Dunier et al. 1993).

Pesticides can harm aquatic life, along with the probable harm to human encounter with them can have. Manufacturing to pesticide application in the field the people involved are high-risk groups for pesticide exposure. Pesticide can pose serious effects to human health when exposed in low doses like immune suppression, hormone disruption, diminished intelligence, reproductive abnormalities, and cancer. In India the first report of poisoning due to pesticides was from Kerala in 1958, where over 100 people died after consuming wheat flour contaminated with parathion (Karunakaran 1958).

5.2.2 Persistent Organic Pollutants (POPs)

POPs are chemical substance persist in the environment and cause the risk to human health and the environment. POPs have high lipid solubility, semi-volatile in nature so they tend to travel a long distance through the atmosphere and its travel through the food web not directly and it starts bio-accumulating. The 12 initially, targeted POPs include eight pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, and toxaphene), two types of industrial chemicals (polychlorinated biphenyls or PCBs and hexachlorobenzene), and two chemical families of unintended by-products of the manufacture, use, and/or combustion of chlorine and chlorine-containing materials (dioxins and furans). All 12 targeted POPs are also endocrine disruptors chemicals that can interfere with the body’s hormones. Endocrine-disrupting chemicals can be hazardous at extremely low doses and pose a particular danger to those exposed in the womb. During prenatal life, endocrine disruptors can alter development and undermine the ability to learn, fight disease, and reproduce (Table 5.1).

In past, the widespread usage of DDT in the agriculture field to eliminate mosquitoes and other pests was a trend that led to the death and disappearance of many birds (bald eagles), later the government banned the usage of DDT. POPs are produced consciously by industries such as pesticides, PCBs, PCNs, etc. and some are produced as a by-product through industrial or combustion processes such as PCDDs, PCDFs, PAHs. After 1995, analyzing the impact of POPs on the environment many international societies are working legally to the binding instrument and eliminate POPs (Eljarrat et al. 2003). Present research studies suggested that emerging contaminates such as polybrominated diphenyl ether (PBDEs) are also tend to transport in remote areas of the aquatic system including deep-sea fish. PCB and PBDEs are structurally identical and widely used in flame retardants, plastic, textile, and electronics (Koenig et al. 2013).

United Nations Environment Program (UNEP) adopted the Stockholm convention in May 2001. Initially, 12 POPs were identified which were named as “dirty dozens.” The treaty laid to eliminate or restrict the use of POPs enforced in May

Table 5.1 Persistent organic pollutants (POPs) and their sources of contamination, toxic effects with their current legal and environmental status

	POP	Source	Effects	Recent status of usage
1.	Aldrin and dieldrin	Pesticide (through dairy products, animal meat, insect repellents)	Major motor convulsions, malaise, incoordination, headache, dizziness, and gastrointestinal disturbances, and acute intoxication including fatalities	The use of both chemicals is severely banned in many parts of the world since the 1970s (since 2003 in India) but in use in many countries and the countries use is banned in still present in the environment due to excessive early use
2.	Chlordane	Pesticide (through the crop, dairy products, animal meat, and direct exposure through air pollution)	Affects the immune system and poses carcinogenic effects	Use is restricted in many countries including India
3.	DDT	Pesticide	Increased risk of cancer and diabetes, reduced reproductive success, and neurological disease	Agriculture use banned, still in use against malarial
4.	Endrin	Through food (insecticide and rodent repellent sprayed on the surface of leaves)	Highly toxic for aquatic animals and humans as a neurotoxin	Banned in many parts of the world including India
5.	Hexachlorobenzene	Food grains (food grains)	Skin disease, debilitation, causes porphyria turcica, a lethal metabolic disorder	Globally banned under Stockholm Convention on POP, including India
6.	Heptachlor	Food (used as soil pesticide)	Low doses result in adverse behavioral changes and declined reproductive success	Globally banned under Stockholm Convention on POP, including India, but still reported being present in rainwater
7.	Polychlorinated biphenyls	Electrical circuits, capacitors, as adhesive in paints, plastics, and	Immune dysfunction, reproductive failure; acute	Globally banned under Stockholm Convention on

(continued)

Table 5.1 (continued)

	POP	Source	Effects	Recent status of usage
		carbonless copy papers, etc.	effects include swelling of the eyelids, along with fatigue, nausea, and vomiting	POP, including India
8.	Toxaphene	Used as an insecticide on crops and livestock, this is present in the environment as residue and often as present in food	Exposure to humans is at a low level, reported as a possible carcinogen; highly toxic to aquatic animals	Globally banned under Stockholm Convention on POP, including India, but present in environment residue due to long half-life
9.	Mirex	As flame retardant in plastic, rubber, and electronic stuff. As insecticide for ants and termites. Environmental residues are a possible source	Toxic to many plant and aquatic species; possible carcinogen for humans	Globally banned under Stockholm Convention on POP, including India, but present in environment residue due to long half-life (one of the most persistent POP)
10.	Chlordecone	Agricultural crops (used as a pesticide)	Toxic to aquatic animals and carcinogenic to humans	Banned throughout the world in the Stockholm list later (extended)
11.	Lindane	Widely used as a pesticide in soil, crops, and as wood treatment	Highly toxic as immunotoxic, neurotoxic, carcinogenic effects to humans	Banned throughout the world in the Stockholm list later (extended) Still present in the environment as one of the most persistent POPs
12.	Endosulfans	Food crop is the most prominent source as used as a pesticide for the crop	It acts as ant antiandrogen, thus disrupts the endocrine system. Causes congenital physical disorders, mental retardation, and lethal in high dose	Banned worldwide under Stockholm Convention later in 2011

2004. There are additions to the list of POPs since then and today number has reached 26 persistent organic pollutants. A class of persistent organic compounds (POPs) are used in the textile industry for the dyeing and bleaching of cloths. Dyes get transported to domestic wastewater during the daily washing of clothes. Dyes are different from pigments as they are soluble in water or any organic solvent; however, pigments are insoluble in both liquid media. Nowadays synthetic dyes are used in large amounts in industries, the untreated effluent is directly transported to the aquatic system. Dyes and their by-products are toxic, carcinogenic, and mutagenic, and exposure to organic dyes can irritate the respiratory tract, skin, eyes, throat, asthma, and allergy to skin (Siyal et al. 2018). A fraction of new textiles releases a high concentration of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). These dioxins and furans transfer to distant matrices via distinct pathways from where it enters in the food chain (Križanec and Majcen Le Marechal 2006). Other persistent organic pollutant dyes are aromatic amines, oxazines, anthraquinone, pentachlorophenol, chloranil, phthalocyanine, and phenolic compounds all of these compounds are carcinogenic (Mustereț et al. 2007).

Another chemical of emerging concern is from the class of perfluorooctanoic acid which is a listed persistent organic pollutant. Perfluorinated alkylated substance and poly-fluoroalkyl substances (PFAS) have been found ubiquitously around worldwide in water, air, sediments, organism, because of their use vastly in all household related processes (e.g. clothing, cooking, furniture, etc.) and its physicochemical properties PFAS residues are lipophobic and hydrophobic and this compound shows strong surface-active properties and usually attach to the natural surface, and due to C-F bond, most of these compounds are virtually indestructible and persist for longer duration in environment. Many studies identified the source of PFAS in the surface water as fluorochemical manufacturing industries, discharge of firefighting foam, landfill leachate, and degradation of precursor compound (Moller et al. 2010). PFAS and their by-products are considered as highly toxic, extraordinarily persistent chemicals and contaminate human blood and wildlife. And due to their unique physio-chemical property, they are still a considerable challenge to environmental scientists and also for regulatory authorities (Roland Kallenborn).

5.2.3 Endocrine-Disrupting Chemicals (EDCs)

EDCs represent a broad class of molecules such as organochlorinated pesticides and industrial chemicals, plastics and plasticizers, fuels, and many other chemicals that are present in the environment or are in widespread use (Haq and Raj 2018). We make several recommendations to increase understanding of the effects of EDCs, including enhancing increased basic and clinical research, invoking the precautionary principle, and advocating involvement of individual and scientific society stakeholders in communicating and implementing changes in public policy and awareness. EDC is a modified chemical or a mixture of chemicals that interferes with any aspects of hormonal activity. EDC disrupts the endocrine system either by forming an enantiomer of the natural hormone or by hindering its functional activity.

Environment Protection Agency (EPA) elaborates EDC as an external factor that might interfere with the development, release, transport, activity, or replacement of natural hormones which help in maintain bodily functions like homeostasis, reproduction, development, and behavior. EDCs include xenoestrogens, phthalates, PCBs, PFAS, etc. chemicals that can cause metabolic (obesity), biological, and reproductive disorders. The group of molecules identified as endocrine disruptors is highly heterogeneous and includes synthetic chemicals used as industrial solvents/lubricants and their by-products [polychlorinated biphenyls (PCBs), polybrominated biphenyls (PBBs), dioxins], plastics [bisphenol A (BPA)], plasticizers (phthalates), pesticides [methoxychlor, chlorpyrifos, dichlorodiphenyltrichloroethane (DDT)], fungicides (vinclozolin), and pharmaceutical agents [diethylstilbestrol (DES)]. Almost all POPs are endocrine disruptors. Nevertheless, in very broad terms, EDCs such as dioxins, PCBs, PBBs, and pesticides often contain halogen group substitutions by chlorine and bromine. They often have a phenolic moiety that is thought to mimic natural steroid hormones and enable EDCs to interact with steroid hormone receptors as analogs or antagonists. Even heavy metals and metalloids may have estrogenic activity, suggesting that these compounds are EDCs as well as more generalized toxicants. Several classes of EDCs act as antiandrogens and as thyroid hormone receptor agonists or antagonists, and more recently, androgenic EDCs have been identified. EDCs do not have any structural similarity; therefore, it is difficult to classify a set of chemicals as EDCs (Diamanti-Kandarakis et al. 2009). These compounds are present in very fewer amounts ranging from ng/L to μg/L in wastewater. However, long-term exposure to such low levels is hazardous for human health. The toxic effect of these molecules is not fully identified.

5.2.4 Pharmaceutical Personal Care Products (PPCPs)

Pharmaceutical personal care products are broadly divided into multiple categories based on their characteristics and usage. Pharmaceutical is divided into antibiotics, analgesics, steroid hormones, anti-inflammatory drugs, cytostatic drugs blood lipid, regulators, etc., However, personal care products (PCPs) are classified as fragrance, disinfectants, insect repellents, preservative, and sunscreen ultraviolet (UV) filters. At present more than 3000 PPCPs have been used in the medical field for humans and animals for the betterment of human standards (Muthanna et al. 2008). Humans are consuming PPCPs in large amount which releases in domestic wastewater as sewage, landfill leachate, biomedical waste, municipal waste, PPCPs may enter into the aquatic environment. Even an individual household is also contributing to PPCPs contamination of water through the addition of expired and unused medicine in sinks and drains as reported by Kummerer et al. (2009). Studies suggest the presence of low, subtoxic concentrations of PPCPs can pose threat to human beings and the environment. Many studies suggested that chemical of pharmaceutical origin is often not eradicated from the wastewater treatment plant and not biodegradable in the environment.

Biomedical waste often contains a high frequency and number of pharmaceutical effluents. Antibiotics are extensively used worldwide in the medical field. In surface and wastewater treatment plant both metabolized and unmetabolized antibiotics have been found, they are partially degraded in the environment and as a consequence, it starts accumulating in water bodies. The prolongation of antibiotics can stimulate the antibiotic-resistant bacteria in aquatic bodies and chances to develop drug-resistant microorganisms (Sui et al. 2015; Ahmed et al. 2015). PPCPs are present in groundwater, surface water as well in effluents coming from different sources, where the concentration of drugs varies from ppt to ppb. Research reveals that approximately 65% of pharmaceutical products are never ingested (Ruhoy et al. 2008). DEET has been used as an active constituent in insect repellents on a broader scale and it tends to persist in the aquatic system for a longer duration. Parabens are the ester of para-hydroxybenzoic acid-containing functional group either alkyl or benzyl group. Influents of sewage treatment plant (STP) paraben especially methylparaben (MEP) and propylparaben (PrP) are present with concentration up to 30–20μg/L, respectively (Yang et al. 2014). Triclosan (TCS) is mainly used in health care products such as cosmetics, deodorant, shampoo, mouth rinses, soap, and toothpaste at a concentration of 0.1–0.3% (w/w) (Thompson 2005). TCS is mainly of two types: dissociated and non-dissociated/methyl TCS, dissociated TCS degrades under sunlight which has less than one-hour lifespan, while non-dissociated/methyl TCS is comparatively more stable to photo-degradation (Subedi et al. 2015).

5.2.5 Naturally Occurring Emerging Contaminants

Plants, humans, and animals contribute toxins in wastewater systems, although domestic wastewater is not the major source of plant toxin pollution, analyzing agricultural runoff is momentous when we track down the presence of mycotoxin in surface waters (Gatidou et al. 2007). There are contradictory theories about the source of mycotoxin or other such naturally produced toxins. Some studies reported the occurrence of zearalenone in bottled water. The presence of these toxins in food items is of major concern to food regulating bodies, most common toxins are phytotoxin (plant origin), mycotoxin (fungal origin), phycotoxin (algal origin), zootoxins (animal origin), and bacterial toxin (bacterial origin). In recent times stakeholder has raised concern about presence and effects of mycotoxins on human health and livestock. Most commonly observed are aflatoxins, ochratoxin A, patulin, zearalenone (ZEA), fumonisins, and nivalenol/deoxynivalenol. Mycotoxins are produced by three infamous fungal genera: Aspergillus, Penicillium, and Fusarium. Mycotoxins can be produced before or after harvest on mold-infected crops, some other natural toxins are produced by organisms as the response to their defense mechanisms. Studies on the prevalence of mycotoxins in the aquatic environment are mainly focused on ZEA due to its strong oestrogenic activities. Phycotoxins impact on human exposure is sparsely explored in the scientific community. Several mycotoxins are neurotoxic, potentially lethal, and associated with chronic adverse health effects. Certain cyanobacteria and marine algal species are well known for causing discoloration of water red tides and green tides, this phenomenon is commonly called “harmful algal blooms.” These toxic or sometimes lethal blooms effects native aquatic life badly. Both healthy and unhealthy humans have high viral loads in their feces and their urine, contributing to high viral loads in municipal sewage. These viruses are only partially eliminated by wastewater treatment systems and are now being considered an emerging contaminant. Some of the most prominent emergent viruses being found in water supplies are human polyomaviruses, hepatitis E virus, and human adenoviruses (Smital 2008).

5.2.6 Microplastic

Plastic pollution is pervasive, it affects the aquatic ecosystem, soil ecosystem, and widely affects natural flora and fauna. According to the recent estimation of plastic production done till 2015, the world has produced 6300 million metric tons of plastic waste; out of which 9% has been recycled, 12% was incinerated and 79% was accumulated in landfills or the natural environments (Geyer et al. 2017) Although we are aggravating the rate of production daily, if we continue with the same rate of production and waste management trends by 2050, we will have 12,000 million tons of plastic waste accumulated in our natural environment. The size continuum of plastic pollutants has been defined from macroplastic (>5 mm), through microplastic (5 mm to 1μm) to neoplastic (<1μm). (Gigault et al. 2018). Plastics are categorized into two main polymer families, i.e. thermoplastics and thermosets. Plastics are synthetic organic polymers derived from natural organic materials such as cellulose, coal, natural gas, salt, and crude oil which is the most common source of naphtha, feedstock for plastic manufacturing. Plastic can be of distinct origin, composition, and properties such as polyethylene (PE), polypropylene (PP), polystyrene (PS), nylon (PA), polytetrafluoroethylene (PTFE), thermoplastic polyester (PET), poly(vinyl chloride) (PVC), cellulose acetate (CA), polyester polystyrene, polycarbonate, polyethylene terephthalate, foamed polystyrene and biodegradable polylactic acid (PLA). Polystyrene is most commonly used in packaging and industrial insulation, polyethylene is used in personal care products (PPCPs) as in facials and scrubs, polypropylene is used in fishing gears, these are some of the most commonly used plastics. The most prominent type of microplastic present or identified in the aquatic environment are spheres, pellets, irregular fragments, and fibers. In residential areas, machine washing can produce more than 1900 fibers (100 particles L^{-1}) in one wash cycle. Microplastic is categorized into primary and secondary based on their process of formation: primary microplastic are generated intentionally in microscopic scale through the process of grinding or extrusion, either precursor to other products and integrated into a variety of activities such as facial exfoliating cleanser, air blasting boat cleaning media and used in medicines as a vector for drugs. Secondary microplastics are the by-products of degraded and fragmented macroplastic due to mechanical, photolytic, or chemical processes. Plastic having a density greater than 1.02 g/cm^3 starts sinking and accumulates over sea beds, while low-density plastic floats on the sea-surface or suspension in the water column, however, low-density plastic tends to sink through biofouling (Alomar et al. 2016). Therefore, via multiple passage microplastic enters into the aquatic system such as water, wastewater (industrial, landfill, municipal, biomedical waste) being discharged into the sea, rivers, and water bodies. Thomson et al. (2004) identify microplastic fragments around UK beaches materials used for clothing (polyester, acrylic), packaging (polyethylene, polypropylene), rope (polyamide). RASFF and ESFA reported the presence of microplastic in food products microplastic or synthetic microplastic have found in canned sardines, sprats, salt, beer, honey, sugar, and the sealed plastic drinking bottle also contain plastic (Rist et al. 2018). Microplastic is especially concerning the ecosystem because of its small size and lack of technology available to quantify the presence of microplastic in the environment and its potential to hurt marine biota and humans.

5.3 Source of Contamination of Emerging Contaminants

The water which becomes unfit for human use after being used for industrial processes and household activities is wastewater. These anthropogenic activities are responsible for the amalgamation of toxic contaminants in natural water bodies. Aquatic systems suffer pollution from many sources including water leakage from septic and sewage tanks, fertilizers and agrochemicals runoff, seepages from landfill sites. Studies suggest that even after being treated in conventional wastewater treatment plants (WWTPs), a significant quantity of emerging contaminants remains untreated in wastewaters (Gogoi et al. 2018). Trace amounts of pharmaceuticals, endocrine-disrupting chemicals (EDCs), personal care products (PCPs), and their by-products have been identified in effluents from WWTPs, these form a group of micro-contaminants that bioaccumulates in the food chain. This contaminant reaches groundwater via surface leakages and groundwater recharging points. Groundwater is highly contaminated due to the continuous mixing of waste coming from wastewater treatment plants (WWTP) in the aquatic system, and it contains multifarious emerging contaminants.

Domestic and industrial wastewater are distinctive in their composition and properties. Due to their distinct properties and composition domestic and industrial waste are generally collected and treated separately, which allows specific pollution mitigation strategies. ECs generated from industries and urban wastewater treatment plants are directly discharged into rivers, lakes, ponds and where their environmental fate is of concern such as leach out in groundwater, sorption in sediments, decreased fertility of the soil. The life and passage of emerging contaminant from the origin point to sinking point (aquatic system) are highly dependent on the ECs properties such as volatility, polarity, adsorption properties, persistence (Farré et al. 2011).

5.3.1 Domestic and Hospital Effluents

Domestic wastewater is rich in a pathogenic microorganism, biodegradable organic matter, and nutrients which are responsible for the aggravation of eutrophication processes in natural water bodies. It poses long-term damage to biodiversity by incorporating nondegradable organic compounds like oil, grease, phenols, cyanide, pesticides, and detergents along with metals that bioaccumulate in the food chain. Domestic wastewater treatment was considered to be more efficient compared to industrial wastewater. There is a significant change in domestic wastewater composition for the past 10–15 years. Increasing the use of personal care products and other strong chemicals in daily household needs is becoming a tough chore to handle (Tjandraatmadja et al. 2010). Domestic wastewaters are a major contributor of microbial contaminants, phosphorus, and nitrogen in natural water bodies. Excess amounts of phosphorus and nitrogen induce eutrophication in water resources, such conditions in the environment may also favor the growth of toxin-producing cyanobacteria. This makes untreated domestic wastewater hazardous for the health of human and aquatic life. Constituent contaminants in wastewater vary geographically based on distinct domestic usage patterns (Tran et al. 2018). Major contaminants from domestic wastewater and their effects are:

- Antibiotics: the concentration level of antibiotics in influent and effluent of WWTPs has been recorded in the range of few tens of microgram per liter. Sulfonamide, macrolides, fluoroquinolones, and trimethoprim are the most common antibiotics found worldwide in wastewater. One of the highly prescribed drugs is β-lactam. However, its insignificant presence in wastewater is due to chemical hydrolysis or chemical transformation in alkaline/acidic conditions. Antifungal and antimicrobial agents like miconazole, thiabendazole, triclocarban, and triclosan are extensively used in household products (shampoos, soaps, shower gels, toothpaste, and dermal creams). Generally, concentration levels of triclocarban and triclosan are higher in wastewater, whereas miconazole and thiabendazole which are used as therapeutics reach the aquatic system in comparatively lower concentrations.
- Therapeutic drugs: beta-adrenoreceptor blocking agents, antiepileptic and antipsychotic drugs, lipid regulators, anti-inflammatory drugs, lipid regulators, steroids, and synthetic hormones like estrogen are all used as medication, some of these are excreted from the human system in non-metabolized form and reach aquatic systems. in long term, these drugs cause a serious threat to aquatic life.
- UV filters are part of personal care products that are used to block UV rays, these are used in sunscreens, beauty creams, dyes, and other cosmetics. These can be introduced in aquatic systems in two ways. Firstly, by water recreational activities like swimming in lakes and rivers. Another is from used domestic water via WWTPs.
- Artificial sweeteners: these are mainly used as food additives (low-calorie dietary products), like sugar substitutes in substantial concentrations. These come out of the human system in unchanged form. Few of these like cyclamate and saccharin

can be biodegraded, whereas, sucralose, which is a chlorinated compound, and acesulfame are persistent and may disrupt the aquatic environment.

5.3.2 Industrial Wastewater

There are several industrial compounds which can be released into the environment, causing adverse effect to the environment. Effluent released from industries including pharmaceutical industries, tannery, iron smelters, textile industry, cellulose production, dishes factory, paper, and pulp factory contains several emerging contaminants. Along with primary compounds that are released in water bodies from industries, there are many degraded by-products from primarily infused contaminants that contribute as emerging contaminate. Industrial emerging contaminants are as follows:

- 1,4-Dioxane: it is used as a solvent in the manufacturing of chemicals and laboratory reagents. When combining with 1,1,1-trichloroethane it can resist natural biodegradable processes and have the ability to persist in groundwater and directly leach out from the soil. 1,4-Dioxane is also present in PPCPs (Abe 1999).
- Benzotriazole derivatives: it is present in many pharmaceutical antibiotics as antifungal, antibacterial, and antihelmintic drugs and tends to persist in an aqueous environment.
- Polybrominated biphenyl ether (PBDEs): PBDEs are the synthetic chemicals used as an additive retard fire and flame for multiple household and commercial purposes. In a coastal and estuarine ecosystem, the presence of PBDEs has been identified. From industrial manufacturing and household products (furniture, electronics, bedding) sites it is reaching the environment. Exposure to PBDEs can potentially cause neurodevelopmental and thyroid dysfunctions (Brown and Nixon 1979) and have potential endocrine-disrupting properties (Rahman et al. 2001).

5.3.3 Agriculture Runoff

The ECs where agriculture is currently the predominant source of surface water contamination, compared to non-agricultural sources, are the natural toxins, veterinary medicines, hormones, and transformation products of man-made chemicals used in agriculture. Emerging contaminant loads of agricultural land soil get transported to aquatic systems by leaching, runoff, and drainage processes. ECs are released in the agricultural environment directly via the application of biosolids, pesticides, or other solid waste materials, and indirectly from veterinary medicines through animal bio-waste. Multifarious ECs have been detected in agricultural systems such as human pharmaceuticals, personal care products, veterinary drugs, hormones, and transformation products of man-made chemicals in a very low ng/l range. Prospective of developing new technology for effective and efficient use of pesticides is high, the existing pesticide may be made into nanoparticulate (1–100 nm particles) form to give the active ingredient beneficial properties for pest control, such as increased solubility, increased stability, the capacity for absorption into plants or increased toxicity to pests (Lyons et al. 2009). Although there are speculations that these nanoparticles will be easily transferred to surface water and contaminate aquatic systems, many man-made substances that enter agricultural systems will be degraded by chemical, physical, and biological processes. While these reactions may result in the complete breakdown of a chemical (i.e. they convert the chemical to carbon dioxide, water, and methane), in many instances the processes may result in the formation of stable intermediate chemicals which we call degradation or transformation products (e.g. Roberts 1998; Roberts and Hutson 1999).

Typical wastewater systems involve a primary treatment phase, where solid material is settled out and removed, followed by a secondary treatment where microbes are used to break down organic matter (including chemicals). One common secondary treatment process is activated sludge treatment (AS). In AS, chemical contaminants may be degraded but can also stick to the sludge particles in the system. At the end of the process, the sludge is removed and, as it is high in nutrients, in many regions, it is then applied to agricultural land as a fertilizer. ECs that stick to sludge can therefore enter the environment when sludge (biosolids) from wastewater treatment works is applied to land (Kinney et al. 2006; Topp et al. 2008).

5.4 Pollution and Toxicity of Emerging Contaminants

Emerging contaminants, such as persistent organic pollutants (POPs), endocrine-disrupting chemicals (EDCs), pharmaceuticals and personal care products (PCPs), etc., and trace levels of their transformation products are major disruptors for the aquatic ecosystem, human health, and biodiversity (Haq and Raj 2019). Lack of advanced technology and health standards regarding newly detected contaminants is another complication in wastewater treatment. The concerning levels of contaminants are released in soil and water via treated water from wastewater treatment plants. The efficiency and mechanism of functioning of current WWTPs are not sufficient to remove all contaminants from wastewaters.

5.4.1 Adverse Impacts on Human Health and Biodiversity

The presence of contaminants implicates acute harmful effects on natural flora and fauna in surface waters, seawater, and soils. In the recent decade, plastic pollution due to microplastic (1–5 mm) and nanoplastic (<1 mm) size particles is of emerging concern for aquatic fauna. Microplastic ingestion has been widely observed in the range of marine animals such as fish, bivalves, and crustaceans which are consumed by humans, along with concern to aquatic life, it raises the concern of microplastic ingestion in humans also. These microplastic get chemicals to adhere to their surfaces and they significantly cause chemical damage to ambient life. These ingested contaminants block the digestive system, alter feeding behavior, disrupt the endocrine system, retard growth and reproductive capabilities. Even artificial aquaculture systems are also affected by these contaminants as a fish meal which is given to cultured fishes, shrimps, or other seafood animals has been taken from natural contaminated sources. Experiments performed on Fulmarus glacialis (Northern fulmar) showed the persistence of ingested plastics in the gizzard, mixed with stomach oil which is used by the bird as an energy source during long flights (Kühn et al. 2020). Due to their small size microplastic is ingested by a benthic organism and has ecological impacts. Rochman suggested that microplastic of range 2–5 mm could take a longer time to digest because of durability and retain for longer duration in organism body as a consequence increase the exposure time to toxins (Rochman et al. 2013). Microplastic abundantly emerging in sea beds and cause a major threat to the marine food web. Some organic contaminants associated with plastic after inhalation it starts interfering with hormone regulation in animal (Teuten et al. 2009). Ingestion of microplastic especially in fiber form poses threat to the organism as it can cause blockage in the digestive tract, be translocated in different tissues within the organism, and undergo accumulation (Wright et al. 2013). Knowledge about the effects of ingestion of microplastic by a human being requires more research and investigation.

Bioaccumulation aggravates the tendency of abnormal hormonal regulators causing reproductive impairments, decreased fecundity, an increase of breast and testosterone cancers, and persistent antibiotic resistance (Tijani et al. 2013). Another similar example is of alternation in the endocrine and reproductive system of Japanese medaka fish because of harmful exposure to the UV filters and oxybenzone (Coronado et al. 2008).

Much research has been performed on the toxicity of pesticides. Many pesticides are carcinogenic to animals and, for this reason, are likely human carcinogens. For example, the pesticides alachlor, dieldrin, and DBCP are each classified under the USEPA designation "probable human carcinogen." Perhaps the greatest threat posed by pesticides, however, is their endocrine-disrupting potential. Exposures can cause reproductive system damage including sterility, decreased fertility, and birth defects, as wells as impaired development, immuno-suppression, and metabolic disorders. Studies have linked low concentrations (0.1 ppb) of the pesticide atrazine to developmental deformities in frogs including the development of multiple sex organs and small feminized larynxes. In another study, frogs exposed to even trace amounts of malathion experienced a near-total collapse of their immune systems, with antibody production limited to as little as 1–2% of normal. Many studies and research have suggested that many emerging organic contaminants (EOC) are endocrine disruptor chemicals (EDCs) (Liu et al. 2009). EDCs are present in a wide range of compounds, include plastic bottles, detergents, flame retardants, toys, cosmetics, pesticides, etc. and they might have adverse developmental and reproductive effects on humans and wildlife. EOCs are toxic and persistent and even it presents in low concentration; it might produce potentially harmful effects on the ecosystem and human health (Jurdo et al. 2012).

Some case studies associated with the chronic effect of synthetic chemicals usage on fauna are, the veterinary use of diclofenac, which is a human pharmaceutical used as an anti-inflammatory treatment, was found to be responsible for the massive decline in populations of vulture species in certain areas of Asia (Oaks et al. 2004). The veterinary drug ivermectin, which is used to treat parasitic infections in livestock, has been shown to affect the growth of aquatic invertebrates at a concentration lower than those that are expected to occur in the aquatic environment (Garric et al. 2007). Ethinylestradiol, one of the active ingredients in the contraceptive pill, has been associated with endocrine disruption in fish (Lange et al. 2001); and there is concern that long-term exposure to antibiotic pharmaceuticals, used in human and veterinary medicine, may be contributing to the selection of resistant bacteria in the environment which may have significant implications for human health (Boxall et al. 2003).

5.4.2 Water Pollution

In recent year the jeopardy of groundwater contamination from emerging contaminants has intensified mainly due to multifarious anthropogenic activities which significantly affect the natural water cycle as well as the passage of contaminants in the aquatic system (Díaz-Cruz and Barceló 2008). Groundwater contamination can be resultant from numerous potential sources, including leakage from sewers, septic tanks, landfills, urban runoff, municipal waste, overuse of fertilizers, gasoline spills, aquaculture, and many more. Furthermore, it is difficult to eliminate contaminants from groundwater because of the slow flow rate movement, long residence times, low microbial populations, and redox controls in the saturated zone. Thus, the emerging contaminates remain stranded in groundwater for a longer period. Compared to other aquatic resource the existence of emerging contaminate is poorly categorized in groundwater. The source of emerging contaminate in groundwater is divided into a point and diffuse source—point source originated from particular locations and the amount of pollution is generally more constrained such as from industrial effluents, municipal solid waste treatment plant, hazardous waste effluent, waste disposal site, biomedical waste site while diffuse pollution, in contrast, originated from scattered sources and occurs over broad geographical scales such as from agricultural runoff, urban-storm runoff leakage from urban sewerage system (Buerge et al. 2011).

One of the major sources of groundwater pollution is pesticides and their metabolites. Present studies have been shifted towards pesticide metabolites also on degraded and reaction products. By their nature, this product is biologically active many are toxic. Research has shown that pesticide metabolites are frequently perceived in groundwater in higher concentrations compared to the parent compound. An extensive series of pharmaceutical products have been spotted in surface and groundwater including wastewater disposal. These have included:

- Veterinary and human antibiotics—e.g. ciprofloxacin, erythromycin, lincomycin, sulfamethoxazole, tetracycline.
- Personal care products—e.g. DEET, parabens, antifungal and bactericide agents (triclosan), polycyclic musk (tonalite, galactoside).
- UV filters/sunscreen—organic filters include benzophenones and methoxycinnamates.

Worldwide freshwater resources are facing challenges of thousands of chemical compounds due to anthropogenic activities. Yearly around 300 million tons of synthetic compounds used in industrial and consumer products generally find their way to natural waters (Schwarzenbach et al. 2006). Due to chemical compounds released from wastewater discharge, incorporated with the agricultural runoff of fertilizers/pesticide, leach out from landfill sites (biomedical waste, hazardous waste), and atmospheric deposition, that majorly affecting the surface water quality and such contamination can increase the problem for drinking supplies also. Streams disperse the emerging contaminates into different water bodies including aquifers, estuaries, and marine systems. ECs are unable to remove from conventional wastewater treatment plants (WWTPs); therefore, many of these chemical or synthetic compounds are directly released into surface waters (Pal et al. 2010). The overapplication of fertilizers and pesticides has increased the discharge rate of nutrients and pollutants into the aquatic system. However, the discharge of nutrients from a point source (WWTP and industry) still contributes to the significant pollution load to the aquatic system (Kronvang et al. 2008). Increased levels of the nutrient in the aquatic system may result in eutrophication, increased water turbidity, oxygen depletion, coral reef destruction, vulnerability increase to marine life (Kalff 2002). Antibiotics can result in the development of resistant bacterial strains and are associated with a public health concern. In China antibiotic frequently detected in surface water has been observer such as macrolides, sulfonamides, and fluoroquinolones (Yang et al. 2014).

5.4.3 Soil Pollution

It is not quite astonishing that contaminants that had spread across the aquatic system have made to retain in soil and sediments. Contaminates of soil reach human, animal, and plant systems via distinct routes of exposure like ingestion of soil and dust particles, uptake in food crops which has been absorbed by plants through roots, inhalation, leaching to groundwater which is commonly used for drinking. Most discussed soil contaminants in the scientific community are lead, petroleum, radon, chromate copper arsenate, and creosote. Anthropogenic activities such as industrial dumping, mining, manufacturing, local waste disposal, pesticide usage in agriculture are major contributors to soil pollution. The type of soil determines the probability of groundwater contamination and can allow more contaminants to pass in groundwater than clay. The presence of organic matter holds contaminants tightly which leads to the accumulation of contaminants in soil. Studies suggest that microplastic pollution can alter the coupling between carbon and nutrient cycling through a significant increase in nutrients in dissolved organic matter and CO_2 fluxes (Geyer et al. 2017). Some emerging contaminants like petroleum are harmful to soil microorganisms and their activity. These microbes play important role in providing nutrients to plant, so plant nutrient availability also gets affected by these contaminants. Petroleum hydrocarbons like benzene, toluene, ethylbenzene, and xylene can cause cancer. There are regulatory standards for safe levels in drinking water.

The challenges posed by emerging contaminants in soils are crucial and require rigorous actions and collaboration. There is a need for monitoring data and risk assessment models, but also for awareness-raising and new guidelines and authority models to deal with emerging contaminants in soils. Detection of these contaminants in soil and sediment is particularly challenging due to the low detection limits required, their intricate nature, and the difficulty in separating these compounds from interfering.

5.5 Removal Approaches

Since the last decades several physical, chemical, and biological technologies have been developed and studied to eliminate or degrade the residues of ECs (Zhang et al. 2008). Biological treatment has been the preferred technology for the removal, including activated sludge, constructed wetlands, membrane bioreactor (MBR), aerobic bioreactor, trickling filter, enzyme treatment, biosorption, and plant-based (Phyto) technologies (Haq et al. 2016a, b; Haq et al. 2017, 2018; Kishor et al. 2018; Mulla et al. 2019; Bharagava et al. 2017, 2018, 2020; Mulla et al. 2020; Kumar et al. 2020; Bharagava and Saxena 2020; Deb et al. 2020; Haq et al. 2020; Saxena et al. 2020a, b, c, d, e, f). Chemical technologies also have been broadly used for the degradation of these micropollutants because some non-biodegradable organic compounds cannot be removed appropriately from biological treatment, it includes conventional oxidation methods such as photocatalysis, photolysis, ozonation, advanced oxidation processes, etc. moreover each method has advantages and challenges (Goutam et al. 2020). Several pesticides and pharmaceutical are highly water-soluble will remain in aqueous system so, physical treatment processes as coagulation and flocculation followed by sedimentation, sand filtration, and disinfection. These processes are not that effective as a comparison to chemical and biological processes it removes around 20–30% of contaminant (Kastl et al. 2004; Stackelberg et al. 2007).

5.5.1 Physical Treatments

Physical treatment may involve the technologies to remove the emerging contaminants without changing their chemical state and may be classified as phase partitioning processes (adsorption processes) or membrane processes. In the adsorption process several adsorbing agents, which may be natural or synthetic or waste materials, are used to adsorb the target contaminant to adsorb on the surface, converting one face transfer to another face transfer is involved (Dhangar and Kumar 2020). In this technology, sore surface area and more porosity may be the good indicator of the optimum success of the technology (Rivera-Utrilla et al. 2013). The removal efficiency may be depending on the selected material as an adsorbent (Rodriguez-Narvaez et al., 2017). These may include activating charcoal from wood or herbaceous plant, biochar, etc.

In the membrane technologies, solutions are filtered by retaining contaminants on the membrane, with variable filtration features (pore size, hydrophobicity, and surface charge as per the material from it has been obtained, determines the efficiency of the removal of the contaminants (Dhangar and Kumar 2020). Hydrostatic pressure performs a crucial part in the membrane processes, allows water and low molecular weights to pass through the membrane by retaining the suspended particles and high molecular weight solutes. Based on the size of the pores and the types of membrane, the processes may be classified into microfiltration (MF), nanofiltration (NF), ultrafiltration (UF), forward osmosis (FO), and reverse osmosis (RO).

5.5.2 Chemical Treatment

Some of the ECs that may not be appropriately removed by biological methods may be remediated by chemical methods which include several oxidation methods like photocatalysis, photolysis, ozonation, advanced oxidation processes. In this method, the ECs may be remediated either by complete mineralization or by their alteration to inorganic molecules such as water, carbon dioxide, and nitrogen. To achieve this goal, these techniques use various chemical agents like ozone, hydrogen peroxide, and chlorine; metal oxides and transition metal-based catalysts; and some energy or radiation sources such as ultrasound, electric current, gamma, solar, and UV-radiation (Dhangar and Kumar 2020).

For example, removal of contaminants such as sulfamethoxazole (SMX), diclofenac (DCF), and carbamazepine (CBZ) may be possible by such above cited (ozonation, sonolysis, and photocatalytic oxidation) chemical methods in synthetically prepared aqueous solutions. To achieve the optimum efficiency for remediation of such ECs may be preferred one of the methods or a different combination of the same, which may depend on the characteristics of the chemical (Fraiese et al. 2019).

The chemical treatments are further classified as conventional oxidation processes and advanced oxidation processes (AOPs). In conventional oxidation processes chlorination, ozonation, Fenton process, and photolysis, etc. may be counted (Dhangar and Kumar 2020). But these conventional methods have some disadvantages, which could be fulfilled by advanced oxidation methods. In these methods high oxidizing state of a chemical or radiation is used to remove the target ECs. This process may include photocatalysis, electro-Fenton process, solar-Fenton process, and ultrasound irradiation (Salami et al. 2017). These chemical processes may be improvised or combined as per the required efficiencies but may also provide few disadvantages as well.

5.5.3 Biological Treatments

Tertiary treatment is widely used for the removal of contaminants from an aqueous system it works on biodegradation and is also known as effluent polishing treatment. Biodegradation is the process of conversion of a substance into new compounds through biochemical actions of microorganisms including bacteria, fungus (Rodriguez-Narvaez et al. 2017). Tertiary treatment mainly divided into aerobic and anaerobic processes-activated sludge, membrane bioreactor, and anaerobic sludge reactor, anaerobic film reactor, respectively. Conventionally biodegradation method has been used for the treatment of wastewater for the removal of EC. The rate of removal of the contaminant is strongly dependent on treatment technology, target contaminant, and treatment conditions. Recognition of degradation products in environmental samples is challenging because it is not present in very low concentration but also present in complex matrixes that may interfere in the detection process (Zhou et al. 2009).

5.5.3.1 Constructed Wetlands

Wetlands have been receiving much attention worldwide due to their intrinsic tendency to remove pesticides, surfactant, PPCPs, and other micro contaminate, hence wetlands offer important ecological benefits (Gregoire et al. 2009). To reduce sediments, nutrients load, and pollution due to anthropogenic activities entering into the surface water and groundwater, some countries as Sweden, Denmark, and the USA has adopted a technique to develop or restored wetlands to revive the ecosystem services that were vanished due to anthropogenic activities such as the conversion of wetlands into the agricultural field, aquaculture (Hoffmann and Baattruo-Pedersen 2007; Thiere et al. 2009; Hoffmann et al. 2011). European Union (EU) water framework directive which states that a good ecological and chemical quality should be reached in water bodies has been adopted by EU members by the end of 2015 (European Commission 2000). Denmark government through Danish Action Plans on a national scale has set the target of increasing the wetlands area and reduce the nutrient load in the sea.

5.5.3.2 Biological Trickling Filter

Bio-trickling filter is used as a conventional treatment method in WWTPs for the removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD), pathogen decontamination, odor, and air pollution control. The efficiencies of treatment methods such as activated sludge, aerated lagoon, trickling filter vary according to the presence of a contaminant in wastewater. Trickling filters or biobeds were used either alone or with association with other treatment methods. Kasprzyk-Horden et al. (2009) run a 5-month monitoring program in South Wales in the UK to analyze the efficiency of two different wastewater treatment technologies which is activated sludge and trickling filter beds, with two distinct wastewater treatment plant (WWTP Cilfynydd and WWTP Coslech) discharging treated water in two different rivers (Taff and Ely). Their outcome was activated sludge treatment which was much more efficient than trickling filter beds. For WWTP using trickling filter, the average came less than 70% removal for 55 PPCPs studied. However WWTP using activated sludge gave efficiency above 85%.

5.5.3.3 Biologically Activated Carbon

Several studies indicated that biologically activated carbon adsorption tends to remove contaminant in a broad spectrum of EC. Eliminate the effluent organic matter from treated water so it can be reused in different activities. To eliminate emerging organic contaminant (EOC) from wastewater the use of adsorbents is a very common method. Activated carbon is highly porous and effective absorbent and used to remove repugnant taste and odor and EOC worldwide (Moreno-Castilla 2004; Quinlivan et al. 2005). Adsorption depends on surface area, pore structure, and surface structure. On the surface of activated carbon, the immobilization of microorganism (biofilm) under appropriate temperature and nutrient condition produces the biological activated carbon and plays a significant role in adsorption and biodegradation simultaneously. This active biofilm effectively removes biodegradable pollutant such as EOC and organic pollutants from the water and increases the lifespan of carbon bed (Hijnen et al. 2014; Korotta-Gamage et al. 2017). Nowadays biologically activated carbon treatment is used after the ozonation process to enhance the process efficiency of treatment and quality of water. When ozonation has not used before biological activated carbon treatment showed lower efficiency in the removal of EDC (e.g. BPA, octylphenol), However, biological activated carbon treatment in combination with ozonation used in the removal of emerging contaminant mainly pesticide (e.g. atrazine and triclosan) and pharmaceuticals (analgesics, antibiotics, lipid regulator and anti-depressant) shows more efficiency (Korotta-Gamage and Sathasivan 2017).

5.5.3.4 Biosorption

Biosorption is a mixture of physicochemical and biological techniques, used to remove pollutants from industrial wastewaters mainly which are not easily biodegradable such as dyes, metal, etc. before discharge into an aqueous system (Gadd 2009). In biosorption-sorption and bio-oxidation occur when microorganism traps/ immobilizes into adsorbents. Both living and non-living microorganism and their components have the tendency and capabilities to detoxify the organic and inorganic pollutants (Gadd and White 1993; Gadd 2007). However, a product such as all organic materials including macroalgae (seaweeds), plants and animal biomass, and derived products (chitosan) are capable of biosorption. Due to their conventional ion-exchange property and deceptive efficiency and availability of biomass and waste bio-products, biosorption has been established as a capable technique for the removal of a pollutant from the environment. Nguyen et al. (2014) by using live cultured and harvested white-rot fungus (Trametes Versicolor) compare the biosorption and biodegradation technique for the removal of trace organic carbon

(TOC) from wastewater. Studies conclude that live white-rot fungi treatment has more efficiency than inactivated white-rot fungi (Biosorption). The removal of ECs such as 4-start-octylphenol, triclosan, pentachlorophenol, etc. had been achieved by more than 80%. And some pharmaceuticals removed completely such as ibuprofen, naproxen, and gemfibrozil.

5.5.3.5 Membrane Bioreactor (MBR)

MBR is the combination of a membrane process (microfiltration and ultrafiltration) and suspended growth bioreactor. Now worldwide MBR is used for industrial and municipal waste treatment and reclamation. Studies have found that MBR is a more effective remover of a wide range of ECs including that compounds are resistant to activated sludge process and constructed wetlands (Radjenovic et al. 2009; Luo et al. 2014) because sludge and physical retention time on the membrane which enhances the microbial degradation of all molecules according to carrying capacity of membranes. The efficiency of MBR treatment depended on sludge age, concentration, and presence of anoxic and anaerobic compartments, the composition of wastewater, operating temperature, pH, and conductivity (Kovalova et al. 2012). Trinh et al. (2012) examined the 48 EC removal efficiency through full-scale MBR. The result showed above 90% of elimination of ECs through the MBR. However, some compounds were partially removed (24–68%) such as amitriptyline, carbamazepine, diazepam, diclofenac, fluoxetine, gemfibrozil, omeprazole, sulfamethoxazole, and trimethoprim.

5.5.3.6 Phytoremediation

It has been observed in the last two decades, varied chemicals and emerging contaminants, such as heavy metals, volatile organic compounds, pesticides, personal care products (PCPs), pharmaceuticals, organics, and pathogenic microbes trouble the water and environment (Rai 2018). Plants are the interface for soil air and water, thus can emerge as eco-friendly, cost-effective, and better tool for removal of emerging contaminants with the technology named phytoremediation (Mishra 2021; Rai 2018). Some research has been done on the elimination of emerging environmental contaminants (volatile organic carbons, pesticides, PPCPs, organics, and pathogenic microbes) and heavy metals with help of worldwide spread plants species particularly wetland plants (Pandey et al. 2020; Rai 2018; Kamusoko and Jingura 2017), but still lacks plenty of work to establish plant-based technology as game-changer. In this technology, pollutants may be absorbed by roots from the medium (soil or water) into the plants and either accumulated or degraded by plant tissues (Mishra 2021). Several plant species have been identified with years of studies, which remediate emerging contaminants of concern. As an example, Typha latifolia, Populus deltoids, Populus trichocarpa, etc. have been reported to remediate trichloroethylene (Amon et al. 2007; Rai 2018). ECs, like pesticides, plants, such as Ceratophyllum demersum, Elodea canadensis, and Lemna minor, have been evidenced to perform rapid biotransformation of metolachlor and atrazine from herbicide-contaminated aquatic bodies (Williams 2002). Scirpus Validus remediate simazine and metolachlor from wastewaters (Stearman 2003). For petroleum and other hydrocarbon contaminated land could be efficiently phytoremediation by Juncus roemerianus (Syranidou et al. 2017).

5.6 Conclusion

In the changing and developing world emerging contaminants unknowingly became an inextricable part of our life, which we could identify with time. Saying this may not be enough as regularly new emerging pollutant comes inexistent as the result of evolution and emergence of new technology developed in the favor and welfare of humans. Some of them are being identified earlier and some are later with their acerbating consequences. A crucial point is that we are not ready yet, for the expected ECs in the coming future; to overcome the situation many vicissitudes can be expected regarding future emerging contaminants. The emergence of ECs would lead to more changing and troublesome political, economic, ecological, and health consequences. Only working on the extenuating counters may not be enough to fight the troublesome consequences of emerging contaminants. It needs careful observation over the developing world to develop more sustainable technologies.

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