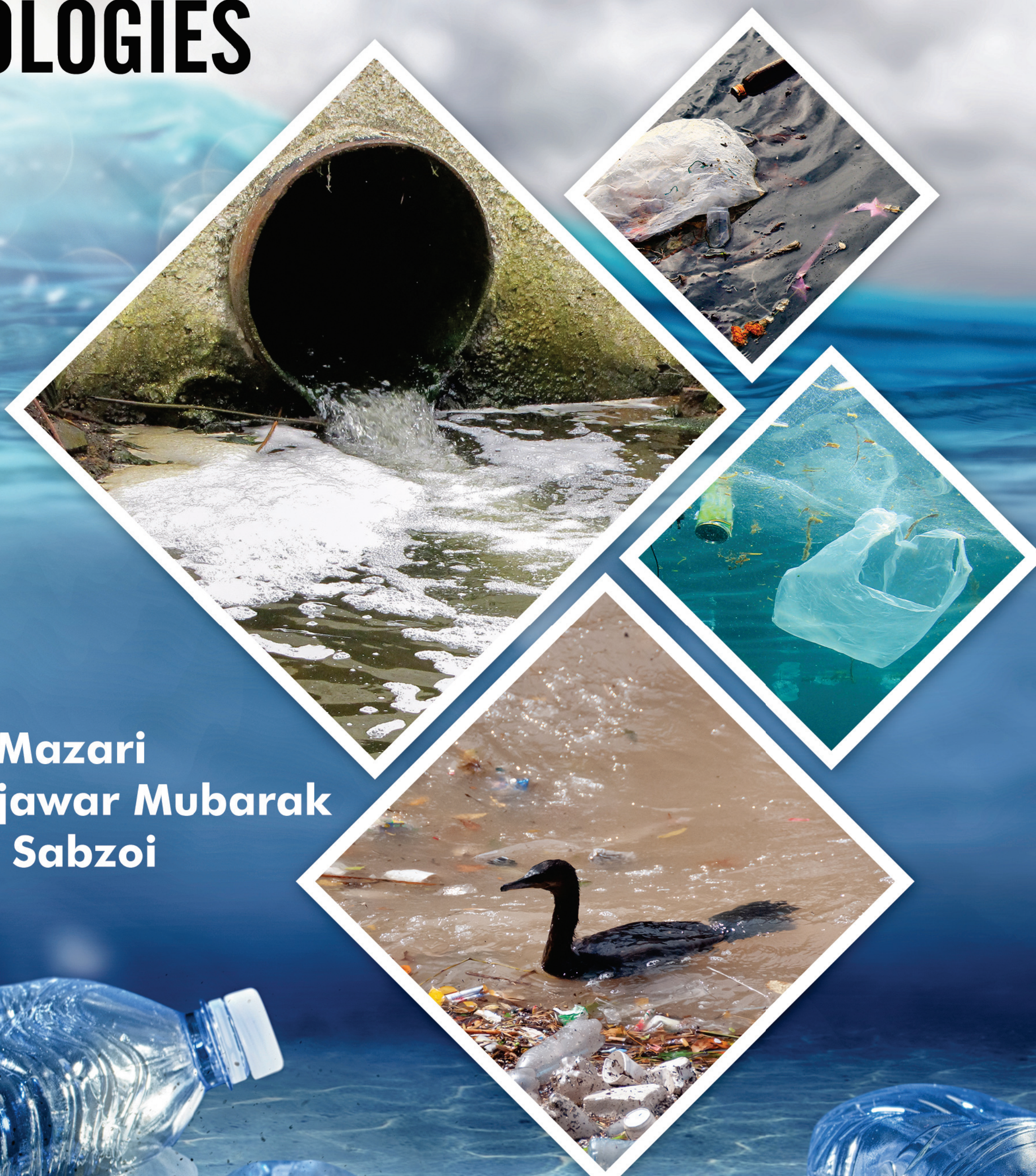
EMERGING WATER POLLUTANTS: CONCERNS AND REMEDIATION TECHNOLOGIES



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Emerging Water Pollutants: Concerns and Remediation Technologies

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Emerging Water Pollutants: Concerns and Remediation Technologies

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CONTENTS

PREFACE

With the increasing population, industrial growth and consumer needs, water is getting adulterated with several new contaminants of concern. Nanomaterials, pharmaceuticals & personal care products, endocrine disrupting compounds, artificial sweeteners, surfactants, *etc*. are some of the emerging sources of water pollutants. Several of these emerging water pollutants introduce noxious effects on humans and the ecosystem. These emerging pollutants need to be removed from wastewater sources. Some of the most investigated technologies for the removal of emerging pollutants from wastewater include catalytic processes including oxidation, membrane process, adsorption, osmotic processes, integrated processes, *etc*. This book cincludes of thirteen chapters. The first five chapters discuss and analyze the sources of emerging water pollutants, their toxicities, and legislations available to monitor and regulate their emissions. The next three chapters (6-8) are on the risk assessment of emerging pollutants, their fate and life cycle assessment. The last five chapters are on the remediation technologies for wastewater treatment containing emerging pollutants. This book is equally good for academia, industry professionals and students for state-of-the-art learning on emerging water pollutants and their remediation methods.

Chapter 1 provides an extensive review on classification of various emerging pollutants reported worldwide along with their physio-chemical properties and potential environmental effects. Moreover, the legislative policy regulations formulated worldwide for the monitoring of various emerging pollutants are also discussed.

Chapter 2 discusses the state-of-the-art global applications of pharmaceuticals and personal care products, the mechanism of water pollution by pharmaceuticals and personal care products, possible biohazards, and negative impacts on the environment. Besides that, various types of pharmaceuticals and personal care products, the most applied chemical compounds in pharmaceuticals and personal care products have been discussed in this chapter. The chapter also presents a future perspective for reducing the pharmaceuticals and personal care products' contamination of surface water with cutting-edge technologies along with wastewater treatment.

Chapter 3 focuses on the release of emerging pollutants from the food and packaging industries. This chapter interconnects the use of chemicals and fertilizers for the production and prevention of food crops and food. Also, the use of drugs for livestock and poultry for the food raw materials are highlighted. Furthermore, this chapter summarizes all aspects of emerging water pollutants from the food and packaging industry and highlights the source-sink relation of emerging water pollutants as well.

Chapter 4 introduces nanomaterials and their release to the environment and the relevant concerns. In addition, the effect of various nanomaterials in the aquatic environment is discussed, including the behavior and toxicity of nanomaterials to the aquatic ecosystem. It is important to identify, assess and reduce the environmental impact of these nanomaterials. The chapter further highlights environment-friendly and advantageous use of engineered nanomaterials for a sustainable world.

Chapter 5 highlights the industrial sources of emerging water pollutants, their possible routes to waterbodies, and their respective impacts on the environment and ecosystem. Furthermore, the concerns of emerging contaminants from industrial operations and processes have also been discussed. Furthermore, an insight into the challenges in minimizing water pollution is also focused on the shared benefit.

Chapter 6 discusses the risk assessment of the emerging water pollutants. The environmental risk assessment of emerging pollutants can help to indicate potential risks associated with these substances, highlighting the importance of the identification of their hazard, dose response, exposure assessment and finally their risk characterization. The chapter provides useful insights into the recent findings related to the pollutants' effects and their assessment approaches.

The major focus of chapter 7 is the fate of emerging water pollutants. The chapter introduces emerging pollutants of concerns, and identifies their routes to sources where they end up. More importantly chapter highlights the end sink of pollutants with potential threats and risk evaluation for plants and human health through the end sink.

Chapter 8 briefs on the lifecycle assessment of emerging water pollutants. This includes the process of lifecycle assessment for various emerging pollutants, including the release and accumulation to examine the impacts and associated risks to water quality, the aquatic environment, and ultimately on the human beings. Furthermore, a deep insight into lifecycle has been provided that may help to understand the flow of pollutants in environment and fill the existing knowledge gaps.

Chapter 9 introduces various conventional wastewater technologies such as disinfection, desalination, coagulation, chemical precipitation, filtration, adsorption, *etc*. Some of these technologies have potential uses for the removal of emerging water pollutants. Furthermore, the chapter discusses the limitations of these processes and their advantages over the others.

Chapter 10 briefly describes advanced membrane processes for the removal of emerging water pollutants. Various membranes, such as nanofiltration, reverse osmosis, membrane bioreactors have been discussed and evaluated for the removal of emerging water pollutants in detail. Furthermore, challenges related to membrane technologies such as their efficiency, prevention from fouling, stability when using cleaning agents, permeability, cost, and energy reduction have been discussed as well.

Chapter 11 discusses osmotic and filtration processes for the removal of emerging water pollutants. A detailed account has been provided for the pressure driven membrane filtration processes including micro-filtration, nano-filtration, ultra-filtration, reverse osmosis, forward osmosis, osmotically driven membrane filtration processes such as pressure retarded osmosis, *etc*. Apart from their technicalities, the performance evaluation of these osmotic processes has also been given.

Chapter 12 brings a detailed account of various catalytic processes for the removal of emerging water pollutants. Some of these processes include ozonation, electrocatalysis process including electrocatalytic oxidation, electro-Fenton process, photoelectro-Fenton process, photocatalysis, reduction by hydrodehalogenation, *etc*. Moreover, the features, mechanisms, and potential applications of catalytic processes in the treatment of emerging water pollutants are discussed in detail.

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CHAPTER 1

Emerging Water Pollutants, their Toxicities, and Global Legislations

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Abstract: Emerging pollutants (EPs) in the environment have become a significant source of pollution and cause of serious concern for the ecosystem and human health. Although during the recent decades, extensive research has been performed worldwide for the detection and analysis of EPs, continuous refinement, and development of specific analytical techniques; a great number of undetected EPs still need to be investigated in different components of the ecosystem and biological tissues. Therefore, this chapter provides extensive reviews of several emerging pollutants reported around the globe along with their physiochemical properties and potential ecological impacts. Moreover, formulated legislations and policy regulations for the monitoring of EPs are also discussed in this chapter.

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Keywords: Antibiotics, Concerns of emerging pollutants, Emerging pollutants, Emerging water pollutants, Legislations, Personal-care-products, Pesticides, Pollutant toxicity.

INTRODUCTION

Over the recent years, owing to the uncontrolled progress in multiple human activities, such as transport, agriculture, industrialization, and urbanization, the world has experienced antagonistic consequences. The change in living standards and unsustainable consumer demand have enhanced the air pollution load, for example, particulate matter, SO_2, NOx, greenhouse gases, and ozone. On the other hand, the water sources are adulterated with numerous manmade chemicals, heavy metals, nondegradable materials, oil spills, nutrients, landfill leachates, *etc* [1, 2]. Emerging contaminants include a variety of anthropogenic chemicals, for example, active pharmaceutical compounds, personal care products, pesticides, and numerous industrial chemicals, which are widely used in the world [3, 4]. It has been estimated that global production of anthropogenic chemicals between 1930 and 2000 reached from 1 million to 400 million tons per year [5]. Hence, increasing chemical demands and their uses have become a reason for several ecological impacts worldwide.

According to the environmental protection agencies, these EPs are newly detected in the environment. Therefore, their impacts are not completely determined. Thus, they are often considered un-regulated trace contaminants [6]. Moreover, conventional water and wastewater treatment facilities cannot completely remove these pollutants. Therefore, numerous studies reported their occurrence in drinking as well as surface and groundwater [5, 7, 8]. Furthermore, various metabolites and transformation by-products of EPs have also been reported by researchers, which are quite harmful and biologically active and become a reason for various adverse effects [9].

The majority of studies related to EPs occurrence and toxicities have been conducted in developed regions of the world. The circumstances are worse in developing countries where the occurrence and concentration of EPs are high owing to less efficient wastewater treatment plants, unskilled personnel, large population size, and disposal of international expired chemicals near rivers, *etc* [10]. The release of these chemicals into the river also pollutes the surrounding environment, including animals and aquatic life [11, 12]. Based on recent research studies, the improved administration and methodology must be formulated and implemented [13]. However, for precise regulations and monitoring of EPs to determine the permissible limit of these pollutants in the environment, there is a dire need for a complete understanding of fate and toxicities [14]. Ecotoxicology study is a major concern of the EPs because most pollutants are persistent and possess bioaccumulation [15].

The ecotoxicity of different emerging toxicants has been evaluated previously on sentinel species recommended by the U.S.-Environmental Protection Agency (USEPA) and the European Union (EU) for the safety potential of xenobiotics. To determine exposure limits of specific pollutants in the environment and decide the safety, various models and experimental protocols have been developed previously by researchers. The two widely used are whole organism battery tests and cell-lines decipher. The whole-organism battery test determines ecological exposure obtained by performing significant co-relation with realistic scenarios. At the same time, laboratory-based information obtained by cell lines deciphers certain limitations in extrapolating the adverse effects information regarding organisms of higher levels, such as humans, and is considered the bottleneck in ecotoxicity assessment.

Based on numerous emerging pollutants in an ecosystem, this chapter provides the classification of potential emerging contaminants, such as active pharmaceutical chemicals, personal care products, pesticides, and emerging industrial chemicals found in the environment. The knowledge of physicochemical properties of pollutants helps determine the fate and transport of specific pollutants, which are also discussed. Moreover, the ecotoxicological impacts of several EPs and available legislations formulated for the monitoring and handling of several EPs in the world are also discussed in this chapter.

PATHWAYS OF EPS IN THE ECOSYSTEM

EPs enter the ecosystem through different paths, including industrial/municipal wastewater, hospital wastewater, treated/partially treated effluent from the treatment plant, farmyard and agricultural runoff released into surface water, and application of sludge and biomass [16, 17]. For example, some pharmaceuticals are not completely metabolites by animals and humans and are released into the environment by urine and feces [8]. The classes of different EPs and their metabolites recently detected in other components of the environment around the globe are described in Table **1**. Most of these pollutants are not completely removed by conventional water and wastewater treatment facilities. Therefore, when released into rivers, lakes, and coastal water, partially or untreated water pollute the water with trace concentration of EPs. Thus, when used for horticulture, irrigation, or other non-potable purposes, water from these natural sources intensifies the concentration of these pollutants from parts per trillion to parts per million, thus deteriorating the quality of surface water, groundwater, and soil [18]. Other possible sources of EPs pollution in the environment might

CHAPTER 2

Emerging Water Pollutants from Pharmaceuticals and Personal Care Products

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Abstract: Pharmaceuticals and personal care products (PCPs) are chemically modified products mostly used for beauty, cleaning, or health, such as disinfectants, fragrances, insect repellents, ultraviolet (UV) filters, and others. Due to the contamination caused by these chemically amended PCPs, water pollution has appeared as a hazardous condition for the water treatment and supply sector. A recent concern is that when these chemical compounds combine with water, they act as water pollutants and harm aquatic lives and the survival of human lives. Nowadays, the concern of water pollution by these chemicals is confined to water treatment complexities this contamination is leaving adverse effects on the environment. Most of these water pollutants borne by sewage effluents through wastewater plants develop because of the insufficient removal from treatment plants. Therefore, the emerging water pollutants caused by PCPs are responsible for environmental pollution. Hence, this chapter emphasized the state-of-the-art global application of PCPs, the mechanism of water pollution by PCPs, possible biohazards, and negative impacts on the environment. Besides that, various types of PCPs, along with the most applied chemical compounds in PCPs, have been discussed in this chapter. To minimize the contamination, suitable removal methods to enhance the removal efficacy have been discussed. The chapter also presents a future perspective for reducing the PCP contamination of surface water with cutting-edge technologies and wastewater treatment.

Keywords: Water pollutants, Pharmaceutical products, Personal care products, Surface water, Wastewater treatment technologies.

INTRODUCTION

The latest water testing strategies allow researchers to distinguish the small sums of chemicals in our water supplies. As a result, modern considerations uncover the

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nearness of drugs, individual care items, and other substances we utilize at workplaces, homes and even on ranches. These substances are commonly alluded to as “emerging pathogens” or “emerging contaminants.” Dynamic fixings and additives of beauty care products, toiletries, and scents have been found in water. Nitro musk compounds utilized as scents in individual care items may have unfavorable natural impacts. These potential water quality contaminants are pharmaceuticals and personal care products (PCPs). Concurring to the Natural Assurance Office, PCPs are alluded to as “any items utilized by people for individual wellbeing or restorative reasons or utilized by agribusiness to improve development or wellbeing of livestock.” Potential water quality contaminants are flushed into groundwater from an assortment of sources. Wastewater from sewage treatment facilities, ranoff from agrarian arrival employments, primarily from mechanical scale animal offices, and discharged from individual septic frameworks are the main prevalent occurrences. The ability of conventional sewage treatment to destroy medication or personal care item buildups varies greatly [1].

Water pollution is caused by a variety of contaminants, some of which can be seen in Fig. (**1**). PCPs are one of these pollutants.

The biological & chemical properties of various PCPs suggest that many properties are not helpfully taken out by ordinary water treatment measures, as displayed by pith in drinking water. In green development, they have been perceived as containing the best variation of woody biomass in maritime conditions [2]. The lipid substance of green growth gives a part in introducing the trophic exchange of lipophilic trademark adulterants. An assessment [3] isolated the closeness of utilized antimicrobial administrators triclocarban (TCC), triclosan (TCS) comparatively as its metabolite methyl-triclosan (M-TCS) in green advancement tests amassed around a treatment plant of wastewater in Texas. Centralizations of target PCPs in-water tests were low, going from 50 to 200mg/L. On the other hand, more vital degrees of 50-400 mg/g of new weight seen in the events' green turn. The resulting bio-aggregation factors ran at 700-1500 for MTCS, 900-2100 for TCS, and 1600-2700 for TCC, respectively. A noteworthy fact raised by many research that the PCPs in water-bodies are able to interconnect with the secretory system to make disproportionate effects/unsettling influence of homeostasis [3]. The World Health Organization described endocrine disruptors (ED) as an 'extranet substance or mix that modifies the secretory system's function(s). It is due to adverse health effects on a creature, its offspring, or a subpopulation.

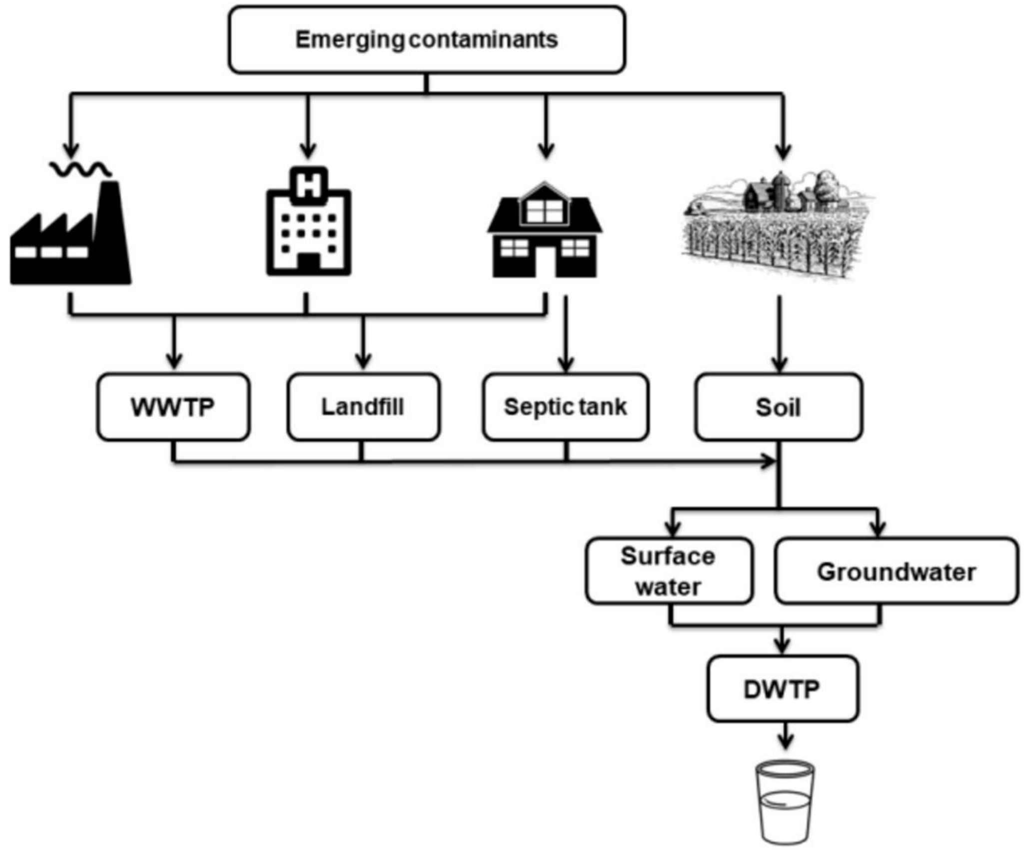

Fig. (1). Some pathways of water contamination [1].

EDs incorporated a tremendous gathering of synthetic concoctions from the standard (for example, mycotoxins and phytoestrogens). They engineered beginning (for instance, diethylstilbesterol (DES) and Bisphenol) in assortments of customer items (for example, PCPs, cleaning items, antimicrobials, food additives, and phthalates. Different endocrine-disrupting personal care products (PCPs) are now present that hamper our daily life. They have subdivided into sections: i) Disinfectants, ii) Conservation agents, iii) Fragrance, and iv) UV screens. The fragrance comes from different chemical compounds: musk xylol, musk ketone, galaxolide, tonalide, celestolied, and others. Also, UV screen is a mixture of varying contaminant chemicals, and they are benzophenone-3, homosalate, 4-methyl-benzylidyne camphor, octyl-methoxynniamine, octyl-dimethyl-PABA, and others [4].

PCPs incorporate countless engineered synthetic compounds utilized in regular items such as cleansers, creams, toothpaste, aroma, beautifying agents, and

CHAPTER 3

Emerging Water Pollutants from Food and Packaging Industry

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Abstract: Rapid industrialization and continuous mechanization of the food industry have increased waste production which is a source of various kinds of contaminants especially emerging water pollutants (EWPs). The industry of food (agriculture and processed food) and packaging industry are major sources of these emerging pollutants. Agrochemicals are also a source of pollutants which are contaminating the food chain and underground water. The dairy and meat industries are source of excess antibiotics, lactating hormones, medicines (*via* exudates and effluents), animal fats, acids, sludge, organic compounds and persisting chemicals in meat and milk. The food processing industry can also contribute various pollutants, like dyes, preservatives, sanitizing and disinfecting agents, as well as alcoholic and phenolic residues from the beverage and wine industries.The food packaging industry is also a major source of food preservatives, dyes, glue, and non-recyclable/one-time-use materials (plastic and polystyrene), which can be broken down into micro/nano plastics leading their way to water reserves and ultimately to the human food chain. Effluents of the food and packaging industry are rich in organic material and can support the growth of various pathogenic bacteria and fungi which can become a source of EWPs and can compromise human health that's why comprehensive information about these pollutants is needed. Keeping in mind all of these aspects present draft is compiled. This chapter covers various aspects of emerging water pollutants released from food-relevant industries.

Keywords: Emerging pollutants, Water pollution, Food industry waste, Packaging industry waste, Plastic waste, Wastewater treatment, Environmental remediation.

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INTRODUCTION

The emerging water pollutants (EWPs) are not new contaminants, but these have been recognized as a threat recently. With an ever-increasing global population, food production and consumption are expected to be rising tremendously in the following years. With increasing demand and production of food, the release of pollutants relevant to the industry is also getting intensified, and multi-pollutant intrusion in water resources is expected to rise [1 - 5]. The main pollutants pertinent to the food industry are pesticide residues [3], heavy metals, pathogens [5], and excessive nutrients [6 - 8], which eventually get dumped into water resources [1]. Livestock is another integral part of food production and is also responsible for the discharge of nutrients [7], pathogens [5], and pharmaceutical products, like antibiotics in water bodies [1]. The emerging pollutants of these kinds have become a concern for global communities and a threat to all freshwater reserves [9]. A key result of a population growth is excessive food production, thus releasing more contaminants into water bodies and very soon most of water bodies are expected to be contaminated with EWPs coming from food production and processing [10, 11]. A similar kind of multi-pollutant contamination can be observed worldwide due to the food production industry. Depleting freshwater resources worldwide and aquatic pollution from excessive fertilizer and manure application (nutrient release *via* runoff) are also major concerns nowadays [2].

Besides the food production industry, the food packaging/processing industry is another major contributor to emerging water pollutants. Industrial effluents (produced over courses of industrial processes) are not properly treated before being discharged into water bodies, and thus are another major source of aquatic pollution. Among the major food processing industries, breweries, soft-drink production companies, and cooking (vegetable) oil-producing industries are prominent. The brewery industry releases wastewater containing various emerging pollutants, like spent cooling water, grain liquor, hop liquor, yeast recovery system liquor, *etc*. These must be processed properly before discharge into water bodies [12, 13]. Food processing waste (sludge and water) is not usually subjected to proper treatment and drained as such in water bodies in developing countries [14]. Waste produced from the food processing industry commonly has a large number of organic materials, suspended solids, high biological oxygen demand (BOD) or chemical oxygen demand (COD), suspended oils/lipids, and most have over permissible levels of other pollutants [15]. Processed food needs to be packed, which gives rise to another industry (food packaging industry) that acts as a leading contributor of pollutants to the aquatic system, like volatile suspended solids and organic materials. Materials being used for packaging come in contact with various synthetic materials like adhesives, coating, and inks which can be washed away and act as a source of hydrocarbon pollution in water [16]. Once reaching landfills, these packages also act as a slow-releasing source of pollutants (*via* landfill leachates), which can contain numerous pollutants along with food remains. Old packaging constituents can be a source of plasticizers and heavy metals like lead (Pb) and cadmium (Cd) being released from inks and pigments [17 - 20].

Henceforward, this contaminant inundation from food production, processing, and packaging industries will get intensified, triggering a massive threat to the aquatic biota, which may impact back society (*via* pathogen contamination) and destroy aquatic nature (*via* algal blooms due to nutrient excess) [21].

TYPES AND CLASSIFICATION OF EMERGING WATER POLLUTANTS FROM THE FOOD INDUSTRY

Agriculture

To meet the needs of the ever-increasing global population, recent decades have seen an immense expansion of agriculture practices, which is putting a lot of pressure on natural resources like water. The area which was meant to be irrigated for agricultural purposes has doubled in the recent century (from 0.139 billion hectares in 1961 to 0.320 billion hectares in 2012) as reported by [22 - 26]. Another major consumer of water in agriculture is aquaculture adoption, which has increased 20-fold since the 1980s, especially in Asia [27 - 30]. This increased water use resulted in untreated/wastewater irrigation as an alternate but accessible approach being opted widely [31 - 34]. The wastewater being applied in agriculture is the source of various pollutants, leaching down to groundwater and moving to freshwater bodies *via* runoff.

Moreover, intensive agriculture has led to excessive application of pesticides and chemical fertilizers, which have become a source of emerging water pollutants. Aquaculture may also add remains of food in the water streams, which can cause the eutrophication of freshwater lakes. Water pollution from agriculture has many adverse effects on human health, like the development of the blue-baby syndrome and methemoglobinemia (a fatal illness in infants caused due to nitrate pollution in water). Pesticide accumulation in water may lead their way into our food chain, which has shown many adverse effects on human and have seen a ban on main broad-spectrum pesticides like dichlorodiphenyltrichloroethane (DDT) and organo-phosphates. However, some of these are still being and used in developing countries [35 - 38]. The aquatic system is on the verge of pollution with emerging pollutants (pesticides, nutrients, and fertilizer residues) responsible for eutrophication, disturbing the aquatic flora and fauna. The agriculture-sourced environment and water pollution have cost billions of dollars annually only in Economic Co-operation and Development (OECD) countries alone [39 - 41].

CHAPTER 4

Engineered Nanomaterials as Emerging Water Pollutants

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Abstract: Nanotechnology has many advantages, and its applications are spread to every field, from engineering to medicine and space to agriculture. Owing to the immense advantages of nano-size particles, nano-based materials are widely applied in wastewater treatment. These nanomaterials are developed and utilized in different sizes, shapes, and chemical compositions. These nanomaterials are characterized by their unique physical, chemical and biological properties. Besides the immense benefits of nanomaterials, they also have few environmental implications. This chapter presents the pros and cons of nanomaterials and their implications on the environment. Further, the effect of various nanomaterials on the aquatic environment, including the behaviour and toxicity on the aquatic ecosystem, is discussed. Finally, future directions to minimize the toxic effect of nanomaterials on the aquatic ecosystem and the need for improvement in the nanomaterials are presented.

Keywords: Engineered nanomaterials, Metal oxide nanomaterials, Carbon-based nanomaterials, Toxicity, Emerging water pollutants, Environmental impact, Environmental assessment, Pollutant monitoring, Nanoelectronic devices, Nanotextile materials, Remediation technologies, Wastewater treatment plants, Sewage treatment plants, Transport and environmental fate of nanomaterials, Nanomaterial waste handling.

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INTRODUCTION

Nanotechnology is a rapidly expanding research field and has found numerous applications in various fields. Currently, nanomaterials can be used in widely diverse applications such as wastewater treatment, catalysis, separation, and purification processes, bio-medical applications, electronic and optoelectronic accessories (such as light-emitting diodes (LEDs), solar cells, *etc*. Over the past decade, the production of nanomaterials has grown exponentially, and further research has now focused on improving their performance and applicability [1 - 3]. No doubt, nanotechnology has been effectively utilized in many areas to improve human efforts [4, 5]. Nanomaterials (NM) are mostly divided into conducive and non-conducive materials depending on their sources and applications [6, 7]. Although NMs available naturally or intentionally produced from organic activities, such as the combustion of fossil fuels or volcanic explosions, construction works, *etc* [8]. However, after the usage of these nanomaterials in various applications, they are left over as sludge or waste material, which eventually is dumped as solid waste. Inappropriate dumping of these NMs poses a severe threat to the environment and water bodies [9, 10]. Therefore, the immense NM applications poses risks to the environment and human health due to their severe ill effects such as toxicity, mutagenicity, *etc*.

Earlier research findings have observed that certain NMs are poisonous to marine creatures, mammals, and birds [11, 12]. Synthesized nanomaterials can be metal-based or carbon-based. Metal-based NMs incorporate metal oxides, magnetic nanoparticles (mNPs), noble metal NPs, silica NPs, and zeolites [13]. Carbon-based NMs are presented as fullerene (C60), graphene oxide (GO), and carbon nanotube (CNT) [14]. Due to their exceptional chemical, mechanical, photosensitive, physical, and thermal characteristics, NMs have attracted great consideration in science and engineering. Further, due to their small size and higher significant area and aspect ratio, they present unique characteristics [15]. CNTs are one-atom-layer sheets of carbon panes into a prolonged, echoing cylindrical structure [16]. Common techniques for synthesizing CNT are arc discharge and graphite CVD. Due to the endless chain of C-C covalent bonds, CNTs have greater mechanical characteristics than other materials. Graphene is a two-dimensional hexagonal frame carbon coating with a thickness of one atom. They have significant thermal, electrical, mechanical, ophthalmic characteristics and can combine with other elements [17, 18].

Several NMs have been utilized for water, effluent, and intake water treatment *via* adsorption, decontamination, membrane filtration, and photocatalysis. NMs incorporate magnetic nanoparticles, dye-doped silica NPs, noble metal NPs, quantum dots, CNTs, metal oxide NPs, nanofibers, zeolites, and graphene [19].

Due to their extremely permeable shape, exceptional geomorphology and geometry, and functionally dynamic surface, nano sorbents have the ability to eliminate toxins with unique hydrophobicity, and enhance the effectiveness of adsorption. Nano sorbents have higher kinetics due to available active sites and free surface, elevated elimination capabilities, and can be chemically stimulated for numerous applications [20]. The use of NMs in larger-scale water treatment raises many fundamental technological issues, including accumulation, difficulty in separating NMs after treatment, leakage into the water, and potential biological and human health consequences [21]. Earlier investigations have described that NMs influence their surrounding; they contaminate the atmosphere, accumulate in the ecosystem, and manipulate the life progression of inhabiting creatures. Although NMs are distributed in marine ecosystems, assessing their future harmful effects remains vague. Thus, there is a pressing need for more research to generate data that can be employed for probability evaluation, checking, and drafting regulatory guidelines.

NMs endure compound revolutions by intermingling with different media and creatures upon penetrating the ecosystem [22]. This results in various processes, such as accumulation, dissolution, alluviation, and translocation of the foodstuff [23]. Ecological experience with NMs can be evaluated by deciding the quantity of NMs circulated throughout the ending-of-life cycle. Though existing risk assessment techniques may help determine the prospective consequences of NMs, a new set of rules should be developed to tackle their exceptional characteristics and impacts. These techniques should consider the risk and dangers presented by NMs. From the numerous accessible methods, life cycle assessment (LCA) procedures for assessing the sustainability of nanotechnology have been encouraged. Moreover, there are few statistics on the impacts of long-term exposure at smaller concentrations.

Furthermore, few surveys about the collaborative effects among NMs, pure organic matter, and micro-toxins. To have a comprehensive analytic appraisal structure, it is essential to utilize a consistent approach and parameters for expecting the toxic effects of NMs. This chapter intends to assess the effect of nanomaterials on water pollution and their impacts on the ecosystem, ascertain the resources of nanomaterials in the marine ecosystem and assess the haulage and future nanomaterials.

SOURCES OF NANOMATERIALS

Engineered and Non-engineered Nanomaterials

Nanomaterials can be roughly divided into engineered and non-engineered nanomaterials . The engineered nanomaterials (ENMs) are synthetic and devised

CHAPTER 5

Emerging Water Pollutants from Industrial Processes

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Abstract: The widespread problem of water pollution endangers human health. Every year unsafe water causes more deaths than war and integrates all other forms of violence. Industrial activities create a large source of emerging water pollutants that are highly harmful to humans and the environment. This leads to increasing concern for the possible ecological impact of these pollutants on the environment. This chapter identifies various emerging water pollutants produced from different industrial processes (*e.g.*, petrochemical production, textile, paper and pulp, semiconductor/ electroplating, and metal production). The possible route of pollution formation is discussed in this chapter. In addition, the impact of the produced water pollutants on the environment and health has been elucidated. Furthermore, the concerns of emerging contaminants remain a moving subject as the new pollutants continuously are being produced in industrial processes. In response, an insight into the challenges of minimizing water pollution is also focused on mutual benefit.

Keywords: Denim industry, Emerging water pollutants, Heavy industries, Industrial engineering, Industrial process, Manufacturing processes, Paper and pulp industry, Petrochemical industry, Semiconductor/electroplating.

INTRODUCTION

Industrial processes utilize water and release numerous compounds in wastewater, which may accumulate in drinking water bodies that disrupt everyday life. The discharge of industrially polluted water into clean water is a significant issue [1]. These practices have produced various contaminations that disrupted the water

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cycle and caused great concern due to their possible effect on the environment and human health [2, 3]. Emerging water pollutants (EWPs) have received much attention from researchers and public administrations. EWPs are defined as ‘any synthetic or naturally occurring chemical or microorganism that is not ordinarily monitored in the environment, however, has a great potential to influent the environment and cause known or suspected adverse ecological and human health effects [4]. EWPs come from organic species such as perfluorinated compounds, pesticides, pharmaceuticals, hormones, micro-pollutants, endocrine disruptors, disinfection by products, sunscreens, flame retardants, industrially related synthetic dyes, and dyes-containing hazardous pollutants, *etc* [5, 6]. Although these pollutants are present in low concentrations of wastewater, they still become a threat to water bodies and the ecosystem if not controlled.

In many developing countries, producing products or goods from the industrial process has become a major activity. These activities result in the discharge of industrial effluents that may contain pollutants at levels that could affect the quality of receiving waters and the aquatic ecosystem [7]. There are regulatory requirements and guidelines in all countries on the discharge of industrial effluents into water bodies. Due to that, most factories must meet the minimum standard requirements. However, not all the chemicals or contaminants are listed in the guidelines, especially the EWPs. The chemical industry may release many substances not considered by regulatory requirements and might be the EWPs. These compounds may be the final products, precursors, intermediates of the process, or impurities and by-products. The main aim of this chapter is to explain in detail the EWPs discharged from industrial processes, specifically in petrochemical production, textile, paper pulp, semiconductor/plating, and metal production industry.

PETROCHEMICAL INDUSTRY

Petrochemical products from the oil and gas industry could be converted into various goods, including polymers, pharmaceuticals, dyes, solvents, and other chemicals [8]. There are about 2500 types of products produced from crude oil. The crude petroleum is extracted from the ground. The crude oil goes through refining processes, separating the fuels and chemicals such as light hydrocarbon, naphtha, kerosene, diesel, gas oil, *etc*. According to the difference between boiling points, these products and intermediates undergo other processes to produce fuel gas, propane, gasoline, jet fuel, petrochemicals, kerosene, diesel, gasoline, and fuel oil precursors. These processes require industries like refineries and petrochemical complexes, and major methods may involve distillation, catalysis reaction, polymerization, purification, *etc*. [9]. The oil and gas industry contributes to a huge portion of the country’s economy, such as 50% (Saudi

Arabia), 30% (UAE), 14.5% (Malaysia), 1.2% (United Kingdom), and 8% (United States of America) of their country's gross domestic product (GDP) value.

The wastewater generation in petroleum refineries and petrochemicals plants (PRPP) is higher than the crude oil production by 40-160% [10]. Some physical parameters measure water quality like other wastewater, including pH, hardness, turbidity, heat, taste, and odor. To carry out the bulk characterization of the water quality, various tests are performed for the determination of oil and grease (O&G), total hydrocarbon (TBC), biochemical oxygen demand (BOD), soluble BOD, chemical oxygen demand (COD), and soluble COD [11]. Metals are frequently found in the PRPP wastewater, such as Cd, Ni, Hg, Pb, and vanadium [12]. Inorganic materials, such as fluorides, phosphates, sulphides, and chlorides, are also found in the PRPP wastewater [12]. The other common contaminants are summarised in Table **1** [10].

Table 1. Common wastewater contaminants from petrochemical processes [10].

Petrochemical Processes	Wastewater Contaminants
Drilling, exploration, transportation	Polymers, ionic emulsifiers, non-ionic emulsifiers
Crude desalting	Free oil. Ammonia, sulfides and suspended solids
Crude oil distillation	Sulfides, ammonia, phenols, oil, chlorides
Thermal cracking	Phenols, hydrogen sulfate, ammonia
Catalytic cracking	Sulfides, ammonia, phenols, oil, cyanide
Hydrocracking	Sulfides
Polymerization	Sulfides, mercaptans, ammonia
Alkylation	Sulfides spent caustic oil
Isomerazation	Phenols
Reforming	Sulfides
Hydro-treating	Sulfides, ammonia, phenols

Besides the contaminants mentioned above, the composition of PRPP wastewater also consists of an aromatic organic compound, which includes polyaromatic hydrocarbons (PAHs), phenolic substances, and aliphatic hydrocarbon compounds. For example, phenols are highly soluble in water, which could be detected in refinery wastewater at a few milligrams per liter to 7000 mg/L [13]. These compounds in the wastewater streams are hardly degradable by nature, thus affecting marine life and the ecosystem.

CHAPTER 6

Risk Assessment of Emerging Water Pollutants

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Abstract: A complex mixture of pollutants in wastewater runs down from different sources into the aquatic environment, with potential hazards to aquatic organisms, human health, and the environment. Among these water pollutants, F^-, NO_3^-, and heavy metals (Cd, Pb Hg, Zn, Cr, Ni, As, *etc*.) are considered conventional pollutants, whereas nanomaterials, pharmaceutical compounds, personal care products, pesticides, endocrine disrupting compounds (EDCs), artificial sweeteners, surfactants, *etc*. are known as emerging water pollutants. This cocktail of water pollutants in the aquatic ecosystem is a real danger, leading to detrimental effects. This chapter discussed the environmental risk assessment (ERA) of the emerging water pollutants, especially the nanomaterials. The ERA of emerging pollutants will help indicate potential risks associated with these substances, highlighting the importance of their hazard identification, dose-response and exposure assessment, and risk characterization. This information will give insights into the recent findings related to the pollutants' effects and their assessment approach.

Keywords: Agrochemicals, Emerging water pollutants, Nanomaterials, Personnel care products, Pharmaceuticals, Risk assessment.

INTRODUCTION

Water is the key component of life. Globally, increased wastewater discharge occurs due to intensive urbanization, industrialization, and several other factors. About 400 billion m^3 of wastewater is released from different sectors annually, contaminating about 5500 billion m^3 of freshwater annually [1]. About 80–90% of the total wastewater contaminated the Asian and Pacific region's surface water sources/environment [2]. According to estimates, the industrial discharge of wast-

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water into the environment will be doubled by 2025 [3], which will lead to further deterioration of surface water reservoirs.

Wastewater is a complex mixture of pollutants discharged from different sources reaching the aquatic environment, with potential hazards to aquatic organisms, human health, and the environment. Among these water pollutants, F^-, NO_3^- and heavy metals (Cd, Cr, Pb Hg, Zn, Ni, As, *etc*.) are considered conventional pollutants [4], whereas nanomaterials, pharmaceuticals & personal care products, endocrine disrupting compounds (EDCs), artificial sweeteners, surfactants, *etc*. are known as emerging water pollutants. Emerging water pollutants are chemical substances that have the potential to threaten human health or the environment and lack published health criteria. An "emerging pollutant" can be determined from an unknown cause, a novel exposure to humans, or *via* a new detection method [5]. Emerging pollutants are mainly the materials that make their way into surface water bodies through various anthropogenic activities [6]. In another study, emerging pollutants are defined as natural or chemical substances synthesized by man, exist in numerous environmental compartments, and have the potential to induce toxicity that can alter the metabolism of living organisms [7]. The compounds containing these emerging pollutants can be divided into three main categories: (i) Compounds that enter the environment by progressive industrialization. (ii) Compounds that have been detected recently, however, entered our environment years ago and (iii) the compounds that are already examined and recognized for having potential adverse impacts on humans or the ecosystem [8]. The modern lifestyle has increased the demand for new products in each sector such as industry, transport, agriculture, pharmaceutics, *etc*. As chemicals are used, they end up in the environment in the form of nonbiodegradable or hazardous wastes. Due to inappropriate wastewater treatment facilities, these chemicals run down from wastewater streams into surface/fresh water and consequently pollute our environment. Therefore, several concerns are rising about the harmful effects of these emerging pollutants, especially on humans and other organisms.

This book chapter discussed several kinds of emerging water pollutants and their sources. These pollutants include a wide range of chemical substances that we use regularly. They are being added to our environment, such as pharmaceutical compounds, engineered nanomaterials, personal care products, pesticides, perfluorinated compounds, *etc*. This chapter mainly discussed the environmental risk assessment (ERA) of these emerging water pollutants, especially the nanomaterials, which will help identify the potential risks associated with these substances.

EMERGING WATER POLLUTANTS

Nanotechnology had left no domain untouched by its scientific novelties. Although nanotechnology is early, it appears to affect different areas significantly. Nanotechnology has great potential and can serve in various sectors, including agriculture, health care, communication, and information technologies. In doing so, the negative effects of nanomaterials must not be ignored, such as ecotoxicity. The term 'nanomaterials' is used for all materials with a nano range size in at least one of their dimensions [9]. The increased use of nanomaterials in various fields has raised a worldwide concern about their release and influence on surroundings and the environment. Nanomaterials are already interacting with our environment since many scientists and engineers are handling the matter at the nanoscale. These nanomaterials are produced at a massive scale and are used directly in numerous commercial products and indirectly released into the environment [10]. As far as the manufacturing of nanomaterials is concerned, it has increased due to the increased demand for these nanomaterials in industries [11], recording a major boost for personal coating and care products, including anti-wetting products, cosmetics, and textiles. Other applications include electronics, engineering, energy, sports, construction, automotive, food and drink, medicines, *etc*. According to the Global Nanomaterials Market Size Report, 2010-2027, the market size of nanomaterials was approximately 8.52 billion USD in 2019, which is estimated to increase up to 9.58 billion USD in 2020. The compound annual growth rate of the nanomaterials market is calculated to increase by 13% from 2019 to 2027 [12]. Likewise, these nanomaterials' prompt synthesis and use have increased their release in the environment and, ultimately, their interaction with abiotic or biotic components. Although Engineered Nanoparticles (ENPs) are noteworthy, their long-lasting exposure and existence in the environment are not bereft of toxic and hazardous biological effects. Therefore, it is crucial to understand the complete interaction of these nanomaterials within the ecosystem, their likely dangerous effects, and their consequences on human health as well as identify and assess nanotechnology for the safe application of these nanomaterials [13].

Among global concerns, the environmental impacts caused by pharmaceutical compounds need serious consideration as their uses cannot be avoided. Therefore, an appropriate risk assessment of their presence in the environment is of key importance. The potential risks of pharmaceutical compounds to humans and other organisms in the aquatic ecosystem are a matter of concern even at sublethal concentrations since the first case was brought to the horizon in 1985 [14]. However, the ecotoxicological risks associated with the increased concentrations of pharmaceutical compounds in aquatic ecosystems are still not known completely [15]. Among other emerging pollutants, personal care products and

CHAPTER 7

Fate of Emerging Water Pollutants

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Abstract: Emerging pollutants reflect a major global water quality problem. When these compounds enter the environment, they cause significant environmental threats to aquatic and human health. Emerging water pollutants (EWPs) include new materials with no regulatory status butthey can adversely affect the environment and human health. Emerging water contaminants can be biological or synthetic that remain unregulated, and pose a potential threat. Major classes of such pollutants are pharmaceuticals, agro-chemicals, endocrine-disrupting chemicals (EDCs), industrial wastes, livestock wastes, synthetic nanomaterials, and petroleum products. These pollutants can enter the environment through numerous sources and pose severe threats to soil organisms, agriculture, aquatic life, and humans. Pharmaceutical waste, industrial effluents, cosmetic and cleansing products, household sanitation, discharge, and synthetic NPs enter water channels, agro-ecosystem, underground water (*via* seepage), *etc*., posing a serious threat. These EWPs have different unknown and known effects on animals, plants, and human health, which must be viewed positively. This chapter summarizes the sources and classification of EWPs, their entry into the environment, and their fate. A major focus will be on the end sink of pollutants with potential threats and risk evaluation for plants and human health.

Keywords: Agro-ecosystem, Classification of EWPs, Effects of EWPs on humans, Emerging water pollutants, Endocrine-disrupting chemicals, Fate of EWPs, Food pollution, Of EWPs plants and animal health, Soil pollution, Sources of EWPs, Underground water, Water channels.

INTRODUCTION

Water pollution is an issue caused mainly by unregulated contamination of the water. This leads to the degradation of the global water quality and is correlated

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with the deaths of 3900 children every day and millions of people per year due to diseases caused by the consumption of contaminated water [1]. Today, one of the key issues is the careless release of new contaminants, such as pharmaceuticals and personal care products, to waterbodies where they remain unattended and move into the human food chain [2]. These emerging pollutants can be described as chemicals whose effects on the environment are unknown and spread worldwide in aquatic ecosystems because they have not been monitored [3, 4].

Personal care products (PCPs), pharmaceuticals, and many other synthetic organic substances have transformed daily life and are now a crucial part of a balanced society. Pharmaceutical-based disease management operations are an important part of developing and preserving healthy livestock and the human population. The PCPs and other pollutants of emerging concern (ECs) are recently noticed in all water bodies like wastewater, groundwater, precipitation, and even drinking water [5]. Also, these pollutants can be found in suspended solids and river sediments [6]. Almost all the ubiquitous effects of pharmaceutical products and other 'emerging pollutants' on the environment have become a major concern even at trace and ultra-trace levels (below ng/L) in recent years [7]. Many personal care products and pharmaceuticals often contain complex chemical structures. Processing plants are the main sources of these products (*e.g.*, paracetamol production in France in 2008 was 3303 tonnes). Prescription and non-prescription pharmaceuticals will finally be incorporated into our PCPs used in our everyday lives [7 - 9]. The efficient source of elimination of human PCPs is urine, which ultimately goes into water bodies (often untreated in developing countries) [10]. Pharmaceuticals are not completely consumed in the body, resulting in the introduction of a portion of the parental (or blended) derivative into the waste treatment facilities *via* biliary (feces) and renal (urine) routes after incomplete degradation [11]. In waste treatment plants or sewage treatment work (STW) and the aquatic setting, almost every human and veterinary pharmaceutical has been found at levels normally not exceeding upper ng/L, whether prescribed or not prescribed.

Personal care products are also responsible for releasing plasticizers used in product linings and packaging and the surfactant residues used in soaps and detergents, particular insecticides, disinfectants, and musk compounds used as fragrances. Recent issues regarding water-substantial contamination by the chemical products used in hydraulic shallow boiling can be seen as novel emerging pollutants (*e.g.*, surfactant naphthalene and clay stabilizer tetramethylammonium chloride) [12]. Most EWPC study reviews tend to be restricted to specific chemicals (*e.g.*, BPA) [13]. Materials are being used in PCPs engineered nanomaterials such as sun protection cosmetics and hip substitutes [14]. At the same time, the release of nanoparticles into the environment is associated with certain harm and concerns about their potential impact on the health of human beings. However, there remains limited awareness of their possible toxicity or damage [15]. Besides this, emerging pollutants include uncommonly controlled agricultural chemicals such as many pesticides, herbicides, and even recreational drug residues, pharmaceuticals, and their metabolites [16]. Several studies have been carried out to determine the toxicity of ECs to the environment. The studies report that veterinary and human drugs can be harmful to fish and a wide range of aquatic animals [17 - 19]. Pharmaceutical originated ECs like estrogens and steroids present in agricultural waste (*e.g*., oestrone, estriol, and estradiol) were established to cause defects in fish and amphibian reproduction [20]. Besides these hormones, certain nanoparticles as ECs, can also disrupt aquatic life like algae growth [21].

Most of these pollutants (15-20 years ago) were unknown or unrecognized and have recently been identified to be pollutants that are important to possible environmental risks. Their fate is still somewhat unknown regarding water/wastewater treatment systems, designed structures, and the environment. Usually, these contaminants are bio-accumulative and bioactive and may be present and persistent. Most EWPs are not monitored, requiring regular monitoring and evaluation of major involvements in the disposal of water supplies. It is now obvious that a combined analysis and method for these classes of pollutants will require many disciplines, including chemical, biological, and technical fields [22]. This chapter focuses on the release of emerging contaminants, their routes of adulteration, and their fate.

CLASSIFICATION OF EMERGING WATER POLLUTANTS

The EWPs contain a broad range of synthetic and natural chemical components that are considered to pose a potential threat. However, there is still no adequate availability of information for each pollutant. These EWPs consist of compounds such as personal care products (PCPs) and endocrine-disrupting chemicals, hormones, pharmaceuticals, pesticides, surfactant metabolites, surfactants, flame retardants, steroids, nanomaterials, gasoline additives, and industrial additives [22]. The typical example of emerging pollutants in surface waters is now pharmaceuticals, nanomaterials, industrial chemicals, and PCPs, whose existence was established recently. The word “EWPs” is generalized and encompasses many chemical pollutants. Thus, chemical emissions may also be classified according to different properties in the following classes [22]:

- CMR: carcinogenic, mutagenic, toxic to reproduction
- PBT: persistent, bio accumulative, toxic
- EDCs: (toxic contaminants)

CHAPTER 8

Lifecycle Assessment of Emerging Water Pollutants

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Abstract: Emerging pollutants (EPs), also known as contaminants of emerging concern, include pharmaceuticals and personal care products (PPCPs), surfactants, plasticizers, pesticides, *etc*., and the pharmaceuticals and personal care products are extensively used for therapeutic and non-therapeutic purposes in health care settings, livestock industry, and agriculture. Consumption and production of PPCPs have generated significant quantities of toxic waste in affluent entering the water streams, which poses a risk to aquatic life, public health, and the ecosystem. Given the potential toxicity impacts, continuous exposure to PPCPs is of critical concern. However, the concentrations of PPCPs in the environment are low. Efforts are being made to synergize efficient and cost-effective PPCPs removal technologies to remediate these pollutants from the environment. Still, the success rate is low because of their low concentration (ppb or ppt) and complex chemical structure. Common wastewater treatment technologies are not found efficient enough to attain their complete elimination from the aquatic matrix. Concurrently, ecological problems associated with water quality and aquatic life are aggravated in the prone areas, particularly in the developing world, owing to inadequate monitoring, data management, and treatment facilities. The lifecycle assessment (LCA) is an effective tool for efficient monitoring, quantification, and damage incurred by various stages from production to possible disposal. This chapter summarizes the LCA process of PPCPs, including the release and accumulation, to examine the impacts and associated risks to water quality, the aquatic environment, and ultimately human beings. Furthermore, the deep insight of

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LCA will help to understand the kinetics of pollutants in environment exchange pools and help fill the existing knowledge gaps that would be a certain better step for management and remediation.

Keywords: Analgesics, Antibiotics, Bioaccumulation, Bioconcentration, Cradle to grave analysis, Emerging pollutants, Endocrine disruptors, Food additives, Hormones, ISO-14001, Lifecycle assessment, Lifecycle impact assessment, Lifecycle inventory, Monitoring, Personal care products, Pharmaceuticals, Steroids, Surfactants, Wastewater treatment, Water footprints.

INTRODUCTION

Emerging Pollutants (EP) are any synthetic/anthropogenic or naturally occurring chemicals or biological organisms (microorganisms) that are not usually monitored in the environment. Still, these compounds can potentially enter different environmental compartments and cause known or suspected adverse environmental and human health effects. More than 700 EPs are categorized into more than 20 classes based on origin. Emerging contaminants comprise a vast array of artificial chemicals in global use, such as disinfection byproducts, perfluorinated compounds, pharmaceuticals, gasoline additives, UV-filters, and manufactured nanomaterials which are important for the progress of modern society (Table **1**) [1]. Moreover, nanomaterials, 1,4-dioxane, and swimming pool disinfection by-products (DBPs) must be included in emerging pollutants [2]. At present, EPs are not monitored in routine examination by monitoring programs, and their interaction and fate in the environment are not yet understood completely. EPs in the environment may result from the point or diffuse pollution. The flow from source to sink depends on the nature of EP and the environmental compartment. In urban areas, EPs released from wastewater treatment plants are discharged into rivers, where they may be degraded, adsorbed, or transported through the medium. Whereas EPs are transported by air in rural areas, runoff, or leaching and contaminating the surface and groundwater [3]. The physicochemical properties of chemicals (*e.g*., vapor pressure, water solubility, and polarity) decide their interaction in the environment. Thus, major sources of environmentally relevant emerging contaminants are primarily wastewater treatment plant effluents and secondarily terrestrial run-offs (from roads pavements, roofs, and agricultural land), including atmospheric deposition [2]. Due to their extensive use in industry, urbanization, transportation, and agriculture, the concentration of these non-biodegradable substances in the environment is increasing rapidly [1]. The EPs in the environment can be as high as a few hundred μg/L or as low as ng/L[4]. European commission-initiated the NORMAN project in 2005 to establish networking, research, and reference laboratories, integrating academia, industry, and government regulatory bodies with 70 participants from 20 countries and maintaining the largest records of emerging pollutants present in the environment [5]. The NORMAN list currently consists of over 1036 EP and their biotransformation products. Moreover, with advancements in the chemical industry and nanotechnology, various such pollutants will be introduced soon [6].

Table 1. Classification of emerging pollutants [2, 7, 8].

Categories	Compounds (Examples)
Drugs of abuse	Amphetamine, cocaine, tetrahydrocannabinol
Flame retardants	Chloroalkanes, polybrominated diphenyl ethers, (2-chloroethyl) phosphate, tetrabromo bisphenol A
Industrial additives and agents	Chelating agents, aromatic sulfonates
Gasoline additives	Dialkyl ethers, methyl-t-butyl ether
Food additive	Sucralose, triacetin
Wood preservative	2,4-Dinitrophenol
Plasticizers	Bisphenol
Personal-care products	Chelating agents (EDTA), aromatic sulfonates
Surfactants and their metabolites	Alkylphenol ethoxylates, alkylphenols, alkylphenol carboxylates
Steroids and hormones	Diethylstilbestrol, estriol, estrone
Fragrances, insect repellants, soaps, sunscreen agents	Nitro, polycyclic and macrocyclic musks; 2-benzyl-4-ch;orophenol
Pharmaceuticals Analgesics, antimicrobials (human and veterinary), antiepileptics, anti-tumoral drugs, blood-lipid regulators, cardiovascular drugs and b2-symphatomimetics, psychiatric drugs, X-ray contrast agents	Acetaminophen, acetylsalicylic acid, benzafibrate, carbamazepine, diclofenac, diazepam, iopromide, iopamidol, ibuprofen, aspirin, trimethoprim, erythromycin, lincomycin, ampicillin, doxycycline, amoxicillin, metoprolol, timolol, bisoprolol, clofibric acid, atorvastatin

The information about EPs' fate, behavior, and ecotoxicity are scarce. Currently, these EPs are not included in routine monitoring programs. However, more research studies are necessary to investigate the assessment, monitoring, and treatment techniques for rapid control action since drinking water is a scarce resource in the present world. This chapter focuses on the lifecycle assessment process of emerging water pollutants, including their release and accumulation, to examine the impacts and associated risks to water quality, the aquatic environment, and ultimately human beings.

CHAPTER 9

Conventional Methods for Removal of Emerging Water Pollutants

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Abstract: Water is essential for life and no creature can survive without clean and usable water. Most water is unusable as it contains salts and many other organic and inorganic impurities. Without taking these impurities out, the water available to us cannot be used. Different techniques can be adapted to purify the water and make it usable. The selection of the water purification technique can be made depending upon the water contamination, its loading, and other parameters. Based on the contamination and other parameters, chemical or physical techniques for water purification can be applied. Disinfection, desalination, coagulation, and chemical precipitation are common chemical methods used for water purification. For adsorption, membrane filtration is used to filter the pollutant out physically. Various char-based materials are synthesized and used for water purification using the adsorption route. Highly porous char materials can contain the contaminants into their pores and allow the clean water to pass through. The overflow of the adsorbent with the pollutant can be solved by using magnetic biochar as the contaminants can be taken out of the magnetic char-based adsorbent and reused. Thus, the process becomes more effective and efficient. The chapter talks about these processes and their limitations, and advantages over the others. It also describes different types of materials used for the water purification processes.

Keywords: Adsorption, Chemical precipitation, Coagulation, Emerging water pollutants, Filtration, Membrane filtration, Reverse osmosis, Water purification.

INTRODUCTION

From primary schools to science documentaries, Earth is referred to as 'the blue planet.' This analogy comes from water covering about 71% of the earth's surface. 326 million cubic miles of water on the planet, from which 97% of the earth's water is found in the oceans, but this source is not reliable due to the presence of excessive salt structure in water which makes it unsuitable for drinking and grow-

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ing crops, and industrial uses except cooling. Only 3% of the earth's water can be considered fresh, but this is not the end of the story. From that 3%, only 2.5% of the earth's freshwater is unavailable for many reasons. The availability of fresh water is locked up in glaciers, polar ice caps, atmosphere, and soil, highly polluted in some places, or lies too far beneath the earth's surface to be extracted inexpensively. Thus, only a quarter of the earth's water is available as freshwater, which in real figures amounts to an average of 8.4 million liters (2.2 million gallons) for each person on earth.

We are facing a shortage of freshwater, and that fixed amount of water is being used by the whole world's population with the freedom of wasting it independently. What about that remaining percentage of water covering nearly the whole globe? By calling it "salty water of no use", we declare it to be polluted, so putting more pollutants in it does not make any difference. Things are not as simple and suitable as they seem. Our oceans, covering a larger amount of earth, are the world for aquatic animals, and aquatic life is equally important for our ecosystem. Still, micro-pollutants are inevitably dumped in our oceans, lakes, ponds, and other water bodies. An estimated 80% of wastewater is dumped into the water bodies. This situation does not seem alarming because water is a universal solvent that dissolves every toxic element from farms, industries, households, *etc*. Researchers are doing work from the recent past in technologies of extracting toxic elements from wastewater to minimize water pollution [18, from global water pollution]. In developing countries like India and others, deploying this technique is still challenging.

Any chemical, synthetic or natural, or any micro-organism that is not readily found in the environment but, if they do so, can cause adverse effects to human health and the ecosystem and be termed as emerging contaminants (ECs) defined by U.S geological survey. ECs are those chemicals that emerge from veterinary and human pharmaceuticals when released into the environment and are of great concern due to their toxic effect potentially. Treating wastewater effectively can create a huge bridge between water resource supply and a rise in the economy [1]. There are many parts of the world where freshwater is not available evenly. Here, the proportion of water is uneven with the ground proportion. As per the WHO (World Health Organization) report, in the year 2008, nearly 25,000 people died due to contamination in water [2]. The water to be used should be proportionate to the water to be supplied. The chain of water from aquifers to its uses should be in proportion. The ratio of using water to storage should be small if we want a sustainable environment. Moreover, some serious steps should be taken to suppress the scarcity of fresh drinking water. Behnam *et al*. reported that chlorinated phenoxyacid herbicides account for most pesticides used worldwide, and their presence in environmental waters is well documented [2].

As technology is rooting expeditiously and living standards and ways of using resources are changing, the emergence of new emerging contaminants is an obvious question to be answered presently [3]. Also, there is an urgent need to identify new emerging contaminates to process further in removing them from the environment. The global corporation is needed to be in the process of assembling this collection. The geological composition of aquifers is structured to lead to the main cause of the leaching of toxic elements into drinking water supplies. The main elements are arsenic, fluoride, selenium, and a few others, such as chromium and uranium, creating chaos. Arsenic has caused the greatest negative health effects among these geogenic contaminants and is a global concern [4].

WATER CONTAMINATION

Biological Contamination

There is a balance in nature weighted with natural habitats on one side and its consumption on the other, and this balance should be thriving rather than shifting needle to one side only. Biological organisms that can contaminate water are classified as Pathogenic microbes, viruses, parasites, and Protista. Microorganisms are the backbone of all infectious diseases, whatever the origin of the former. The source can be general or sporadic, but infection from them is inevitable. The microorganisms category is considered to be fungi, bacteria, viruses, and even parasites [5, 6]. Insects and animals are the main transmitters of these microorganisms, and sometimes contaminated food and water also play a contagious role in the human body and Environment. Typhoid, Chickenpox, and measles are some infectious diseases, and researchers have found that the origin of the emergence of these diseases is the pathogens present in the polluted water. These pathogens present in contaminated water are a global concern to draw a clear separation between groundwater to freshwater.

Water supplies include groundwater from aquifers, seas or oceans, lakes, ponds, or wastewater from sewage treatment and municipal wastewater treatment. There is a list of pathogenic microorganisms, including viruses, bacteria, micro-organisms, heavy metals, and protozoans. Researchers are not very much concerned about the number of toxins they produce. Still, the effect of these pathogenic factors is rancor, and it is alarming to manage freshwater management [7]. In highly developed countries, outbreaks caused by pathogenic *E. coli* and cryptosporidiosis are reported more often. Legionella pneumophila is increasing in a concerning manner in warm water supplies and air-conditioning systems of large buildings, such as hospitals. Outbreaks of typhoid fever occur only sporadically. The most petrified disease caused by pathogens is Alzheimer's disease, the leading cause of cognitive and behavioral impairment in

CHAPTER 10

Advanced Membrane Processes for the Removal of Emerging Water Pollutants

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Abstract: This chapter demonstrates the source and pathway of emerging contaminants (ECs) and their removal by advanced membrane technologies. These ECs are naturally occurring or synthetic organic pollutants, including pharmaceuticals and personal care products, estrogens, industrial chemicals, UV filters, pesticides, and endocrine-disrupting chemicals ubiquitously detected in wastewater and wastewater-impacted surface waterbodies. Emerging contaminants have detrimental effects on aquatic flora and fauna and may affect human health. Due to the persistent nature of ECs, they are resistant to conventional wastewater treatments. Moreover, different physicochemical processes have shown ineffectiveness for the removal of ECs. Therefore, there is a need for robust wastewater treatment processes such as advanced membrane technologies that can effectively remove these ECs. Advanced membrane technologies use membranes that separate ECs from the solution and include forward osmosis, reverse osmosis, nanofiltration, ultrafiltration, microfiltration, catalytic membranes, and membrane bioreactors. Briefly, the focus of this chapter is to provide an overview of different membrane separation technologies and illustrate various examples of ECs removal.

Keywords: Catalytic membranes, Ceramic membrane, Emerging contaminants, Membrane bioreactor, Forward osmosis, Hollow fiber, Membrane fouling, Nanofiltration, Polymer membranes, Rejection of contaminants, Reverse osmosis, Ultrafiltration, Water reuse.

INTRODUCTION

Current demographic, technological, and economic advancement throughout the world has knowingly and unknowingly altered the environment we live in. Our actions affect the global environment, impacting the quality and quantity of freshwater resources [1]. Among all the available water on the earth (97% salt

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water and 2% ice), only 1% is present as freshwater, which mainly occurs in groundwater, rivers, and lakes and is used to meet water demands [2]. Water is required for drinking, irrigation, fisheries, and food production. It is also needed on an industrial scale for energy generation-hydropower, fossil fuel extraction, and a coolant in nuclear power plants. The food industry accounts for 70% of water use globally, and the energy sector consumes 10% of available water resources [3, 4]. With an ever-growing population and higher living standards, water demand increases. Under the water-energy-food nexus approach, three tiers are well connected, and impact in one sector can significantly affect the performance of other sectors [5, 6]. Today, the world is worried about water scarcity due to increasing water demand and its impacts on the food and energy sector. In recent years, water demand on a global scale has exceeded twice that of the population. Moreover, urban development, the spread of infectious disease, and the detection of emerging contaminants also stressed the current water supply [1]. Logically, to sustain life, we need to practice "3R," which is reducing (preserving existing water resources), reusing (wastewater use) and recycling (treatment of wastewater).

During the last few decades, many emerging contaminants, including pharmaceuticals and personal care products (PPCPs), industrial chemicals, endocrine-disrupting chemicals, and pesticides, have been detected in soil and water, including drinking water, surface water, and groundwater [7]. Emerging contaminants are found in a few nanograms to micrograms per liter in wastewater and wastewater impacted surface water bodies [8]. Antibiotics, a particular class of PPCPs, are extensively used by humans to cure animal diseases and are ubiquitously detected in wastewater. They are highly persistent and biologically active compounds that cannot be completely metabolized and thus continuously enter the environment through urine and feces [9]. Emerging contaminants have detrimental effects on humans and aquatic lives due to continuous exposure. Therefore, their complete removal from wastewater is essential for safe disposal in the environment. Current wastewater treatment plants are not designed to remove emerging pollutants from wastewater. Thus, complete elimination of emerging contaminants cannot be achieved through activated sludge treatment [10]. Different physicochemical and advanced oxidation processes are being used to remove these pollutants. Membrane separation processes have been considered an efficient treatment for removing emerging contaminants [11].

Membrane technology is a promising candidate for the removal of emerging contaminants. The membrane process generally involves feed that passes through the membrane and retains solute particles in the feed reactor by different phenomena, including adsorption, size excursion, differential interaction, and charge repulsion. Based on particle size and membrane types, membrane technologies can be classified as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). MF with a nominal pore size of 100-1000 nm and UF with less than 100 nm can reject some macro and micro molecules. They are applied to separate suspended solids, emulsions, large collides, proteins, bacteria, and viruses [12].

NF and RO are used to remove dyes, ionic species, and emerging contaminants. Membrane processes are used in biotechnology and wastewater treatment from different resources such as textile plant effluent, hospital wastewater, and refinery wastewater. The application of membrane technologies for bioprocesses involves replacing conventional separation processes such as centrifugation, evaporation, and demineralization in the dairy industry. Other applications include separating protein/peptides, recycling cleaning solutions, impurities removal, filtration of fermentation broths, and extraction and purification of micro chemicals. For instance, centrifugation is used in drug manufacturing industries to clarify vaccine and cell culture and involves high capital and maintenance costs. Membrane processes can be used as an alternative to centrifugation for vaccine production [13]. Recently, Muniandi *et al.* [14] used tangential flow filtration for clarification during the manufacturing processes of tetanus toxin. Various examples of tangential flow and normal membrane filtration in vaccine manufacturing industries are available in the literature. During product recovery and purification, membrane filtration processes such as MF, UF, and NF are also used. González *et al.* [13] studied the lactic acid recovery from whey fermentation broths and used UF for cell recycling and RO for pre-concentration. Also, membrane processes have been used to extract and purify pharmaceuticals due to their simple operation. In a study, the ultrafiltration membrane was used in the solvent extraction process to remove bio-emulsifier from benzylpenicillin-containing fermentation broth [15].

Membrane processes also remove emerging contaminants from wastewater received from different resources. MF is only effective for the removal of bacteria and viruses. At the same time, UF can only remove some ECs, and removal depends on the physicochemical properties of contaminants and membrane type [16, 17]. Nanofiltration can significantly remove the ECs compared to MF and UF membranes [18, 19]. Radjenović *et al.* [20] reported greater than 85% removal of selected pharmaceuticals, namely, ketoprofen, diclofenac, acetaminophen, propyphenazone, sotalol, metoprolol, carbamazepine, sulfamethoxazole, gemfibrozil, and hydrochlorothiazide in the NF system. Another study reported 99% removal of diclofenac through the nanofiltration membrane process [21]. Recently, nanotechnology-based membrane processes have gained much attraction for the removal of ECs. In this technology, nanomaterials such as carbon nanotubes, polymers, silver, and silica have been used to fabricate

CHAPTER 11

Osmotic and Filtration Processes for the Removal of Emerging Water Pollutants

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Abstract: Emerging pollutants (EPs) in water and wastewater are one of the global water quality challenges and have substantially adverse and serious effects on ecosystems and human health. However, the presence of these EP's is generally in minute quantities ranging from microgram per liter to nanogram per liter in the environment. These emerging water pollutants may contain endocrine-disrupting compounds (EDCs), personal care and pharmaceutical products, surfactants, hormones, steroids, *etc*. EPs can also be generated from the synthesis of new chemicals and their by-products in industries. Considering the potential impact of these EPs, an appropriate and effective wastewater treatment approach is needed, which can remove the wide variety of these EPs. Membrane technologies have gained more attention in water filtration processes as membrane technology can remove the emerging water and wastewater pollutants with different membranes. The presence of the membrane barrier is one of the main advantages of the membrane filtration process, which offers a wide variety of supplementary adsorption mechanisms for EPs. The pressure-driven membrane filtration processes include micro-filtration (MF), nano-filtration (NF), ultra-filtration (UF), and reverse osmosis (RO). In contrast, the osmotically driven membrane filtration processes (ODMFP) include pressure retarded osmosis (PRO) and forward osmosis (FO) only. This chapter will review the major characteristics, advancements, and principles of NF, RO, ODMFP, and other emerging membrane filtration technology for treating EPs in water and wastewater.

Keywords: Emerging pollutants, Filtration processes, Forward osmosis, Osmotically driven membranes, Pressure-driven membranes.

INTRODUCTION

Due to the innovative analytical techniques and advanced analytical instrumentations in present days, many chemicals with very few concentrations can be

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detected within nature and drinking waters. These chemicals are called emerging pollutants (EPs) which may not have instantaneous toxic effects on humans, although these are present in natural and drinking water bodies at low concentrations. Hence, it is very important to find out the attention of these EPs in water reservoirs and natural sources to avoid greater risks to human health, the economy, and the environment. At very low concentrations of some emerging pollutants, their direct adverse effects on human health and ecology have not been observed. Still, long-term accumulation can be a public concern that may affect human health and ecology [1]. The major pathways of many EPs from different sources in the aquatic environment are industrial, agricultural, hospital waste, and municipal wastewater, as shown in Fig. (**1**).

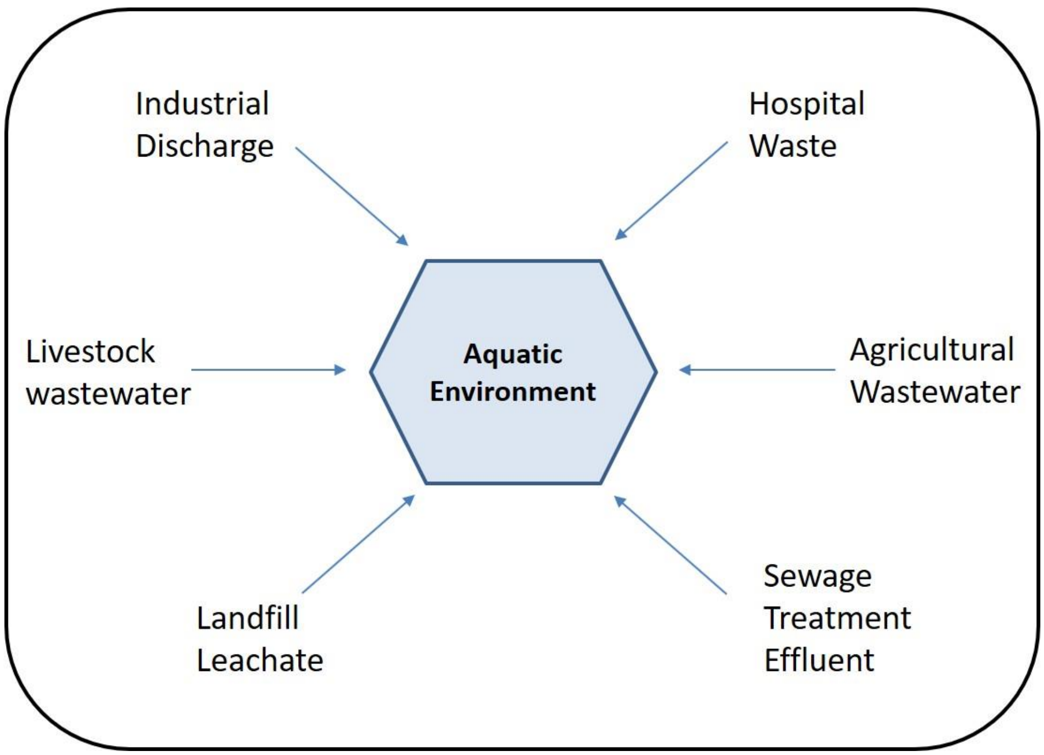

Fig. (1). Pathways of emerging pollutants from different sources in the aquatic environment.

Depending upon the use, properties, and origin, EPs may be classified into different groups, normally comprising endocrine-disrupting compounds (EDCs), personal care and pharmaceutical products, nanoparticles, surfactants, hormones, steroids, *etc*. The examples of some major EPs present in an aquatic environment are mentioned in Table **1**. EPs can also be generated in industries during the synthesis of new chemicals and their by-products [2]. Only some EPs have acidic and basic functional groups, while most are polar compared to the traditional contaminants. The analytical finding and removal methods can create unique challenges coupled with the occurrence at trace levels (*i.e.*, in very small quantities from microgram per liter to nanogram per liter in the environment). The source of these EPs can be found in the manufacturing plants. But their paths of exposure to the environment after discharging from the manufacturing plants become less understood, more complex, and vary between rural and urban environments. Most EPs are presently not regulated. Hence, regular monitoring of their possible presence in the effluent discharge and water supplies is required [2].

Table 1. Some major emerging pollutants present in an aquatic environment (Adopted from [2]).

Emerging Pollutant Class	Examples
Personal Care Items	Poly-siloxane Glaxolides
Hormones	Estrone Endocrine
Pharmaceutical	Caffeine Ibuprofen
Livestock and human antibiotics	Trimethoprim Lincomycin

Due to the rapid population growth, change in climate, and high consumption of water, experts are proposing and implementing water recycling methods to meet the increasing demand. The fate of EPs in water reservoirs and water recycling intensity is an important concern according to the use of EPs. It is also remarkable that the guidelines for water recycling are more stringent than drinking water. Environmental/chemical engineers and scientists must understand the removal mechanisms of EPs, and the design of more effective and explicit water and wastewater treatment processes must be understood by environmental/chemical engineers scientists [3, 4].

Membrane Filtration Technologies

A membrane can be defined as a thin layer/selective barrier of semi-permeable matter which can separate solute in a solution. Only those materials can pass through the pores of the membranes that have smaller pore sizes than the pores of the membrane while stopping others. Membrane filtration is generally used to remove microorganisms, natural organic materials, and emerging pollutants (Fig. **2**). Conventional treatment systems, including activated sludge process, sand filtration, trickling filtration, and coagulation/flocculation, are mostly ineffective and not considered to remove EPs. Thus, in osmotically driven membrane

CHAPTER 12

Catalytic Processes for Removal of Emerging Water Pollutants

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Abstract: An unprecedented increase in urbanization and industrialization ignited by an upsurge in the development of consumer goods. This has been steadily destroying the environmental balance and ecosystem and diminishing the water quality. Inevitably, we are facing one of the biggest challenges of the time, which needs to be resolved with proper remediation strategies to provide clean water as one of the essential components for human beings and agriculture, livestock, and several industrial survivals. With the growing demand for water and sustainable improvement, utilizing unconventional water supplies such as contaminated fresh water, brackish water, and wastewater is required. Although some of the traditional water treatment and purification methods still retain their importance. However, there is a need to provide faster and more efficient technologies beyond conventional methods for treating various contaminated water sources, including emerging pollutants. Recently, catalytic processes such as ozonation and electrocatalysis, including electrocatalytic oxidation, electro-Fenton process, photo electro-Fenton process, photocatalysis, and reduction by hydrodehalogenation, exhibited unique features and have opened wide opportunities in the field of water treatment. This chapter describes various types of

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emerging contaminants, their effect on human health and the ecosystem, and analytical methods of ECs quantification. Moreover, the features, mechanisms, and potential applications of catalytic processes in treating emerging pollutants are discussed in detail.

Keywords: Catalytic processes, Emerging pollutants, Environmental application, Fenton processes, Oxidation processes, Remediation, Water treatment.

INTRODUCTION

The industrial revolution resulted in changes in lifestyle and the patterns of consumption and production, causing serious environmental hazards due to the release of new substances into the environment. These materials may impact differently from the traditional recognized environmental contaminants. However, traditional investigations into water quality mainly focus on microbial pollutants, heavy metals, and nutrients as the essential factors in providing safe drinking water to human beings, animals, and wildlife. Traditional analytical methods encounter instrumental restrictions in detecting and measuring the organic contaminants from the abovementioned sources. As an illustrative example, perfluorinated compounds (PFAS) as water repellent dates back to the 1950s, while this class of pollutants was recognized in the environment until the 2000s due to the lack of appropriate monitoring instruments [1]. As a result, the term "emerging" does not necessarily refer to a new class of substances. Still, it also indicates the materials that have been recently recognized as environmentally hazardous materials with potentially eco-toxicity effects.

Recently, several groups of chemical substances have been recognized as emerging contaminants (EC), and their number is continuously increasing. Among others, pharmaceutical residuals [2], personal care products [3, 4], food additives and artificial sweeteners [5, 6], synthetic organic materials, and recently nanoparticles [7, 8] excited more interest. Unfortunately, the lack of available data about occurrence routes, risk assessments, and, more importantly, the eco-toxicity effect of the materials makes the prediction of their health effects difficult. So, this is imperative to different types of ECs, the route of occurrence, their health effects, analytical methods for their quantification, and, more importantly, technological options for their removal.

The catalytic techniques include ozonation, electrocatalysis (including electro-catalytic oxidation, electro-Fenton, photo electro-Fenton), photocatalysis, sonocatalysis, and reduction by hydrodehalogenation have gained a reputation for removal or degradation of emerging water pollutants. The ozonation method benefits from the powerful oxidizer of ozone. In the electro-Fenton method, Fenton reagents oxidize the contaminants on the surface of the anode in the presence of •OH radicals (generated *via* ferrous ions (Fe^{2+})). At present, many photocatalytic materials responsive to visible light have been developed. However, applying UV/visible light radiations can effectively increase the efficiency of Fenton reactions. Photocatalysis is based on the formation of electron/hole pairs on the surface of the catalyst and a series of oxidation and reduction reactions for photodegradation of the contaminants. In the sonocatalysis method, the generation of hotspots due to sequential nucleation, growth, and collision of micro-bubbles is the main factor for the degradation of pollutants.

In this chapter, we aim to discuss different kinds of ECs, the route of their occurrence, their health effect, the analytical methods for their quantification, and in-detail mechanism and procedures of each of the catalytic techniques for removal of ECs from water. In addition, the overall pros and cons of each of these technologies are mentioned and briefly debated.

EMERGING WATER CONTAMINANTS

Researchers have realized that some organic pollutants profoundly impact the quality of the water bodies. These pollutants occur in relatively low concentrations (ng/L-µg/L) and have lately been recognized as considerable water pollutants [9]. The following sections describe different types of ECs, their effects, pathways, and various existing analytical detection methods in detail. The operations of various industries release directly and indirectly various substances which enter the waterbodies. Investigation of these compounds revealed their toxicity and detrimental effects on both human health and the environment in the long term. For this reason, several researchers have investigated their monitoring mechanisms. However, there is no exact agreement on the compounds that should be monitored.

Pharmaceuticals are widely used by humans and poultry, livestock, and fish farming to reduce illnesses and diseases. However, these chemicals are one of the most important emerging contaminants, which may cause a huge concern due to their frequent occurrence by remaining residual chemical groups such as steroids in the ecosystem (*i.e.*, drinking, surface, ground, waste, and storm waters) potentially endangering all human beings [10]. It has been estimated that more than 3000 different pharmaceutical ingredients (such as antibiotics, illicit drugs, hormones, antineoplastic compounds, beta-blockers, antidiabetics, and anti-inflammatory) [1, 11]. However, research studies have recognized just a small ratio of these contaminants released in aquatic systems. Beyond the potential adverse effect on the quality of potable water supplies and the health of human beings, bioaccumulation of these compounds interrupting hormonal control and inducing breast and testosterone cancers can worsen circumstances. The major

CHAPTER 13

Integrated Processes for Removal of Emerging Water Pollutants

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Abstract: As the world advances rapidly in technology, industries are experiencing rampant growth, and the healthcare sector is reaching new heights; however, novel challenges are emerging that threaten humanity in entirely new ways. Industrial development, large-scale urbanization, and hazardous effluent from healthcare facilities increase concentrations of emerging pollutants in our surface waters. Emerging pollutants have puzzled the researchers as they are relatively in smaller quantities than other pollutants, yet they pass through the conventional water treatment processes unscathed. Innovative integrated methods must be employed to enhance the water quality by significantly removing these persistent emerging pollutants. This chapter dives deeper into modern research to remove emerging water pollutants effectively. Integrated methods such as integrated electrocoagulation, activated sludge with membrane technology, and construction of wetlands are thoroughly presented.

Keywords: Integrated wastewater processes, Removal of hazardous materials, Wastewater, Wastewater treatment.

INTRODUCTION

Water and oxygen are the essential components to sustain life on planet Earth. Water bodies cover nearly 70% of the total Earth. Unfortunately, as little as 1% of total water is available as fresh water for human, plant, and animal consumption in rivers, lakes, ponds, and wells. The influx of masses towards urban areas in search of a better life, increasing industrialization, and growing economy are the

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important factors that account for water stress and less freshwater availability. The problem is further exacerbated by anthropogenic activities' addition of harmful pollutants to water resources, which renders the freshwater bodies unpleasant to the environment and hazardous for consumption. This uncontrolled problem adds to the phenomenon known as water scarcity [1]. United Nations World Water Development reported that more than 700 million people around the globe suffer from access to potable water. Additionally, industrial water demand (*e.g.*, pharmaceutical, textile, and agriculture) would possibly be increased by 400% by 2050.

The addition of nutrients in water causes dissolved oxygen to drop as microorganisms begin feeding on them. Still, due to rapid urbanization and industrial growth, researchers have identified new contaminants that are toxic to human health and threaten civilization. The water pollutants like phenols, organic dyes, benzene compounds, antibiotics, Bisphenol A, Clofibric acid, Benzotriazole, Atrazine, Carbamazepine, Diclofenac, Estriol, Gemifibrozil, Iopamidole, Naproxen, Primidone, Tonalide, Triclosan, Tolyltriazole, Sulfamethoxazole, Ibuprofen, Acetaminophen, Estrone, and halogenated hydrocarbon are among some of the known emerging water pollutants [2]. These emerging pollutants disrupt the food chain and significantly hamper the environmental equilibrium. These hazardous pollutants are concentrated in effluents from pharmaceutical, food processing, and polymer industries, particularly [3]. Effluents from the industries mentioned above are largely released in receiving waters without any treatment, posing a danger to human and animal lives and altering both species' fertility [4]. Owing to the immense dependence of the economy on industries, emerging pollutants are the most common contaminant in industrial wastewater. They have a harmful effect on humans. These pollutants can cause reproductive system malfunction, disruption of thyroid function, hypertension, diabetes mellitus, insulin resistance, cardiovascular diseases, blood disorders, and hormone-dependent cancer [5].

Concerned about the rampant growth in water-borne diseases and problems, researchers have focused on eradicating water contamination through cost-effective treatment systems. Novel integrated approaches, which require the combination of two or more technologies to tackle this issue and successfully remove emerging pollutants from the wastewaters, are being studied and developed. Integrated technologies have garnered much interest due to higher removal efficiency and performance than stand-alone methods. Other approaches such as waste volume reduction [6], zero liquid discharge [7, 8], and recovery of salts/minerals [9, 10] are being researched. Removal of emerging pollutants is a challenge that is now being tackled as a top priority. Technologies like electrocoagulation, constructed wetlands with waste stabilization ponds, and activated sludge processes with physical processes like ultrafiltration and reverse osmosis are extensively explored worldwide and discussed in this chapter.

INTEGRATED ELECTROCOAGULATION TREATMENT PROCESS

Electrocoagulation (EC) plays a vital role in wastewater treatment technologies and alternative treatment systems designed for the different types of wastewater due to its low footprint, durability, flexibility, simplicity, and sustainable process for nature [11]. It is an electrochemical process in which wastewater pollutants get eliminated due to the direct current (DC) supply affecting electrode dissolution. Together with all impurities available in the effluent, it can be easily separated through the electrolytic mixture [12]. The geometry of EC is very simple, which relates to the factors like DC power supply and electrodes occupied with the protected containers for wastewater treatment. EC reduces the moving parts during the process due to the simplicity of the system, which decreases the maintenance and proves the hybrid EC with chemical coagulation (CC) for the higher chemical oxygen demand (COD) removal efficiency of the oil industry effluents [12 - 14].

Electricity is used for moving the parts of the EC process, and required chemical addition is made in the CC process. Underdeveloped countries have a shortage of electricity, and chemicals are costly. Due to the electricity shortage in developing countries, alternative energy sources like solar power have been investigated. Similar ideas for running the EC process have been reported with remarkable results [15 - 17]. The utilization of alternative energy sources for the electrocoagulation process plays a vital role in the environmental and economic sector for sustainability in wastewater treatment. EC treatment process studies have been widely conducted for treating various wastewaters like oily, municipal, textile, tannery, and mineral processing, urban laundry, metalworking fluids, palm oil mill effluent (POME), industrial wastewater, *etc* [11]. EC wastewater treatment combines with other technologies and can help reduce the EC limitations and increase the efficiencies of the system. Hybrid technologies can help reduce the scarcity of fresh water and reuse water for further processes in industries. It is reported that the efficiencies of any combined system are higher than the single treatment process; for instance, there are 20% higher efficiencies of a combined processes system as compared to the electrocoagulation alone [18]. Due to limitations associated with EC technology, recently, various research studies have reported on integrated systems with EC to enhance the removal efficiency of pollutants [11].

The combination of peroxidation with EC plays a vital role in the integrated technologies system for wastewater treatment. Peroxidation is broadly used with

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