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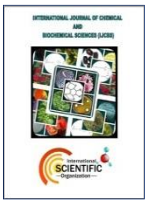

Strategies and Technologies for Emerging Contaminants

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Abstract

There are major health and environmental issues regarding the prevalence and permanence of emerging contaminants (ECs), such as endocrine-disrupting chemicals (EDCs), personal care products (PCPs), medications, and their converted products. Extensive research has been conducted on the environmental sources, ecological effects, and treatment technologies of ECs. Nevertheless, there is a dearth of comprehensive information especially in wastewater treatment plants (WWTPs) which despite being inefficient at removing ECs, serve as the main barriers against the spread of ECs. Strategies encompass both conventional and advanced treatment methods, including physical, chemical, and biological processes. Physical methods such as filtration and adsorption offer effective removal of contaminants like microplastics and nanoparticles. Chemical treatments involve ozonation, and advanced oxidation processes (AOPs), which target organic pollutants and pharmaceuticals. Biological treatment, including activated sludge systems and biofiltration, has shown promise in degrading certain contaminants through microbial metabolism. Additionally, emerging technologies such as membrane-based processes, nanotechnology, and photocatalysis are gaining attention for their efficiency in contaminant removal. Hybrid systems have frequently been proven to be more efficient, but as of right now, no single technology can eliminate ECs. Some ECs, especially pesticides and medications, were shown to be significantly removed by a hybrid Ozonation and activated carbon approach. However, challenges remain in achieving complete removal and ensuring the sustainability of treatment processes. Future research directions focus on developing cost-effective, energy-efficient, and environmentally sustainable solutions to mitigate the impact of emerging contaminants on water resources.

Keywords: Emerging Contaminants, Treatment Technologies, Adsorption, Nanomaterials, Hybrid Treatment, Wastewater.

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1. Introduction

Water quality is primarily determined by the concentration of various chemicals and particles, including microbes, heavy metals, nutrients, and prioritized pollutants. But recently, the public's attention and concerns have turned to organic contaminants, also referred to as emerging contaminants (ECs), which pose serious problems to the efficacy of current water treatment systems in eliminating them, in addition to drastically lowering water quality [1]. Emerging contaminants include pesticides, medications, hormones, plasticizers, personal care products, wood preservatives, food additives, surfactants, detergents, disinfectants, and flame retardants, among other organic pollutants illustrated in figure 1. Due to the widespread usage of these compounds, it appears to be extremely difficult to remove them from products shortly [2-5]. These substances do not necessarily require to be persistent to have undesirable effects on many creatures because they are continuously released into the environment at a rate that is somewhat rising (a phenomenon known as "pseudo persistence"). One of the primary sources of ECs, which are often discharged into surface waterways before finding their way into sediment, soil, groundwater, and oceans, is the WWTP's effluent [6]. The remaining ECs in the effluent are caused by the fact that most WWTPs are not built to handle such materials in extremely tiny amounts (usually in micro or nanogram per liter), as they are intended for wastewater partial purification [7]. ECs can damage animal and human endocrine systems, propagate antibiotic resistance, and bioaccumulate in lipid-rich tissues of various species due to their water-repellent properties [8]. Endocrine-disrupting chemicals (EDCs) are chemicals that have been identified as causing prostate, endometriosis, breast, and testicular cancer. Additionally, they have the potential to seriously impair the reproductive health of both animals and humans by weakening the immune systems of aquatic animals, reducing the number of sperm in humans, and producing fragile eggs [9-10]. Several pharmaceuticals, including food supplements, analgesics, stimulants, lipid regulators, diuretics, and their metabolites, are linked to a decline in reproductive health, an increase in antimicrobial resistance, and a heightened susceptibility of human health and ecosystems [11-12]. Research and monitoring are still needed to fully understand the long-term dangers associated with ECs. Several national, regional, and worldwide entities are actively working to address the impacts of ECs on the health of humans and the environment by utilizing contaminants removal technology. Reducing pollution to lessen the need for water is made possible by a variety of treatment technologies with a broad range of applications. The two main types of current EC removal methods are conventional methods and sophisticated treatment procedures [13]. Nevertheless, present wastewater treatment plants (WWTPs) use management methods that are unable to successfully eliminate ECs because of the compound's non-biodegradability, complex structure, and low concentration in the water [14]. While photolysis, sorption, biodegradation, and volatilization are examples of natural attenuation processes, they can be less effective and efficient despite being more straightforward and economically viable [15-16].

High amounts of ECs can be effectively eliminated by conventional methods integrated into WWTPs [14]. With the ability to remove considerable amounts of EC from urban wastewater, the advanced oxidation process (AOP) is one of the most well-liked progressive treatment systems that are extensively investigated [17]. AOPs have not yet been used on an industrial basis, though. While several sophisticated treatment methods, including as-built bioelectrical systems, wetlands, and treatment by enzymes, have shown great success in removing EC in WWTPs where they have been used, they are primarily still in the research stage [18]. Particularly in the tertiary stages, activated carbon and ozonation are among the best treatment methods [19]. Various strategies were employed to lessen wastewater effluent toxicity and promote sustainable use. To handle newly discovered toxins in wastewater, a thorough strategy is required. This entails improving biological treatment procedures for better removal, modernizing wastewater treatment plants with cutting-edge technology like advanced oxidation and membrane filtration, and putting source control measures in place to restrict the input of contaminants. To track pollutant concentrations, comprehensive monitoring procedures should be set up, and discharge control requires the enforcement of rules. Campaigns for correct disposal can be supported by public education, but research into new treatment methods should be prioritized. The efficient control of developing pollutants in wastewater is ensured by the constant adaptation of techniques based on new understanding. To address these newly discovered pollutants, numerous approaches have been devised, such as chemical oxidation, bio-degradation, adsorption, etc. [20].

The objective of this article is to conduct a thorough analysis of the treatment technologies used in WWTPs to remove ECs, as well as a review of various treatment approaches for various kinds of water pollutants. It provides a succinct overview of the body of information regarding ECs.

2. Sources, occurrence, and transport of ECs

Hospital wastes, aquaculture discharges, household discharges, and medicinal waste are the main sources of ECs [21]. These pollutants can enter wastewater through a variety of channels, including incorrect disposal, runoff, and industrial discharge. Because of their extensive usage and the imperfect metabolism of pharmaceuticals and personal care items, like hormones, antibiotics, and scents, in the human body, these substances are frequently detected in wastewater [22]. Pesticides and herbicides are present in wastewater due to agricultural activities. Runoff from agricultural areas has the potential to introduce these pollutants into water bodies. Numerous chemicals, such as plasticizers (including bisphenol A), flame retardants, and industrial solvents can leak into wastewater as a result of industrial activities. If these substances are disposed of incorrectly or spilled accidentally, they could end up in water supplies. Microbeads in personal care products, degradation of bigger plastic debris, and synthetic clothing fibers are some of the ways that micropollutants, such as microplastics, which are microscopic plastic particles, can find their way into wastewater systems [23]. EDCs have the ability to interact with the endocrine system and affect how hormones operate in both people and animals. The main way that endocrine-disrupting chemicals (EDS) are introduced to humans is through the consumption of food and drink items that have encountered contaminated water, soil, microorganisms, plants, or animals as discussed briefly in table 1. Pesticides, some medications, and industrial chemicals are some of the sources of EDCs found in wastewater [24].

Water-repellent textiles, non-stick cookware, firefighting foams, and other industrial and consumer goods are only a few examples of synthetic compounds known as per and polyfluoroalkyl substances, or PFAS. Leaching from consumer products and industrial discharge are two ways in which these chemicals might get up in wastewater. Drug usage and inappropriate disposal of unwanted drugs can result in the detection of illicit drug residues in wastewater, including cocaine, methamphetamine, and opioids. Concerns regarding the possible environmental effects of engineered nanomaterials used in consumer goods, electronics, and medical applications are raised by the fact that they can enter wastewater through a variety of channels. Common home chemicals, such as flame retardants, detergents, and disinfectants, can lead to the emergence of pollutants in wastewater due to incorrect disposal and domestic activities. When chemical residues from water disinfection procedures, including chlorination, linger in wastewater and provide health hazards, they can also be categorized as emerging pollutants. The amount of EC from these sources varies depending on the type of pesticides or biocides used, the features of the surface water bodies, and the climate [25-26].

3. Harmful effects of emerging contaminants on the environment and public health

Since it is most affected, the aquatic environment would be the main area of attention. ECs have a wide range of negative consequences. There are more than 700 ECs, and they are likely to infiltrate water bodies together with their metabolites and transformation products, severely harming the aquatic ecology. Aquatic life is extremely sensitive to even the smallest changes in its surroundings. The discharge of wastewater containing ECs suggests that EDCs have entered the water bodies. The presence of EDCs may lead to mutations in aquatic organism's genetic code, which can change one body component into another and result in genetic and reproductive problems. Among the harmful effects of ECs are immune system abnormalities, sex ratio variation, behavioral changes, and feminization of aquatic creatures, etc. By ingestion or skin absorption through the process known as bioaccumulation, ECs build up the poisons in an organism's body. Due to their direct exposure to ECs, producers and primary consumers are typically where bioaccumulation happens in food webs. When the toxicity reaches its maximum level, the organism will die as a result. A species would go extinct if it kept dying off, which would upset the ecosystem's balance. Any issue with the aquatic ecosystem has the potential to alter the climate [27]. The toxicity and durability of ECs have the potential to even change the metabolism of living things. The process through which the concentration of harmful substances increases at higher rungs of the food chain is known as biomagnification. Toxins are transferred to higher organisms that eat smaller organisms in the food chain whose bodies contain them. This process is known as bio-amplification. Therefore, long-term bioaccumulation leads to biomagnification. The insecticide DDT (Dichlorodiphenyltrichloroethane) is the most relevant example which is not very soluble in water, and accumulates in zooplanktons, which are living organisms, particularly crustaceans and fish larvae. These are subsequently eaten by big fish, which are then ravaged by birds that eat fish. DDT was present in zooplankton at a concentration of about 0.04 ppm, but as it entered the bodies of fish-eating organisms, it rose to 25 ppm (an increase of ten million times). While the direct effects of ECs on people are still being studied, the impacts of ECs on animals have received much reporting. ECs represent serious potential dangers to humans, even in small concentrations. This can take the form of bioaccumulation and biomagnification, especially for animals at the top of the food chain. Since surface water runoff, seepage, WWTPs, and landfill sites are the primary sources of heavy metals, EDCs, and bisphenol-A (BPA), their toxicity and impacts are unclear [27]. One of the effects of an endocrine disruption is that by inhibiting, imitating, or changing the hormones activity, it affects the endocrine systems of both human and animal species. Additionally, EDCs exposure has been linked to an increase in ovarian, testicular, breast cancer, and prostate as well as reproductive issues and a drop in male sperm count [28]. Exposure in youngsters has been linked to reduced IQ and delayed brain development. Research has revealed evidence of abnormalities in animals, including estradiol, ethinyl estradiol, estrone, and disordered reproductive tissue. However these contaminants are only present at exceptionally low levels, making removal challenging [29].

4. ECs in water; causes, effects, and analysis

As more substances are found to fall within this classification, the chemical groups number that make up ECs continues to increase. The EC group contains a wide range of substances, such as naphthenic acids, nanomaterials, perfluorinated compounds, algal toxins, by-products of drinking water and pool disinfection, musks, sunscreens, benzothiazoles, UV filters, siloxanes, prions, and flame retardants [30].It is anticipated that as the chemical industry develops, the range of substances discharged into the environment that could eventually affect humans and the ecosystem will increase dramatically [31]. Researchers have revealed an increase in interest in EC monitoring, although there is no consensus on the list of compounds that should be watched [32].

4.1 Pharmaceuticals

Pharmaceuticals constitute a substantial class of ECs, and the possibility of estrogenic and other unfavorable effects on people and wildlife has led to serious concerns. An estimated three thousand distinct compounds, such as beta-blockers, contraceptives, antibiotics, antidepressants, painkillers, lipid regulators, and impotence medications, are employed as constituents in pharmaceutical products. Environmental studies have only investigated a limited portion of these ECs. It causes many disorders such as fertility, ulcers, bleeding in the stomach, affect lactation and gastrointestinal. Pharmaceuticals are now more prevalent in metropolitan areas in groundwater, surface water, wastewater, and stormwater runoff due to their use [33].

4.2 Pesticides, biocides, and antibiotics

The main worries about biocides, antibiotics, and pesticides are the rise of bacterial resistance following their discharge into the environment as well as the negative impact on plant material biodegradation, which upsets the main food chain in aquatic environments [34]. The phrase "biocide" refers to chemicals used in urban contexts, whereas the term "pesticide" refers to chemicals used for agricultural purposes and cause hormonal changes, pregnancy complications and damages to male reproductivity. Stormwater runoff during rain events introduces biocides and insecticides into surface and groundwater [35].

4.3 Personal care product

These substances, which include sunscreens, scents, and antifungal agents, are commonly encountered in urban settings. These substances are easily released into aquatic habitats because they were created to be used externally and do not undergo any metabolic modifications. These substances cause cancer, affect the thyroid gland, endocrine disruptors, and fertility problems. Recently their presence in groundwater and urban runoff has also dramatically grown [36].

5. Treatment technologies

Non-traditional water treatment technologies have evolved throughout time because of the development of new methodologies. Phase-changing biological therapy, technologies, and sophisticated oxidation techniques can all be used to classify these treatments. This study assesses the most often discussed therapy modalities together with their functional attributes. While definitions of removal efficiencies vary among authors, comparing the concentration of ECs before and after treatment is the most often used technique for calculating removal efficiencies. Overview of wastewater technologies is shown in figure 3.

5.1 Physical, chemical, and biological techniques

To eliminate developing contaminants and pharmaceutical and personal care products (PPCPs) from aquatic streams, a variety of approaches are available. Yet, because physical treatment methods do not use chemical or biological agents, contaminants are eliminated and deprived of changing biochemical makeup [37]. A variety of physical techniques, including adsorption, membrane filtering, sedimentation, and others, are employed in WWTPs to remove PPCPs. Due to the hydrophilic character of some PPCPs, sedimentation entails the exclusion of suspended solids by the action of gravity, which is less effective [38]. Innovative polishing approaches that involve chemical treatment, such as chemical oxidation processes, are utilized to improve the removal efficiency. By changing the pollutants into inorganic molecules, chemical treatments typically mineralize them into harmless (less dangerous) or biodegradable states [39]. But in addition to the sun (UV radiation), gammas, ultrasound, and electric current, a variety of external chemicals must be used, including hydrogen peroxide, metal oxides, ozone, chlorine, and metal-based catalysts [40]. Biological treatment can successfully remove most of the targeted EC. During degradation, high molecular weight organic compounds are broken down into simple compounds, which ultimately get biomineralized to inorganic molecules (water, CO_2) by microbes like fungi, bacteria, and microalgae [41]. Biological treatments can be classified as conventional or non-conventional based on many factors such as wastewater parameters, maintenance, operation, and removal efficiency [42]. The role of different treatment technologies are discussed in table 2.

5.1.1 Adsorption process

The physical process known as adsorption occurs when soluble molecules are attracted to and removed by solid surfaces. Because adsorbents have a very specific surface area, adsorption is one of the most effective physical therapy techniques. Before use, the adsorbates from the adsorbents must be removed to activate this particular surface area. For a smoother and more efficient activation of the adsorbents, activated carbon is therefore widely utilized [43]. By use of the adsorption process, hazardous, inorganic, and organic contaminants may also be eliminated. Adsorption capacities are affected by the size, temperature, concentration, molecular chemical properties, and molecular mass of the contaminants. Selective ECs can be removed more successfully using activated carbons than with alternative adsorbents such as carbon nanotubes and charcoal [44]. These days, ECs taken from a separate system and microplastic are utilized as adsorbents [45].

5.1.2 Membrane-based technology

With the use of specialized membranes and with a range of filtration properties (hydrophobicity, surface charge, and pore size), membrane technology is a physical method for filtering wastewater that can remove contaminants in a variety of size ranges (micro to nano). Emerging contaminants have been eliminated through the use of novel high-pressure membrane technologies such as nanofiltration and reverse osmosis [46]. Commercial applications of these methods include the recycling and purification of drinking water, as well as the elimination of ECs from contaminated surface water. Though not useful on a wide scale, there are a few other membrane techniques such as electrodialysis, distillation, and forward osmosis that may be used to treat ECs Reverse osmosis (RO) is one membrane approach that has been created to provide a significantly improved and effective removal rate (99%) for pollutants [43]. Degradation (90–99%) of thirteen phenolic and seventeen non-phenolic contaminants has been demonstrated by integrating membrane distillation by an enzyme bioreactor. For newly emerging ionized pollutants, electrodialysis reversal can be used. Pharmaceutical medications can be eliminated using electrostatic repulsion, nanofiltration (NF) membranes, and adsorption [47]. Reverse osmosis (RO) uses a semipermeable membrane to help remove particles smaller than 1 nm. These membrane technologies or filtration methods can be classified according to the size of the pores in the membrane [48]. This is a potential method for treating a variety of ECs. According to research on the management of pharmaceutical substances, such as platelet activators, inhibitors, antibiotics (fluoroquinolone, nitroimidazole, macrolides, sulfonamides), H_2 receptor antagonists, antipsychotics, and anti-inflammatory or inflammatory drugs, RO uses bioactive membranes to get effective (99%) removal. Therefore, when it comes to removing contaminants, physical treatments such as adsorption and membrane filtration work better than biological or chemical ones. But to use these methods widely for treating a variety of PPCPs and ECs, more investigation and refinement are required. Furthermore, after treatment, disposing of the residual stream of pollutants is extremely difficult since two different effluents the concentrated and the diluted need to be disposed of separately [49]. The remaining pollutants must be broken down while utilizing additional environmentally friendly methods. Studies show that integrated techniques result in better detention and degrading efficiency. For example, the combination of physical methods with chemical oxidation has improved removal effectiveness and reduced disposal problems [50].

5.1.3 Conventional treatment

Conventional therapy is a blend of chemical, physical, and biological processes. The effectiveness of this treatment is determined by two main elimination techniques: mineralization and biological metabolism[43]. Conventional techniques encompass a variety of techniques such as activated sludge, nitrification, moving bed biofilm reactors, biological AC, fungi, bacteria, and microalgae treatment [51]. ECs could be effectively removed from water using a biological treatment using microalgae and fungi. Pesticides could not disintegrate under the same conditions as endocrine disruptors and PPCPs, although they were degraded 95–100% of the time. For this reason, more investigation is required to determine how to combine traditional biological treatment with alternative biologically active processes (BAP) to improve pesticide removal. When bacteria, pollutants, granular activated carbon (GAC), and dissolved oxygen come into contact with BAP, they simultaneously carry out adsorption and biodegradation [52]. In all sewage treatment facilities (three to four out of five), sludge removal is made easier by facultative, aerobic, and anaerobic microbiological processes. In these facilities, suspended particles accept energy from the ECs. The degradation of ECs and pharmaceuticals was tolerable (though low), but PPCPs and a few beta-blockers could not be broken down by biodigesters, lagoons, stabilization ponds, or bioreactors. Based on a facultative anaerobic-aerobic method, all pollutants were removed. The drawback of these procedures is that they require a lengthy period for sludge retention [53]. Biodegradation in an aeration tank, carried out as the activated sludge process (ASP) is the global principal removal method for ECs [40]. The ASP treatment has demonstrated exceptional efficacies for PPCPs (>78%), endocrine disruptors (>75%), and surfactants (>95%), but a poor removal efficacy (>65%) for medications [54]. This method was less successful in eliminating some organic compounds (E3, PPCPs, medicines, bisphenol A, and octylphenol) than it was in eliminating certain chemicals (beta-blockers, pesticides, and drugs). Consequently, to expedite the removal of contaminants, this technology must be combined with other technologies to create hybrids. Combining this method with MBR can result in excellent removal efficiency [55].

Table 1. Sources and effects of emerging contaminants.

Classification of ECs	Sources	Effects	Examples
Personal care product	WWTPs effluent, land surface water	Cancer and thyroid gland	Surfactants, moisturizers, cosmetics
Pharmaceutical Complexes	Hospitals, livestock farms, and domestic wastewater	Ulcer, affect fertility, carcinogenic	Antibiotics, steroids hormones, vaccine
Herbicides, Pesticides	Agricultural runoff, surface water, and aquafarming	Damage to male productivity, hormonal changes, thyroid problems, miscarriage	Glyphosate, Aldrin, boric acid
Microplastic	Plastic materials and runoff, synthetic textiles, cosmetic products	Environmental pollution, habitat alteration	Microbeads, microfiber
Industrial chemical	Domestic and industrial wastewater	Developmental issues, immune system suppression	Per and poly-fluoroalkyl substances
Emerging organic contaminants	Consumer product	Reproductive abnormalities and impacting overall ecosystem health	Flame retardants, UV filters
Heavy metals	Industries, urban runoff	Toxicity and bioaccumulation in aquatic food web, organ damage	Lead, mercury, cadmium
Nanomaterials	Cosmetics, textiles and electronics	Toxicity to aquatic organisms and impacting ecosystem dynamics	Silver nanoparticles in food packing, titanium dioxide in cosmetics, carbon n Nanotubes in electronics

Table 2. Role and outcomes of treatment technologies.

	Treatment technologies	Main tasks	Outcomes	Application
Physical treatments	Adsorption	Remove soluble substances by solid substrate having a specific surface area	Assures very accurate and efficient removal of emerging contaminants	Wastewater treatment
	Membrane-based technology	Process of filtration using a porous membrane that isolates contaminants on size and types	Specific to contaminant isolation as per the size and type that assist in removing emerging contaminants of interest	Wastewater treatment
Biological treatments	Conventional method	remove pollutants including organic matter, and pathogens through screening and sedimentation	removal of suspended solids and organic matter resulting in cleaner water suitable for discharge into the environment	Wastewater treatment
	Nonconventional method	utilize innovative and alternative methods beyond traditional processes, such as advanced oxidation processes,	effective removal of pollutants and contaminants through innovative methods, leading to improved water quality	Wastewater treatment
Chemical treatments	Ozonation	Reduces turbidity caused by suspended particle sedimentation	Effective at getting rid of micropollutants	Wastewater treatment
	Advanced oxidation process	ECs are removed with high efficiency in a short period of time	degradation of organic pollutants and removal of color, odor, and micropollutants	Wastewater treatment

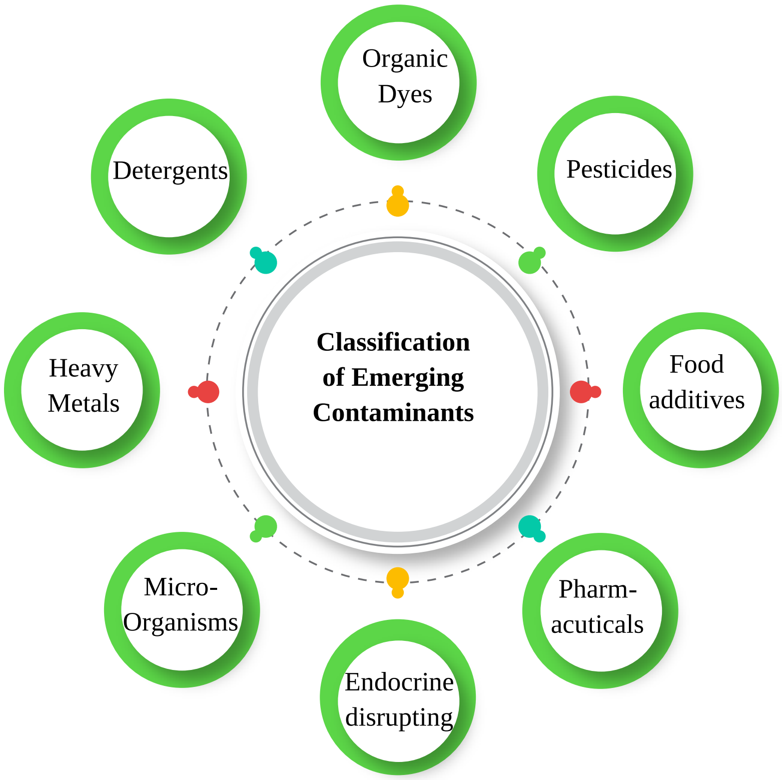

Figure 1. Classification of emerging technologies.

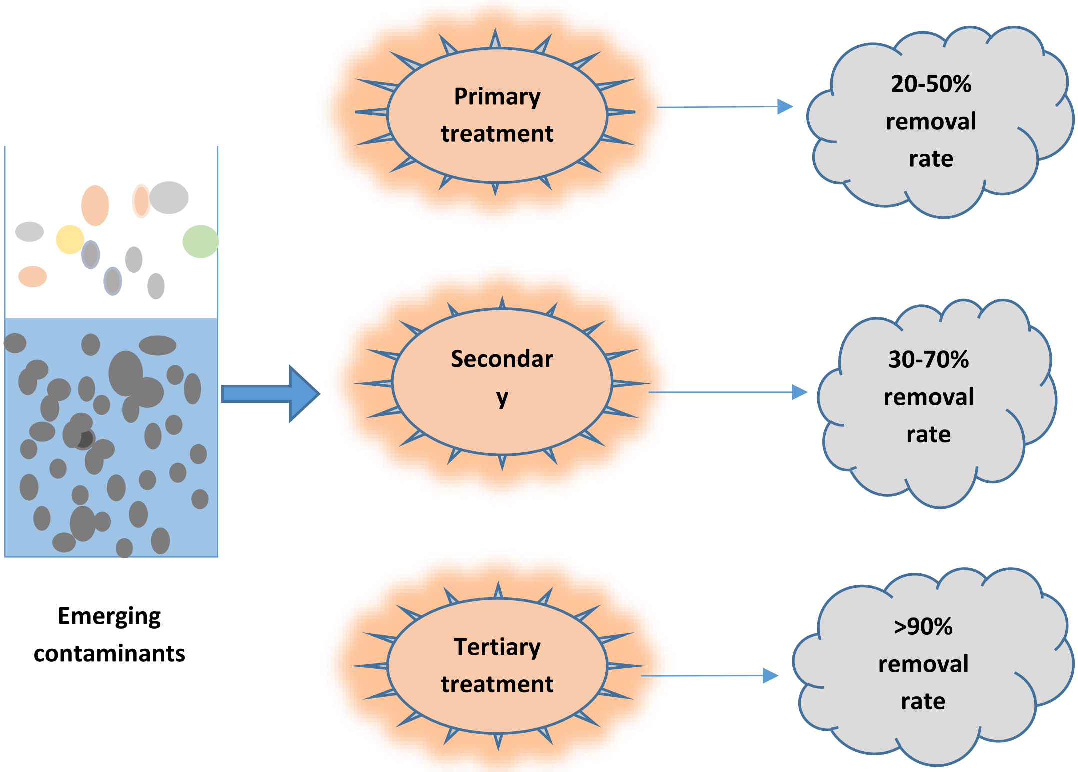

Figure 2. Efficiency of different treatments.

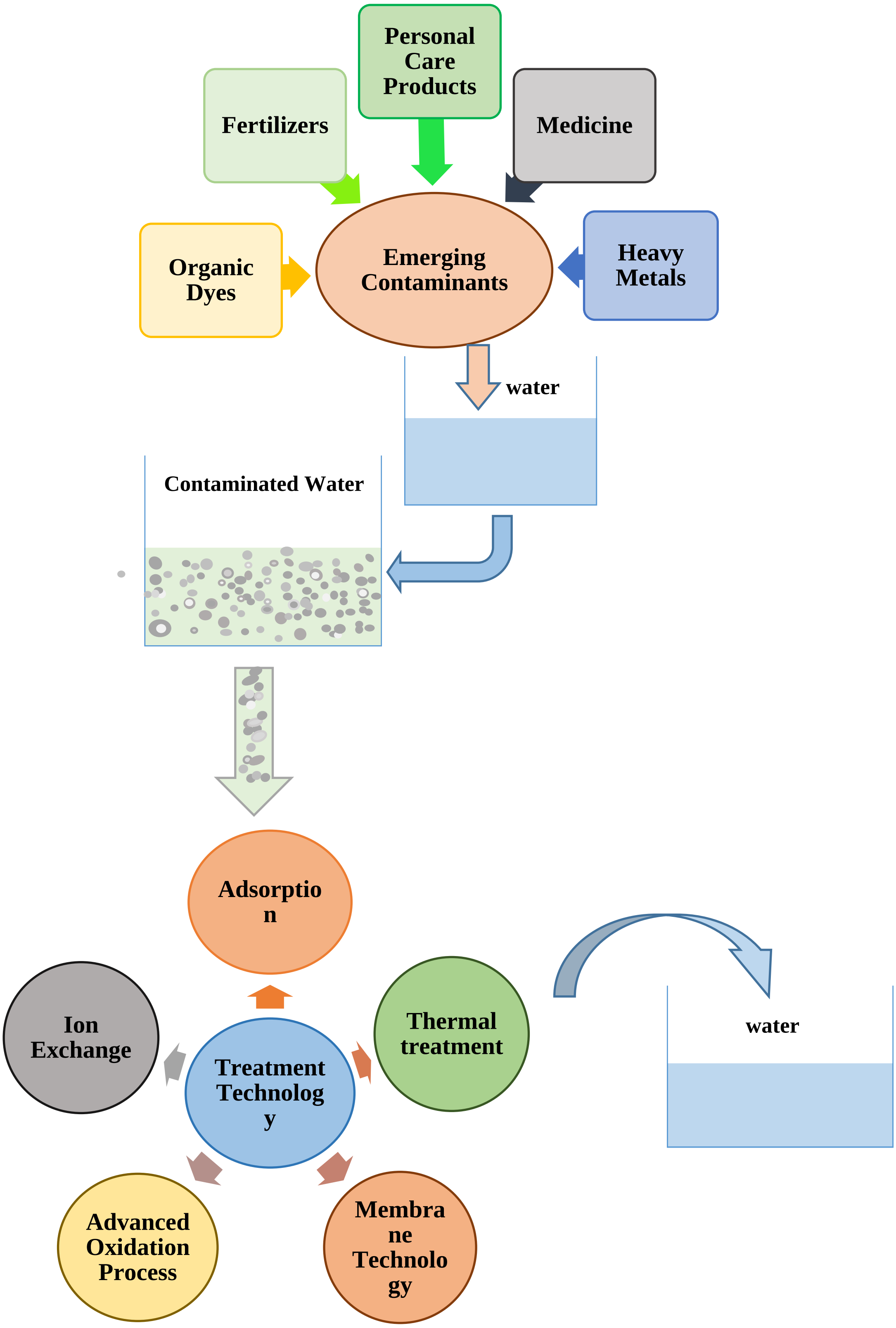

Figure 2. Overview of wastewater technologies.

5.1.4 Non-conventional treatment

Non-conventional treatment is regarded as a cutting-edge, integrated method that combines biodegradation with sorption and oxidation in a single system. Among them include biosorption, (membrane bioreactor) MBR, and artificial wetlands [55]. In this instance, the microorganisms are rendered immobile through the use of biomass oxidation, biomass, or adsorbents a biological treatment technique that has gained popularity recently [56]. This approach thereby improves the interaction between microbial biomass and the pollutants. Bio sorption can be done with bacteria or other biological materials, but for maximum effectiveness, the microbes need to be living [57]. Using biosorption, a wide range of ECs can be eliminated, including 17-estradiol-17-acetate, naprox, ibuprofen, gemfibrozil, triclosan, 4-tert-octylphenol, bisphenol A and pentachlorophenol. MBR can provide high-quality effluents free of emerging contaminants [51].

By preventing high molecular weight molecules from migrating and subjecting them to microbiological biodegradation, MBRs physically retain organic chemicals at the membrane surface. Due to its dual mechanism of sorption followed by biodegradation, MBR may be more successful in removing contaminants than ASP (activated sludge process). Wastewater can be treated with MBR to get rid of PPCPs, beta-blockers, medications, pesticides, and endocrine disruptors. MBR is an effective way to get rid of atendol (97%), propylparaben (92%), salicylic acid (99%), triclosan (99%), beta-blockers (70–80%), and other medications (75–95%). However, some pesticides are not adequately eliminated by MBR and ASP. Nonetheless, MBR has numerous drawbacks and restrictions, such as more expenses (in comparison to ASP), issues with operation, membrane blockage and fouling, and inadequate EC removal. One way to reduce these drawbacks and improve EC removal efficacy is to combine MBR with ozonation, membrane filters such as ultra, RO, and nanofiltration, AOP, or other physicochemical treatment methods [40].

5.1.5 Photolysis

In the photolysis process, energy is transported from electromagnetic radiation to the breaking of water molecules, leading to the creation of hydroxyl free radicals. Photolysis can occur from a variety of radiation sources, including UV and solar radiation [58]. However, each radiation has a distinct purpose when it comes to wastewater treatment. It was discovered that UV photolysis was a useful technique for getting rid of color from wastewater. Since photolysis doesn't need the use of catalysts or other oxidizing agents, it is known to be a very advantageous technique that lowers the cost of using chemicals. However, there are also some significant drawbacks to this traditional oxidation process. For instance, organic compounds that exhibit photosensitizer-like behavior may cause the media to become more turbid, which will hinder the water's ability to absorb UV light. Eventually, this results in photolysis being a less effective mechanism [59].

5.1.6 Ozonation

The complex oxidation process known as "ozonation," which is brought about by adding ozone, is what greatly increases the biodegradability of wastewater. Numerous investigations show that ozonation is an extremely operative method for eliminating most pharmaceutical and personal care compounds. Unquestionably, though, ozone has a short half-life. Over the past ten years, its utilization in wastewater treatment has proven crucial if its concentration rises above a specific point, which is almost 23%. Ozone can react with ECs indirectly or directly by the formation of secondary oxidants called hydroxyl radicals ($HO^{\bullet}$), which are produced when ozone reacts with a particular class of effluent organic matter (EfOM) such as phenols or amines. While $HO^{\bullet}$ acts quickly and is non-selective, it can attack a variety of ECs, including those that are resistant to ozone, at relatively high pH levels. Ozone has a selective nature, preferring to attack electron-rich ECs like sulfamethoxazoles, and ECs with amine groups that are deprotonated such as trimethoprim, primarily at low pH [60].

Oxidation by-product production is a significant problem associated with ozonization methods. The ozonation mechanisms that impede the breakdown of ECs are reliant on pH, temperature, and ozone concentrations [61]. Insufficient ozone application doses will cause transformation products or oxidation by-products to form rather than full mineralization. Sometimes the production of harmful oxidation by-products is blamed for a brief increase in toxicity following ozonation. After ozonation, the following biological treatment step can further lower the toxicity [62]. Furthermore, for further innovation in ECs removal efficiency, consideration must be given to the method's drawbacks, which include high energy consumption, high method costs because of the short ozone layer's lifetime, and interference by $HO^{\bullet}$ scavengers in wastewater.

5.1.7 Advanced oxidation processes (AOPs)

AOPs have demonstrated effective removal rates of 80–90%, which are further increased when combined with additional methods such as coagulation, nanofiltration, Fenton's reaction, electrocatalytic oxidation, UV light, oncolysis, and ozonation [63]. Radiation from the sun can produce hydroxyl radicals. Research has shown that AOPs enable drinking water management systems and new WWTPs are remarkably successful and productive. Although they are strong oxidizers that can oxidize the target organic contaminants, hydroxyl radicals are not catalysts. But for any treatment strategy to be effective, the wastewater to be treated must be well characterized [47]. By using UV or chlorine-mediated advanced oxidation, organic contaminants such as desethylatrazine, carbamazepine, iopamidol, benzotriazoles, diclofenac, and tolyl triazole can be efficiently eliminated. AOP can use ozone to remove major pharmaceuticals and other ECs from wastewater. AOPs can be used to remove a variety of PPCPs and medications, including ketorolac, acetaminophen, and diclofenac, by heterogeneous solar photocatalysis with TiO_2 [64].

Different AOP tactics have been looked at about water treatment. AOPs are very effective in removing pollutants by degradation promoting [65]. They often use methods like ozonation, photocatalytic oxidation, oncolysis, or a combination of these [66]. Conventional oxidization methods have drawbacks and are labor-intensive. AOPs have solved these issues [43]. Strong oxidant and disinfectant ferrate (FeO_4^{2-}) can be used to eliminate estrogen, arsenic, and numerous developing contaminants. Fe^{3+} and Fe^{6+} can be used, respectively, to coagulate and ozonate ECs. AOPs can be used to remove atendol, metoprolol, acetaminophen, tetracycline, triclosan, sulfamethoxazole, and propranolol from wastewater effluents, even at complex or high concentrations.

5.1.8 Photocatalysis

Photocatalysis is one AOP that needs the catalysts use; it is the process of transferring energy from a photon to a water molecule. When it came to lowering total carbon content (TOC), UV photocatalysis required three times as much energy as color reduction [67]. So far, the most researched oxidation method that has demonstrated potential in removing impurities and microorganisms from wastewater is photocatalysis, which employs TiO_2 as a catalyst. Lower costs, the catalyst's reusability, its activity at room temperature and pressure, and its capacity to radiate the catalyst using sunlight are the key advantages of this improved oxidation treatment. Moreover, several compounds are completely mineralized by this action. Nevertheless, the photocatalysis approach has several important disadvantages, including the cost of the catalyst's post-use separation treatment and the challenge of evenly producing radiation across the entire catalyst surface on a wider scale [59].

5.2 Phase-changing technologies

Technologies are always changing; agents that have the potential to transport pollutants from one phase (water, for example) into another (solid, for example) have been widely reported to be effective in eliminating newly discovered pollutants. Many contaminants have been thoroughly examined about adsorption techniques for their removal [68]. The use of several phase-changing techniques for the elimination of ECs from water is covered in detail in the sections that follow.

5.2.1 Adsorption using activated carbon (AC)

Activated carbon (AC) is the material that is used most frequently because of its specific surface area and high porosity. These features make AC amazingly effective and adsorptive at removing a wide range of pollutants. When ECs were extracted from a variety of compounds using AC, more than 90% of the ECs were eliminated, indicating that certain ECs in water may only be extracted using this technique [69]. AC selectivity is demonstrated in the case of ciprofloxacin. By using AC, this pollutant can be immediately eliminated, and the overall concentration can be rapidly reduced to below the technique detection limit [70]. On the other hand, 90% clearance rates were achieved for a few other contaminants under study, but only after a significant amount of time had passed. Granular activated carbon was utilized in an advanced wastewater reclamation plant to remove a set of developing contaminants, such as N, N-diethyl-m-toluamide, trimethoprim, ciprofloxacin, erythromycin, diclofenac, carbamazepine, ibuprofen, lincomycin, and primidone [71].

Since different sources provide notably varied removal rates, the origin of the raw material utilized in AC is an important factor to consider. Acetaminophen removal rates, for instance, ranged from 60 to 87% when using AC from other sources, but >90% when using AC from wood [71]. Comparable to the over 90% clearance of diclofenac with olive waste cake and granular AC, Filtrasorb 400 did not sufficiently remove the drug. Tetracycline was extracted from water using AC derived from four distinct sources: sugar beet pulp, peanut hulls, coconut shells, and wood that had been activated with papaya acid. Tetracycline elimination was found to be more than 90%. AC from activated wood was only able to remove 75% of them, and the coconut shell only offered 30% removal [72].

It is believed that the differences between the various types of sources stem from the carbon structure of the raw material, which has compressed fibers in the pores of coconut shells and/or unclogs and enlarges existing holes. Using AC to remove ECs from water has positive results. When utilizing the Norit Rox AC from Sigma to remove ciprofloxacin, the removal efficiencies range from greater than 99% to 30% when using coconut shell AC to remove tetracycline. Particularly, Calgon Filtrasorb 400 was advertised as having the ability to eliminate as little as 5% of diclofenac, while simultaneously demonstrating remarkable efficacy in the removal of Norfloxacin and caffeine [73]. Interestingly, it has been shown that AC from waste sources can successfully remove certain ECs, such as anti-inflammatory drugs, antibiotics, and paracetamol. Sequential application of adsorption-based systems with other treatment methods is possible. To eliminate ECs, for example, it has been proposed to combine three different therapies: AC, ultrafiltration, and coagulation [74].

Combining the three treatments resulted in an eradication of between 84 and 88%, with significant clearance of the individual contaminants, as determined by the chemical oxygen demand (COD). It is less clear how additional factors affect the functionality of adsorption-based systems. Comprehending scaling-up parameters is a significant unmet requirement. While discussing laboratory scale experiments, most research articles do not provide recommendations for scaling up or ensuring the techniques are viable at full scale. This seriously hinders the ability of research findings to be applied.

5.2.2 Adsorption in carbon nanotubes

One carbon allotrope that resembles graphite in structure is called a carbon nanotube (CNT). The curl's degree, the original sheet's formation method, internal geometry, diameter, physicochemical properties, and the synthesis method all affect the adsorption properties of CNTs. The terms for CNTs are most generally used to designate two different types: single-walled nanotubes (SWNT), having an internal diameter of 1 nm, and multiwalled nanotubes (MWNT), which are composed of several concentric tubes or laminated graphene layers. Carbon-based materials vary depending on how they are produced, as demonstrated by the comparison of AC, biochar, and CNT's treatment capacities. The efficiency of CNTs in getting rid of ECs depends on their surface area. The presence of single or multi-walled structures frequently affects the surface area of CNTs, even when the same contamination is present. This may result in different clearance rates. Using the same experimental setup, for example, were able to eliminate 92% of tetracycline using SWNT but just 16% with MWNT [75]. Moreover, MWNT effectively eliminated other ECs such as ciprofloxacin (6.7%), amoxicillin (>90%), and ibuprofen/triclosan (100%). Much as how single-walled CNTs eliminated norfloxacin, multi-walled CNTs only partially removed it. To increase the contact area and number of adsorption-active sites and hence enhance the efficiency of pollutant removal, multi-walled carbon nanotubes (CNTs) can be synthesized from single-walled CNTs by additional chemical processes. All these characteristics might not always convert into improved performance because of the molecular sieving effects that take place in MWNTs [76].

Since there are currently few studies available and more experimental data is needed to corroborate the already indicated tendencies, the eradication of ECs using CNTs is an important topic for further research. There is a lack of extensive research comparing the performance of single- and multi-walled carbon nanotubes (CNTs). Demonstrating that the former outperformed the latter and even yielded different results when the same kind of CNTs were used to eliminate the same pollution [77]. Combining CNTs adsorptive qualities with those of other reactive nanomaterials is an area that requires further investigation. For example, combining carbon nanotubes (CNTs) with other adsorption methods or utilizing zero-valent iron nanoparticles trapped on the CNT surface to speed up the degrading process could lead to a completely new field of study with fascinating applications.

5.2.3 Adsorption by clay minerals

Adsorption by mineral clay in wastewater treatment involves the use of clay minerals, such as bentonite, kaolinite, or montmorillonite, to remove contaminants from wastewater. Clay minerals have a high surface area with negatively charged sites that can attract and bind positively charged ions or molecules through electrostatic interactions. This property makes them particularly effective for the removal of heavy metals and other contaminants from wastewater. The clay minerals are typically prepared in a suitable form for wastewater treatment, such as powdered or granular forms. This increases the surface area available for adsorption and enhances their effectiveness in removing contaminants [78].

Adsorption onto clay minerals can occur through various mechanisms, including ion exchange, surface complexation, and physical adsorption. These mechanisms depend on contaminants nature and the properties of the clay minerals. The efficiency of adsorption by mineral clay in wastewater treatment depends on factors such as the type and concentration of contaminants, pH, temperature, contact time, and dosage of the adsorbent. Optimization of these parameters is crucial to maximize treatment efficiency. After adsorption, the clay adsorbent may become saturated with contaminants and require regeneration or disposal. Regeneration methods may involve the desorption of contaminants using appropriate eluents or thermal treatments. Disposal methods should comply with environmental regulations to prevent secondary pollution.

Overall, adsorption by mineral clay is an environmentally friendly and cost-effective approach for wastewater treatment, particularly for removing heavy metals and organic pollutants. However, its effectiveness may vary depending on the specific characteristics of the wastewater and the clay minerals used. Since they offer the chance to use semiconductors for the degradation of pollutants and to boost the metal oxide's activity by increasing its active surface area, pillared clays have drawn a lot of attention lately [79]. To prevent catalyst impregnation in the matrix following the reaction (such as clay mineral), the system used with advanced oxidation processes, in particular Fenton and Fenton-like reactions. The matrix can then be recovered using conventional (like settling) or non-conventional (like magnetic) methods [80]. The amount of iron, nitrogen, or other minerals present can affect the removal efficiency of the same type of clay [81].

5.3 Hybrid treatments

Both traditional and advanced oxidation methods have garnered a lot of attention lately for the treatment of wastewater; nevertheless, they come with several disadvantages, including high energy requirements and maintenance and operating expenses. In contrast, hybrid wastewater treatment integrates two or more treatment processes to remove ECs from wastewater. In terms of energy savings and effectiveness of treatment, this method is consistent and durable [82]. One of the advantages of hybrid systems is that they can generate bioenergy, which lowers the system's operating costs. To address this general drawback, researchers are exploring and studying hybrid treatment approaches that integrate physical, chemical, and/or biological therapy modalities to enable the effective elimination of various ECs. According to recent research, these technologies can only be used in an industrial context to address a significant portion of the present wastewater treatment problems. These hybrid solutions minimize energy consumption and enhance the effectiveness of water contaminant separation [83]. Hybrid biological absorbents can be used to remove certain hazardous metals, such as zinc, from industrial effluents. According to an experiment, a zinc content of between 84 and 99% could be successfully removed by the hybrid treatment utilizing biosorbent [84].

6. Fate and removal of ECs in WWTPs

Traditional wastewater treatment plants (WWTPs) are the industry standard for eliminating a variety of contaminants from wastewater, such as nutrients, pathogens, suspended and colloidal particles, and dissolved organics. However, emerging contaminants (ECs) are not intended to be efficiently removed by WWTPs. The degree of EC persistence, physicochemical characteristics, treatment technologies employed and the operating environmental conditions all have a major influence on how well ECs are removed. The three treatment processes used by WWTPs are usually primary, secondary, and occasionally tertiary. The removal of colloidal and suspended matter is the primary goal of treatment stages. The secondary step of therapy aims to eliminate organic materials or nutrients using biological degradations. At this stage, the ECs are subjected to numerous processes, including dispersion, sorption, dilution, and biodegradation, deterioration due to photolysis and volatility. The range for considerably greater removal effectiveness of 30–70% is obtained in the procedures of the secondary process, whereas the primary treatment's EC removal efficiency is reported to be between 20 and 50% [85].

In WWTPs, there are also cases of negative elimination of ECs, meaning that some ECs have effluent concentrations after treatment that are higher than the concentrations of their influents. Given that most ECs are excreted as a combination of parent compounds and conjugates through urine and feces, this makes sense. Conjugates can be reversibly broken down by enzymes to return to their parent molecules after biological treatment, which increases the concentration of the pertinent ECs. Comparably, it has been found that the tertiary treatment stages intended to remove pathogens, suspended particles, and nutrients also significantly increase the effectiveness of EC removal, especially for the recalcitrant ones that are removed using standard oxidation processes that resemble Ozonation [86].

6.1 Impact of primary treatment technology on the elimination of ECs

Due to the reported lower than 10% efficiency for ECs by other physical processes such as flocculation and sedimentation, sorption is the primary physicochemical process used for treating ECs within the primary treatment category [87]. The processes by which ECs are adsorbed on the surface of sludge particles and absorbed onto the lipid portion of the primary sludge via hydrophobic interactions are both referred to as "sorption." Sulfur (sludge) and wastewater (liquid phase) are the two phases that ECs shift into during the phase change process known as sorption. For this reason, sorption can only reduce risk temporarily. As it is currently unknown how ECs are removed, more research is necessary to determine if degradation occurs after sorption or the other way around. However, ECs may also desorb after achieving an equilibrium return to the liquid phase. In other words, sorption to biosolids may be a prelude to biodegradation [8]. A cautious sludge disposal plan is required since the persistent ECs in sludge have the potential to leak out further during sludge treatment and/or disposal, creating a major difficulty. Better outcomes can therefore be achieved by integrating sorption-based systems with other treatment technologies.

6.2 Impact of secondary treatment technologies on the elimination of ECs

Biodegradation/biotransformation and sorption are the primary mechanisms for removing organic contaminants (ECs) from wastewater. Photodegradation and volatilization, on the other hand, have negligible effects on the effectiveness of EC removal [88]. Since highly concentrated particulate matter in wastewater blocks sunlight, photo degradation-mediated EC removal is negligible during secondary treatment [89]. This is because light exposure is limited about effluent treatment volume. The technologies most used worldwide for the elimination of ECs are secondary biological treatment systems. The most often used secondary biological process in traditional WWTPs is activated sludge processing (ASP). Additional high-rate secondary biological processes include artificial wetlands, trickling filters, membrane bioreactors, biological aerated filters (BAF), oxidation ditches, fungal bioreactors, microalgal bioreactors, rotating biological contactors, moving bed biological reactors (MBBRs), and so on [90]. Since there is a knowledge gap regarding the presence of ECs in the sludge due to the complicated matrix and lack of sensitive analytical tools to monitor ECs in sludge samples, managing secondary sludge produced during ASP is also a crucial issue to address [8].

6.3 Impact of tertiary treatment technologies on the elimination of ECs

To create high-quality discharge water that may be reused, WWTPs typically use tertiary or advanced treatment technologies like polishing procedures. Because of their resistant character or potential toxicity to microorganisms, persistent ECs that evade subsequent treatment steps are eliminated using advanced treatment procedures, which thus complement secondary treatment technologies [91]. Oxidation can mineralize ECs and their byproducts to H_2O, CO_2, simple inorganic ions and activated carbon-based sorption of a range of ECs from secondary wastewater are the main mechanisms for EC removal during tertiary treatment [92]. Oxidation procedures such as UV treatment, ozonation, photocatalysis, chlorination, etc are utilized to oxidize ECs [93]. Similarly, a variety of commercially accessible adsorbents are employed for the adsorption of extracellular clay minerals, carbon nanotubes, charcoal, AC, and so on [8]. Ozonation and AC treatment are the only two techniques that are considered economically viable and will be used for the WWTP upgrade in Switzerland [94]. Efficiency of different treatments is shown in figure 2.

7. Removal of contaminants from wastewater by nanotechnology

The topic of wastewater treatment has seen a lot of research and development into nanomaterials [95]. Nanomaterials can provide good adsorption, enhanced resolution mobility, and reactivity capacity because of their greater and smaller unique surface area. Emerging contaminants have been successfully extracted from wastewater by nanomaterials [96]. Wastewater treatment uses a variety of nanomaterial types, including carbon nanomaterials, metal oxide nanoparticles, zero-valent metal nanoparticles, and nanocomposites [97].

7.1 Zero-valent metal nanomaterials

Zero-valent metal has strong reactivity, making it a significant product for water treatment. It also has many other favorable qualities. To successfully remove the ECs from contaminated areas, it facilitates subsurface displacement and infusion in aqueous slurries [98]. In recent years, research on mitigating water contamination has shown a great deal of interest in various zero-valent metal nanoparticles, including nickel, silver, iron, zinc, and aluminum. Strong antibacterial properties of silver nanoparticles are demonstrated against a variety of bacteria, viruses, and fungi [99]. Due to its potent antibacterial properties, silver is frequently utilized in disinfection applications. Silver nanoparticles combined with filter materials were thought to be promising for water disinfection due to their strong antibacterial properties and affordability [100]. Its multiple wastewater treatment paths and high reactivity have been demonstrated, along with its affordability and environmental friendliness. It was demonstrated that the iron (oxy) hydroxide layer surrounding the FeO core served as a heavy adsorbent. Iron nanomaterials are effective at removing pollutants like cadmium from wastewater[101].

Other pollutants such as nitrate, dyes, environment-persistent hazardous substances, and antibiotics can also be removed by iron nanoparticles through adsorption, oxidation, reduction, and co-precipitation. Zero-valent metal nanoparticles for wastewater treatment using a two-step method. The zero-valent nanomaterial has a capping oxide layer and 78% Fe(0) [102]. It was created via the borohydride method, and its capacity to extract gold ions from wastewater was evaluated in a lab setting. A zero-valent nanomaterial was used to lower the concentration of gold ions to 0.1 $\mu g\ L^{-1}$ (ppb).

7.2 Metal oxides nanomaterials

Growing interest has been generated by the superior quality and affordable cost of metal oxides in the removal of contaminants. The oxides of ferric, manganese, aluminum, and titanium are among the metal oxide nanomaterials. Numerous investigations have demonstrated the great ability and selectivity of metal oxide's positive sorption in eliminating contaminants such as organics, phosphate, uranium, and arsenic. Titanium oxide is a metal oxide nanomaterial that exhibits good photostability, low cost, and exceptional photocatalytic activity, making it a viable photocatalyst [103]. UV stimulation is used to generate charge separation in the materials due to its large-scale (3.2 eV) energy gap. Titanium oxide nanoparticles are sufficient for the degradation of several pollutants, such as pesticides, organic chlorine, polycyclic aromatic hydrocarbons, dyes, phenols, and heavy metals, due to their low selectivity [104].

Zinc oxide (ZnO) nanomaterials are another kind of metal oxide. They are effective in cleaning wastewater due to their high-performing qualities, which include their superior photocatalytic properties, wide wavelength range, and potent oxidizing capacity [101]. Because they do not harm living things, zinc oxide nanomaterials are perfect for treating wastewater and are therefore environmentally beneficial. Of all the semiconducting metal oxides, zinc oxide nanoparticles are the most adept at absorbing light energy. Nevertheless, it has been suggested that iron oxide nanoparticles might be a good option for wastewater treatment. Heavy metals are being removed from wastewater increasingly often with iron oxides because of their availability and adaptability. Magneto-iron oxide sorbents offered a practical and workable substitute for other nanomaterials by producing an external magnetic field. Heavy metals such as arsenic, chromium, selenium, copper, lead, and nickel are adsorbed by magnetites and maghemites in both artificial and natural water systems [101]. The potential of tin oxide (SnO_2) embedded ZnO nanocomposites to remove Cd^{2+} at different concentrations of SnO_2 in ZnO. To remove more contaminants from drinking water, a precipitation process to create a flower-like structure of ZnO with a dose of 4 g/L in a solution with a pH of less than 5 for 90 minutes at 50°C [105]. They stated that hydroxyl ions are widely available on the surface of produced nanomaterials and that oxyanions are created by the arsenic oxide at high pH in the aqueous medium led to the greatest removal of as ions in acidic medium.

7.3 Carbon-based nanomaterials

Due to their distinct structural and electrical qualities, carbon nanoparticles are useful in sorption processes [106]. They are also suitable for a variety of complicated applications. The advantages of these materials are attributed to their extensive surface area, fast kinetics, high adsorption capacity, and selectivity towards aromatic compounds. Numerous materials are made of carbon, such as carbon fibers, carbon beads, carbon nanotubes, and nonporous carbon [107]. A graphene cylinder as thin as 1 nm in diameter is rolled up to form carbon nanotubes. Carbon nanotubes are a novel adsorbent that has generated a lot of interest due to its unique qualities [108]. They can adsorb a wide range of pollutants, such as dichlorobenzene, ethylbenzene, Cu^{2+}, Cd^{2+}, Zn^{2+}, and Pb^{2+} as well as colors, with remarkable effectiveness thanks to their particular surface area, porous materials variety, high adsorption capability [109].

Graphene is a single carbon atom layer with an organized structure resembling a honeycomb of carbon atoms, representing another class of nanomaterials [37]. Carbonyl, carboxyl, epoxy, and hydroxyl groups are present in graphene oxide, a graphene layer. Heavy metals like arsenic, cadmium, lead, zinc, copper, and mercury are reported to be removed by graphene oxide [106-110]. Single-layer graphene hybrids with manganese ferrite magnetic nanoparticles are an effective way to remove Pb(II), As(III), and As(V) from contaminated water [111]. Carbon nanotubes (CNTs) and f-CNTs were examined and their adsorption potentials were compared under a range of operating conditions (temperature, touch times, pH, etc.) [112]. f-CNTs have a higher adsorption potential than pristine CNTs due to the inclusion of specific functional units. For instance, the highest adsorption level of methylene blue (MB) achieved with functionalized multi-walled carbon nanotubes (f-MWCNTs) was higher than that of raw MWCNTs, at 166.7 mg/g and 100 mg/g, respectively. The intimate relationship between phenol and functionalized carbon nanotube systems can be explained by the simultaneous presence of π–π stacking and H-bonding, which gives functionalized carbon nanotubes a greater capacity for phenol adsorption than virgin carbon nanotubes.

8. Benefits and drawbacks of wastewater treatment strategies

Unwanted chemical releases into water sources are the main issues people in the 21st century deal with since they interfere with the ecosystem's ability to function. An increasing amount of freshwater is needed due to the increasing global population. There has been a surge in the amount of wastewater produced by industries and people, which has been discharged into the environment due to increasing urbanization and population growth [113]. Wastewater sources that are not appropriately managed will hurt a nation's ability to grow, draw in investment, and provide for the basic requirements of its citizens as well as the environment. There are serious health and environmental risks for nearby communities when wastewater from businesses and residential areas is improperly managed before being disposed of community awareness and a waste management system with high performance and low cost are therefore necessary. The noticeable consequences on biophysical surroundings and living beings make wastewater treatment a difficult undertaking now. In addition to laws governing waste disposal, regional and socioeconomic factors also play a role in wastewater-related issues. It is challenging to pinpoint a single technique that can remove every contaminant from wastewater. Wastewater treatment rarely discusses cost estimation or the viability of developing systems on a wide scale. In the past three decades, several physical, biological, and chemical wastewater treatment systems have been documented [114].

However, the most effective method has not yet been determined because each treatment has unique advantages and disadvantages in terms of operational difficulty, environmental impact, sludge production, effectiveness, feasibility, practicability, and cost-efficiency. Biological, chemical and physical techniques can eliminate many emerging pollutants, but none of them can adequately treat industrial effluents because of their complexity [115]. There is a lot of information on adsorbent cost estimation for treating pharmaceuticals in wastewater. Adsorption is often less costly than any other method [68]. Expensive chemicals and energy are required for modern, effective procedures like AOPs, which ultimately results in high treatment costs [116-117]. In real-world applications, two or more methods are combined to provide the best possible water quality at the lowest feasible cost.

9. Conclusions and future prospective

It is difficult to remove ECs with a single treatment technique. Promising solutions for effective EC removal from the environment seem to be the use of integrated systems where the limits of the individual treatment technologies can be addressed. The bulk of alternative treatment technologies that have been researched or suggested, however, are in the lab and do not have the implementation feasibility data for full-scale WWTPs. While the majority of the often-studied ECs were significantly decreased in the effluent of WWTPs, some remained; some were discovered to be more harmful than the parent compounds, and only a small number showed negative removal efficiency. Adsorption is a straightforward technique that is favored due to its affordability and ease of use, while the majority of these methods are costly. However, the appropriate choice of adsorbents is the only factor that determines efficiency. Further technological developments have resulted in the creation of effective hybrid treatment techniques (combining photocatalysis and physical adsorption with biodegradation).

New developments in the study of these hybrid systems have produced important discoveries such as nano adsorbents and modified adsorbents that can be used in conjunction with other forms of therapy. To address the problem caused by the development of harmful oxidation by-products during ozonation and their existence in both dissolved and particulate phases, a biological post-treatment is required. Several persistent ECs are reported to be very effectively removed by MBRs through highly concentrated active biomass retention. Although total EC removal has not yet been accomplished, tertiary treatment technologies are thought to be the most appropriate alternatives for EC treatment based on the reported greatest EC removal efficiency. Maintaining a high level of priority is the optimization of WWTPs with tertiary and combination treatment to create an absolute barrier to EC emission. Thus, it is certain that additional developments in treatment technologies will be required to completely eradicate ECs from WWTPs.

- Because ECs are difficult to detect and treat, legislation that restricts the compounds' release into the environment and raises public awareness must prioritize concentration reduction at the source.
- Because their persistence and toxicity are unknown, transform products of ECs are typically not monitored. The extraction of ECs or their transformation products from complicated environmental matrices, such as sludge, and their identification and quantification should be the main goals of developing novel procedures.
- MBRs frequently experience membrane fouling, which limits the range of applications possible for them. But by interacting with the fouling layer, ECs can be trapped and then eliminated. Therefore, an analysis of the positive and negative contributions of fouling mechanisms is required.
- Hydroxyl radicals can either mineralize the ECs or produce transform byproducts during the advanced oxidation process. Consequently, to stop additional potential environmental risks, knowledge of produced intermediates and their characterization is crucial.
- AC adsorption removes ECs from one phase and concentrates in another, therefore even with its high EC removal effectiveness, it only offers a partial solution. Consequently, more study is required to remediate EC-saturated AC for reuse or appropriate disposal in the future.
- With their improved catalytic and adsorptive qualities, metal and non-metallic pillared clays are finding wide-ranging environmental uses. It will be crucial for future studies to examine how these materials might be used to eliminate ECs.

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