Reflection/Review

Microalgal Technologies: Treatment Strategy for Contaminants of Emerging Concern

Kranjc Požar Ajda[1, *], Atanasova Nataša[1], Griessler Bulc Tjaša[2], Istenič Darja[1,2]

1. University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia
2. University of Ljubljana, Faculty of Health Sciences, Ljubljana, Slovenia

* Correspondence: akranjcp@fgg.uni-lj.si

Abstract:
The increasing presence of contaminants of emerging concern (CEC) in aquatic environments poses significant risks to ecosystems and human health. Traditional wastewater treatment plants (WWTPs) are not equipped to efficiently remove these pollutants, necessitating the development of advanced treatment methods. This article explores the potential of microalgal technologies as a sustainable and cost-effective strategy for CEC removal. Microalgae, such as *Chlorella* sp., *Chlamydomonas* sp., and *Scenedesmus* sp., demonstrate resilience to high concentrations of CEC and offer multiple mechanisms for pollutant removal, including biosorption, bioaccumulation, biodegradation, photodegradation, and volatilization. The article discusses various cultivation methods, including planktonic, immobilized, and mixed biofilm cultures, and highlights the advantages and challenges associated with each. Further research is needed to optimize microalgal cultivation conditions and integration into wastewater treatment processes in order to achieve high CEC removal efficiency. By addressing these challenges, microalgal technologies can enhance the efficiency and sustainability of wastewater treatment systems, contributing to improved water quality and environmental protection.

Keywords: Microalgae; wastewater treatment plants; quaternary treatment; *Chlorella* sp.; cultivation methods

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1. Introduction

Traditionally, water quality management has concentrated on addressing key pollutants such as nutrients, organic matter, suspended solids, heavy metals, and human pathogens (Pal et al., 2014); however, in recent years, growing attention has been directed toward contaminants of emerging concern (CEC). These contaminants pose significant risks to aquatic ecosystems and human health, sparking widespread concern and prompting further research (Tran et al., 2018).

CEC encompass both naturally occurring and artificially synthesized chemicals that are associated with known or uncertain adverse effects on human health and the environment (Ahmed et al., 2021). These substances are characterized by their relative polarity, resistance to natural biodegradation, and potential for bioaccumulation (Kumar et al., 2022). CEC include a wide array of compounds, such as pharmaceuticals and personal care products, endocrine-disrupting compounds, perfluorinated compounds, surfactants, gasoline additives, disinfection by-products, algal and cyanobacterial toxins, organometallic compounds, brominated and organophosphate flame retardants, plasticizers, and nanoparticles.

Most CEC enter waterways through human-mediated routes, including the direct discharge of raw or treated municipal wastewater, landfill leachate, urban and rural runoff, groundwater infiltration, and industrial waste discharge (Tran et al., 2018). Among these, municipal wastewater treatment plants (WWTPs) are the most significant contributors to the continuous discharge of CEC into aquatic environments. The number of specific CEC detected in wastewater discharge ranges from 25 to 200 compounds, a figure likely to increase with advancements in analytical techniques and the industrial use of newly synthesized compounds (Norvill et al., 2016; Tran et al., 2018; Villar-Navarro et al., 2018; Wang et al., 2016).

Conventional WWTPs were originally designed to remove nutrients and organic matter and are not equipped to efficiently eliminate CEC (Lopez et al., 2022). These traditional methods, including processes like waste stabilization ponds, up-flow anaerobic sludge blankets, activated sludge anoxic-aerobic process and sequencing batch reactors, achieve CEC removal rates of only 40–68% (Dubey et al., 2023).

To address these limitations, several advanced technologies have been introduced to enhance the removal of CEC in WWTP effluents, such as chemical precipitation, advanced oxidation process, reverse osmosis, ion exchange, adsorption-based technologies and electroflocculation. However, these methods often incur high costs due to the need for specialized materials like photocatalysts and synthesized adsorbents, as well as fluctuating factors such as material availability, labor, electricity, and recycling costs (Patel et al., 2019).

Given these challenges, the development of cost-effective and sustainable treatment methods for CEC removal is imperative. Integrating microalgae into wastewater treatment systems presents a promising, eco-friendly approach (Kumar et al., 2022), with high potential of resources recovery and reuse (e.g. algal biomass) The goal of this paper is to provide a critical review of algal-based technologies for removal of CEC in order to assess their potential and indicate the direction of further research to address their challenges.

2. Advantages of microalgal - based bioremediation

The algal-based technologies have emerged as a promising approach for wastewater treatment, offering numerous advantages. Research has shown that various microalgae species, such as *Chlorella* sp., *Chlamydomonas* sp., *Scenedesmus* sp., and *Picocystis* sp., exhibit resistance to a wide range of CEC even at high concentrations. This resilience makes them valuable candidates for removing pollutants from wastewater with elevated contamination levels (Hom-Diaz et al., 2015; Kumar et al., 2022; Prosenc et al., 2021; Quan et al., 2023). Microalgae can efficiently assimilate nutrients present in wastewater, performing bioremediation while significantly reducing the expenses associated with chemical inputs (Kumar et al., 2022). Additionally, this process is environmentally friendly, enhancing CO_2 sequestration and increasing dissolved oxygen (DO) levels in water through the photosynthetic activity of microalgal cells (Qi et al., 2021). Furthermore, microalgae inhibit the growth of harmful bacteria and bloom-forming organisms, thereby reducing microbial loads in aquatic systems (Zhang et al., 2022).

Beyond improving wastewater treatment efficiency, this strategy also supports wastewater valorization by generating valuable biomass. This biomass can be utilized to produce eco-friendly bioproducts, contributing to the circular bioeconomy and promoting sustainable resource management (Kumar et al., 2022).

3. Microalgal mechanisms for mitigating CEC

3.1 Biosorption/bioadsorption

Bioadsorption by microalgal cells occurs when contaminants are adsorbed either onto the cell wall components or onto organic substances, such as extracellular polysaccharides (EPS), excreted by the cells into the surrounding environment (Saavedra et al., 2018). This process is non-selective and reversible, allowing various types of CEC to be simultaneously captured on the microalgal cell surfaces (Prosenc et al., 2021). As a passive, non-metabolic interaction, bioadsorption involves the binding of CEC to the negatively charged cell surfaces, which include both the cell wall and secreted substances (collectively termed cell surfaces). These surfaces exhibit a chemical affinity for positively charged contaminants (Xiong et al., 2017).

The ability of CEC to adsorb onto microalgal surfaces depends on its chemical structure. Hydrophobic, cationic contaminants are drawn to the microalgal surface through electrostatic interactions, while hydrophilic CEC tend to be repelled (Xiong et al., 2017). Once a CEC reaches the cell surface, the extent of adsorption is determined by the surface area and chemical composition of the microalgal cells (Norvill et al., 2016). Microalgal cell surfaces contain a variety of functional groups, including carboxyl, hydroxyl and sulfate groups, each with varying affinities for organic and inorganic compounds (Çetinkaya Dönmez et al., 1999).

Bioadsorption involves several chemical processes at the cell surface, including adsorption reactions, ion exchange, surface complexation reactions, chelation, and microprecipitation (Çetinkaya Dönmez et al., 1999). The rate and thermodynamics of the adsorption process are influenced by the physico-chemical properties of the surrounding environment, such as temperature, redox potential and pH.

As bioadsorption is a non-metabolic process, contaminants can bind to both living and non-living microalgal cells, as most cell receptors for CEC remain functional even after the cell has died (Choi & Lee, 2015).

3.2 Bioaccumulation

Bioaccumulation is an active, energy-driven process by which CEC are stored in their original form within microalgal cells. This occurs through the crossing of the cell membrane, where CEC bind to intracellular proteins and other compounds. Unlike bioadsorption, bioaccumulation is slower and occurs exclusively in living cells (Xiong et al., 2018).

Microalgal cells can uptake CEC through three primary mechanisms: passive diffusion, passive-facilitated diffusion and energy-dependent/active uptake across the cell membrane.

In passive diffusion, CEC move across the membrane from areas of high external concentration to areas of low internal concentration without requiring energy expenditure from the cell. This process is facilitated by the hydrophobic nature of the cell membrane, which allows low molecular weight, non-polar, lipid-soluble contaminants to diffuse through. However, polar molecules, high molecular weight compounds, and ions cannot pass through the membrane passively (Xiong et al., 2018).

Passive-facilitated diffusion refers to the process by which CEC cross the cell membrane with the assistance of transporter proteins. These proteins facilitate the influx of polar molecules into the cell (Wilde & Benemann, 1993).

The final mechanism, active transport, involves the movement of CEC across the cell membrane, a process that requires energy expenditure by the cell. In active transport, the compound often moves against a concentration gradient, though this is not always the case

Regardless of the mechanism, bio-uptake is influenced by various factors in the surrounding environment. These include the physico-chemical conditions, such as temperature and pH, the metabolic state and health of the cell, and the presence of any metabolic inhibitors (Wilde & Benemann, 1993).

3.3 Biodegradation (biotransformation)

Biodegradation of CEC by microalgae is one of the most promising pathways for the remediation of these pollutants. Unlike bioadsorption or bioaccumulation, which function primarily as biological filters to concentrate and remove CEC from the surrounding aqueous solution, biodegradation involves the metabolic transformation of complex compounds into simpler, less harmful molecules. This process offers an advantage over bioadsorption and bioaccumulation by addressing the issue of managing CEC-laden microalgal biomass generated during these treatments (Tiwari et al., 2017).

Microalgal biodegradation can occur through two primary mechanisms: metabolic degradation and co-metabolism. In metabolic degradation, the CEC serves as a carbon source or electron donor/acceptor for the microalga, enabling its breakdown, while in co-metabolism, the CEC is degraded by enzymes that catalyze the degradation of other substrates present in the environment (Tiwari et al., 2017).

The process of biodegradation can occur either intracellularly, extracellularly, or through a combination of both. In the intracellular process, the CEC is bio-uptaken by the microalga. Extracellular degradation, on the other hand, occurs when microalgae secrete enzymes into the extracellular polymeric substances (EPS), which act as an external digestive system. The EPS can also serve as a surfactant and emulsifier, increasing the bioavailability of CEC and facilitating their subsequent uptake by the cell. In combination process, initial degradation typically occurs outside the cell, with the breakdown products being further degraded inside the cell (Tiwari et al., 2017; Xiong et al., 2018).

3.4 Photodegradation and volatilization

Even if a CEC cannot be bioremediated by microalgae through bioadsorption, bioaccumulation, or biodegradation, microalgae may still contribute to its successful remediation. Two processes—photodegradation and volatilization—can be enhanced by the presence of microalgae or the microalgal treatment system itself (Abo et al., 2016).

Photodegradation of a CEC can occur through two mechanisms: photolysis and photooxidative degradation. Photolysis happens when a contaminant absorbs light, causing direct chemical alteration and subsequent degradation of the compound. In contrast, photooxidative degradation involves the breakdown of the contaminant through interactions with hydroxyl radicals or other oxidants, which are formed from reactions with dissolved organic molecules or nitrate under light exposure (Abo et al., 2016).

Light exposure is essential for photodegradation, but in microalgal treatment systems, light is often absorbed or scattered by the cells, reducing its availability. This can slow down photodegradation. However, the design and operation of these systems can be adjusted to improve light penetration. Microalgae release dissolved organic molecules (DOM) into the water, which can enhance photodegradation. DOM includes compounds like hydrophilic organic acids and humic substances. These molecules can facilitate photodegradation through various mechanisms, such as producing hydroxyl radicals or participating in redox reactions. This process helps break down CEC. (Norvill et al., 2016). For example, studies have shown that microalgal DOM can aid in the removal of pharmaceuticals like ibuprofen through indirect photodegradation (de Wilt et al., 2016).

Volatilization refers to the loss of volatile organic compounds from the liquid phase into the atmosphere. This process depends on the physico-chemical properties of the CEC, such as the Henry's law constant, and the operating conditions of the treatment system, including factors like aeration or agitation rates, temperature, and atmospheric pressure (Tran et al., 2018). In microalgal-based treatment systems, high aeration rates provided by mixing devices (such as paddlewheels, bubble lift columns, and stirrers), along with increased sunlight and higher temperatures compared to conventional wastewater treatment systems, can enhance the removal of volatile CEC (Matamoros et al., 2015).

4. Efficiency of microalgal CEC removal

Several species of microalgae have been tested for their ability to remove CEC, and the choice of species can significantly impact the efficiency of the bioremediation process (Wang et al., 2016).

Microalgae-based systems with optimized conditions, such as high aeration rates, ample sunlight exposure and suitable operating temperatures (whether during warm or cold seasons), can significantly enhance the removal of volatile CEC, including musk fragrances like tonalide and galaxolide (Matamoros et al., 2015).

Among the most frequently studied species for CEC removal are *Chlorella* sp., *Chlamydomonas* sp., and *Scenedesmus* sp., which have been extensively tested in proof-of-concept studies. These species are particularly valued for their robustness and adaptability under stressful environmental conditions. Despite the high diversity of microalgae species, only a few have been sufficiently studied for their potential in bioremediating CEC (Maryjoseph & Ketheesan, 2020). Appendix 1 presents selected CEC and microalgal cultures utilized in various studies, along with their transfer pathways.

Microalgae can be cultivated either individually or combined in both open and closed systems. These cultivation methods are gaining recognition for their potential in secondary and/or tertiary treatment in wastewater treatment plants (Norvill et al., 2016) and for the removal of CEC (Chi et al., 2019; Kurade et al., 2016). The following sections describe three main cultivation methods: planktonic cultures, immobilized cultures and mixed biofilm cultures.

4.1 Planktonic cultures

Open systems are commonly categorized as stabilization ponds and high-rate algal ponds (HRAPs) (Norvill et al., 2016). The main advantages of open systems include their simplicity in construction and operation, along with low operating costs. However, these systems face several challenges, such as susceptibility to contamination by other microorganisms, loss of CO_2 to the atmosphere, and the requirement for large land areas (De Godos et al., 2012). Additionally, their reliance on environmental factors—such as temperature and light—can limit the efficiency of the cultivation process (Matamoros et al., 2016; Matamoros et al., 2015).

Closed photobioreactors (PBRs) offer an alternative to open ponds and come in various configurations, such as tubular, bubble column, air-lift, and flat panel (Torgal, 2016). Unlike open systems, PBRs reduce microbial contamination and allow for the control of variables like pH, temperature, light, and CO_2 concentration (Huang et al., 2017). However, in both open and closed systems, nutrient composition and biological contamination can impact microalgal biomass production and the removal of contaminants of emerging concern (CEC) (Procházková et al., 2014).

4.2 Immobilized cultures

Cell immobilization refers to the restriction of cell mobility through entrapment or attachment to an organic or inorganic water-insoluble solid support (Bouabidi et al., 2019). Common immobilization methods include adsorption onto surfaces, aggregation, encapsulation in semi-permeable membranes, covalent bonding, and entrapment within porous or fibrous polymers. The inherent ability of microorganisms to attach to surfaces often leads to the formation of biofilms, contributing to the immobilization process (Gonçalves et al., 2017).

Immobilized systems offer several advantages, such as maintaining high microalgal concentrations and activity, improving the efficiency of CEC removal, simplifying harvesting, and enhancing resilience to stress, including exposure to toxic contaminants (Zhang et al., 2016). Immobilized microalgae have been successfully used to remove nitrogen, phosphate, and heavy metals from wastewater (Shen et al., 2009). More recently, they have also been employed to remove CEC from wastewater.

4.3 Mixed cultures

Consortia of microorganisms can exhibit greater robustness and stability in response to sudden environmental conditions, as well as protection against invasion by predators and competitor species, compared to individual species (Subashchandrabose et al., 2011). The presence of bacteria can benefit microalgae growth by removing oxygen and supplying carbon dioxide, altering the surrounding environment and providing essential nutrients and growth factors, such as chelators and phytohormones (Wang et al., 2016).

Several studies have demonstrated enhanced microalgal growth when associated with bacteria, with mutual benefits arising from the excretion of bacterial growth-promoting factors, including microalgal extracellular polymeric substances (EPS) (Cho et al., 2015; Hernandez et al., 2009).

5. Challenges and prospects of microalgal-based removal of CEC

Recent advances in microalgal-based bioremediation of CEC present promising, sustainable alternatives to traditional physicochemical processes in wastewater treatment. However, several significant challenges must be addressed before microalgae can be fully implemented as an eco-friendly and effective bioremediation platform for CEC in wastewater. One of the key obstacles is the relatively low performance of microalgae, as different species exhibit varying levels of adaptability and tolerance to CEC toxicity. Future research should focus on isolating and selecting microalgae strains with high growth rates and improved contaminant removal efficiency, as well as enhancing strain performance through methods such as random mutagenesis, genetic engineering, and adaptive laboratory evolution (Arora & Philippidis, 2021).

Another challenge lies in the potential use of microalgal biomass after CEC treatment for food, feed, or biofertilizer applications. Bioaccumulation of CEC in microalgae may hinder such uses, as contaminants could re-enter the food chain and affect the environment (Hena et al., 2020). Therefore, further studies are needed to ensure the safe and sustainable use of microalgal biomass following CEC treatment. Recent research has shown that laccase enzymes can effectively degrade contaminants like Bisphenol A from growth media (Clark et al., 2022). Toxicity in wastewater can also hinder the growth of certain microalgal species, particularly in large-scale real-world applications. The toxicity of wastewater depends on its source and composition (Pittman et al., 2011). Acclimation or adaptation of microalgae to these conditions is a key area of study. Genetic adaptation has been shown to enable microalgae to tolerate high doses of contaminants such as antibiotics, herbicides, and mine waste (García-Balboa et al., 2013). Additionally, microalgae have demonstrated the ability to acclimate to sub-lethal stresses like heavy metals, singlet oxygen, salinity, and high light conditions, often leading to the production of toxic-degrading enzymes (Osundeko et al., 2014; Singh et al., 2020).

A major bottleneck in the application of microalgae for CEC treatment is the lack of suitable cultivation facilities. Conventional systems like open ponds, raceway systems, and high-rate algal ponds are cost-effective and scalable but face limitations, including inefficient light utilization, contamination from predators and heterotrophs, and the need for large land areas (Cheng et al., 2021). To overcome these limitations, closed photobioreactors such as vertical column, tubular, flat plate, membrane, and biofilm-based systems have been developed. However, these systems are more costly to install and maintain, making them less suitable for large-scale, cost-effective wastewater treatment (Sathinathan et al., 2023).

Therefore, an engineering breakthrough is needed to develop economical, efficient, and practical in situ treatment systems for microalgal-based CEC wastewater treatment. Furthermore, most studies on microalgal-based CEC bioremediation focus on synthetic water or culture media under laboratory conditions, with only a few studies addressing natural wastewater or surface water. To ensure the real-world applicability of this technology, further research is required to explore the practical use of microalgae for CEC removal in industrial-scale wastewater treatment systems (Kumar & Shukla, 2023).

Also, further research is essential to determine the most effective stage of wastewater treatment for integrating microalgal cultures. Specifically, studies should focus on identifying whether microalgal cultures are most efficient in the secondary, tertiary, or quaternary stages of treatment. Additionally, research should explore the optimal forms and configurations of microalgal cultures, such as planktonic, immobilized, or mixed biofilm cultures, to maximize the removal of CEC. Understanding these factors will help optimize the design and operation of wastewater treatment systems, enhancing their efficiency and sustainability.

6. Conclusions

In conclusion, microalgal technologies present a promising and sustainable approach for the treatment of CEC in wastewater. The integration of microalgae into wastewater treatment systems offers numerous advantages, including bio- or photo- degradation of CEC as opposed to just displacement from water, cost-effectiveness, environmental benefits, and the potential for wastewater valorization. Microalgae can effectively remove a wide range of CEC through mechanisms such as biosorption, bioaccumulation, biodegradation, photodegradation, and volatilization.
However, several challenges must be addressed to fully realize the potential of microalgal-based bioremediation. These include optimizing the selection and enhancement of microalgal strains, efficient integration into existing wastewater treatment systems, ensuring the safe use of microalgal biomass post-treatment, and developing economical and efficient cultivation systems. Further research is essential to determine the most effective stage of wastewater treatment for integrating microalgal cultures and to explore the optimal forms and configurations of these cultures.

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Appendix A Table A1. Selected CEC and microalgal cultures with removal efficiency and their transfer pathways.

Appendix 1

Table 1A. Selected CECs and microalgal cultures with removal efficiency and their transfer pathways

Contaminants	Microalgal species	Removal efficiency [%]	Mechanisms (pathways)	Reference
17 α-Boldenone	Mixed consortia	82	Not determined	(Zhou et al., 2014)
17 α-Estradiol	Scenedesmus dimorphus	85	Biodegradation	(Zhang et al., 2014)
17 α-Ethynylestradiol	Chlamydomonas reinhardtii	100	Bioadsorption, bio-uptake, biodegradation	(Hom-Diaz et al., 2015)
	Selenastrum capricornutum	60-95		
	Nannochloris sp.	60		(Bai & Acharya, 2019)
	Desmodesmus subspicatus	68		(Maes et al., 2014)
17 β-Boldenone	Mixed consortia	75-86	Not determined	(Zhou et al., 2014)
17 β-Estradiol	Chlamydomonas reinhardtii	100	Bioaccumulation,	(Hom-Diaz et al., 2015)

	Desmodesmus subspicatus	95	bioadsorption, biodegradation	
	Selenastrum capricornutum	88		
	Nannochloris sp.	60		(Bai & Acharya, 2019)
	Chlorella	>92		(Huang et al., 2016)
7-amino cephalosporanie acid	Chlorella sp.	100	Photodegradation, bioadsorption	(Guo et al., 2016)
	Chlamydomonas sp.	100		
	Mychonastes sp.	100		
Acetaminophen	Mixed consortia	99	Not determined	(Matamoros et al., 2016)
Alprazolam	Mixed consortia	87	Not determined	(Hom-Diaz et al., 2017a, 2017b)
Amitriptyline	Chlorella sorokiniana	68	Bioadsorption	(Gojkovic et al., 2019)
	Chlorella vulgaris	42		
	Chlorella saccharophila	92		
	Coelastrella sp.	60		
	Coelastrum astroideum	68		
	Desmodesmus sp.	37-47		
	Scenedesmus sp.	85		
	Scenedesmus obliquus	69		
Amoxicillin	Chlorella pyrenoidosa	77	Not determined	(Li et al., 2015)
	Microcystis aeruginosa	18-31		(Liu et al., 2015)
Atenolol	Mixed consortia	85-98	Not determined	(Hom-Diaz et al., 2017a, 2017b)
Azithromycin	Mixed consortia	89	Not determined	(Hom-Diaz et al., 2017a, 2017b)

Biperiden	Chlorella sorokiniana	35	Bioadsorption	(Gojkovic et al., 2019)
	Chlorella vulgaris	93		
	Chlorella saccharophila	89		
	Coelastrum astroideum	9		
	Desmodesmus sp.	41-71		
	Scenedesmus sp.	53		
	Scenedesmus obliquus	48		
Bisphenol A	Chlorella pyrenoidosa	43	Bio-uptake, biodegradation	(Fu et al., 2023)
	Desmodesmus sp. WR1	26		(Wang et al., 2017)
	Chlamydomonas mexicana	24		(Ji et al., 2014)
	Chlorella vulgaris	24		
Bupropion	Chlorella sorokiniana	60	Bioadsorption	(Gojkovic et al., 2019)
	Chlorella vulgaris	82		
	Chlorella saccharophila	88		
	Coelastrella sp.	89		
	Coelastrum astroideum	94		
	Desmodesmus sp.	86-90		
	Scenedesmus sp.	70		
	Scenedesmus obliquus	95		
Caffeine	Mixed consortia	99	Biodegradation	(Matamoros et al., 2016)
	Mixed consortia	26-81		(Gojkovic et al., 2019)
Carbamazepine	Mixed consortia	4-15	Bioadsorption, biodegradation	(Zhou et al., 2014)
	Mixed consortia	20		(Matamoros et al., 2016)

	Chlamydomonas mexicana	35		(Xiong et al., 2017b)
	Scenedesmus obliquus	35		
	Chlorella sorokiniana	10-30		(de Wilt et al., 2016)
	Nannochloris sp.	20		(Bai & Acharya, 2016)
	Desmodesmus sp.	71		(Gojkovic et al., 2019)
Carbendazim	Mixed consortia	14-30	Not determined	(Zhou et al., 2014)
Cefradine	Chlorella pyrenoidosa	23	Not determined	(Li et al., 2015)
Cefradine	Chlorella pyrenoidosa	76	Not determined	(Chen et al., 2015)
Ciprofloxacin	Chlorella vulgaris	89,9	Biodegradation, bioadsorption, photodegradati on	(Al-Mashhadani and Al-Mashhadani, 2023)
	Chlamydomonas sp.Tai-03	100		(Xie et al., 2020)
	Mixed consortia	74-79		(Zhou et al., 2014)
	Mixed consortia	20-30		(Hom-Diaz et al., 2017a, 2017b)
	Chlamydomonas mexicana	13-56		(Xiong et al., 2017b)
	Nannochloris sp.	100		(Bai & Acharya, 2016)
	Dictyosphaerium sp.	11		(Gentili & Fick, 2017)
Clarithromycin	Mixed consortia	100	Not determined	(Zhou et al., 2014)
Climbazole	Mixed consortia	30-70	Biodegradation	(Zhou et al., 2014)
	Scenedesmus obliquus	88		(Pan et al., 2018)
Clofibric acid	Mixed consortia	0-30	Not determined	(Zhou et al., 2014)

Clomipramine	Chlorella sorokiniana	96	Bioadsorption	(Gojkovic et al., 2019)
	Chlorella vulgaris	100		
	Chlorella saccharophila	100		
	Coelastrella sp.	34		
	Desmodesmus sp.	29-42		
	Scenedesmus sp.	73		
	Scenedesmus obliquus	78		
Codeine	Chlorella sorokiniana	50	Biodegradation, photodegradati on	(Gojkovic et al., 2019)
	Chlorella vulgaris	57		
	Chlorella saccharophila	42		
	Coelastrella sp.	46		
	Coelastrum astroideum	72		
	Desmodesmus sp.	37-80		
	Scenedesmus sp.	33		
	Scenedesmus obliquus	59		
Diazinon	Chlorella vulgaris	94	Biodegradation	(Kurade et al., 2016)
Diclofenac	Picocystis sp. CINS 23	>90	Bioadsorption, bioaccumulatio n, biodegradation	(Ali et al., 2022)
	Mixed consortia	92		(Matamoros et al., 2016)
	Chlorella sorokiniana	40-60		(de Wilt et al., 2016)
	Chlorella sorokiniana	30		(Escapa et al., 2015)
	Chlorella vulgaris	21		
	Mixed consortia	55		(Villar-Navarro et al., 2018)
Diltiazem	Mixed consortia	72-77	Not determined	(Hom-Diaz et al., 2017a, 2017b)

Di-n-butyl phthalate	Chaetoceros muelleri	22,5	Biodegradation	(Chi et al., 2019)
	Cylindrotheca closterium	91,4		
Diphenhydramine	Chlorella sorokiniana	73	Biodegradation	(Gojkovic et al., 2019)
	Chlorella vulgaris	98		
	Chlorella saccharophila	93		
	Coelastrella sp.	87		
	Coelastrum astroideum	87		
	Desmodesmus sp.	88-92		
	Scenedesmus sp.	86		
	Scenedesmus obliquus	85		
Enrofloxacin	Mixed consortia	75-77	Not determined	(Zhou et al., 2014)
Erythromycin	Mixed consortia	63-86	Not determined	(Zhou et al., 2014)
	Mixed consortia	85		(Hom-Diaz et al., 2017a, 2017b)
Estriol	Scenedesmus dimorphus	85	Biodegradation	(Zhang et al., 2014)
Estrone	Mixed consortia	85	Biodegradation	(Zhou et al., 2014)
	Scenedesmus dimorphus	85		
Flecainide	Chlorella sorokiniana	71	Photodegradation	(Gojkovic et al., 2019)
	Chlorella vulgaris	100		
	Chlorella saccharophila	100		
	Coelastrella sp.	52		
	Coelastrum astroideum	66		
	Desmodesmus sp.	72-96		
	Scenedesmus sp.	40		

	Scenedesmus obliquus	93		
Fluconazol	Desmodesmus sp.	33	Bioadsorption	(Gojkovic et al., 2019)
Fluoxastrobin	Synechococcus sp.	Not determined	Bioadsorption	(Stravs et al., 2017)
Fluxonazole	Mixed consortia	25	Not determined	(Zhou et al., 2014)
Hydrochlorothiazide	Mixed consortia	44-84	Not determined	(Hom-Diaz et al., 2017a, 2017b)
Hydroxyzine	Chlorella sorokiniana	76	Biodegradation	(Gojkovic et al., 2019)
	Chlorella vulgaris	93		
	Chlorella saccharophila	93		
	Coelastrella sp.	80		
	Coelastrum astroideum	96		
	Desmodesmus sp.	87-100		
	Scenedesmus sp.	73		
	Scenedesmus obliquus	95		
Ibuprofen	Mixed consortia	99	Bio-uptake, biodegradation	(Matamoros et al., 2016)
	Mixed consortia	98		(Hom-Diaz et al., 2017a, 2017b)
	Chlorella sorokiniana	100		(de Wilt et al., 2016)
	Nannochloris sp.	40		(Bai and Acharya, 2016)
	Navicula sp.	60		(Ding et al., 2017)
Ketoprofen	Mixed consortia	36-85	Not determined	(Hom-Diaz et al., 2017a, 2017b)
Kresoxim-methyl	Mixed consortia	Not determined	Not determined	(Stravs et al., 2017)

Levofloxacin	Scenedesmus obliquus	93,4	Biodegradation, bioaccumulation, bioadsorption	(Xiong et al., 2017a)
	Chlorella vulgaris	10-90		
Lincomycin	Mixed consortia	80	Not determined	(Zhou et al., 2014)
Lorazepam	Mixed consortia	30-60	Not determined	(de Wilt et al., 2016)
Memantine	Chlorella sorokiniana	87	Bioadsorption, biodegradation	(Gojkovic et al., 2019)
	Chlorella vulgaris	100		
	Chlorella saccharophila	100		
	Coelastrella sp.	78		
	Coelastrum astroideum	73		
	Desmodesmus sp.	44-86		
	Scenedesmus sp.	92		
	Scenedesmus obliquus	86		
Metoprolol	Chlorella sorokiniana	100	Biodegradation	(de Wilt et al., 2016)
	Dictyosphaerium sp.	99		(Gentili & Fick, 2017)
	Chlamydomonas reinhardtii	99		(Stravs et al., 2017)
Metronidazole	Chlorella vulgaris	100	bioadsorption	(Hena et al., 2020)
Mitrazapine	Chlorella sorokiniana	63	Bioadsorption, biodegradation	(Gojkovic et al., 2019)
	Chlorella vulgaris	69		
	Chlorella saccharophila	80		
	Coelastrella sp.	70		
	Coelastrum astroideum	67		
	Desmodesmus sp.	55-85		
	Scenedesmus sp.	77		
	Scenedesmus obliquus	62		

Naproxen	Mixed consortia	89	Biodegradation	(Matamoros et al., 2016)
	Mixed consortia	10-70		(Hom-Diaz et al., 2017a, 2017b)
Nonylphenol	Chlorella pyrenoidosa	48	biodegradation	(Feng et al., 2022)
Norfloxacin	Mixed consortia	41-53	Not determined	(Zhou et al., 2014)
Norgestrel	Chlorella pyrenoidosa	60	Biodegradation	(Peng et al., 2014)
	Scenedesmus obliquus	95		
Ofloxacin	Mixed consortia	43-52	Not determined	(Zhou et al., 2014)
	Mixed consortia	66		(Hom-Diaz et al., 2017a, 2017b)
Orphenadrine	Chlorella sorokiniana	82	Bioadsorption	(Gojkovic et al., 2019)
	Chlorella vulgaris	100		
	Chlorella saccharophila	98		
	Coelastrella sp.	78		
	Coelastrum astroideum	66		
	Desmodesmus sp.	75-82		
	Scenedesmus sp.	79		
	Scenedesmus obliquus	95		
Oxytetracycline	Picocystis sp. CINS 23	100	Bioadsorption, bioaccumulation, biodegradation	(Ali et al., 2022)
Paracetamol	Mixed consortia	88-94	Biodegradation, photodegradation	(Zhou et al., 2014)
	Chlorella sorokiniana	100		(de Wilt et al., 2016)
	Chlorella sorokiniana	41-69		(Escapa et al., 2015)

Paroxetine	Mixed consortia	99	Not determined	(Hom-Diaz et al., 2017a, 2017b)
Phthalic acid esters	Chaetoceros muelleri	95,5	Biodegradation	(Chi et al., 2019)
	Cylindrotheca closterium	97,7		
Progesterone	Mixed consortia	83-87	Biodegradation	(Zhou et al., 2014)
	Chlorella pyrenoidosa	95		(Peng et al., 2014)
	Scenedesmus obliquus	95		
Roxithromycin	Mixed consortia	87-94	Not determined	(Zhou et al., 2014)
Salicylic acid	Mixed consortia	97	Bio-uptake, biodegradation	(Zhou et al., 2014)
	Nannochloris sp.	60		(Bai & Acharya, 2019)
	Mixed consortia	33		(Hom-Diaz et al., 2017a, 2017b)
	Chlorella sorokiniana	73		(Escapa et al., 2015)
	Mixed consortia	90		(Villar-Navarro et al., 2018)
	Chlorella sorokiniana	93-98		(Escapa et al., 2015)
	Chlorella vulgaris	25		(Escapa et al., 2017)
	Scenedesmus obliquus	93		
Salinomycin	Mixed consortia	71-79	Not determined	(Zhou et al., 2014)
Sulfadiazine	Mixed consortia	52-75	Not determined	(Zhou et al., 2014)
Sulfadimethoxine	Mixed consortia	56-78	Not determined	(Zhou et al., 2014)
Sulfamethazine	Mixed consortia	18-48	Not determined	(Zhou et al., 2014)
Sulfamethoxazole	Nannochloris sp.	32	Bioadsorption, biodegradation,	(Bai & Acharya, 2019)

	Nannochloris sp.	40	photodegradation	(Bai & Acharya, 2016)
	Mixed consortia	0-18		(Stravs et al., 2017; Zhou et al., 2014)
Sulfapyridine	Mixed consortia	98	Not determined	(Zhou et al., 2014)
Testosterone	Mixed consortia	100	Not determined	(Zhou et al., 2014)
Tetrabromobisphenol A	Chlorella sphaericum & Scenedesmus quadricauda	98	Biodegradation	(Peng et al., 2014)
Tetracycline	Chlorella sp.	68	Bioadsorption, photodegradation	(Suárez-Martínez et al., 2022)
	Scenedesmus quadricauda	48,84		(Daneshvar et al., 2018)
	Chlorella vulgaris	69		(De Godos et al., 2012)
Thiamethoxam	Chlorella sp. TXH	97,5	Biodegradation, bioadsorption, bioaccumulation	(Quan et al., 2023)
Thiamphenicol	Chlorella sp. L38	77,7	Biodegradation, bioaccumulation, and biosorption	(Song et al., 2020)
	Chlorella sp. UTEX1602	87,3		
Tramadol	Dictyosphaerium sp.	57	Bio-uptake, biodegradation	(Gentili & Fick, 2017)
	Scenedesmus obliquus	91		(Ali et al., 2018)
	Chlorella vulgaris	51		(Gojkovic et al., 2019)
	Desmodesmus sp.	14-45		
Trichlorfon	Chlamydomonas reinhardtii	100	Biodegradation	(Wan et al., 2020)
Triclocarban	Mixed consortia	81-99	Not determined	(Zhou et al., 2014)
Triclosan	Mixed consortia	31-58		(Zhou et al., 2014)

	Mixed consortia	95	Biodegradation, photodegradation	(Matamoros et al., 2016)
	Nannochloris sp.	100		(Xiong et al., 2017b)
	Nannochloris sp.	72		(Bai & Acharya, 2016)
	Chlorella pyrenoidosa	77		(Wang et al., 2013)
	Microcystis aeruginosa	46		(Wang et al., 2016)
	Nannochloris sp.	100		(Rühmland et al., 2015)
Trihexyphenidyl	Chlorella sorokiniana	40	Bioadsorption	(Gojkovic et al., 2019)
	Chlorella vulgaris	100		
	Chlorella saccharophila	95		
	Coelastrum astroideum	54		
	Desmodesmus sp.	63-73		
	Scenedesmus sp.	49		
	Scenedesmus obliquus	60		
Trimethoprim	Mixed consortia	0-37	Not determined	(Zhou et al., 2014)
	Chlorella sorokiniana	40-60		(de Wilt et al., 2016)
	Dictyosphaerium sp.	<4		(Gentili & Fick, 2017)
	Chlorella sorokiniana	60		(Escapa et al., 2015)
Tylosin	Mixed consortia	75	Not determined	(Zhou et al., 2014)

References

1. Abo R, Kummer NA, Merkel BJ. Optimized photodegradation of Bisphenol A in water using ZnO, TiO2 and SnO2 photocatalysts under UV radiation as a decontamination procedure. Drink Water Eng Sci. 2016; 9:27-35. https://doi.org/10.5194/dwes-9-27-2016
2. Ahmed S, Khan FSA, Mubarak NM, et al. Emerging pollutants and their removal using visible-light responsive photocatalysis – A comprehensive review. Journal of Environmental Chemical Engineering. 2021; 9:106643. DOI:10.1016/j.jece.2021.106643
3. Ali MEM, Abd El-Aty AM, Badawy MI, Ali RK. Removal of pharmaceutical pollutants from synthetic wastewater using chemically modified biomass of green alga Scenedesmus obliquus. Ecotoxicol Environ Saf. 2018; 151:144-152. doi:10.1016/j.ecoenv.2018.01.012
4. Ali RB, Ben Ouada S, Leboulanger C, Jebali A, Sayadi S, Ben Ouada H. Emerging contaminants and nutrients recovery by Picocystis sp. under continuous culture in contaminated secondary municipal wastewater effluent. Algal Res. 2022; 102804. DOI: 10.1016/j.algal.2022.102804
5. Al-Mashhadani E, Al-Mashhadani M. Utilization of Chlorella vulgaris after the Extraction Process in Wastewater Treatment as a Biosorption Material for Ciprofloxacin Removal. J Ecol Eng. 2023;24(4):1-15. doi:10.12911/22998993/159336
6. Arora N, Philippidis GP. Microalgae strain improvement strategies: random mutagenesis and adaptive laboratory evolution. Trends in Plant Science. 2021; 26:1199-1200. DOI: 10.1016/j.tplants.2021.06.005
7. Bai X, Acharya K. Removal of trimethoprim, sulfamethoxazole, and triclosan by the green alga Nannochloris sp. J Hazard Mater. 2016;315:70-75. doi:10.1016/j.jhazmat.2016.04.067
8. Bai X, Acharya K. Removal of seven endocrine disrupting chemicals (EDCs) from municipal wastewater effluents by a freshwater green alga. Environ Pollut. 2019;247:534-540. doi:10.1016/j.envpol.2019.01.075
9. Bouabidi ZB, El-Naas MH, Zhang Z. Immobilization of microbial cells for the biotreatment of wastewater: A review. Environ Chem Lett. 2019; 17:241-257. DOI:10.1007/s10311-018-0795-7
10. Çetinkaya Dönmez G, Aksu Z, Öztürk A, Kutsal T. A comparative study on heavy metal biosorption characteristics of some algae. Process Biochemistry. 1999; 34:885-892. https://doi.org/10.1016/S0032-9592(99)00005-9
11. Chen J, Zheng F, Guo R. Algal Feedback and Removal Efficiency in a Sequencing Batch Reactor Algae Process (SBAR) to Treat the Antibiotic Cefradine. Freedman JH, ed. PLOS ONE. 2015;10(7):e0133273. doi:10.1371/journal.pone.0133273
12. Cheng YW, Lim JSM, Chong CC, et al. Unravelling CO2 capture performance of microalgae cultivation and other technologies via comparative carbon balance analysis. Journal of Environmental Chemical Engineering. 2021; 9:106519. DOI:10.1016/j.jece.2021.106519
13. Chi J, Li Y, Gao J. Interaction between three marine microalgae and two phthalate acid esters. Ecotoxicology and Environmental Safety. 2019; 170:407-411. DOI: 10.1016/j.ecoenv.2018.12.012
14. Cho DH, Ramanan R, Heo J, et al. Enhancing microalgal biomass productivity by engineering a microalgal–bacterial community. Bioresource Technology. 2015;175:578-585. DOI: 10.1016/j.biortech.2014.10.159
15. Choi HJ, Lee SM. Heavy metal removal from acid mine drainage by calcined eggshell and microalgae hybrid system. Environ Sci Pollut Res. 2015; 22:13404-13411. DOI: 10.1007/s11356-015-4623-3
16. Clark M, Tepper K, Petroll K, Kumar S, Sunna A, Maselko M. Bioremediation of Industrial Pollutants by Insects Expressing a Fungal Laccase. ACS Synth Biol. 2022; 11:308-316. DOI: 10.1021/acssynbio.1c00427
17. Daneshvar E, Zarrinmehr MJ, Hashtjin AM, Farhadian O, Bhatnagar A. Versatile applications of freshwater and marine water microalgae in dairy wastewater treatment, lipid extraction and tetracycline biosorption. Bioresour Technol. 2018;268:523-530. doi:10.1016/j.biortech.2018.08.032
18. De Godos I, Muñoz R, Guieysse B. Tetracycline removal during wastewater treatment in high-rate algal ponds. Journal of Hazardous Materials. 2012; 229-230:446-449. DOI: 10.1016/j.jhazmat.2012.05.106
19. Ding T, Lin K, Yang B, et al. Biodegradation of naproxen by freshwater algae Cymbella sp. and Scenedesmus quadricauda and the comparative toxicity. Bioresour Technol. 2017;238:164-173. doi:10.1016/j.biortech.2017.04.018
20. de Wilt A, Butkovskyi A, Tuantet K, et al. Micropollutant removal in an algal treatment system fed with source separated wastewater streams. Journal of Hazardous Materials. 2016; 304:84-92. DOI: 10.1016/j.jhazmat.2015.10.033
21. Dubey M, Vellanki BP, Kazmi AA. Removal of emerging contaminants in conventional and advanced biological wastewater treatment plants in India-a comparison of treatment technologies. Environmental Research. 2023; 218:115012. DOI: 10.1016/j.envres.2022.115012
22. Escapa C, Coimbra RN, Paniagua S, García AI, Otero M. Nutrients and pharmaceuticals removal from wastewater by culture and harvesting of Chlorella sorokiniana. Bioresour Technol. 2015;185:276-284. doi:10.1016/j.biortech.2015.03.004

23. Escapa C, Coimbra RN, Paniagua S, García AI, Otero M. Paracetamol and salicylic acid removal from contaminated water by microalgae. J Environ Manage. 2017;203:799-806. doi:10.1016/j.jenvman.2016.06.051
24. Feng Y, Wang A, Fu W, Song D. Growth performance, antioxidant response, biodegradation and transcriptome analysis of Chlorella pyrenoidosa after nonylphenol exposure. Sci Total Environ. 2022;806:150507. doi:10.1016/j.scitotenv.2021.150507
25. Fu W, Li X, Yang Y, Song D. Enhanced degradation of bisphenol A: Influence of optimization of removal, kinetic model studies, application of machine learning and microalgae-bacteria consortia. Sci Total Environ. 2023;858:159876. doi:10.1016/j.scitotenv.2022.159876
26. García-Balboa C, Baselga-Cervera B, García-Sanchez A, Igual JM, Lopez-Rodas V, Costas E. Rapid adaptation of microalgae to bodies of water with extreme pollution from uranium mining: An explanation of how mesophilic organisms can rapidly colonise extremely toxic environments. Aquatic Toxicology. 2013; 144-145:116-123. DOI: 10.1016/j.aquatox.2013.10.003
27. Gentili FG, Fick J. Algal cultivation in urban wastewater: an efficient way to reduce pharmaceutical pollutants. J Appl Phycol. 2017;29(1):255-262. doi:10.1007/s10811-016-0950-0
28. Gojkovic Z, Lindberg RH, Tysklind M, Funk C. Northern green algae have the capacity to remove active pharmaceutical ingredients. Ecotoxicol Environ Saf. 2019;170:644-656. doi:10.1016/j.ecoenv.2018.12.032
29. Gonçalves AL, Pires JCM, Simões M. A review on the use of microalgal consortia for wastewater treatment. Algal Research. 2017;24:403-415. DOI:10.1016/j.algal.2016.11.008
30. Guo WQ, Zheng HS, Li S, et al. Removal of cephalosporin antibiotics 7-ACA from wastewater during the cultivation of lipid-accumulating microalgae. Bioresour Technol. 2016;221:284-290. doi:10.1016/j.biortech.2016.09.036
31. Hena S, Gutierrez L, Croué JP. Removal of metronidazole from aqueous media by C. vulgaris. J Hazard Mater. 2020;384:121400. doi:10.1016/j.jhazmat.2019.121400
32. Hernandez JP, de-Bashan LE, Rodriguez DJ, Rodriguez Y, Bashan Y. Growth promotion of the freshwater microalga Chlorella vulgaris by the nitrogen-fixing, plant growth-promoting bacterium Bacillus pumilus from arid zone soils. European Journal of Soil Biology. 2009; 45:88-93. https://doi.org/10.1016/j.ejsobi.2008.08.004
33. Hom-Diaz A, Llorca M, Rodríguez-Mozaz S, Vicent T, Barceló D, Blánquez P. Microalgae cultivation on wastewater digestate: β-estradiol and 17α-ethynylestradiol degradation and transformation products identification. Journal of Environmental Management. 2015; 155:106-113. DOI: 10.1016/j.jenvman.2015.03.003
34. Hom-Diaz A, Jaén-Gil A, Bello-Laserna I, et al. Performance of a microalgal photobioreactor treating toilet wastewater: Pharmaceutically active compound removal and biomass harvesting. Sci Total Environ. 2017a;592:1-11. doi:10.1016/j.scitotenv.2017.02.224
35. Hom-Diaz A, Norvill ZN, Blánquez P, Vicent T, Guieysse B. Ciprofloxacin removal during secondary domestic wastewater treatment in high rate algal ponds. Chemosphere. 2017b;180:33-41. doi:10.1016/j.chemosphere.2017.03.125
36. Huang X, Tu Y, Song C, et al. Interactions between the antimicrobial agent triclosan and the bloom-forming cyanobacteria Microcystis aeruginosa. Aquat Toxicol. 2016;172:103-110. doi:10.1016/j.aquatox.2016.01.002
37. Huang Q, Jiang F, Wang L, Yang C. Design of Photobioreactors for Mass Cultivation of Photosynthetic Organisms. Engineering. 2017; 3:318-329. https://doi.org/10.1016/J.ENG.2017.03.020
38. Ji MK, Kabra AN, Choi J, et al. Biodegradation of bisphenol A by the freshwater microalgae Chlamydomonas mexicana and Chlorella vulgaris. Ecol Eng. 2014;73:260-269. doi:10.1016/j.ecoleng.2014.09.070
39. Kumar N, Banerjee C, Chang JS, Shukla P. Valorization of wastewater through microalgae as a prospect for generation of biofuel and high-value products. Journal of Cleaner Production. 2022; 362:132114. https://doi.org/10.1016/j.jclepro.2022.132114
40. Kumar N, Shukla P. Microalgal-based bioremediation of emerging contaminants: Mechanisms and challenges. Environmental Pollution. 2023; 337:122591. DOI: 10.1016/j.envpol.2023.122591
41. Kurade MB, Kim JR, Govindwar SP, Jeon BH. Insights into microalgae mediated biodegradation of diazinon by Chlorella vulgaris : Microalgal tolerance to xenobiotic pollutants and metabolism. Algal Research. 2016; 20:126-134. DOI:10.1016/j.algal.2016.10.003
42. Li H, Pan Y, Wang Z, Chen S, Guo R, Chen J. An algal process treatment combined with the Fenton reaction for high concentrations of amoxicillin and cefradine. RSC Adv. 2015;5(122):100775-100782. doi:10.1039/C5RA21508K
43. Liu Y, Wang F, Chen X, Zhang J, Gao B. Cellular responses and biodegradation of amoxicillin in Microcystis aeruginosa at different nitrogen levels. Ecotoxicol Environ Saf. 2015;111:138-145. doi:10.1016/j.ecoenv.2014.10.011
44. Lopez FJ, Pitarch E, Botero-Coy AM, et al. Removal efficiency for emerging contaminants in a WWTP from Madrid (Spain) after secondary and tertiary treatment and environmental impact on the Manzanares River. Science of The Total Environment. 2022; 812:152567. DOI: 10.1016/j.scitotenv.2021.152567

45. Maes HM, Maletz SX, Ratte HT, Hollender J, Schaeffer A. Uptake, Elimination, and Biotransformation of 17α-Ethinylestradiol by the Freshwater Alga Desmodesmus subspicatus. Environ Sci Technol. 2014;48(20):12354-12361. doi:10.1021/es503574z
46. Maryjoseph S, Ketheesan B. Microalgae based wastewater treatment for the removal of emerging contaminants: A review of challenges and opportunities. Case Studies in Chemical and Environmental Engineering. 2020; 2:100046. https://doi.org/10.1016/j.cscee.2020.100046
47. Matamoros V, Gutiérrez R, Ferrer I, García J, Bayona JM. Capability of microalgae-based wastewater treatment systems to remove emerging organic contaminants: A pilot-scale study. Journal of Hazardous Materials. 2015; 288:34-42. DOI: 10.1016/j.jhazmat.2015.02.002
48. Matamoros V, Rodríguez Y, Albaigés J. A comparative assessment of intensive and extensive wastewater treatment technologies for removing emerging contaminants in small communities. Water Research. 2016; 88:777-785. DOI: 10.1016/j.watres.2015.10.058
49. Norvill ZN, Shilton A, Guieysse B. Emerging contaminant degradation and removal in algal wastewater treatment ponds: Identifying the research gaps. Journal of Hazardous Materials. 2016; 313:291-309. DOI: 10.1016/j.jhazmat.2016.03.085
50. Osundeko O, Dean AP, Davies H, Pittman JK. Acclimation of Microalgae to Wastewater Environments Involves Increased Oxidative Stress Tolerance Activity. Plant and Cell Physiology. 2014; 55:1848-1857. DOI: 10.1093/pcp/pcu113
51. Pal A, He Y, Jekel M, Reinhard M, Gin KYH. Emerging contaminants of public health significance as water quality indicator compounds in the urban water cycle. Environment International. 2014;71:46-62. DOI: 10.1016/j.envint.2014.05.025
52. Pan CG, Peng FJ, Ying GG. Removal, biotransformation and toxicity variations of climbazole by freshwater algae Scenedesmus obliquus. Environ Pollut. 2018;240:534-540. doi:10.1016/j.envpol.2018.05.020
53. Patel M, Kumar R, Kishor K, Mlsna T, Pittman CU, Mohan D. Pharmaceuticals of Emerging Concern in Aquatic Systems: Chemistry, Occurrence, Effects, and Removal Methods. Chem Rev. 2019; 119:3510-3673. DOI: 10.1021/acs.chemrev.8b00299
54. Peng FQ, Ying GG, Yang B, et al. Biotransformation of progesterone and norgestrel by two freshwater microalgae (Scenedesmus obliquus and Chlorella pyrenoidosa): Transformation kinetics and products identification. Chemosphere. 2014;95:581-588. doi:10.1016/j.chemosphere.2013.10.013
55. Pittman JK, Dean AP, Osundeko O. The potential of sustainable algal biofuel production using wastewater resources. Bioresource Technology. 2011; 102:17-25. DOI: 10.1016/j.biortech.2010.06.035
56. Procházková G, Brányiková I, Zachleder V, Brányik T. Effect of nutrient supply status on biomass composition of eukaryotic green microalgae. J Appl Phycol. 2014; 26:1359-1377. DOI:10.1007/s10811-013-0154-9
57. Prosenc F, Piechocka J, Škufca D, et al. Microalgae-based removal of contaminants of emerging concern: Mechanisms in Chlorella vulgaris and mixed algal-bacterial cultures. Journal of Hazardous Materials. 2021;418:126284. DOI: 10.1016/j.jhazmat.2021.126284
58. Qi F, Jia Y, Mu R, et al. Convergent community structure of algal–bacterial consortia and its effects on advanced wastewater treatment and biomass production. Sci Rep. 2021; 11:21118. https://doi.org/10.1038/s41598-021-00517-x
59. Quan L, Cheng Y, Wang J, et al. Efficient removal of thiamethoxam by freshwater microalgae Scenedesmus sp. TXH: Removal mechanism, metabolic degradation and application. Journal of Environmental Management. 2023; 332:117388. DOI: 10.1016/j.jenvman.2023.117388
60. Rühmland S, Wick A, Ternes TA, Barjenbruch M. Fate of pharmaceuticals in a subsurface flow constructed wetland and two ponds. Ecol Eng. 2015;80:125-139. doi:10.1016/j.ecoleng.2015.01.036
61. Saavedra R, Muñoz R, Taboada ME, Vega M, Bolado S. Comparative uptake study of arsenic, boron, copper, manganese and zinc from water by different green microalgae. Bioresource Technology. 2018; 263:49-57. DOI: 10.1016/j.biortech.2018.04.101
62. Sathinathan P, Parab HM, Yusoff R, Ibrahim S, Vello V, Ngoh GC. Photobioreactor design and parameters essential for algal cultivation using industrial wastewater: A review. Renewable and Sustainable Energy Reviews. 2023; 173:113096. https://doi.org/10.1016/j.rser.2022.113096
63. Singh A, Ummalyma SB, Sahoo D. Bioremediation and biomass production of microalgae cultivation in river water contaminated with pharmaceutical effluent. Bioresource Technology. 2020; 307:123233. DOI: 10.1016/j.biortech.2020.123233
64. Song C, Wei Y, Sun J, Song Y, Li S, Kitamura Y. Biodegradation and metabolic fate of thiamphenicol via Chlorella sp. UTEX1602 and L38. Bioresour Technol. 2020;296:122320. doi:10.1016/j.biortech.2019.122320
65. Stravs MA, Pomati F, Hollender J. Exploring micropollutant biotransformation in three freshwater phytoplankton species. Environ Sci Process Impacts. 2017;19(6):822-832. doi:10.1039/C7EM00100B

66. Suárez-Martínez D, Angulo-Mercado E, Mercado-Martínez I, Vacca-Jimeno V, Tapia-Larios C, Cubillán N. Enhanced Tetracycline Removal from Highly Concentrated Aqueous Media by Lipid-Free Chlorella sp. Biomass. ACS Omega. 2022;7(16):14128-14137. doi:10.1021/acsomega.2c00696
67. Subashchandrabose SR, Ramakrishnan B, Megharaj M, Venkateswarlu K, Naidu R. Consortia of cyanobacteria/microalgae and bacteria: Biotechnological potential. Biotechnology Advances. 2011; 29:896-907. DOI: 10.1016/j.biotechadv.2011.07.009
68. Tiwari B, Sellamuthu B, Ouarda Y, Drogui P, Tyagi RD, Buelna G. Review on fate and mechanism of removal of pharmaceutical pollutants from wastewater using biological approach. Bioresource Technology. 2017; 224:1-12. DOI: 10.1016/j.biortech.2016.11.042
69. Torgal FP. Introduction to nano-and biotech-based materials for energy building efficiency, Nano and Biotech Based Materials for Energy Building Efficiency. Springer. 2016; 2016:1-16. DOI 10.1007/978-3-319-27505-5
70. Tran NH, Reinhard M, Gin KYH. Occurrence and fate of emerging contaminants in municipal wastewater treatment plants from different geographical regions-a review. Water Research. 2018; 133:182-207. DOI: 10.1016/j.watres.2017.12.029
71. Shen Y, Yuan W, Pei ZJ, Wu Q, Mao E. Microalgae Mass Production Methods. Transactions of the ASABE. 2009; 52:1275-1287. DOI:10.13031/2013.27771
72. Villar-Navarro E, Baena-Nogueras RM, Paniw M, Perales JA, Lara-Martín PA. Removal of pharmaceuticals in urban wastewater: High rate algae pond (HRAP) based technologies as an alternative to activated sludge based processes. Water Research. 2018; 139:19-29. DOI: 10.1016/j.watres.2018.03.072
73. Wan L, Wu Y, Ding H, Zhang W. Toxicity, Biodegradation, and Metabolic Fate of Organophosphorus Pesticide Trichlorfon on the Freshwater Algae Chlamydomonas reinhardtii. J Agric Food Chem. 2020;68(6):1645-1653. doi:10.1021/acs.jafc.9b05765
74. Wang R, Diao P, Chen Q, Wu H, Xu N, Duan S. Identification of novel pathways for biodegradation of bisphenol A by the green alga Desmodesmus sp.WR1, combined with mechanistic analysis at the transcriptome level. Chem Eng J. 2017;321:424-431. doi:10.1016/j.cej.2017.03.121
75. Wang S, Wang X, Poon K, et al. Removal and reductive dechlorination of triclosan by Chlorella pyrenoidosa. Chemosphere. 2013;92(11):1498-1505. doi:10.1016/j.chemosphere.2013.03.067
76. Wang Y, Ho SH, Cheng CL, et al. Perspectives on the feasibility of using microalgae for industrial wastewater treatment. Bioresource Technology. 2016; 222:485-497. DOI: 10.1016/j.biortech.2016.09.106
77. Wilde EW, Benemann JR. Bioremoval of heavy metals by the use of microalgae. Biotechnology Advances. 1993; 11:781-812. DOI: 10.1016/0734-9750(93)90003-6
78. Xie P, Chen C, Zhang C, Su G, Ren N, Ho SH. Revealing the role of adsorption in ciprofloxacin and sulfadiazine elimination routes in microalgae. Water Res. 2020;172:115475. doi:10.1016/j.watres.2020.115475
79. Xiong JQ, Kurade MB, Jeon BH. Can Microalgae Remove Pharmaceutical Contaminants from Water? Trends in Biotechnology. 2018;36(1):30-44. DOI: 10.1016/j.tibtech.2017.09.003
80. Xiong JQ, Kurade MB, Jeon BH. Biodegradation of levofloxacin by an acclimated freshwater microalga, Chlorella vulgaris. Chem Eng J. 2017a;313:1251-1257. doi:10.1016/j.cej.2016.11.017
81. Xiong JQ, Kurade MB, Kim JR, Roh HS, Jeon BH. Ciprofloxacin toxicity and its co-metabolic removal by a freshwater microalga Chlamydomonas mexicana. Journal of Hazardous Materials. 2017b; 323:212-219. DOI: 10.1016/j.jhazmat.2016.04.073
82. Zhang D, Gersberg RM, Ng WJ, Tan SK. Removal of pharmaceuticals and personal care products in aquatic plant-based systems: A review. Environ Pollut. 2014;184:620-639. doi:10.1016/j.envpol.2013.09.009
83. Zhang N, Guo X, Han T, Tan L, Xue Q, Wang J. Isolation and identification of allelochemicals produced by Phaeodactylum tricornutum for Prorocentrum donghaiense. Algal Research. 2022; 66:102808. DOI:10.1016/j.algal.2022.102808
84. Zhang X, You S, Ma L, Chen C, Li C. The Application of Immobilized Microorganism Technology in Wastewater Treatment. In: Proceedings of the 2015 2nd International Conference on Machinery, Materials Engineering, Chemical Engineering and Biotechnology. Atlantis Press; 2016. DOI:10.2991/mmeceb-15.2016.22
85. Zhou GJ, Ying GG, Liu S, Zhou LJ, Chen ZF, Peng FQ. Simultaneous removal of inorganic and organic compounds in wastewater by freshwater green microalgae. Environ Sci Process Impacts. 2014;16(8):2018. doi:10.1039/C4EM00094C