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Review

Performance of secondary wastewater treatment methods for the removal of contaminants of emerging concern implicated in crop uptake and antibiotic resistance spread: A review

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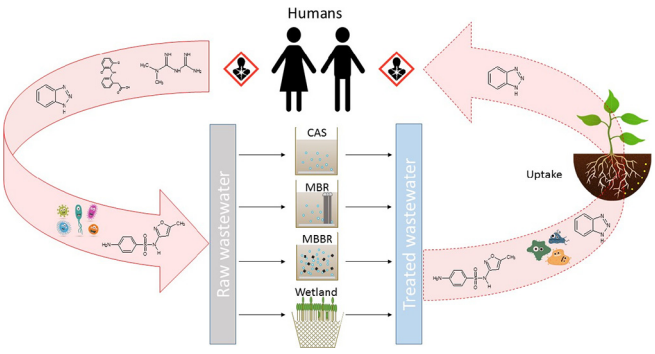
HIGHLIGHTS

- Fate of CEC relevant for crop uptake during secondary treatment was analysed.
- Target CEC selection resulted from the indications of the NEREUS COST Action.
- Effects of secondary treatment on microbial CEC (ARBs and ARGs) fate were described.
- Most applied and promising technologies for urban wastewater treatment were compared.
- Impact of CEC removal on WWTP upgrading, design and operation was discussed.

GRAPHICAL ABSTRACT



Abbreviations: A^2O, anaerobic–anoxic–oxic; ACTM, Acetamiprid; ARB, antibiotic resistant bacteria; ARGs, antibiotic resistance genes; AZM, Azithromycin; BDL, below detection limit; BHT, 2,6-Ditert-butyl-4-methylphenol; BOD, biochemical oxygen demand; BTA, benzotriazole; CAS, conventional activated sludge; CBZ, carbamazepine; CEC, contaminants of emerging concern; CIP, ciprofloxacin; COD, chemical oxygen demand; CW, constructed wetland; Da, dalton; DCF, diclofenac; DO, dissolved oxygen; DOC, dissolved organic carbon; E1, estrone; E2, 17-beta-estradiol; EE2, 17-alpha-ethynylestradiol; EDG, electron donating functional groups; EHMC, 2-ethylhexyl 4-methoxycinnamate; ENR, enrofloxacin; ERY, erythromycin; EWG, electron withdrawing functional groups; EU, European Union; F/M, food to microorganisms ratio; HBCD, hexabromocyclododecane; HGT, horizontal gene transfer; HRT, hydraulic retention time; IntI1, class 1 integron; K_{biol}, kinetic reaction rate constant, $L/g_{SS}\cdot day$; K_d, solid-water partition coefficient, L/kg_{SS}; K_{ow}, octanol-water partition coefficient; LCA, Life Cycle Assessment; MBBR, moving bed biofilm reactor; MBR, membrane bioreactor; MDR, multi-drug resistance; MF, microfiltration; MLSS, mixed liquor suspended solids; MLVSS, mixed liquor volatile suspended solids; MRSA, methicillin-resistant *Staphylococcus aureus*; N.A., not available; NDMA, *N*-Nitrosodimethylamine; NEREUS, COST Action ES1403 'New and emerging challenges and opportunities in wastewater reuse'; NORMAN, network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances; NSAID, non-steroidal anti-inflammatory compound; PCPs, personal care products; PE, population equivalent; PFBA, perfluorobutanoic acid; PFHxA, perfluorohexanoic acid; PFPeA, perfluoropentanoic acid; QMRA, quantitative microbial risk assessment; q-PCR, quantitative polymerase chain reaction; SF CW, surface flow CWs; SMX, Sulfamethoxazole; SRT, sludge retention time; SWWTP, small WWTP of <5.000 PE; TBBPA, tetrabromobisphenol A; TCS, triclosan; TCEP, tris(2-chloroethyl)phosphate; TMP, trimethoprim; TPs, transformation products; TSS, total suspended solids; UF, ultrafiltration; USGS, United States Geological Survey; VRE, Vancomycin-resistant enterococci; WWTP, wastewater treatment plant.

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ABSTRACT

Contaminants of emerging concern (CEC) discharged in effluents of wastewater treatment plants (WWTPs), not specifically designed for their removal, pose serious hazards to human health and ecosystems. Their impact is of particular relevance to wastewater disposal and re-use in agricultural settings due to CEC uptake and accumulation in food crops and consequent diffusion into the food-chain. This is the reason why the chemical CEC discussed in this review have been selected considering, besides recalcitrance, frequency of detection and entity of potential hazards, their relevance for crop uptake. Antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) have been included as microbial CEC because of the potential of secondary wastewater treatment to offer conditions favourable to the survival and proliferation of ARB, and dissemination of ARGs. Given the adverse effects of chemical and microbial CEC, their removal is being considered as an additional design criterion, which highlights the necessity of upgrading conventional WWTPs with more effective technologies. In this review, the performance of currently applied biological treatment methods for secondary treatment is analysed. To this end, technological solutions including conventional activated sludge (CAS), membrane bioreactors (MBRs), moving bed biofilm reactors (MBBRs), and nature-based solutions such as constructed wetlands (CWs) are compared for the achievable removal efficiencies of the selected CEC and their potential of acting as reservoirs of ARB&ARGs. With the aim of giving a picture of real systems, this review focuses on data from full-scale and pilot-scale plants treating real urban wastewater. To achieve an integrated assessment, technologies are compared considering also other relevant evaluation parameters such as investment and management costs, complexity of layout and management, present scale of application and need of a post-treatment. Comparison results allow the definition of design and operation strategies for the implementation of CEC removal in WWTPs, when agricultural reuse of effluents is planned.

Contents

1. Introduction and objectives

A discussion on the performance of technologies applied in wastewater treatment plants (WWTPs) for secondary treatment cannot disregard the presence of contaminants of emerging concern (CEC) in wastewaters, when assessing hazards to human health and ecosystems. According to the NORMAN network (2017), a CEC is "*a substance currently not included in routine environmental monitoring programmes and may be candidate for future legislation due to its adverse effects and/or persistency*". Also, according to the United States Geological Survey (USGS) CEC include: "*any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects*" (Klaper and Welch, 2011).

Currently, there is no standardized categorization of CEC, and generally, examined categories include among others, pharmaceuticals, personal care products, plasticizers, flame retardants, and pesticides.

The release of CEC to the aquatic environment has been occurring for a long time, but suitable detection methods were not available until recently. As a result, nowadays we are able to identify and quantify these compounds. The synthesis of new chemicals, or changes in use and disposal of existing chemicals can create new sources of CEC into aquatic environments.

In addition to the occurrence of chemical CEC in water environments, the widespread use and misuse of antibiotic residues and their