Open Access Library Journal
2020, Volume 7, e6088
ISSN Online: 2333-9721
ISSN Print: 2333-9705

On the Treatment Trains for Municipal Wastewater Reuse for Irrigation

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How to cite this paper: Ghernaout, D. and Elboughdiri, N. (2020) On the Treatment Trains for Municipal Wastewater Reuse for Irrigation. *Open Access Library Journal*, **7**: e6088.
https://doi.org/10.4236/oalib.1106088

Received: January 19, 2020
Accepted: February 14, 2020
Published: February 17, 2020

Abstract

Traditional urban wastewater treatment plants (UWTPs) are badly efficient in eliminating most contaminants of emerging concern (CECs), comprising antibiotics, antibiotic-resistant bacteria and antibiotic resistance genes (ARB & ARGs). Such pollutants induce some worry for nature and human health, especially if UWTPs effluents are reused for crop irrigation. In all probability, traditional UWTPs will need extra advanced treatment stages to satisfy water quality limits for wastewater reuse. Recently, Rizzo and his co-workers [1] published an excellent review that aims to suggest potential advanced treatment solutions, especially concerning the elimination of CECs and ARB & ARGs. They deeply assessed the performance of the best available technologies (BATs) for domestic wastewater treatment to decrease CECs and ARB & ARGs. Especially, they evaluated ozonation, activated carbon adsorption, chemical disinfection, UV radiation, advanced oxidation processes (AOPs) and membrane filtration focusing on their capacity to efficiently eliminate CECs and ARB & ARGs, as well as their benefits and disadvantages. This work focuses on likely treatment trains involving the aforesaid BATs. As concluded by Rizzo *et al.* [1] a one advanced treatment technique is not enough to reduce the liberation of chemical CECs and ARB & ARGs and make wastewater reuse for crop irrigation safer; however, an impertinent integration of them and an appropriate controlling program would be needed. There is no miraculous BAT for treating wastewater for water reuse in agriculture. An appropriate combination of many techniques would be suggested following each case.

Subject Areas

Environmental Sciences

Keywords

Water Reuse, Treatment Trains (TTs), Contaminants of Emerging Concern (CECs), Antibiotic-Resistant Bacteria (ARB), Antibiotic Resistance Genes (ARGs), Best Available Technologies (BATs)

1. Introduction

Wastewater reuse stays one of the most significant options to traditional water sources to both (1) treat wastewater pollutants at their origin before their emanation in nature and (2) manage water lack [1] [2] [3] [4]. At most, about 1.2 billion people live in regions touched by grave water deficiency situations and 1.8 billion people are expected to be living in areas impacted by water lack by 2025 [1]. For irrigation in agriculture, wastewater reuse remains by far the most accepted end-use for recovered water [1] [5] [6]. Nevertheless, during the time that thinking through water lacks, wastewater reuse may induce public health hazards if treatment, storage, and piping are not appropriate especially in poor countries [7] [8]. More dangers reside in the microbial hazard (even if efficient disinfection methods are usually comprised in the treatment train (TT)) and contaminants of emerging concern (CECs), like pesticides, pharmaceuticals, illicit drugs, synthetic and natural hormones, personal care products, and resistant microorganisms (*i.e.* antibiotic-resistant bacteria and genes (ARB & ARGs)) [9] [10] [11].

It is well established that traditional TTs in UWTPs are badly efficacious to completely eliminate CECs [12] [13] [14] [15], which are ultimately liberated into nature, forming a special worry if effluents are reused for crop irrigation. To eliminate CECs, advanced treatment stages must be applied in classical UWTPs [14] [16] [17] [18]. Nevertheless, although the impact of biological processes [14] [19] [20] [21] and advanced treatment technologies [16] [22]-[28] on chemical CECs has been discussed in many publications, fewer details are at hand regarding ARB & ARGs and, most significantly, on feasible TTs merging many techniques to greatly manage such dares [1].

In their recent and comprehensive review, Rizzo *et al.* [1] presented and discussed the best available technologies (BATs) for advanced treatment of domestic wastewater, as well as potential TTs to dominate the liberation of CECs, comprising ARB & ARGs, to treat wastewater for secure and likely reuse applications in agriculture. Most importantly, they discussed the capacity of ozonation, activated carbon adsorption, chemical oxidants/disinfectants, ultraviolet (UV) radiation, advanced oxidation processes (AOPs) [29] [30] [31] and membrane filtration [32] [33] [34] [35] [36] to remove CECs and ARB & ARGs comprising the benefits and disadvantages of such techniques. Then, they compared the aforesaid technologies for CECs related to crop uptake. Moreover, they assessed the probable TTs involving the above-discussed BATs for likely implementation. In the end, they summarized probable benefits, disadvantages, and recommendations of the suggested TTs.

This work focuses on the last part of the Rizzo *et al.* [1]'s review that concerns the conceivable TTs implying the above-mentioned BATs for likely implementation for water reuse in agriculture.

2. Multi-Barrier Strategy for Safely Treated Wastewater Reuse in Agriculture

2.1. Treatment Trains (TTs) for a Safe Reuse

To make wastewater reuse secure for crop irrigation, a multi-barrier procedure to wastewater treatment is required [37] [38] [39]. Such barriers have to involve standard techniques for municipal wastewater treatment (that is, primary mechanical pre-treatment, possible primary settling, biological treatment, etc.) and advanced treatments. Conceivable choices of TTs presenting diverse effluent qualities are shown in **Figure 1**.

The lowest treatment scheme for safe reuse must involve a traditional depth filtration downstream of a biological process (or an ultrafiltration (UF) membrane [40] as in case of membranebiological reactor (MBR), **Figure 1(b)**), pursued via a disinfectionstage with UV radiation (**Figure 1(a)**). This TT has to efficiently permit to handle standard factors (like biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspendedsolids (TSS), *E. coli* [41] [42] [43], etc.) put in wastewater reuse regulation and guidelines [1].

Chemical disinfection (especially via chlorine [44] [45] [46] [47] [48]) (**Figure 1(c)**) is cheapercontrasted to other disinfection choices; however, the generation of disinfection by-products (DBPs) [49] [50] [51] [52] must be taken into account, and the TT may become costly contrasted to other solutions if DBPs are eliminated before reuse [1] [53].

It has to be mentioned that, chemical disinfectants (like chlorine), as well as an MBR with UF membrane and UV radiation, are deficiently efficacious in dealing with CECs [1].

As long as, if (i) the corresponding limit for bacterial indicators is so stringent that UV disinfection is not enough and/or (ii) CECs pollution has to be efficiently decreased, other more efficacious treatment techniques require to be adopted (**Figures 1(d)-(g)**) [1].

In the middle of AOPs, ozonation and photochemical techniques presented good performances in reducing CECs and ARB. Especially, in the short term, ozonation and UV/H_2O_2 methods are more interesting choices (**Figure 1(d)**) contrasted to other photo-driven AOPs to remove CECs as well as to efficiently demobilize pathogens [16] since:

1. Their performance has been established via numerous researches found in

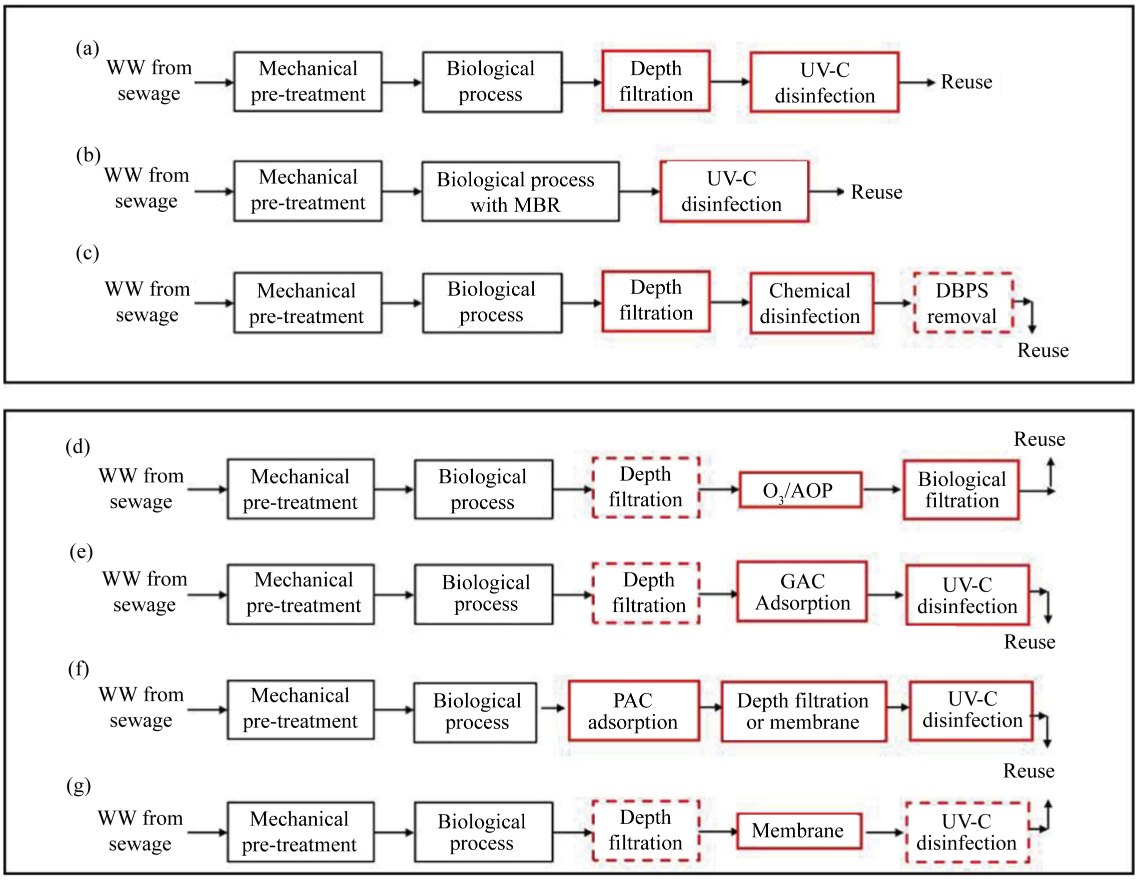

Figure 1. Different options of treatment trains (TTs) for urban wastewater reuse to address traditional parameters set in wastewater reuse regulation and guidelines (e.g., BOD, COD, TSS, *E. coli* etc.) (a, b, c) and to effectively remove CECs in addition to the typical parameters (d, e, f, g). Advanced treatment in red lines; red dotted lines mean that process application should be evaluated case by case. "Biological process" followed by "depth filtration" may be replaced by "MBR" for TTs "d" and "e" [1].

publications. Nevertheless, ozonation requires much less energy contrasted to UV/H_2O_2 remediation for the identical CEC decrease degree and illustrates full-scale implementation;

2. Other homogeneous photocatalytic techniques (like photo-Fenton) may need extra expenses (such as pH adjustment, chelating agents' addition) and/or have not yet been thoroughly studied (like UV/free chlorine, sulfate radical based AOPs, etc.);

3. Heterogeneous photocatalytic techniques until now have critical practical hindrances for full-scale utilization [1].

It should be mentioned that ozonation and AOPs basically necessitate biological post-treatment (*i.e.* biological sand or activated carbon filtration) to reduce biodegradable oxidation by-products and transformation products (**Figure 1(d)**). Rapid depth filtration or otherwisea dissolved air flotation treatment may be employed as a pretreatment technique just prior to AOP in the case that residual suspended solids should interfere with subsequent processes [1].

Adsorption on granular activated carbon (GAC) in packed reactors pursued by UV disinfection (in contrast to O_3 and UV/H_2O_2, adsorption is not a disinfection technology) is one more choice to enhance the quality of effluent wastewater prior to reuse (**Figure 1(e)**). To prohibit GAC packed reactors from a rapid blocking and elevate back flushing periods, cloth or rapid sand filtration may be utilized to eliminate suspended solids prior to the adsorption method [1].

Provided that PAC adsorption is employed in integration with the biological method (via introducing PAC into the biological setup) or as a distinct component subsequently, either depth filtration and/or MF/UF membrane processes have to be utilized to eliminate residual PAC particles prior to discharge (**Figure 1(f)**). Like in GAC remediation, a UV disinfection must be put [1].

Finally, membrane filtration with NF or RO pursued by UV disinfectionis one more conceivable choice for advanced treatment of wastewater prior to reuse (**Figure 1(g)**). Pre-treatment via sand filtration may be implemented to reduce suspended solids to dominate membrane fouling, even if it is more frequent to filter settled effluent directly using MF or UF membranes. Further, MF and UF membranes give appropriate pre-treatment for the NF or RO stage (in such a situation ultimate disinfection via UV radiation is not required for crop irrigation). Most importantly, RO treatment would be also useful for crop irrigation thanks to the elimination of salts from the effluent. Nevertheless, for membrane techniques to be potential, there is a necessity of a thorough investigation of the appropriate treatment and/or recycling of concentrates on a case by case basis. Employing efficient concentrate treatment possesses the capacity to improve treatment performance, move to a near zero-liquid discharge and evade undesirable discharge of CEC [1].

2.2. Benefits, Disadvantages, and Recommendations of the Treatment Trains (TTs)

This debate aims to propose the "best available technologies (BATs) able to minimize the release of micro-contaminants including ARB & ARGs, and biological risk, and fulfill requirements for safe reuse for crop irrigation" [1]. For all the TTs presented above, the main problems are listed in **Table 1**. As a result, and taking into account that no detailed comparative investigations handling CECs and ARB & ARGs reduction via advanced treatment techniques are published [16], a comparative economic evaluation would be controversial. Especially, advanced treatment techniques have been compared in terms of either CECs elimination, costs, disinfection performance, ARB & ARGs reduction, generation of DBPs and oxidation reaction products, and final toxicity; however, the total effect on nature via the simultaneous assessment of all these problems has not been examined [16].

3. Conclusions

From this work, the following conclusions can be drawn:

1) The safety of treated wastewater to be reused for crop irrigation is a relevant

Table 1. Benefits, obstacles, and recommendations for each TT in Figure 1 [1].

TT (advanced treatment)	Benefits	Obstacles	Recommendations
a or b (UV)	• Efficient disinfection (comprising ARB demobilization) • No DBPs generation contrasted to chemical disinfection	• Poor/no CECs elimination • •Partial elimination of ARGs	• Compliance with local residual bacterial density standards should be evaluated
c (chemical disinfection)	• Efficient disinfection (comprising ARB demobilization)	• Poor/no reduction of CECs and ARGs • Generation of DBPs	• Toxicity trials recommended • DBPs (following the disinfectants utilized) must be controlled
d (O_3/AOP and biological post-treatment)	• Efficient disinfection (comprising ARB demobilization) • CECs reduction: Elevated throughout ozonationand (solar) photo Fenton, moderate with UV/H_2O_2 • Full-scale evidence on practicability onlyfor O_3	• Generation of numerous DBPs (*N*nitrosodimethylamine (NDMA), bromate) throughout ozonation • Production of oxidation transformation products throughout AOP and ozonation • Partial ARGs reduction	• Toxicity trials recommended • NDMA and bromate must be controlled inO_3 treatment
e (GAC and UV)	• Efficient disinfection via UV • Elevated CECs reductionvia GAC • Full-scale evidence on practicability	• Poor/no reduction of ARB & ARGs via GACalone • For UV see above, TT a & b	• Reducing adsorption capacity with elevating bed volume must be considered
f (PAC and UV)	• Efficient disinfection via UV • Elevated CECs eliminationvia PAC • Full-scale evidence on practicability forCEC removal by PAC	• Poor/no reduction of ARB & ARGs via PACalone • • For UV see above, TT a & b	
g (NF or RO membrane filtration, with potential pre-treatment with MF or UF membranes)	• Efficient disinfection for bacteria (comprising ARB) and protozoa for all membranes; viruses well removed by UF, NF & RO • ARGs well removed by NF and RO • CECs removal from poor (MF, UF) to verygood (NF, RO) following membrane type • RO and partially also NF reduce salinity • For post UV-C see TT a & b	• Poor/no reduction of ARGs at full-scale byMF (for UF some reduction is expected) • Poor CECs elimination for MF and UF • Elevated energy needs for NF and RO • Formation of a substantial concentrate waste stream by NF and RO • For post UV-C see TT a & b	• Effect of membrane features on disinfection, ARB, ARG, and CEC reduction has to be carefully taken into account in design • Consider AOP instead of UV disinfection ifthe risk of unknowns and spills is considered high • Consider high UV doses if NDMA can be suspected in the membrane effluent (e.g. following prior chloramination)

issue worldwide. For that reason, the objective of this work is to focus on the main results of an excellent review presented lately by Rizzo *et al.* [1] who presented a technical contribution via suggesting likely advanced treatment choices to make wastewater reuse safer, in particular with regard to the removal of CECs and ARB & ARGs. They discussed possible BATs for the advanced treatment of urban wastewater involving their benefits and disadvantages.

2) Rizzo *et al.* [1] deduced that a one advanced treatment technique is not enough to reduce the liberation of chemical CECs and ARB & ARGs and make

wastewater reuse for crop irrigation safer; however, an impertinent integration of them (**Figure 1**) and an appropriate controlling program (**Table 1**) would be needed. Such reasoning emerges from the attention that each treatment technique possesses its proper weaknesses/drawbacks, as an illustration:

- a biological post-treatment to eliminate oxidation by-products may be needed when ozonation or AOP is employed as advanced treatment;
- ozonation and AOPs need toxicity monitoring due to probable generation of problematic oxidation reaction products;
- adsorption techniques must be pursued by an efficient disinfection method (*i.e.*, UV disinfection);
- if PAC is utilized, a posterior filtration or membrane process has to be added to eliminate the adsorbent particles;
- chemical disinfection is not efficacious in dealing with CECs and ARGs; therefore, it has to be combined with more advanced treatment techniques. Over and above, probable generation of DBPs (*i.e.*, chlorination by-products) must be taken into account, and the next treatment for their elimination is requisite;
- NF or RO membrane technology needs a pre-treatment (*i.e.*, sand filtration) to avoid blocking and a potential solution for the recycling of membrane concentrate.

3) More comparative investigations between various advanced treatment techniques on real wastewater, following diverse criteria (*i.e.*, CECs removal, ARB & ARGs, toxicity, DBPs, costs) are suggested [1].

4) As seen through this work, there is no miraculous BAT for treating wastewater for water reuse in agriculture. An appropriate combination of many techniques would be suggested following each case.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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