Risk assessment for a wastewater treatment plant including ozonation and GAC filtration as reclamation steps in view of a reuse.

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Abstract
Properly treated wastewater may be an alternative water source for reuse. In this context, in order to assess and manage the risks for the environment and the human health, EU Regulation 2020/741 requires the implementation of a water reuse risk management plan. To this end, the current study presents the risk assessment carried out for a wastewater treatment plant (preliminary treatment, sedimentation, conventional activated sludge system) where the reclamation facility consists of an ozonation followed by a granular activated carbon filtration with a UV disinfection as a safety/emergency step. Attention is towards the suitability of the final effluent for reuse and the health of the plant workers. At first, failure modes and the related effects are identified by means of the Failure Mode and Effects Analysis; then scores (1-5) are assigned to the expected probability of occurrence of each failure and to the magnitude of the related effects (1,2, 4, 8, 16). Finally the two scores are multiplied providing a final score measuring the risk associated to each failure mode. The higher the final score, the higher the risk. Critical failures are those with a final score greater than 32, according to WHO recommendations. Among the eighty failure modes identified for the 55 treatment components, the critical ones were only three (final score = 64) and referred to the aerator and the sludge recirculation pump. According to this analysis, the existing preventive safety measures were reviewed and new ones were suggested to improve the reliability of the system.

Keywords
FMEA, GAC, ozonation, reclaimed water reuse, risk assessment

INTRODUCTION

Currently, the availability of water for irrigation is becoming increasingly scarce, partly due to climate change. European and national regulations highlight the need to provide viable alternative water sources to reduce pressure on water bodies, such as the reuse of reclaimed water. In common urban wastewater treatment plants (WWTPs), additional end-of-pipe treatments are required to ensure that the final effluent meets the quality standards set by the EU Regulation 2020/741 for water reuse. Different consolidated technologies are available (Rizzo et al., 2020). The minimum treatment scheme including a depth filtration and a disinfection aims to reduce suspended solids, bacteria and viruses, but its efficiency in removing organic contaminants of emerging concern (CECs) is not relevant. To reduce their content, the recently revised urban wastewater treatment plant directive UWWTD (EU Directive 2024/3019) requires the implementation of a quaternary treatment. An option could be ozonation followed by adsorption/filtration on granular activated carbon (GAC), as it is already adopted in full-scale WWTPs, e.g. in Switzerland and in Germany (Bourgin et al., 2018; Bealù et al., 2024).

One of the public concerns limiting the practice of reclaimed water reuse is related to the environmental and human health risks. The EU Regulation 2020/741 sets minimum requirements for safe water reuse, including the implementation of a water reuse risk management plan from the production to the supply of reclaimed water. EU Delegated Regulation 2024/1765 remarks that the assessment and the management of the risks for the environment and the human health is a complex exercise which should be based on a multidisciplinary approach. Existing international guidelines or standards, such as the Sanitary Safety Plan (SSP) by WHO (WHO, 2022) can be followed.

Within the framework of the SSP, this study carries out a risk assessment by means of the Failure Mode and Effects Analysis (FMEA) referring to the whole treatment plant where the end-of -pipe treatments (ozonation, GAC filtration and the optional UV disinfection) represent the reclamation facility with the aim of producing an effluent suitable for irrigation needs. The study leads to the identification of the major risks for the final effluent quality and the worker health and it completes with the analysis of the effectiveness of the existing preventive safety measures and the need to adopt new ones to reduce the risks.

MATERIALS AND METHODS

The treatment steps under study are reported in Figure 1 and consist of preliminary treatments (screening, degritting and degreasing), primary sedimentation, conventional activated sludge system (with denitrification -nitrification and phosphorus coprecipitation followed by a secondary sedimentation), ozonation (including air pretreatments, ozone generation, ozone contact and ozone destruction), GAC adsorption/filtration. In addition a UV disinfection is included acting as a safety/emergency step to guarantee a disinfected effluent mainly for the reuse period.

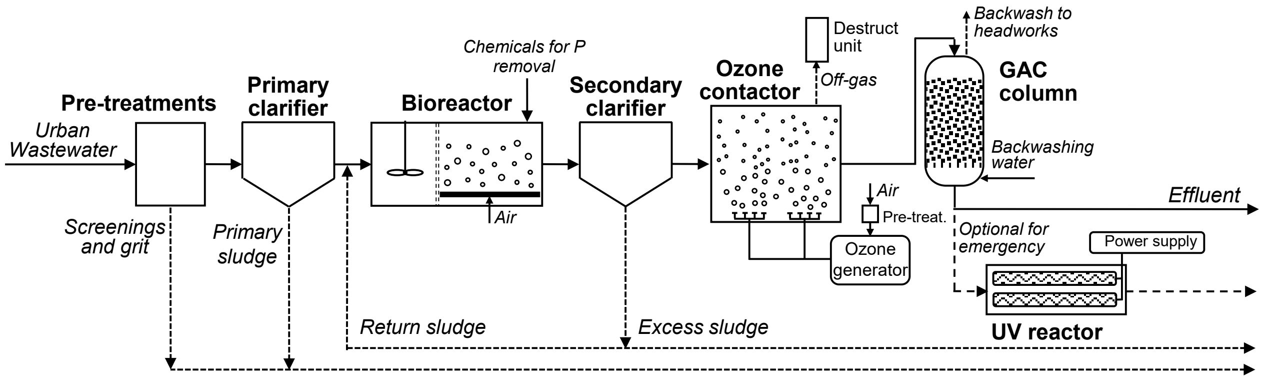

Figure 1. Treatment train under study with the different steps.

The risk assessment carried out starts with a Failure Mode and Effects Analysis (FMEA) in order to identify the failure modes of the components of the different treatment steps (i.e. malfunctions, leaks, ruptures, releases, etc.) and their main potential effects on the suitability of the final effluent for irrigation needs and the worker health. The results of this analysis are compiled in a table. Then, according to the SSP guidelines (WHO, 2022), the study assigns a score to the expected probability of the occurrence S_O (1–5), and the magnitude of the effects S_M (1,2,4,8,16) of each failure mode: the higher the expected probability of occurrence and the magnitude, the higher the score.
Due to the lack of experimental data, the scores were assigned on the basis of interviews to 3 experts in urban wastewater treatment and reuse ((waste)water utility company staff). In the case of discrepancies among the scores, the highest values were assumed.
The product of the two scores leads to a final score S (eq. 1) measuring the risk associated to each failure mode and ranging from 1 to 80:

$$S = S_O \times S_M \qquad \text{eq. 1}$$

Failure modes are then ranked according to the decreasing S values. In agreement with WHO (2022), the risk for a failure is low if $S < 6$; the risk is medium if $6 \leq S \leq 12$; it is high if $12 < S \leq 32$ and very high if $S > 32$. The failure modes with the highest values of S are the most critical for the system under study.
A risk reduction requires an evaluation of how to reduce the occurrence of the failures or how to mitigate the effects.

RESULTS AND DISCUSSION

The FMEA was developed for the identified 55 components of the treatment steps reported in Figure 1 leading to a list of 80 failure modes with the related effects. Scores were assigned to the expected probability of occurrence of each failure and to the magnitude of its effects, as described in Materials and methods, and then the final scores were evaluated by eq. 1.

Figure 2 reports the distribution of the frequency of *S* for the studied treatment train. It emerges that the highest frequencies of the final score *S* were found for $S = 4$ (low risk level, frequency equal to 15%) corresponding to 12 failure modes, $S = 32$ (high risk level, frequency equal to 13.75%), corresponding to 11 failure modes, and $S = 3$ (low risk, frequency equal to 12.5 %) and $S = 8$ (medium risk, frequency of 12.5 %) referring to 10 failures modes each. A very high risk ($S = 64$, frequency equal to 3.66 %) was found for 3 failure modes referring to the biological compartment as described in Table 1. The main risk for the health of the WWTP workers is related to the confined workplace where ozone is produced and the resulting final score corresponds to high risk.

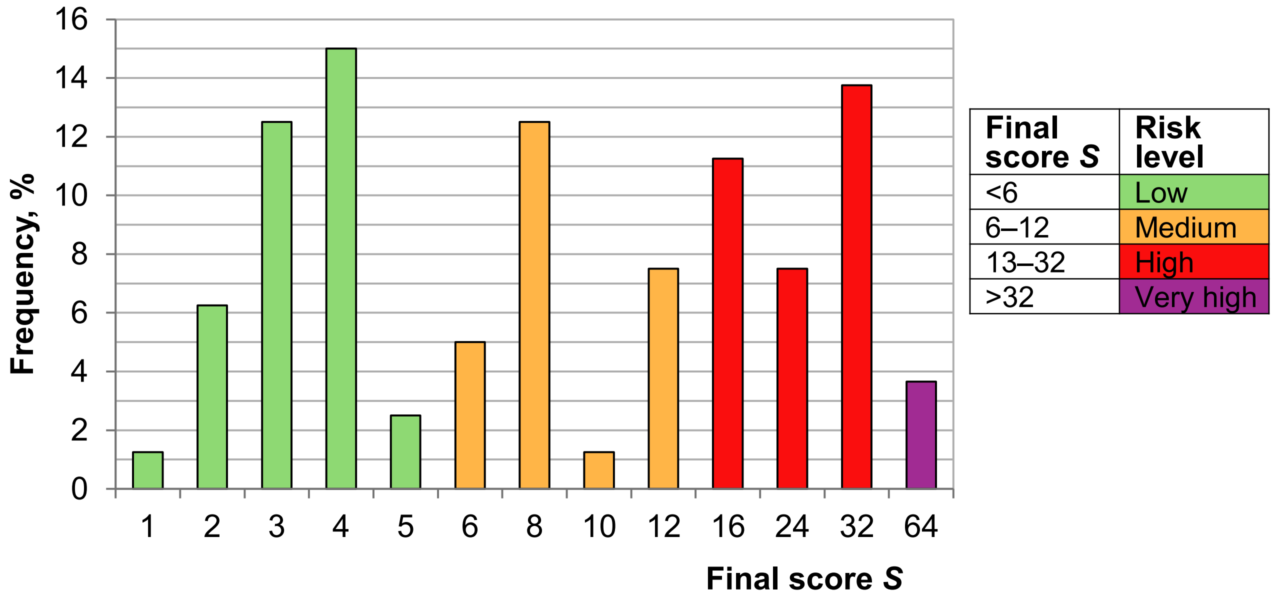

Figure 2. Distribution of the final score for the listed failure modes

Table 1. Details of the failure modes resulting with a very high risk: treatment step, component, failure mode, effects and final score.

Treatment step	Component	Failure mode	Effects	Final score
Bioreactor	Aerator	Breakage of the blower	No oxidation of carbon and nitrogen compounds	64
	Recirculation pump	Pump fails to close	Higher amount of sludge returned to the bioreactor and too high sludge sent to the sedimentation tank	64
	Recirculation pump	Pump fails to open	Lower amount of sludge returned to the bioreactor, lower removal of carbon and nitrogen	64

In order to reduce the risk associated to these failure modes, actions may be suggested to reduce the expected probability of their occurrence and to improve the reliability of the treatment train and thus the quality of the final effluent. These actions consist of:

- planning a higher frequency of inspection of the blower;
- providing a standby blower to alternate during the operation;
- planning higher frequency of inspection of the recirculation pump;

- providing a standby pump to alternate during the operation.

CONCLUSION

The current study wants to identify the risks associated to the failure modes which may occur in an urban WWTP including end-of-pipe-treatments (quaternary treatments) in order to produce an effluent adequate for a direct reuse. By means of the FMEA approach, a list of failure modes and the corresponding effects for the effluent quality and the human health was developed. Then based on experts' opinion, scores were assigned to the expected probability of occurrence (S_O) and magnitude of effects (S_M) for each failure mode. The final score obtaining by their product measures the risk for each failure: the higher the value, the higher the risk.

In this way it was possible to identify the most critical failures corresponding to those with the highest risk and find actions to reduce the risk: by reducing the expected probability of occurrence of the corresponding failure modes or by mitigating their effects. The list of potential actions allows to select the most effective ones, that are the new preventive safety measures to add.

These results and more in general the described approach can be useful to WWTP practitioners, involved in the development of a water reuse risk management plan according to the EU Delegated Regulation 2024/1765.

REFERENCES

Béalu, Z., Walther, J., Abusafia, A., Altmann, K., Meurer, M., Gretzschel, O., Schäfer, M., Steinmetz, H., 2024. Removal of Organic Micropollutants and Microplastics via Ozonation Followed by Granular Activated Carbon Filtration, *Environments*, **11**(11), 241. https://doi.org/10.3390/environments11110241

Bourgin, M., Beck, B., Boehler, M., Borowska, E., Fleiner, J., Salhi, E., Teichler, R., von Gunten, U., Siegrist, H., McArdell, C.S., 2018. Evaluation of a full-scale wastewater treatment plant upgraded with ozonation and biological post-treatments: Abatement of micropollutants, formation of transformation products and oxidation by-products, *Water Research*, **129**, 486-498, https://doi.org/10.1016/j.watres.2017.10.036

EU Delegated Regulation 2024/1765. Commission Delegated Regulation (EU) 2024/1765 of 11 March 2024 supplementing Regulation (EU) 2020/741 of the European Parliament and of the Council with regard to technical specifications of the key elements of risk management, *Official Journal of the European Union*, 2024, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024R1765

EU Directive 2024/3019. Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment, *Official Journal of the European Union*, 2024, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=OJ%3AL_202403019

EU Regulation 2020/741. Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, *Official Journal of the European Union*, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0741&from=EN

Rizzo, L., Gernjak, W., Krzeminski, P., Malato, S., McArdell, C.S., Perez, J.A.S., Schaar, H., Fatta-Kassinos, D., 2020. Best available technologies and treatment trains to address current challenges in urban wastewater reuse for irrigation of crops in EU countries. *Science of the Total Environment*. **710**, 136312. https://doi.org/10.1016/j.scitotenv.2019.136312

WHO, 2022. Sanitation safety planning: step-by-step risk management for safely managed sanitation systems, World Health Organization, Genova, https://www.who.int/publications/i/item/9789240062887