Wastewater Reclamation – opportunities and challenges

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Abstract
Water scarcity poses a growing global challenge, intensified by climate change, population growth, and rising water demand. Municipal wastewater reclamation offers a sustainable solution, transforming waste into a resource. This study, conducted within the ReNutriWater project, evaluates the potential of reclaimed water to supplement fertilizer nutrient demand, focusing on nitrogen (N), phosphorus (P), potassium (K), and total organic carbon (TOC). Treated wastewater from a large municipal WWTP was disinfected using three methods: chlorination, ozonation, and UV irradiation. Results indicate that ozonation provides the most effective microbial disinfection but reduces nutrient concentrations more than chlorination or UV. Nutrient retention was highest following UV and chlorination, with potassium showing the greatest potential for meeting plant nutrient requirements. The study underscores that nutrient levels in reclaimed water depend on both the disinfection method and the operational parameters of the treatment plant. Thus, optimized WWTP control strategies can enhance nutrient recovery and support water reuse. This work highlights key challenges and opportunities for integrated water and nutrient recycling systems.
Keywords: water scarcity, municipal wastewater, water recovery

1. Introduction

Water scarcity is a global phenomenon severely impacting numerous communities worldwide. In 2022 alone, over 2 billion people lacked access to safely managed water. Furthermore, the problem of water shortages is projected to be intensified by the climate change-related rise of global temperatures, growing population, and increasing water demand. Undoubtedly, there is a growing need for solutions addressing the issue of freshwater shortages and providing both sustainable and accessible water supply in the future. Such solutions include municipal wastewater reclamation, which is tapping into the potential of turning hazardous waste into a valuable resource.
Water recovery technologies are very different; several processes are usually combined and selected for a specific purpose of water use. When choosing a technology, it is essential to consider three main aspects: 1) ecological, 2) economical, 3) regulatory. Well-selected technology removes various pollutants, including micropollutants (heavy metals, pharmaceuticals, pesticides, biocides, perfluoroalkyl substances, and microplastics). It also allows for the destruction of living and spore forms of pathogenic organisms and prevents their secondary development. Simultaneous recycling of water and nutrients is also possible, i.e. selecting the amounts and chemical forms of nitrogen (N), phosphorus (P), potassium (K), and total organic carbon (TOC), which can influence nutrient availability and microbial activity, affecting soil health and crop productivity (Weinrich 2010).
Recovering water from wastewater is a concept that is becoming interesting for urban WWTPs operators. Most operators close internal circuits or use treated wastewater in the technological processes of plants. However, external use, e.g., washing streets or watering public green areas, is still unpopular. The potential is most significant here due to saving resources (drinking water). Integrating nutrient recovery into water reuse supports circular economy goals and reduces environmental impacts (Zhang et al. 2020). Ozonation enhances biodegradability (Yang et al. 2010), and when combined with coagulation, improves removal of dissolved organic nitrogen (Wu et al. 2021). UV-chlorine treatment reduces micro-pollutants (Zhang et al. 2020). Ozonation also aids sludge reduction and nutrient release (Semblante et al. 2017).
In the ReNutriWater project, the possibility of using reclaimed water is assessed depending on the local conditions of a given WWTP. Particular attention will be paid to the challenges faced in the context of water recovery from municipal wastewater. This study investigates the effect of three disinfection methods - chlorination, ozonation, and UV irradiation - on the concentrations of N, P, K, and TOC in reclaimed water. Understanding these interactions is essential for optimizing urban water reuse strategies while preserving nutrient value in the reclaimed water.

2. Methods

The concentrations of nitrogen (N), phosphorus (P), potassium (K), and total organic carbon (TOC) before and after disinfection processes were measured. Three disinfection methods were analyzed. Chlorination was performed using sodium hypochlorite (NaOCl, 4 mg Cl_2/l) with contact time 20 min. Ozonation was carried out using an ozone generator from KoronaLab (flow rate 8 l/min, 5 min. contact time). UV disinfection was conducted using 279 mJ/cm^2 irradiation dose.
The concentrations of phosphorus (P), and potassium (K) were determined using a Hach DR3900 spectrophotometer and dedicated Hach cuvette tests (LCK 349, LCK 228). Nitrogen (N) and total organic carbon (TOC) were marked on a Shimadzu TOC-L CSN total organic carbon analyzer with TNM-L total nitrogen determination device. Each determination was repeated three times.
The wastewater samples originated from municipal WWTP with population equivalents (PE) of 2 425 000.

3. Results

The best effect in terms of disinfection was obtained for ozonation (Table 1).

Table 1. Values of selected indicators in terated wastewater (TW) and after disinfection processes

Parameter	TW	Chlorination t=20 min.; 4,0 mg Cl_2/l	Ozonation t=5 min.; 125 mg O_3/l	UV 279 [mJ/cm^2]
Escherichia coli [number/100 ml]	>80	16	0	44
TPC at 22°C [cfu/1 ml]	1370	31	33	720
TPC at 36°C [cfu/1 ml]	2430	132	43	179
N [mg/l]	5.213	4.183	3.372	5.194
P [mg/l]	0.269	0.265	0.259	0.262
K [mg/l]	25	24.5	23.4	21.4
TOC [mg/l]	6.245	4.826	5.005	6.208

However, when analysing the results in terms of nutrient changes, it can be observed that chlorination and UV cause the smallest reductions.

Assuming water demand for grass of 0.5-3.0 l/m^2 and a 5-month watering period, the seasonal coverage of nutrient requirements was determined (Table 2). The highest demand coverage in all disinfection method is observed for K.

Table 2. Determining the coverage of the demand for nutrients for grass

covering the demand [%]	TW	Reclaimed water		
		Chlorination	Ozonation	UV
N	1.63-9.77	1.31-7.84	1.05-6.32	1.62-9.74
P	0.34-2.02	0.33-1.99	0.32-1.94	0.33-1.97
K	15.63-93.75	15.31-91.88	14.63-87.75	13.38-80.25

4. Conclusions

Water reuse processes can significantly contribute to meeting the demand for fertilizer nutrients, supporting sustainable agriculture. However, the efficiency of nutrient recovery depends on their concentrations in treated wastewater, which are influenced by wastewater treatment plant operations. Optimizing process control can therefore enhance the availability of recovered nutrients.

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