

Risk Assessment for Water Reuse in Irrigating Green Areas on a University Campus



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Abstract The increasing scarcity of water resources, exacerbated by climate change, calls for more sustainable and innovative approaches to water management. This study examines the feasibility and benefits of using Water for Reuse (WfR) for irrigation at the Polytechnic Institute of Viseu campus in Portugal. By using WfR, the university aims to reduce its reliance on potable water, promote sustainability, and enhance the resilience of its landscape management practices. However, assessing potential risks is crucial. Risks associated with the WfR from the Viseu Sul Wastewater Treatment Plant (WWTP) for green space irrigation on campus were evaluated, focusing on public health and water resource impacts. A semi-quantitative risk assessment methodology was applied, analysing microbiological, chemical, and physical parameters to ensure the treated water meets safety standards for its intended use. Three receptor groups were considered: maintenance workers, students/faculty, and visitors. Results showed the feasibility of producing and using WfR for irrigation, with the overall risk being below 3, considered negligible. The global public health risk was 0.72, with maintenance workers having the highest individual risk (0.75). The global risk for water resources was 2.30 for nitrogen and phosphorus, and 0.8 for microbiological risks. All risks were considered insignificant, making the use of WfR a viable and safe solution for sustainable water management.

Keywords Wastewater reuse · Risk assessment · Irrigation of green areas

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1 Introduction

One of the major environmental challenges today is water scarcity. Climate change, combined with industrial, agricultural, and population growth, is exacerbating this situation [1]. Access to water and sanitation is one of the United Nations (UN) Sustainable Development Goals (SDGs), specifically SDG 6—Clean Water and Sanitation [2]. In this context, the reuse of treated wastewater, usually defined as Water for Reuse (WfR), emerges as one of the strategies to achieve this goal, presenting an innovative and sustainable solution to reduce the impacts related to water scarcity. This process enables the treatment and reuse of urban wastewater, thus reducing pressure on freshwater sources [3].

WfR is essential for central Portugal, especially during summer when water shortages compromise public supply [4]. The use of WfR emerges as a sustainable alternative, reducing dependence on potable sources. However, its uncontrolled use can negatively affect soils and plants in the long term [5, 6]. While it provides nutrients and reduces fertilizer costs, it may also cause soil and plant contamination with metals, organic compounds, and pathogenic microorganisms [6], impacting fertility and food safety.

To mitigate these risks, it is crucial to adopt a risk management approach based on quality standards such as ISO 16075–1:2015, ensuring that WfR meets the required standards [7].

In this context, this study evaluates the feasibility of WfR from the Viseu Sul Wastewater Treatment Plant (WWTP) for irrigating green areas at the Polytechnic Institute of Viseu (IPV). Despite the recognition of WfR as a sustainable solution, there is a lack of studies that assess the risks in an integrated manner in urban contexts such as university campuses. Universities play a key role in promoting sustainable practices, and this project can serve as a model for efficient water management, ensuring water security, environmental protection, and the valorization of treated wastewater, aligned with the principles of the circular economy and sustainable water management.

2 Materials and Methods

2.1 Case Study

The risk assessment for using WfR from the WWTP Viseu Sul for irrigating the campus green spaces has been conducted. The water will be transported by tank truck to the campus, where it will be stored in a lagoon (3200 m³), with no additional treatment of WfR. This lagoon has a water capture system that directs the water to the irrigation system for the green areas, ensuring efficient use of WfR. Irrigation will be carried out during the summer months and preferably at night, to reduce the exposure of the receptors.

The Viseu Sul WWTP treats wastewater from urban and industrial sources, serving 73,900 people and treating an average of 14,500 m³ of water per day. Managed by SMASV (Serviços Municipalizados de Água e Saneamento de Viseu), it includes pre-treatment, biological treatment, and membrane ultrafiltration, providing tertiary treatment with a membrane bioreactor (MBR) and optional chlorination disinfection, with treated water quality monitored through chemical and microbiological analyses. SMASV is licensing WfR for the irrigation of Viseu's green areas, including the campus.

The campus is 14.5 acres, including 5 acres of permeable, green spaces. It has 5000 m² of landscaped areas. Figure 1 shows the layout of the Campus green areas.

Water consumption is significant, around 4000 m³/year. Since 2018, IPV has been certified as Sustainable Campus—Portugal. The reuse of treated water from the Viseu Sul WWTP for irrigation reduces the dependence on other water sources.

The Campus is in the Vouga, Mondego, and Lis hydrographic regions (RH4), within the Central-Iberian Zone of the ancient undifferentiated massif [8]. This area is mainly of eruptive and metasedimentary rocks with low hydrogeological suitability, leading to poor aquifers and limited groundwater resources [9]. The water infiltration rate in the Ancient Massif is estimated at 10–20% [9].

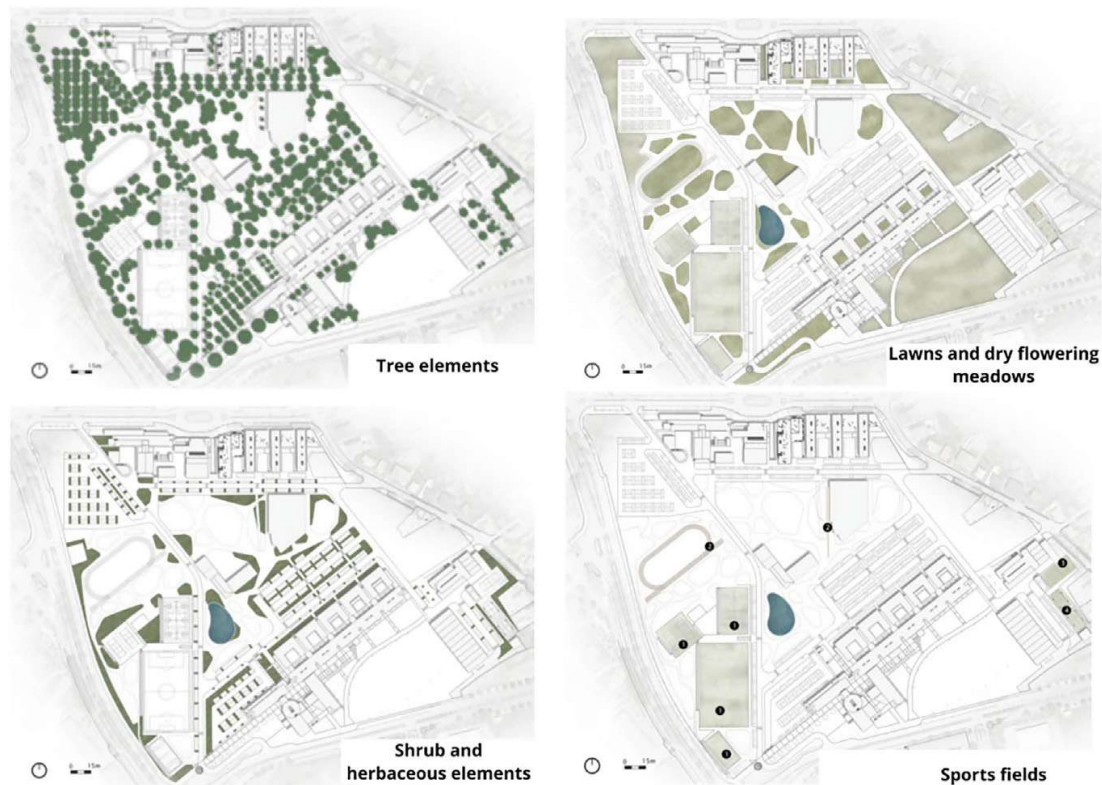


Fig. 1 Mapping of major landscape components on campus, including trees, lawns and dry flower plantings, shrub and herbaceous vegetation, and athletic areas

2.2 Risk Assessment

The risk assessment analyzes threats to public health and water resources using a semiquantitative model based on Saaty’s importance scale [10], ranging from 1 (low importance) to 9 (absolute importance). The methodology follows the “Guide for Water Reuse—Non-Potable Uses” by the Portuguese Environment Agency (APA) [11].

For public health, risks are assessed using microbial indicators, primarily Escherichia coli (E. coli) as risk indicator. For water resources, risks include chemical and microbiological contaminants, with nitrogen and phosphorus as key hazards in vulnerable areas.

Exposure assessment determines hazard significance through pathways and scenarios [12]. Public exposure occurs via ingestion, inhalation, or dermal absorption, each assigned an importance factor ($f_{i.via}$) and adjusted by contact probability (f_{iC} , Prob) to obtain a corrected importance factor ($f_{i.cen}$). Risk-reducing barriers (Beq) are considered. Water resources are exposed through emissions, discharges, and leaks, with barriers assigned specific importance values ($f_{i b}$).

Receiver vulnerability (V_{rec}) is determined by exposure route importance ($f_{i.via}$), corrected scenario importance ($f_{i.cen}$), and a normalization factor (f_{normal}). Global vulnerability (V_g) is calculated from the vulnerability of groundwater ($V_{pag sub}$) and surface water ($V_{pag sup}$), weighted by implemented barriers (f_{ib}) and their respective importance factors—Eqs. 1–6 (Table 1).

Damage assessment combines the probability of barrier failure with event severity, affecting both human health and water resources. Global damage (D) integrates partial damages (d_i) across barriers, normalized by the highest importance value (f_{imax})—Eqs. 7 and 8.

For public health, receptor risk (R_{rec}) is computed by multiplying hazard level (P), receptor vulnerability (V_{rec}), and damage (D). Global risk (R_{global}) is the average

Table 1 Equations for calculating risk assessment for WfR for public health and water resources [11]

	Public health	Eq.	Water resources	Eq.
Vulnerability	$V_{rec} = \frac{f_{i.via} \times f_{i.cen}}{f_{normal}}$	(1)	$V_g = V_{hri} \times \frac{\sum f_{ib}}{f_{i \max} \times n_{cen}^o}$	(3)
			$V_{rh} = V_{pagsub} \times f_{pagsub} + V_{pag sup} \times f_{pag sup}$	(4)
	$f_{normal} = f_{i \max} \times (f_{i.via} \times n_{cen}^o)$	(2)	$f_{pagsub} = \frac{V_{pagsub}}{V_{pagsub} + V_{pag sup}}$	(5)
			$f_{pag sup} = \frac{V_{pag sup}}{V_{pagsub} + V_{pag sup}}$	(6)
Damage	$D = \frac{\sum (d_i \times n)}{f_{i \max} \times n}$			(7)
	$d = \frac{S \times P}{5}$			(8)
Risk	$R_{rec} = P \times V_{rec} \times D$	(9)	$R_{rh} = \frac{P \times V_g \times D}{9}$	(11)
	$R_{global} = \frac{\sum R_{rec}}{n_{rec}^o}$	(10)		

of all receptor risks—Eqs. 9 and 10. For water resources, risk (R_{rh}) is determined by multiplying hazard level (P), global vulnerability (V_g), and damage (D), normalized by 9—Eq. 11.

The risk was divided into three levels regarding the acceptability of the global risks presented: Risk is considered low (<3), moderate ($3-7$), or high (>7).

3 Results

3.1 Public Health Risk Assessment

As the hazard indicator for water reuse is the concentration of *E. coli* in WfR, the value referring to the hazard found for use in irrigation of green spaces was considered an importance factor of 1, very low. This is due to the advanced water treatment method, including MBR ultrafiltration, which ensures that the recovered water meets the quality standards required for irrigation [13].

Three groups of receptors were determined for the use of WfR in the irrigation of green spaces, namely: Worker—Green Area (Workers responsible for the maintenance of green areas), Teachers/Students (They frequent the location more regularly), General Population (Local community that frequents the location less regularly). According to Rebelo et al. [14] microbial contaminants, such as enteric viruses and *E. coli*, pose significant risks to human and animal health, which explains the importance of a semi-quantitative assessment to effectively assess these risks.

Evaluating all possible routes of exposure—ingestion, dermal contact, and inhalation—is crucial to understanding the risks associated with using reclaimed water. Water quality at the point be considered [15]. In this context, 47 exposure scenarios were identified, divided between ingestion, inhalation and dermal adsorption (Table 2).

The General Population has the most exposure scenarios (44) but is not the most vulnerable (0.88). The most vulnerable group is Green Area Workers, with 29 scenarios and a vulnerability of 0.91, due to their direct contact with WfR, increasing both the importance factor and probability of exposure. Five barriers were implemented in the project (Drip irrigation, sprinkler irrigation, worker's training, use of personal protective equipment -PPE and non-potable water signaling), and the total

Table 2 shows the receivers' vulnerabilities and scenarios Table 2. Vulnerability, in terms of public health of receptors for using WfR in irrigating green spaces

Receiver	No. scenarios	Vulnerability
Worker—green area	29	0.91
Teachers/Students	30	0.85
General population	44	0.88

Table 3 Risks, in terms of public health of using WfR in watering green space

Receiver	Hazard	Vulnerability	Damage	Risk
Worker—green area	1	0.91	0.82	0.75
Teachers/Students	1	0.85	0.82	0.70
General population	1	0.88	0.82	0.72
Global risk	0.72—Despicable			

damage was 0.82. The presence of multiple barriers helped reduce the overall risk, following the concept that more barriers lead to greater damage reduction.

The general risk of the project for each recipient was calculated after defining the hazard, vulnerability and damage (Table 3).

It is possible to observe that the factor that most influences individual risk was the vulnerability of the recipient, as the damage and danger remain the same for different recipients. Workers in green areas have the highest individual risk, with values of 0.75. This is because these receptors have the greatest exposure to WfRs.

The overall risk of the project was 0.72, considered negligible, which means that the use of WfR in irrigation does not pose any relevant risks to public health.

3.2 Risk Assessment for Water Resources

The IPV is located in a sensitive area as defined by Decree-Law no. 152/97 and its subsequent amendments. The identified hazard indicators were nitrogen and phosphorus concentrations in treated wastewater and microbiological risk (*E. coli*). In 2022, the treated wastewater showed average concentrations of nitrogen and phosphorus, both assigned an importance factor of 3, while *E. coli* had an importance factor of 1. According to Ganoulis [16], it is essential to assess the potential of contaminants to affect local ecosystems, including soil and water bodies, especially WfR use for irrigation. Despite the possibility of implementing barriers, no barriers were implemented after risk assessments showed low risks and good water quality. The importance factors, partial damage, probability, and severity were all given maximum values of 9, 9, 5, and 5, respectively, resulting in a damage value of 1. The receptors were classified based on the region's hydrogeological characteristics: surface water with medium runoff, and groundwater with no hydrological continuity and low infiltration. These classifications allowed for the calculation of vulnerability (Table 4).

For surface waters, the partial vulnerability was high (6), while for groundwater, it was low (2). The global vulnerability was 7, considered high. With the hazards, vulnerability, and damage defined, the global risk value for each indicator was then evaluated (Table 5).

Table 4 Receptor and global vulnerability for water resources

Receiver	Partial vulnerability (V_p)	Vulnerability resources H. (V_{hr})	Vulnerability R. H. in importance ($V_{hr i}$)
Surface water	6	5	7
Subterranean water	2		
Global vulnerability (V_g)		7	

Table 5 Global risks to water resources

Indicator	Hazard	Vulnerability	Damage	Global risk
Nitrogen	3	7	1	2.33—Despicable
Phosphor	3	7	1	2.33—Despicable
Microbiological	1	7	1	0.80—Despicable

The general risks to water resources from nitrogen, phosphorus, and microbiological indicators were assessed at 2.33 and 0.80, respectively. The risk is considered despicable for all three indicators, showing no significant risks.

The use of WfR is an essential strategy for water sustainability, as it can meet a significant fraction of irrigation needs, expanding cultivated areas and reducing pressure on conventional water resources [17]. This practice promotes nutrient recycling, reducing dependence on chemical fertilisers and improving soil health, while helping to sequester carbon and mitigate CO₂ emissions, contributing to sustainability goals [18]. The results of this study indicate that the risks of WfR are negligible, demonstrating the viability of using WfR for irrigation of green areas on the IPV campus. This practice is environmentally responsible because it reduces the extraction of water from natural sources, minimizes the discharge of effluents into water bodies, contributes to the recycling of nutrients in the soil and helps to mitigate CO₂ emissions, promoting a sustainable cycle of water resource management [16]. The management of information for all stakeholders, sustaining individual motivation and exhibiting organizational commitment, encouraging communication and public dialogue, guaranteeing a fair and sound decision-making process and outcome, and establishing and preserving trust are also key features for fostering and preserving public confidence in water resource management and water reuse decision-making. The head responsible should have guidelines for evaluating community awareness and creating a principle-based strategy for public engagement, education, and outreach [19].

4 Conclusions

The risk assessment for the WfR on campus demonstrates the viability of this practice for irrigating green spaces. With a public health risk of 0.72 and risks to water resources of 2.33 for nitrogen and phosphorus indicators and 0.78 for microbiological risk, the results indicate that WfR for irrigation on campus is feasible and does not present significant concerns for the population or the environment.

These results emphasise the importance of water reuse as an effective solution to mitigate water scarcity effects, aligning with IPV's sustainability practices. The institution is committed to implement good environmental practices and sustainable development, promoting efficient water resource management on campus.

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