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# Office Greywater Influents: Variability and Impact on Decentralised Treatment in Sustainable Building Systems

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## ABSTRACT

The performance of decentralised greywater treatment systems is strongly influenced by influent variability and user behaviour. Greywater, typically the output of sinks and showers, is increasingly recognised as a recoverable water source which can be used to reduce potable water demand in buildings. This study investigates the characteristics of light greywater generated from handwashing basins in a complex of commercial buildings, with a focus on intra-building variability and behaviour-driven influences. Greywater samples were collected from three sinks located across two separate buildings: two within the main office building and one within a workshop building representing distinct user groups over five consecutive working days. Composite samples were obtained by combining greywater collected during morning and post-lunch periods to represent typical daily conditions. Samples were analysed for chemical oxygen demand (COD), biochemical oxygen demand (BOD), and methylene blue active substances (MBAS) to evaluate organic loading, biodegradability, and surfactant content. The results demonstrate measurable differences in greywater composition between sampling locations, indicating that user behaviour and workplace activities influence both organic and surfactant loads which should be carefully considered when specifying and developing greywater treatment systems for different users. COD of greywater in the trial varied from 20 mg/L to 1500 mg/L over the period of analysis. These represent a range between 20% and 300% of the typical literature values demonstrating the importance of understanding handwashing in commercial environments. The combined analysis of COD, BOD, and MBAS provides insight into the relative contributions of biodegradable and surfactant-derived fractions of greywater. These findings highlight the importance of accounting for variability in greywater influent when developing design assumptions for decentralized treatment systems. The study contributes to the limited body of empirical data on office greywater and emphasises the role of behaviour-driven variability in shaping wastewater characteristics relevant to system performance and resilience.

KEYWORDS Greywater, Decentralised treatment, Influent variability, User behaviour, Surfactants

## 1. Introduction

In January 2026 The United Nations said “The world has moved beyond a water crisis and into a state of global water bankruptcy” (UN News 2026). Now more than ever, innovative solutions to recover non-sewage water are needed to ensure access to water for the population.

Water scarcity is an increasing global challenge affecting domestic, industrial, and agricultural sectors (Gutiérrez and Glückler 2022). Optimising water resources is essential to balance rising demand driven by population growth, urbanisation, and climate change (Oteng-Peprah *et al.* 2018; Lim *et al.* 2015). In the UK, a severe deficit is projected by 2055, with an estimated shortfall of 5 billion

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litres per day (Stormsaver Ltd no date). Agriculture remains one of the most water-intensive sectors, with approximately 307 million hectares under irrigation (Simmons *et al.* 2022). To address these pressures, water reuse systems are being promoted, with projections suggesting that up to 1 billion litres per day could be saved in new buildings between 2026 and 2050 (Stormsaver Ltd no date). As freshwater resources become increasingly limited, greywater reuse is emerging as a viable strategy to reduce demand on potable supplies (Abed *et al.* 2020).

Greywater is domestic wastewater from non-toilet sources, including bathing, handwashing, laundry, and dishwashing, typically accounting for 50–80% of household wastewater (Radingoana *et al.* 2020). It contains suspended solids, organic matter, nutrients, surfactants, oils, and microorganisms, generally at lower concentrations than blackwater (Radingoana *et al.* 2020). This makes it suitable for non-potable reuse applications such as irrigation and toilet flushing, contributing to decentralised water management. However, its composition remains complex and variable, including organic and inorganic substances, heavy metals, and microbial contaminants (Van de Walle *et al.* 2023). While treatment is generally less energy intensive than for blackwater (González *et al.* 2025), variability in greywater quality presents challenges for system design.

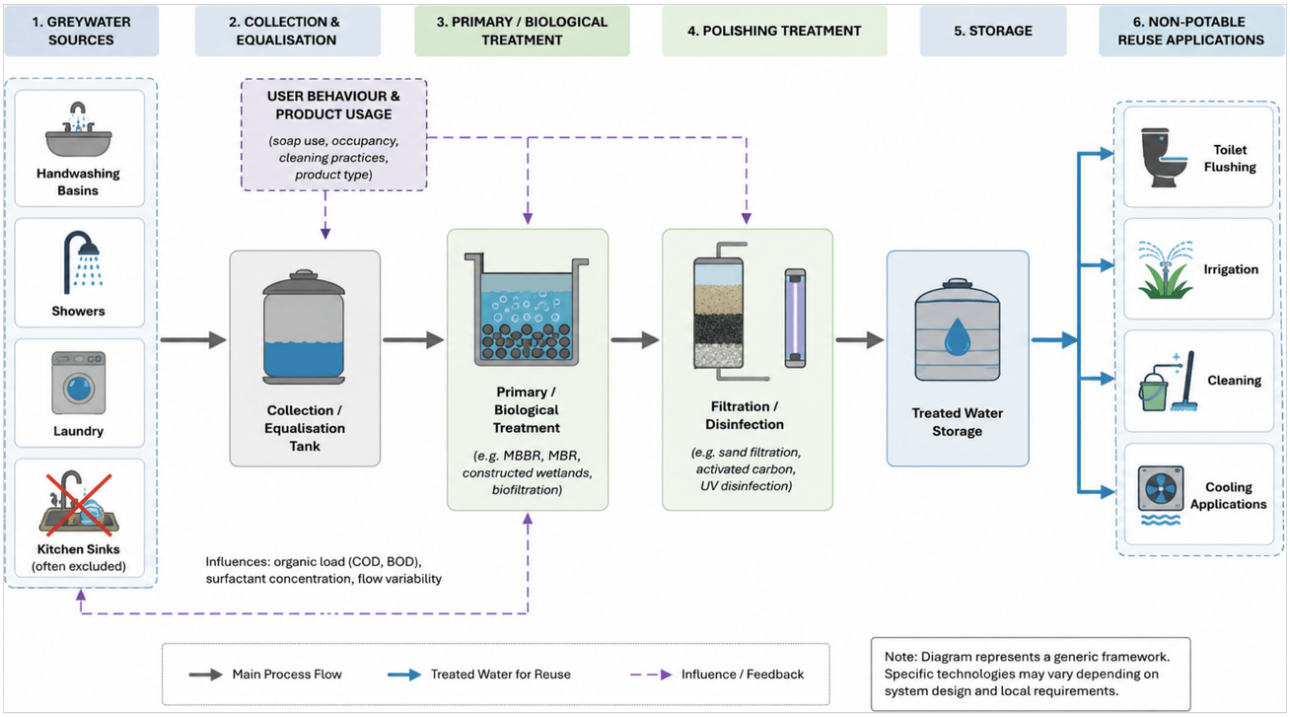


**Figure 1.** Conceptual framework of decentralised greywater treatment and reuse pathways in sustainable buildings.

Influent quality is a critical determinant of treatment performance, influencing reactor sizing, process selection, and operational stability. Greywater variability, driven by usage patterns, dilution, and product inputs, is typically characterised using bulk parameters such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand ($BOD_5$), and Methylene Blue Active Substances (MBAS) (González *et al.* 2025). COD represents total oxidisable matter and typically ranges from ~100–800 mg/L (Van de Walle *et al.* 2023; Khan *et al.* 2026), while $BOD_5$, indicating biodegradable content, commonly ranges from ~50–400 mg/L (Van de Walle *et al.* 2023; Khan *et al.* 2026). The BOD/COD ratio (typically ~0.3–0.7) provides insight into biodegradability and treatment suitability (Khan *et al.* 2026). MBAS quantify anionic surfactants from detergents (Naimah *et al.* 2026), which can inhibit biological processes and affect system performance. Reported MBAS concentrations range from ~40–450 mg/L (Noutsopoulos *et al.* 2018; Van de Walle *et al.* 2023), often exceeding 10 mg/L (Larsen *et al.* 2013). Together, these parameters define total load, biodegradability, and surfactant influence, all of which are essential for effective treatment design (Van de Walle *et al.* 2023; Khan *et al.* 2026).

Despite extensive research on greywater, most studies focus on residential systems (Lim *et al.* 2015; Radingoana *et al.* 2020; González *et al.* 2025; Noutsopoulos *et al.* 2018), with limited attention to office environments. Office greywater is generated under different conditions, characterised by lower organic loads, higher variability, and behaviour-driven usage patterns. Factors such as handwashing frequency, product type, and intermittent flows influence key parameters (COD, BOD, MBAS), yet these behavioural effects are rarely quantified.

Consequently, there is a lack of site-specific data linking user behaviour to influent quality in office greywater systems, creating uncertainty in design and performance prediction. This study addresses this gap by characterising office-derived greywater and assessing the influence of behaviour on key water quality parameters, providing an evidence base for improved system design and operation.

## 2. Literature review

This chapter reviews the existing literature relevant to greywater reuse, with a particular focus on influent characterisation and its implications for treatment design. It begins by outlining the fundamental properties of greywater, including typical sources, composition, and variability, before examining commonly used water quality indicators such as COD, BOD, and surfactants, which are critical for assessing treatment requirements.

The chapter then evaluates established treatment approaches for greywater, with emphasis on biological and physical processes applicable to decentralised systems. Particular attention is given to how influent quality influences process selection, sizing, and operational stability. Finally, the review highlights current knowledge gaps, especially the limited empirical data on office-derived greywater and the influence of user behaviour on wastewater characteristics, thereby establishing the context and justification for the present study.

### 2.1. Greywater Characteristics

Greywater is a heterogeneous wastewater stream whose composition depends strongly on its source within a building. Typical concentrations of chemical oxygen demand (COD) in greywater are reported in the range of approximately 100–800 mg/L, while biochemical oxygen demand ($BOD_5$) commonly falls between 50–400 mg/L (Van de Walle *et al.* 2023; Khan *et al.* 2026; Bogart *et al.* 2025). These values, however, are highly variable and should be treated with caution, as they are influenced by water use habits, dilution, and product usage patterns (Noutsopoulos *et al.* 2018).

Significant differences exist between greywater sources. Bathroom greywater (showers and hand basins) generally exhibits lower organic strength and solids content but may contain personal care products and microorganisms (Van de Walle *et al.* 2023; González *et al.* 2025). Laundry greywater is often characterised by elevated surfactant concentrations and moderate organic loads due to detergents and fabric residues (Ziemba *et al.* 2018). In contrast, kitchen greywater typically contains higher concentrations of organic matter, oils, and grease, resulting in substantially higher COD and BOD values; for this reason, it is sometimes excluded from greywater definitions in treatment studies (Khalil and Liu 2021).

A key challenge in greywater characterisation is its temporal and spatial variability. Flow and composition can fluctuate significantly throughout the day depending on occupancy patterns and water use behaviour, leading to inconsistent influent quality (Van de Walle *et al.* 2023). This variability complicates treatment design, as systems must be robust enough to handle fluctuations in organic loading, surfactant concentrations, and hydraulic conditions.

### 2.2. Greywater Treatment Systems

A range of treatment technologies has been developed for greywater reuse, with selection largely dependent on influent quality and intended reuse applications. Membrane bioreactors (MBRs) offer high effluent quality and effective removal of suspended solids and microorganisms but are

associated with higher operational complexity and membrane fouling potential (Van de Walle *et al.* 2023; Hamidi 2025). Moving bed biofilm reactors (MBBRs) provide a more robust and flexible biological treatment option, particularly suited to variable loading conditions, due to the retention of biomass on carrier media (Van de Walle *et al.* 2023; González *et al.* 2025). Constructed wetlands represent a low-energy alternative, utilising natural processes for contaminant removal, though they typically require larger land areas and may exhibit lower treatment efficiency under fluctuating conditions (Muniz Sacco *et al.* 2024; Gutiérrez *et al.* 2025; Bidira *et al.* 2024; Muniz Sacco *et al.* 2026; Mascoli Junior *et al.* 2023).

Across all systems, influent stability is a critical design consideration. Variations in organic load, hydraulic flow, and chemical composition can impact process performance, particularly in biological systems where microbial communities require relatively stable conditions to function optimally (Van de Walle *et al.* 2023; González *et al.* 2025).

Surfactants, commonly present in greywater from detergents and cleaning products, are of particular concern (Mascoli Junior *et al.* 2023). Elevated concentrations can inhibit microbial activity, contribute to foaming, and interfere with oxygen transfer, thereby reducing treatment efficiency in systems such as MBBRs and MBRs (Oteng-Peprah *et al.* 2018; Van de Walle *et al.* 2023; Budeli and Sibali 2025). As a result, understanding and accounting for surfactant loads is essential in process design and operation.

## 2.3. Behaviour and Product Influence

User behaviour and product usage are key but often overlooked determinants of greywater quality. The use of soaps, detergents, shampoos, and cleaning agents introduces a wide range of chemical compounds, including surfactants, fragrances, preservatives, and antimicrobial agents, into the wastewater stream (Khalil and Liu 2021; Hardie *et al.* 2021). More recently, the increased use of hand sanitizers and disinfectants has further altered greywater composition, particularly in non-residential settings (Budeli and Sibali 2025).

These inputs directly influence measurable water quality parameters. For example, detergent use contributes to increased COD due to the presence of organic compounds, while also affecting BOD/COD ratios, as some surfactants are less readily biodegradable (González *et al.* 2025; Monsalves *et al.* 2023; Jena *et al.* 2023; Li *et al.* 2009). This can reduce the apparent biodegradability of greywater and impact the performance of biological treatment systems. Additionally, certain compounds may exert inhibitory effects on microbial communities, further complicating treatment processes (Van de Walle *et al.* 2023; Budeli and Sibali 2025; Jena *et al.* 2023).

Despite their importance, there is a notable lack of studies that directly link quantified user behaviour (e.g., frequency and type of product use) to observed changes in greywater quality parameters such as COD, BOD, and surfactant concentrations. Most existing studies infer these relationships indirectly, highlighting a gap in empirical, behaviour-linked data (Oteng-Peprah *et al.* 2018; Van de Walle *et al.* 2023; González *et al.* 2025; Khan *et al.* 2026; Budeli and Sibali 2025).

## 2.4. Identified Research Gaps

Based on the reviewed literature, several key gaps can be identified. Firstly, there is a limited body of empirical data on office-derived greywater, with most studies focusing on residential settings. This limits the applicability of existing design assumptions to non-domestic environments, where water use patterns and influent characteristics may differ significantly (Lim *et al.* 2015; Radingoana *et al.* 2020; González *et al.* 2025; Muniz Sacco *et al.* 2024).

Previous studies have extensively examined greywater characteristics and treatment technologies, these have primarily focused on residential settings (Ziemba *et al.* 2018), with limited data available for office environments, particularly regarding the influence of user behaviour on wastewater composition. Such commercial buildings represent a larger opportunity for decentralised treatment systems.

Secondly, while surfactants are recognised as important constituents of greywater, there is a lack of detailed quantification and reporting, particularly using standardised methods such as MBAS. This restricts the ability to assess their impact on treatment processes and to incorporate them effectively into design criteria (Van de Walle *et al.* 2023; Bogart *et al.* 2025; Hamidi 2025; Budeli and Sibali 2025; Jena *et al.* 2023).

Finally, there is a lack of studies examining intra-building variability, where greywater quality may differ between locations within the same building due to variations in user behaviour, fixture type, and product usage. This represents a critical gap, as such variability can have significant implications for decentralised treatment system performance and reliability (Van de Walle *et al.* 2023; Khalil and Liu 2021; Muniz Sacco *et al.* 2026).

Addressing these gaps is essential for improving the understanding of greywater systems in non-residential settings and for developing more accurate and resilient treatment design approaches.

## 3. Materials and Methods

This chapter outlines the methodological approach adopted to characterise office-derived greywater and assess its variability in relation to user behaviour and product use. It describes the study site, sampling strategy, and analytical procedures used to quantify key water quality parameters, alongside the data analysis methods applied to interpret the results. Emphasis is placed on capturing temporal and spatial variability within the building, in order to provide a representative assessment of influent quality relevant to treatment design.

### 3.1. Study Site

The study was conducted within an office building accommodating approximately 35–40 occupants, representing a mixed-use environment with both administrative (office-based) and practical (workshop-based) activities. Greywater was generated primarily from three handwashing sinks, which served distinct user groups: office staff and workshop personnel as shown in Figure 2. This distinction was considered important, as differences in hygiene practices, frequency of use, and product types (e.g., standard hand soap versus industrial cleaners) were expected to influence greywater composition.

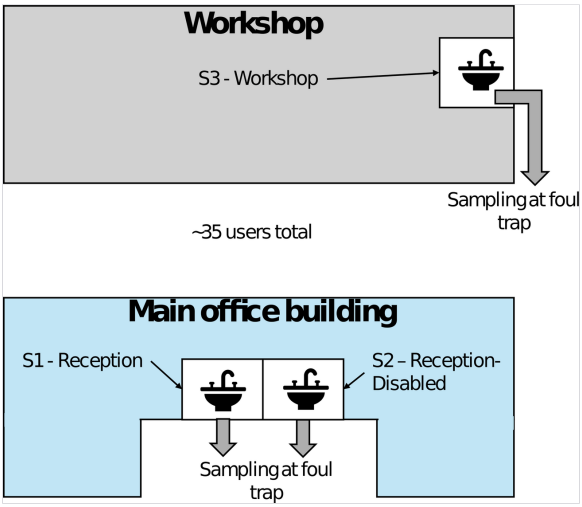


**Figure 2.** Study site layout.

The selected site provides a representative case of non-residential greywater generation, where usage patterns are intermittent and behaviour-driven, in contrast to more consistent residential flows (Radingoana *et al.* 2020; Van de Walle *et al.* 2023; Muniz Sacco *et al.* 2024).

### 3.2. Sampling Strategy

A composite sampling approach was adopted to account for temporal variability in greywater quality. Samples were collected from each sink via the foul trap (Figure 2), ensuring capture of wastewater representative of actual discharge conditions prior to dilution or downstream mixing.

To reflect key usage periods, composite samples were formed by combining aliquots collected during:

- Morning usage (start of occupancy)
- Post-lunch period (peak hygiene activity)

Sampling was conducted repeatedly over 5 days to capture variability associated with daily behavioural patterns and occupancy fluctuations. This repeated-measures approach improves the reliability of observed trends and reduces the influence of anomalous events (Jefferson *et al.* 2000).

Composite and time-distributed sampling methods are commonly recommended for wastewater characterisation due to the highly variable nature of greywater flows and contaminant loads (Eriksson *et al.* 2002).

### 3.3. Analytical Methods

The analysis focused on key parameters relevant to greywater treatment design: COD, $BOD_5$, and anionic surfactants (MBAS).

- Chemical Oxygen Demand (COD) was measured using the closed reflux colorimetric method, which quantifies the total oxidisable organic matter present in the sample. Standard methods such as APHA Standard Methods for the Examination of Water and Wastewater Method 5220 were followed (Rice and Bridgewater 2012).
- Biochemical Oxygen Demand ($BOD_5$) was determined using the 5-day incubation method, measuring the biodegradable fraction of organic matter under controlled conditions (typically 20 °C in the dark). Procedures aligned with Standard Method 5210 (Rice and Bridgewater 2012; Tintometer Group 2024).
- Methylene Blue Active Substances (MBAS) were analysed to quantify anionic surfactants, using a colorimetric extraction method based on complex formation with methylene blue dye. This method is widely used as a proxy for detergent-derived surfactants in greywater (Rice and Bridgewater 2012; Gross *et al.* 2015).

All analyses were conducted using calibrated laboratory equipment, with appropriate blanks and standards included to ensure data quality and repeatability.

### 3.4. Data Analysis Approach

Data analysis was designed to assess both spatial variability between sinks and relationships between key water quality parameters.

Firstly, results were compared across the three sinks to identify differences associated with user groups and usage patterns. This comparison aimed to highlight intra-building variability in greywater quality, which is often overlooked in design assumptions.

Secondly, the $BOD_5$/COD ratio was evaluated as an indicator of biodegradability. Ratios approaching 1 suggest highly biodegradable wastewater, whereas lower ratios indicate a greater proportion of non-biodegradable or slowly degradable compounds. This metric was used to infer the suitability of biological treatment processes under varying influent conditions (Tchobanoglous *et al.* 2014).

Finally, a qualitative assessment of the relationship between MBAS and $BOD_5$/COD was undertaken. Elevated MBAS concentrations were interpreted as indicative of increased detergent

input, which may contribute to higher COD values while simultaneously reducing biodegradability. This approach allows for indirect linkage between user behaviour (product use) and measurable water quality parameters, addressing a key gap identified in the literature (Van de Walle *et al.* 2023; Khan *et al.* 2026; Li *et al.* 2009; Ziemba *et al.* 2018; Tchobanoglous *et al.* 2014).

A limitation of this approach is that the linkage between behaviour and water quality parameters remains qualitative rather than directly quantified. While trends can be identified, causality between specific user actions (e.g., product type or frequency of use) and measured parameters cannot be definitively established within the scope of this study.

## 4. Results

This section presents the experimental results obtained from the analysis of greywater samples collected across three sampling locations. The results are structured to first examine individual parameters (COD, BOD, and MBAS), followed by an assessment of biodegradability and an integrated analysis of relationships between variables.

### 4.1. COD and BOD Results

The measured chemical oxygen demand (COD) and biochemical oxygen demand (BOD) varied significantly across the three sampling locations, as shown in Figure 3 and Figure 4, respectively.

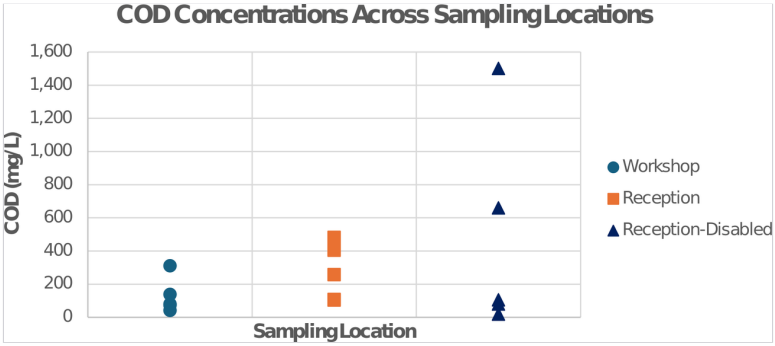


**Figure 3.** COD concentration across sampling locations.

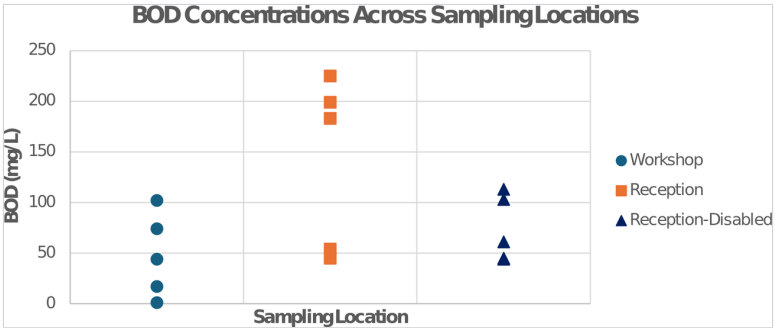


**Figure 4.** BOD concentration across sampling locations.

The workshop sink exhibited consistently low COD values (43–311 mg/L) and relatively low BOD (1–102 mg/L), indicating a comparatively low organic load. In contrast, the reception sink showed moderate to high COD concentrations (104–482 mg/L) and elevated BOD values (45–225 mg/L), suggesting a higher presence of biodegradable organic matter.

The reception–disabled sink demonstrated the greatest variability, with COD ranging from 20 to 1501 mg/L (Figure 3) and BOD from 45 to 113 mg/L (Figure 4). The presence of an extreme COD value highlights episodic high-strength discharges.

Overall, the results indicate clear intra-building variability, with the reception sink generally exhibiting higher and more consistent organic loading compared to the workshop, while the reception–disabled sink is characterised by irregular but occasionally extreme values.

## 4.2. COD/BOD Ratio

The BOD/COD ratio, used as an indicator of biodegradability, varied considerably between sampling locations, as illustrated in Figure 5.

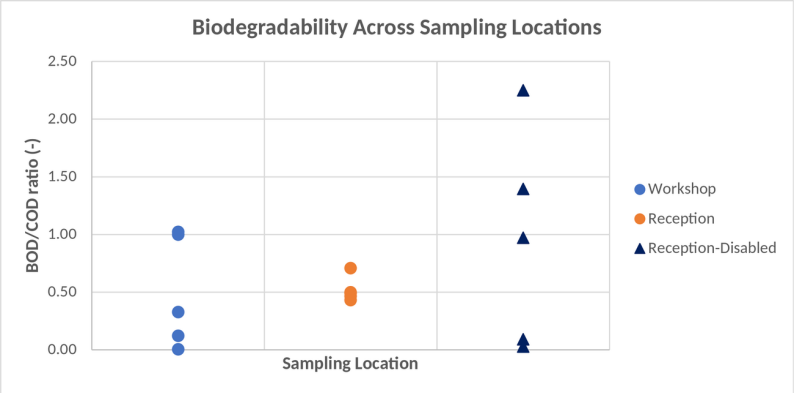


**Figure 5.** BOD/COD ratio across locations.

The reception sink exhibited relatively stable ratios (≈0.43–0.71), indicating a predominantly biodegradable organic fraction. The workshop sink showed lower and more variable ratios, including values approaching zero, suggesting the presence of less biodegradable or dilute organic matter.

The reception–disabled sink displayed the widest range (≈0.5–2.25), including values exceeding 1 (Figure 5). While such values are not physically typical, they may arise from analytical variability or sample heterogeneity and indicate uncertainty in the relative balance of biodegradable and total organic matter.

These results suggest that biodegradability is strongly influenced by user behaviour and varies significantly even within a single building.

## 4.3. Surfactant (MBAS) Results

Surfactant concentrations, expressed as methylene blue active substances (MBAS), also varied across sampling locations, as shown in Figure 6. MBAS is a standard analytical proxy for anionic surfactants commonly present in soaps and detergents.

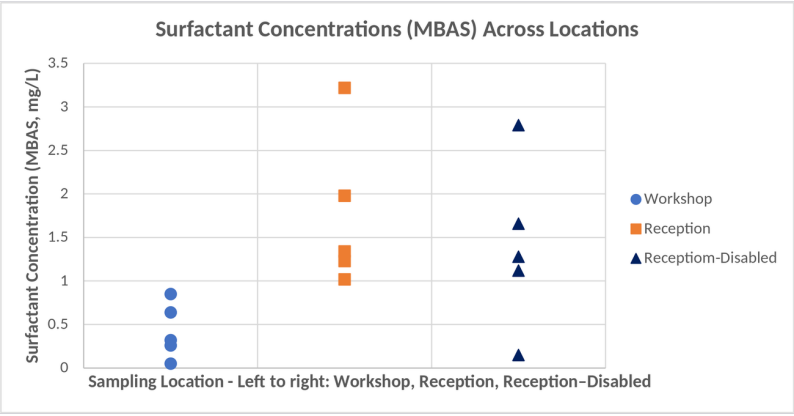


**Figure 6.** Surfactant concentrations across locations.

The reception sink showed the highest concentrations (1–3.22 mg/L), indicating more frequent or intensive use of cleaning products. The workshop sink exhibited consistently low MBAS values (0.05–0.85 mg/L), suggesting limited soap usage or more effective rinsing. The reception–disabled sink displayed high variability (0.15–2.8 mg/L), reflecting inconsistent usage patterns (Figure 6).

These findings indicate that surfactant loading is strongly dependent on user behaviour and differs markedly between functional areas within the building.

## 4.4. Combined Analysis

The relationship between COD and MBAS is presented in Figure 7, providing insight into the contribution of surfactants to the overall organic load. A general positive association is observed for the reception sink, where higher MBAS concentrations correspond to increased COD, indicating surfactant-driven organic loading.

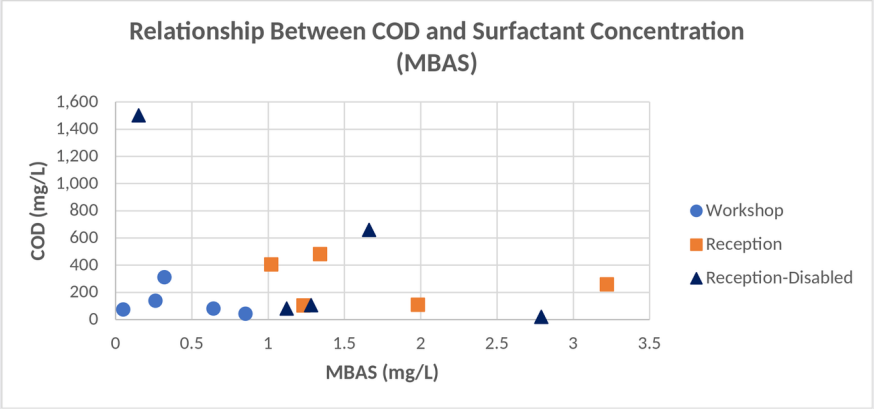


**Figure 7.** COD and MBAS relationship.

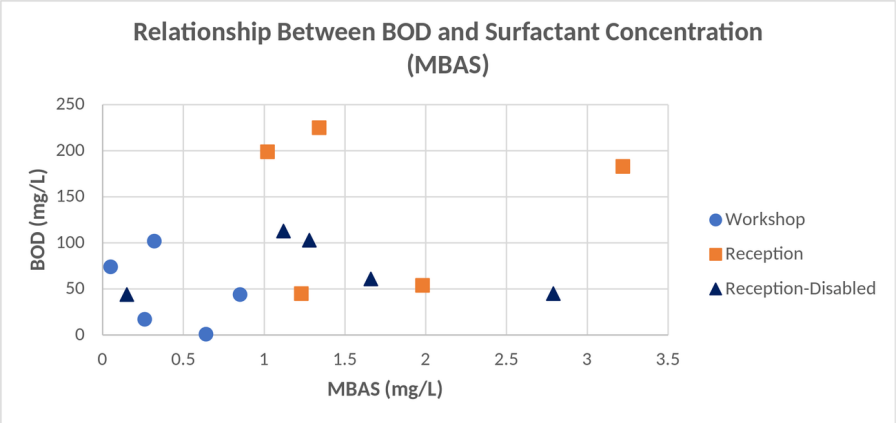


**Figure 8.** BOD and MBAS relationship.

In contrast, the workshop sink shows low MBAS concentrations with variable COD (Figure 7), suggesting that organic loading is not primarily driven by surfactants. The reception–disabled sink exhibits scattered behaviour, including high COD at low MBAS, indicating episodic inputs unrelated to typical handwashing activities.

The relationship between BOD and MBAS (Figure 8) shows weaker and less consistent trends, indicating that surfactants do not directly correlate with the biodegradable fraction of organic matter.

Based on these observations, three distinct sink profiles can be identified:

- Reception: surfactant-driven, relatively consistent loading
- Workshop: low surfactant input, non-specific organic sources
- Reception–disabled: highly variable, behaviour-driven spikes

This combined analysis demonstrates that greywater composition is not only location-dependent but also strongly influenced by user behaviour and activity patterns.

## 5. Discussion & Conclusion

The results presented in Chapter 4 highlight significant variability in greywater composition within an office environment. This section interprets these findings in the context of user behaviour and discusses their implications for decentralised greywater treatment system design and operation.

### 5.1. Behavioural Influence on Greywater Composition

The observed differences in COD, BOD, and MBAS concentrations (Figure 3, Figure 4, Figure 6) can be directly linked to user behaviour. Higher surfactant levels in the reception sink suggest frequent use of soaps and cleaning products, while lower concentrations in the workshop may indicate reduced usage or more thorough rinsing.

The variability observed in the reception–disabled sink, including the extreme COD value shown in Figure 3, highlights the impact of irregular usage patterns and potential episodic discharges. These findings support the premise that human behaviour is a key driver of greywater composition, particularly in non-residential settings.

### 5.2. Implications for Treatment Systems

The variability observed (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7) has direct implications for decentralised greywater treatment. Fluctuating organic loads can reduce biological treatment stability, while elevated surfactant concentrations (Figure 6) may inhibit microbial activity. The relationship between COD and MBAS (Figure 7) indicates that surfactants can contribute significantly to organic loading.

These results emphasise the need for equalisation and conservative design assumptions, rather than reliance on average influent values.

### 5.3. Limitations and Future Work

This study is based on a limited dataset collected over five days using composite sampling, which restricts temporal resolution and may mask short-term variability. Sampling from foul traps may also introduce mixing effects, while uncertainty in BOD measurements, reflected in Figure 4, affects calculated ratios.

Future work should focus on time-resolved sampling, larger datasets across multiple buildings, and inclusion of additional parameters (e.g. nutrients and micropollutants) to better characterise greywater variability and inform treatment design.

## 6. Conclusion

Greywater composition in office environments varies significantly between user groups and locations. Surfactants (MBAS) contribute to organic loading, particularly in areas with frequent soap use, while behaviour-driven variability strongly influences both COD and biodegradability.

These findings demonstrate that influent variability must be considered in the design and operation of decentralised greywater treatment systems, particularly in relation to system stability and sizing.

Overall, the study provides empirical evidence that user behaviour is a key factor in greywater characteristics and should be accounted for in practical system design.

## Declarations

**Author contributions.** George Milev: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing (original draft), Writing (review and editing), Visualization, Validation, Resources, Software. Amin Al-Habaibeh: Writing (review and editing), Validation, Supervision, Project administration, Funding acquisition. Greg Rolleston: Methodology, Writing (review and editing), Validation, Supervision, Project administration. Michael Farnsworth: Writing (review and editing), Supervision, Project administration, Funding acquisition. Rob Morris: Methodology, Writing (review and editing), Validation, Supervision, Software, Resources.

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**Conflicts of interest.** The authors declare no competing interests.

**Data availability.** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Generative AI.** AI-assisted tool was used only for Figure 1: Conceptual framework of decentralised greywater treatment and reuse pathways in sustainable buildings of the paper.

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