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ASSESSING WATER CONSUMPTION AND WASTEWATER QUALITY IN UNDERGRADUATE CHEMISTRY AND PHARMACY LABORATORIES: IMPLICATIONS FOR SUSTAINABLE WATER RESOURCE MANAGEMENT AND OCCUPATIONAL HEALTH AND SAFETY

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ABSTRACT: *Academic institutions play a crucial role in fostering skills development, advancing environmental sustainability, and addressing global socio-economic challenges, including those outlined in the Sustainable Development Goals (SDGs). A key factor ensuring the effective functioning of universities is the consistent availability and reliable access to clean water. This is especially critical in the face of increasing climate variability. In particular, droughts, which are caused by climate change, pose a significant threat to institutional resilience, operations, and academic continuity. This study focused on quantifying water usage and wastewater generation during Chemistry and Pharmacy undergraduate practical sessions conducted over four weeks. Among the sessions analysed, the highest average consumption of distilled water occurred in Pharmaceutics 4, amounting to 96.50 ± 1.60 L. While Pharmaceutical Chemistry 3 generated the highest average volume of wastewater at 128.70 ± 3.05 L. The most heavily polluted wastewater was recorded in Pharmaceutics 3. The observed average values for key contamination indicators were Total Bacteria of $3.75 \times 10^4 \pm 1.07 \times 10^4$ CFU/100 mL, Chemical Oxygen Demand of 6050.00 ± 450.92 mg/L, Electrical Conductivity of 0.77 ± 0.43 mS/cm, pH of 8.20 ± 0.29, Surface Tension of 39.75 ± 2.99 mN/m, Total Suspended Solids of 273.00 ± 47.81 mg/L, and Turbidity of 263.50 ± 54.71 NTU. The continuation of this research is essential. It will enhance the understanding of water-related risks in academic institutions and contribute significantly to disaster risk management, resource planning, and promoting environmentally sustainable practices in higher education.*

KEYWORDS: *Academic institutions. Climate change. Drought. Water usage and wastewater quality. Water resource management.*

INTRODUCTION

Universities are important in developing a skilled workforce and significantly affect the sustainability of the environment, for instance, impact on achieving the SDGs (Mukwevho & Togo, 2020; Bovea & Valls-Val, 2021; Galvao *et al.,* 2024; Nyambiya *et al.,* 2024). Water is one of the most consumed resources on university campuses because it is essential for health, well-being and daily business functioning (Broering *et al.,* 2024; Galvao *et al.,* 2024). Specifically, in Chemistry and Pharmacy undergraduate laboratories with more students, high volumes of water are used for experiments, cleaning, and equipment maintenance. The wastewater from these laboratories is contaminated with chemical and pharmaceutical pollutants, which are posing public health and environmental health risks. Water management is challenged by climate change impacts (i.e. drought and floods), exponential population growth, and improper waste management. The challenges, such as higher water demand and inconsistent supply, show the need for efficient water usage and wastewater treatment and reuse practices in all sectors, including higher education institutions (Arriga-Medina & Piedra-Miranda, 2021; Gherhes & Cernicova-Buca, 2025). At the same time, universities have conducted surveys on drinking water and implemented various sustainable water resource management initiatives (Espinosa-Garcia *et al.,* 2015; Siruma *et al.,* 2015; Mahler, 2018; Azaki & Rivett, 2020; Mahmood *et al.,* 2024; Tshivhase & Bisschoff, 2024; Alnasrawy and Ali, 2025; Al-Sumati *et al.,* 2025; Hashim *et al.,* 2025; Kalumba *et al.,* 2025). Limited research focuses on water consumption patterns and wastewater quality in specific academic settings, such as Chemistry and Pharmacy undergraduate laboratories.

1. WATER SCARCITY IS A DISASTROUS CHALLENGE IN ACADEMIC INSTITUTIONS

Water scarcity and quality concern environmental and public health and are pressing disaster risks, particularly in academic institutions, as they rely primarily on water for educational, operational, and safety functions. The management in academic institutions and laboratories tends to underestimate institutional disaster preparedness planning, such as sustainable water resources and wastewater management. Many universities' science laboratories are designed without water-saving and recycling systems. Designing and operating efficient water-saving, treatment, recycling systems, and efficient distributing infrastructure is important to ensure sustainable water management and use (Assi *et al.,* 2021; Val *et al.,* 2021; Ferreante *et al.,* 2024). Apart from the impactful natural disasters such as earthquakes, tsunamis, tropical cyclones (floods), and tornadoes (Abedin & Shaw, 2015; Georges *et al.,* 2017), prolonged drought can also severely affect functioning in academic institutions (Dzvimbo *et al.,* 2022; Luttik & Maters, 2023).

Unsustainable water supply can result in academic disruption, compromised safety, and improper sanitation and hygiene (Afiatun *et al.,* 2019). For instance, Barreiros *et al.* (2023) reported that the amount of water needed per person on campus ranges from 1.8 to 23.5 litres per day. Although safety observations, equipment and procedures are provided in laboratory settings, fire and explosion accidents have been reported to be frequent and cause an alarming number of deaths (Schroder *et al.,* 2016; Sonawane *et al.,* 2022; Wu *et al.,* 2023; Yang *et al.,* 2023; Zhao *et al.,* 2024; Liu *et al.,* 2025). In addition to the risk assessments and suggestions on safety protocols and management in university laboratories (Payne *et al.,* 2020; Li *et al.,* 2021; Wang *et al.,* 2021; Ezenwa *et al.,* 2022; Kuzmina *et al.,* 2022; Li *et al.,* 2022; Tziakou *et al.,* 2023; Zhao *et al.,* 2023; Zhong *et al.,* 2023; Lin *et al.,* 2024; Abedsoltan & Shiflett, 2024), consistent water supply is also essential because emergency fire extinguishing requires high volumes of water (Van Zyl & Haarhoff, 1997; Kondashov *et al.,* 2023; Ilemobade, 2023). During periods of drought and extended municipal water cut-offs, laboratory activities are restricted or completely stopped, resulting in ineffective delivery and assimilation of the information and research outcomes. Additionally, institutions struggle to maintain adequate functional, sanitation and hygiene standards, resulting in practices that compromise human and environmental health and academic integrity. For instance, inadequate sanitation and hygiene can lead to evolving and spread of diseases (Alwan *et al.,* 2023). At the same time, insufficient water availability in laboratories can result in improper dilution and disposal of hazardous reagents, leading to highly concentrated pollutants in wastewater networks (Gadipelly *et al.,* 2014; Munzhelele *et al.,* 2024). This increases environmental health risks and regulatory non-compliance (Foster, 2005; Gomes *et al.,* 2023).

Therefore, concerning water scarcity as a disaster risk in academic institutions gives insights and plans such as sustainable water resource and wastewater management, resilience building and preparedness. Practical approaches for executing these insights and plans include quantifying water consumption and wastewater quality in undergraduate laboratories and designing water-saving and wastewater treatment systems. These approaches are essential for preparedness and resilience during long drought conditions caused by unpredicted climate change (Dzvimbo *et al.,* 2022). Continuous analysis of laboratory wastewater quality is also important for tracking environmental impacts.

WATER CONSUMPTION AND WASTEWATER QUALITY IN UNDERGRADUATE LABORATORIES

The design and setting of the Chemistry and Pharmacy undergraduate laboratories are mainly for hands-on activities requiring significant amounts of water for preparing reagents, conducting experiments and cleaning the glassware before and after use. The water for laboratory operation is sourced from the Municipality reservoir. The water used to prepare the reagents is distilled/deionised, treated and obtained from ultrafiltration systems such as the Millipore Milli-Q Direct 16 Water Purification System. The washing of the hands and glassware and preparation of the water baths are done using tap water. The amount of water that is used in these activities is not metered or monitored. Hence, there is a shortage of data on water usage in these laboratories. The lack of water quantification systems in undergraduate laboratories results in inefficiency in water usage. The quantification of water consumption is an essential step towards designing and implementing water-saving systems within the undergraduate laboratory setting. Additionally, continuous assessment of water usage in undergraduate laboratories is aligned with the sustainable water resource management strategy in academic institutions.

The quality of wastewater from the Chemistry and Pharmacy laboratories comprises hazardous constituents such as heavy metals, inorganic/organic solvents, and pharmaceutical compounds. Laboratory wastewater poses high health risks to the public and environment because it can contaminate tap water distribution networks via pipe leakage and affect aquatic ecosystems through disposal to surface water such as rivers (Madikizela & Ncube, 2022; Udebuani *et al.,* 2023; Paiga & Delerue-Matos, 2024; Newman *et al.,* 2024). Alarming concentrations of chemical and pharmaceutical contaminants have been reported to be present in surface waters, wastewater and effluent networks and subsequently in municipal taps (Madikizela *et al.,* 2022; Ogunlaja *et al.,* 2022; Oluwalana *et al.,* 2022; Archer *et al.,* 2023; Manyepa *et al.,* 2024; Nsibande *et al.,* 2024; Netshithothole *et al.,* 2024; Netshithothole and Madikizela, 2024; Sihlahla & Mngadi, 2024; Munzhelele *et al.,* 2024; Olaoluwa *et al.,* 2024; Mazhundu & Mashifana, 2024). Disposal of wastewater with high concentrations of chemical and pharmaceutical residues is also a risk of regulatory violation. Hence, performing quality wastewater analysis throughout undergraduate practical sessions is important. The knowledge of the composition of wastewater from different experiments/practical sessions is important for designing and implementing treatments, such as adsorption-filtering systems within the undergraduate laboratory drainage network (Ajiboye *et al.,* 2024; Sihlahla & Mngadi, 2024). This would be a sustainable approach to decrease the chemical and pharmaceutical contamination load that is deposited to the general wastewater network, thereby reducing public and environmental health risks (Letsoalo *et al.,* 2023; Manyepa *et al.,* 2024; Inarmal & Moodley, 2025).

SUSTAINABLE WATER RESOURCE MANAGEMENT IN ACADEMIC INSTITUTIONS

Sustainable water resource management in academic institutions refers to the implementation of strategies that encourage water conservation, efficient usage, and effective wastewater treatment and reuse. These strategies are implemented and practised through the aid of research centres because they are essential for alleviating climate change impacts such as prolonged drought, which turns out to be disastrous. Over the years, efforts on sustainable water resource management have been put by different universities across South Africa and globally (Gleick, 2010; Ilemobade *et al.,* 2011; Powell & Larsen, 2012; Marinho *et al.,* 2014; Crow-Miller *et al.,* 2016; Afiatum & Gustria, 2019); Barreiros *et al.,* 2023; Chowdhury *et al.,* 2024). These efforts include implementing rainwater harvesting systems, underground water abstraction and treating greywater from student residences and academic buildings (Ilemobade *et al.,* 2011; Malapane *et al.,* 2012; Chivenge *et al.*, 2024). The higher education institutes have also created a network and engagement with communities to emphasise awareness of efficient water usage and continuous quality assessment (Malapane *et al.,* 2012; Saito *et al.,* 2012; Siruma *et al.,* 2015). The key pillars to support the universities include policies and strategies such as the National Water Act of 1998, National Water Resource Strategy (NWRS), Integrated Water Resource Management (IWRM), Resource Directed Measures (RDMS) and Source Directed Controls (SDCs), Water Conservation and Water Demand Management (WC/WDM) Strategy, and Drought Management Plan (DMP).

The quantification of water usage and wastewater quality analysis from undergraduate science laboratories is rarely performed. It is a crucial approach to encouraging sustainable water resource management and managing drought disasters. Quantifying water usage in undergraduate laboratory sessions is a preparedness strategy because sufficient volumes of water can be predicted and supplied for catering practical sessions or experiments during drought seasons, particularly when municipal water supply is stopped. This would then mitigate the impact of drought disasters on academic progress. Quality analysis of wastewater generated during the experiment sessions is also a proactive approach that informs the design and formulation of wastewater treatment systems that can be built or retrofitted within the laboratory drainage systems. This would reduce concentrations of chemical and pharmaceutical residues that potentially contaminate municipal tap water and surface waters. Additionally, treated laboratory wastewater can be recovered and preserved for reuse in toilet flushing and emergency firefighting. This approach aligns with the above policies and strategies and the SENDAI Framework for Disaster Reduction 2015-2030 (2018).

Therefore, this study aims to assess the water consumption patterns and wastewater quality in undergraduate Chemistry and Pharmacy laboratories at Rhodes University. The objectives include the quantification of the water that is used and the analysis of the microbiological and physicochemical quality of wastewater generated during specific practical sessions. The findings of this study will provide valuable insights into the water usage and wastewater quality in university laboratories, informing the ongoing development of policies and practices that promote sustainable water resource management and preparedness for drought disasters in higher education institutions.

2. METHODOLOGY

This project was conducted during the second term of the 2025 academic year. Data and observations were collected over four-weeks from the practical sessions in Chemistry Extended/Foundation studies, Pharmaceutical Chemistry 3, and Pharmaceutics 3 and 4. Lecturers, laboratory demonstrators, and technicians responsible for each session were asked to report the number of attending students and provide information about the experiment titles/topics and protocols. The data collection focused on the number of students attending each practical session, the titles and protocols of the experiments, the types and quantities of glassware and reagents used, the volume of distilled water used to prepare experimental solutions, and the volume of water used for rinsing and washing glassware before and after the experiments. To collect wastewater samples, six pairs of students were instructed to place stoppers in their sinks to prevent drainage during rinsing and washing. The resulting wastewater was aseptically collected for microbiological and physicochemical analysis.

QUANTIFICATION OF WATER CONSUMPTION

In the practical sessions, distilled/Milli-Q water was supplied by an ultrafiltration system (Millipore Milli-Q Elix, Merck) and provided in 25-liter barrels. Students accessed the water via taps on the barrels to prepare their solutions (Figure 1). The amount of distilled/Milli-Q water used was calculated using Equation 1.

Figure 1 Supply and access of distilled/deionised water for preparing solutions

$$Wu\ (L) = Vi - Vf \quad (1)$$

where: *Wu (L)*– water used in litres,
Vi – Initial volume before the practical session
Vf – Final volume after the practical session

The amount of water used for rinsing and washing glassware before and after experiments was quantified using laboratory sink dynamics and calculated based on Equation 2.

$$V\ (L) = \frac{L\ .\ W.\ D}{1000} \quad (2)$$

where: *V (L)*– Volume in litres,
L – Lenght in cm
W – Widht in cm
D- Depth in cm

The dynamics varied between sinks due to differences in laboratory design. In these calculations (Equation 2), Depth was treated as the dependent variable, as it represented the actual water level in the closed sink during measurements (Figure 2). The total water usage was calculated by summing the volume of water used to prepare solutions and the volume used for rinsing and washing glassware. The water consumption/usage per student during practical sessions was then determined using Equation 3.

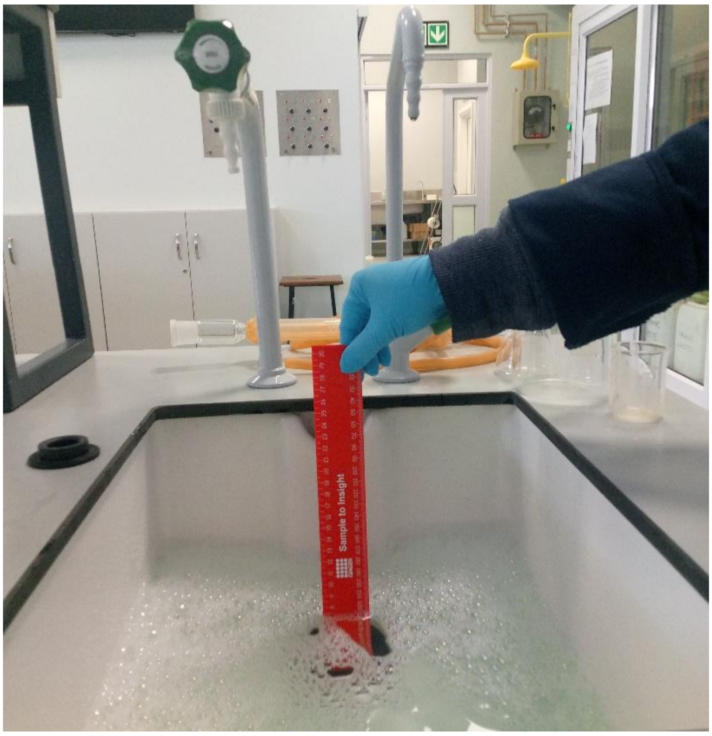

Figure 2 Measurement of generated wastewater after rinsing and washing of the glassware

$$Wups\ (L) = \frac{Wt}{Ns} \quad (3)$$

where: *Wups (L)*– Water used per student in litres,
Wt– Total water used in litres
Ns – Number of students in a practical session

QUANTIFICATION OF WATER CONSUMPTION

Wastewater generated from rinsing and washing glassware was collected in the sinks and aseptically sampled using sterile 500 mL Schott bottles, which had been autoclaved using an Equitron autoclave. The samples were immediately transported to the laboratory for microbiological (Total Bacteria and Faecal Coliforms) and physicochemical analyses, which included Chemical Oxygen Demand (COD), Electrical Conductivity (EC), pH, Surface Tension (ST), Total Suspended Solids (TSS), and Turbidity.
Total bacterial analysis was conducted by spread plating 100 µL of the wastewater sample onto Nutrient Agar plates (NEOGEN culture media). The number of colony-forming units per 100 mL (CFU/100 mL) for both Total Bacteria and Faecal Coliforms was calculated using Equation 4.

$$CFU = \frac{Nc\,.\,Df}{Vp}.100 \quad (4)$$

where: *CFU* – Colony Forming Units per 100 ml,
Nc– Number of colonies
Df- Dillution factor
Vp – Volume platted in ml

The analysis of Faecal Coliforms, COD, EC, pH, TSS, and Turbidity was performed according to the methods described by Bani *et al.* (2024a, b). Surface tension (ST) was measured at room temperature using a KRÜSS tensiometer, with distilled water and 0.05 M sodium lauryl sulphate used as standards.

DATA ANALYSIS AND PRESENTATION

The average ± standard deviation (n=4) amount of distilled/Milli-Q water used, generated wastewater, and water used per student over the four weeks in all the practical sessions are presented in a bar graph (Figure 3). The significance of the difference across all the practical sessions on the amount of distilled/Milli-Q water used, generated wastewater, and water used per student is calculated using one-way ANOVA statistics. Figure 3 and ANOVA (p-value) statistical analysis are used to evaluate the level and significance of the difference in the consumption of water across the observed practical sessions.

The average ± standard deviation (STDEV) (n=4) of the wastewater quality in all the practical sessions over four weeks is presented in Table 1. The microbiological quality parameters (Total bacteria and Faecal Coliforms are presented as Geometric mean ± STDEV). The significance of the difference (one-way ANOVA statistics) of the wastewater quality parameters across all the practical sessions is also presented in Table 1. The calculations of the average, geometric mean, STDEV, and one-way ANOVA statistics were performed using Excel (Microsoft Office Professional Plus 2019).

3. RESULTS AND DISCUSSION

The analysis of the results obtained from each practical session reports contributing factors to the observed differences. Variations in the consumption of distilled or Milli-Q water is associated with the number of students attended and the specific experimental protocols conducted during each practical session. Also, the variation in the volume and quality of wastewater generated is influenced by the capacity of the laboratory sinks, the number, type and degree of contamination of the used glassware. The level of contamination of the glassware and subsequently wastewater is linked to the used reagents and complexity of the experiments conducted, which vary across practical sessions.

WATER CONSUMTPTION IN THE PRACTICAL SESSIONS

Over four weeks, the average levels of distilled water consumption, wastewater generation, and water usage per student during Chemistry and Pharmacy practical sessions are presented in Figure 3. A statistically significant difference in distilled water usage was observed between the practical sessions (p-value = 5.03×10^{-14}), with Chemistry sessions consuming lower volumes. The Chemistry practical sessions focused on introductory scientific concepts and methods. The experiments included identifying inorganic substances, determining vinegar concentration using volumetric analysis, and applying Le Chatelier's Principle to study the solubility of acids and bases in water and Soap formulation. Across the Chemistry experiments, distilled water consumption by 30 pairs of students ranged from 5.00 ± 1.00 to 10.00 ± 2.00 L, with an average of 6.50 ± 2.00 L. The laboratory sink capacity, calculated based on measured dimensions (length = 31 cm, width = 25 cm, depth = 14.5 cm), was 11.24 L. The wastewater generated by the same group over four weeks ranged from 69.00 ± 0.50 to 93.00 ± 3.10 L, with an average of 76.00 ± 2.22 L. The water usage per student over the four weeks ranged from 1.22 ± 1.71 to 1.74 ± 3.80 L, with an average of 1.40 ± 2.28 L.

In the Pharmaceutical Chemistry 3 practical sessions, the experiments that were performed over four weeks included the Isolation of red pigment from paprika, the Synthesis of local anaesthetic benzocaine, the Synthesis of Sulphanilamide, and the Synthesis of 4-cholestene-3-one from cholesterol. Across these experiments, the distilled water consumption by 42 students ranged from 42.00 ± 2.00 to 46.00 ±

1.45 L, with an average of 43.25 ± 1.56 L. According to the measured dimensions (length = 42.5 cm, width = 32 cm, depth – 22.5 cm), the laboratory sink capacity was found to be 30.6 L, and the wastewater generated by 42 students over four weeks ranged from 114.24 ± 1.56 to 199.50 ± 2.21 L, with an average of 160.55 ± 2.34 L. The water usage per student over the four weeks ranged from 3.76 ± 4.12 to 5.75 ± 3.52 L, with an average of 8.85 ± 4.72 L. Distilled water consumption was due to refluxing which was essential step experiments, while elevated wastewater generation was caused by multiple rinsing and washing of the glassware (round bottom flasks, Erlenmeyer flasks, reflux condensers, beakers, and watch glasses) before and after the experiments.

The Pharmaceutics 3 practical sessions were based on an assessment of suppositories, which included examination of their external appearance, weight, internal appearance, and disintegration test using 0.3 L of 37 °C distilled water per suppository. The following experiments involved the formulation of suppositories using different dye/base combinations, which included Amaranth, Sudan III Red, Macrogol, and Theobroma oil. Each formulated suppository was placed in beakers containing 0.3 L of 37 °C distilled water to observe the rate and behaviour of dye release. Across these experiments, the distilled water consumption by 57 students (29 pairs) ranged from 17.40 ± 3.21 to 26.10 ± 0.56 L, with an average of 21.75 ± 1.82 L. The laboratory sink capacity (length =34.5 cm, width = 24.5 cm, depth = 15 cm) was found to be 12.68 L, and the wastewater generated by 29 pairs of students over four weeks ranged from 61.28 ± 5.67 to 196.10 ± 1.23 L, with an average of 128.70 ± 3.05 L. The water usage per student over the four weeks ranged from 3.76 ± 4.12 to 5.75 ± 3.52 L, with an average of 2.64 ± 2.60 L. Low values of distilled water were consumed in the Pharmaceutics 3 compared to the Pharmaceutical Chemistry 3 practical sessions. The washing of glassware stained with Sudan III Red and Theobroma oil resulted in a high generation of wastewater from these experiments.

The experiments performed in Pharmaceutics 4 practical sessions included quantifying the active pharmaceutical ingredient (API), which was done by producing a calibration curve of paracetamol in water using a UV-VIS spectrophotometer. The second experiment focused on chemical kinetics, which was mainly on the evaluation of the pH stability of a drug by dissolving in water (about 0.1 L) to produce a calibration curve. The third experiment was based on releasing an API from two suppository formulations, which consume 1.00 L of 37 °C distilled water as a dissolution medium. The fourth experiment focused on releasing an API from 3 tablet formulations, which consumes 3.00 L of 37 °C of distilled water as a dissolution medium. Across these experiments, the consumption of distilled water by 31 students (16 pairs) over four weeks ranged from 93.00 ± 1.03 to 99.00 ± 2.10 L, with an average of 96.50 ± 1.60 L. The laboratory sink capacity (length = 30 cm, width = 25.5 cm, depth= 17.5 cm) was found to be 13.39 L, and the wastewater generated by 16 pairs of students ranging from 85.20 ± 3.20 to 109.54 ± 2.10 L, with an average of 89.93 ± 2.05 L. the water demand or water usage per student in these experiments ranged from 5.56 ± 3.21 to 6.53 ± 1.54 L, with an average of 6.01 ± 2.14 L. Amongst the observed practical sessions, Pharmaceutics 4 consumed high volumes of distilled water and this is due to the dissolution experiments. The rinsing and washing of dissolution beakers before and after the experiments resulted in high volumes of wastewater from the Pharmaceutics 4 practical sessions. The laboratory sink capacity, which was found to be high in Pharmaceutical Chemistry 3, impacts wastewater generation; students tend to rinse the glassware several times.

Although the quantification of water usage and wastewater generation in university laboratories is rarely conducted or reported, it is evident that water consumption mainly depends on the nature of the experiments. The observed demand for distilled water and the volume of wastewater shows the need for reliable and sustainable water access in academic laboratories. Therefore, ongoing data collection and observation of water usage during practical sessions are essential to effective and sustainable water resource management. Additionally, the volumes of generated wastewater show the potential for treatment and reuse for non-portable purposes to alleviate the impacts of drought disasters in higher education institutes.

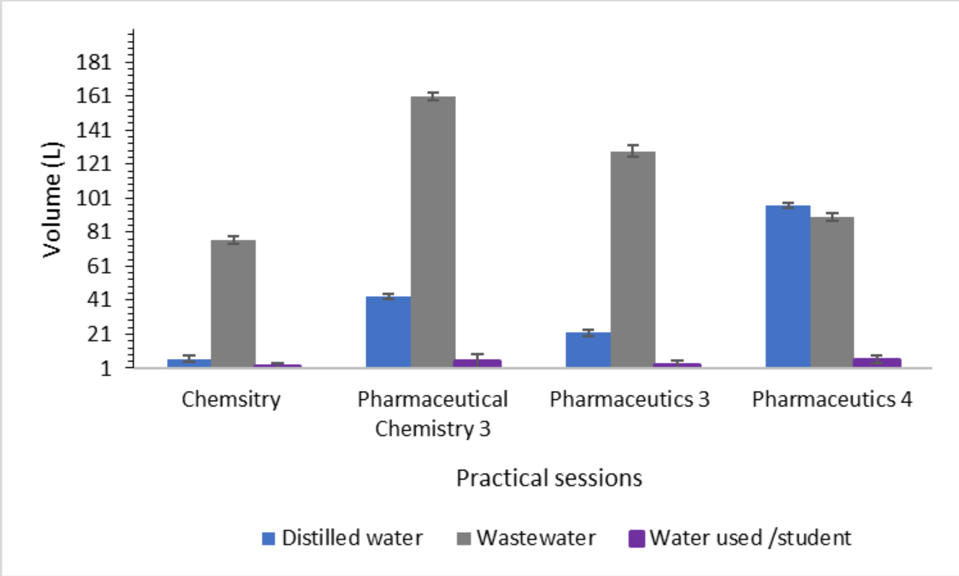

Figure 3 Levels of distilled water consumption, wastewater generation and water used per student in Chemistry and Pharmacy practical sessions

QUALITY OF WASTEWATER GENERATED FROM THE PRACTICAL SESSIONS

As shown in Table 1, the wastewater samples from the Chemistry, Pharmaceutical Chemistry 3, and Pharmaceutics 4 practical sessions contained Total Bacteria and Faecal Coliforms in the range below 0 CFU/10 ml (designated as TFTC in further text of the article) and, therefore, insignificant in representing microbial concentration. In contrast, the Total Bacteria count in the Pharmaceutics 3 wastewater was significantly higher, measured at $3.75 \times 10^4 \pm 1.07 \times 10^4$ CFU/100 ml. The low bacterial counts in Chemistry, Pharmaceutical Chemistry 3, and Pharmaceutics 4 practical sessions are likely due to the presence of residual reagents and the use of detergents during glassware washing, which disinfected the microorganisms in the wastewater. However, in the case of Pharmaceutics 3, the use of warm water for washing, combined with the presence of recalcitrant reagent residues such as Theobroma oil and Sudan Red III dye, have promoted microbial proliferation rather than inhibition.

Among the physicochemical contaminants analysed,COD levels were found to be high in the wastewater from Pharmaceutics 3, Pharmaceutical Chemistry 3, and Pharmaceutics 4. In contrast, the Chemistry wastewater showed low COD concentrations due to the lower quantities of reagents and salts used in the experiments, as well as minimal detergent use during glassware cleaning. The differences in EC and pH values across all practical sessions were found to be statistically insignificant. However, ST was highest in the Chemistry wastewater, suggesting limited use of detergent, while lower ST values in the other sessions indicate more extensive detergent use. High TSS and Turbidity levels were also observed in the Pharmaceutical Chemistry 3 wastewater. This was primarily due to the presence of Theobroma oil aggregates and Sudan Red III dye, which contributed to brownish colouration. Among all the practical sessions, Pharmaceutics 3 generated the most contaminated wastewater due to the nature and intensity of the experiments conducted over four weeks.

The analysis of laboratory wastewater quality has important implications for public health and environmental safety. It informs the profiling and mitigation of health risks, supports environmental protection efforts, and guides decisions regarding appropriate treatment for reuse or safe discharge (Reed, 2006). Notably, the evaluation of wastewater from Pharmaceutics 3 practical sessions revealed issues such as microbial regrowth and residual reagents. These factors not only pose direct health risks but also contribute to the emergence of antimicrobial-resistant strains in surface waters and wastewater treatment plants (Odjadjare and Olaniran, 2015; Olaniran *et al.,* 2015; Pillay & Olaniran, 2016; Booth *et al.,* 2020; Holton *et al.,* 2022) Additionally, elevated COD levels show the concentration of organic and inorganic pollutants which are hazardous to surface water bodies, as they lead to oxygen depletion, which results in disruption of aquatic ecosystems and threaten livestock and biodiversity (Mamba *et al.,* 2009; Wilhelm, 2009; Chigor *et al.,* 2013; Li and Liu, 2019; Han *et al.,* 2022).In addition to these concerns, the quality of wastewater generated across all practical sessions indicates the potential for efficient on-site treatment. Adsorbent-filter-based systems show promise for integration into existing laboratory plumbing networks to reduce pollutant loads before discharge or reuse (Nondlazi *et al.,* 2017; Bani *et al.,* 2024a, b). Implementing laboratory wastewater treatment technologies addresses contamination concerns and supports strategies for sustainable water resource management. This approach is important in academic institutions vulnerable to water scarcity and drought conditions.

Table 1 Microbiological and Physicochemical quality of wastewater generated from the Practical sessions

	Microbiological quality		**Physicochemical quality**					
	Geometric mean ± STDEV		**Average ± STDEV**					
Practical session	**Total Bacteria (CFU/100 ml)**	**Faecal Coliforms (CFU/100 ml)**	**COD (mg/l)**	**EC (mS/cm)**	**pH**	**ST (mN/m)**	**TSS (mg/l)**	**Turbidity (NTU)**
Chemistry	TFTC	TFTC	128.25 ± 7.37	0.75 ± 0.24	8.10 ± 0.28	68.25 ± 1.71	47.00 ± 17.40	37.50 ± 17.46
Pharmaceutical Chemistry 3	TFTC	TFTC	4000.00 ± 509.90	0.87 ± 0.23	8.35 ± 0.44	35.00 ± 3.92	54.75 ± 8.73	46.50 ± 6.86
Pharmaceutics 3	$3.75 \times 10^{4} \pm 1.07 \times 10^{4}$	TFTC	6050.00 ± 450.92	0.77 ± 0.43	8.20 ± 0.29	39.75 ± 2.99	273.00 ± 47.81	263.50 ± 54.71
Pharmaceutics 4	TFTC	TFTC	2575.00 ± 403.11	1.04 ± 0.15	8.00 ± 0.34	41.75 ± 4.50	53.00 ± 12.75	48.25 ± 13.91
ANOVA (p-value)	-	-	6.48×10^{-10}	4.64×10^{-1}	5.44×10^{-1}	4.58×10^{-8}	8.05×10^{-8}	2.90×10^{-7}

CONCLUSION

Overall, this study has emphasized the important role of academic institutions as centres for human skill development, environmental sustainability, and contributions to global socio-economic objectives, including the SDGs. The effective functioning of universities relies on various resources, among which water is particularly critical. However, climate change impacts such as droughts and floods increasingly contribute to water scarcity via reduced rainfall or siltation of water reservoirs. Among natural disasters, prolonged droughts have a particularly disruptive effect on academic institutions. Consequences include operational interruptions, intense anxiety among staff and students, compromised health and safety conditions, and increased vulnerability to emergencies such as laboratory fires. Reliable water access is essential for maintaining safe and efficient operations in science laboratories and supporting the broader delivery of knowledge and skills.

The quantification of water usage and wastewater generation in Chemistry, Pharmaceutical Chemistry, and Pharmaceutics 3 and 4 practical sessions provide valuable insights into sustainable water resource management within universities. Moreover, analysing laboratory wastewater quality provides a foundation for designing and integrating efficient treatment technologies. Such approaches enable safer discharge into wastewater systems or reuse for non-potable applications such as toilet flushing and firefighting, thus supporting sustainability and disaster preparedness.

Future phases of this research will involve continued data collection and observation of additional practical sessions during the 2025 second semester. Additional analysis is recommended, including identification of bacterial strains and pharmaceutical residues in the wastewater. These efforts will enhance the impact and details of the study and association with local and international disaster management strategies and policies.

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