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# Physicochemical and microbiological characterization and of hospital wastewater in Tanzania

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ABSTRACT

Given the complex composition of hospital wastewater and the high risk of initiating disease outbreaks, comprehensive monitoring and treatment of hospital wastewater are required to prevent social and environmental consequences. This study investigated the physicochemical and microbiological characteristics of wastewater from the Benjamin Mkapa Hospital in Dodoma Tanzania. The wastewater from this hospital is treated in a horizontal flow Constructed Wetland (CW) planted with *Typha latifolia* before being discharged into the environments. Wastewater samples were collected at the CW inlet and outlet from 02nd May 2022 to 25th July 2022. The results shows that the effluent discharged had pH 7.48 ± 0.63, electrical conductivity 2441 ± 623 μS/cm, Total dissolved solids 1305.5 ± 396 mg/L, Total suspended solids 49.17 ± 53.11 mg/L, Turbidity 9.1 ± 14.83 NTU, COD 170.4 ± 40.6 mg/L, $BOD_5$ 74.8 ± 33.5 mg/L, $NO_3$-N 45.4 ± 39.97 mg/L and $PO_4$-P 4.52 ± 2.30 mg/L. The CW removed TSS by 82% and turbidity 94%. COD, BOD and $NO_3$-N were removed by 48%, 47% and 58% respectively. *E. coli* concentration in effluent samples ranged from $1.1 \times 10^1$ CFU/mL to $1.1 \times 10^2$ CFU/mL with an average of 1.77logCFU/mL. Average $BOD_5$/COD ratio was 0.5 and 0.4 for influent and effluent respectively. The effluent contained higher levels of EC, TDS, and $PO_4$-P than the influent. According to the findings of this study, most of the parameters of wastewater effluent discharged wasn't within the effluent discharge standards.

## Introduction

The production of hospital wastewater has increased in recent decades as a result of advancements in medical services and products (Amouei et al., 2015). The produced hospital wastewater is influenced by a number of factors, including the water supply, number of beds available, general services such as air conditioning, kitchen and laundry, the types and number of units or wards and management practices. All of these operations contribute to total produced wastewater (Khan et al., 2021). The complex mixtures of compounds present in hospital wastewater include not only pharmaceuticals and their metabolites, but also disinfectants, diagnostic agents, and other substances coming from laboratory, research and diagnostic operations, as well as patients' excretion (Fatta-Kassinos et al., 2011; Santos et al., 2013).

When compared to domestic wastewater, hospital wastewater has higher levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, and nitrogen (Hocaoglu et al., 2021; Pirsaheb et al., 2015). Hospital wastewater is less biodegradable than municipal wastewater, making it challenging for conventional biological systems to treat it (Majumder et al., 2020). The intrinsic toxicity of hospital effluents has been shown to be 5–15 times higher than that of a municipal effluent based on composition (Kumari et al., 2020). A wide variety of microbes, including bacteria, viruses, fungus, and parasites, are present in hospital wastewater. Furthermore, a lot of resistant bacteria have been found in hospital wastewater, which inhibits the growth of susceptible bacteria and boosts the population of resistant bacteria in the receiving water (Yuan & Pian, 2023). Because of the cost and analytical challenges associated with detecting and counting the microbes in water samples, it is routine practice to test for indicator microorganisms that indicate the presence of faecal contamination. One of the most commonly used indicator organisms is a bacterium called *Escherichia coli*, which is a member of the faecal coliform group (Wu et al., 2016).

*Escherichia coli* (*E. coli*) are Gram-negative bacteria with rounded ends. Their major habitat is the intestines of endotherms (Ishii & Sadowsky, 2008; Osińska et al., 2022; Poolman, 2016) which they alternate with other environmental habitats (secondary habitats) such as

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water, silt, and soils throughout their life cycle (Petersen and Hubbart, 2020). As a result, the presence of *E. coli* in drinkable water is utilized as a sign of contamination with human or animal excrement and is known as the "coliform index."(Percival & Williams, 2013). Both biotic and abiotic factors have the potential to affect the growth and survival of *E. coli* in their natural habitats. Temperature, the availability of water and nutrients, pH, and sun radiation are examples of abiotic variables. The existence of other microbes, as well as *E. coli*'s capacity to consume resources, outcompete other microbes, and build biofilms in natural habitats, are all examples of biotic factors (Jang et al., 2017). *E. coli* may live in a variety of habitats, including wastewater, soil, and water, as well as plants, fruits and vegetables, raw meat, and unpasteurized milk (Osińska et al., 2022). Although these bacteria are gut commensals, they can also cause intestinal and extraintestinal diseases, such as septicemia, meningitis, and urinary tract infections in humans and colibacillosis in poultry (Osińska et al., 2022).

In developing countries, hospital wastewater is commonly discharged into municipal wastewater systems and released into water bodies without treatment (Aukidy et al., 2017; Reddy et al., 2020; Santoro et al., 2015). Some studies suggest that mixing hospital and municipal wastewater has the potential to inhibit the activated sludge of wastewater treatment plants (Kumari et al., 2020). This makes it necessary to consider separate treatment of hospital wastewater to avoid contamination that may occur when hospital wastewater is mixed with municipal wastewater (Lee et al., 2014). Different technologies including functionalized membrane filtration, persulfate activated degradation, heterogeneous photocatalysis, Fenton-like degradation and adsorption have been investigated for removal of pollutants from hospital wastewater (Vieira et al., 2021). Conventional wastewater treatment technologies have proven to be effective in the treatment of wastewater (Desta et al., 2014). However, these technologies are ineffective in eliminating pharmaceuticals (Otieno et al., 2017; Rachman, 2018; Yang et al., 2017). Furthermore, they are extremely expensive and energy consuming, making them impractical for developing economies (Hdidou et al., 2022; Valipour & Ahn, 2017). According to researchers, there is no single universal treatment technique that is effective for all types of contaminants and all sources; rather, an efficient treatment approach should include the use of two or more technologies in combination (Hassan et al., 2021).

Constructed wetlands (CW) are wastewater treatment systems that remove contaminants by utilizing natural processes involving plants, substrates, and their associated microbial communities (Rani et al., 2011; Yalçuk & Ugurlu, 2020). The treatment process in CWs involves physical (filtration, sedimentation), chemical (adsorption, precipitation) and biological (plant uptake, assimilation and biodegradation) processes (Barya et al., 2020; El Ghadraoui et al., 2020). Microorganisms are regarded as vital components in the treatment process, therefore any aspect that changes their composition, biodegradation efficiency, or concentrations has a substantial effect on the entire CW (Shelef et al., 2013). When CWs are compared to conventional treatment technologies, they are less expensive, require less maintenance, use less energy, and are more environmentally friendly (Chavan & Mutnuri, 2021; Ilyas & van Hullebusch, 2019; Mustapha et al., 2018; Pinninti et al., 2022; Vymaza, 2022). This makes CWs to be an interesting option for developing countries where advanced wastewater treatment technologies are neither practical nor affordable (Ali et al., 2018). Several studies have evaluated the performance of CWs for treatment of hospital wastewater, and they found that the systems are capable of significantly removing a variety of pollutants such as TSS, COD, BOD, turbidity, nitrate, phosphate, heavy metals and Coliforms (Aukidy et al., 2017; Ilyas & van Hullebusch, 2020; Parashar et al., 2022; Swarnakar et al., 2022; Uluseker et al., 2021). The technology of CW has been adopted in different African countries including Tanzania for treatment of wastewater from different sources such as domestic, tannery, distillery and winery, agricultural, food processing, acid mine drainage, petrochemical, paper and pulp, textile, chemical, abattoir, urban storm-water and landfill leachate (Mekonnen et al., 2015). The first research on CW in Tanzania was launched in 1998 at the University of Dar es Salaam (Njau et al., 2011). Several pilot and full scale CWs are now operating in different places in Tanzania (Kimwaga et al., 2013).

One of the plant species most planted in CWs in Tanzania is *Typha latifolia*. This plant which is also known as cattail, is a perennial herbaceous wetland plant with long, slender green stalks that are topped with brown, fluffy, sausage-shaped flowering heads (Papadopoulos & Zalidis, 2019). It thrives in a broad variety of climates, including tropical, subtropical, temperate, humid coastal, and dry continental. It can be found in rivers, brackish and freshwater marshes, irrigation ditches, ponds, and lakes (Rana & Maiti, 2018). Also, this plant grows very quickly, produces a lot of biomasses, and can reach heights of up to 3 m (Irshad et al., 2021). Wind-propagated seeds allow them to rapidly colonize new wetlands and normally grow as dense monocultures (Fitch, 2014). This plant provides significant ecosystem services such as bioremediation in constructed wetlands (Bansal et al., 2019). It is one of the plants most frequently used for constructed wetlands, and some research demonstrate that this really performs better at wastewater treatments (Fitch, 2014). It has demonstrated high effectiveness in the removal of organic matter and inorganic nutrients (Camacho et al., 2018). It has the ability to bioaccumulate heavy metals such as Zn, Ni, Pb, Cd, Se, and Cu. It can also tolerate and detoxify organic pollutants such as synthetic pesticides (Papadopoulos & Zalidis, 2019).

Therefore, the aim of this study was to investigate the physicochemical and microbiological characteristics of wastewater from the Benjamin Mkapa Hospital in Dodoma Tanzania which is treated in constructed wetland planted with *Typha latifolia*. This study is important due to possible health risk and environmental pollution due to complex mixture of pollutants in hospital wastewater.

## Materials and methods

### Description of the study area

The study was undertaken in May 2022 at the Benjamin Mkapa Hospital (BMH) in Dodoma city, Tanzania. This is a tertiary public hospital situated in the campus of the University of Dodoma (UDOM). This hospital was founded in 2015 to provide specialist and super-specialized health services, as well as to coordinate and monitor research and learning activities. Dodoma, Tanzania's capital, is located between 6°00′ and 6°30′ South and 35°30′ and 36°02′ East with a total area of 2769 $Km^2$. The average coverage rainfall is 570 mm and about 85% of this falling between December and April. On average, the temperature ranges between 18 °C and 31 °C (Mkude & Saria, 2014). The wastewater from this hospital is treated in the horizontal subsurface flow CW (Layout Fig. 1) before being released into the environment. This CW is planted with *Typha latifolia* which covers about 3/5 of the system while the remaining part is not planted. A gravel bed (around 2.5 cm) is laid over an impermeable concrete structure to make the CW's media.

### Wastewater sampling

Wastewater sampling was done for three months from 02nd May 2022 to 25th July 2022 where sampling was done once (every monday) every week. The days were sunshine, and the average temperature of the water was 25.6 °C. Sampling was done at the inlet and outlet point of a CW. Daily composite samples were made by blending two morning and evening grab samples and placing them in 1.5L plastic bottles (Kayombo & Ladegaard, 2004; Majewsky et al., 2011; Paing et al., 2015; Reungoat et al., 2010). Physical parameters such as temperature, pH, electrical conductivity, TDS, DO and turbidity were measured on site (Schaider et al., 2017). The samples were then kept up in an ice-box with ice packs to keep them below 4 $^0$C before being taken to the laboratory for more investigation. Samples were analyzed as soon as they arrived at the

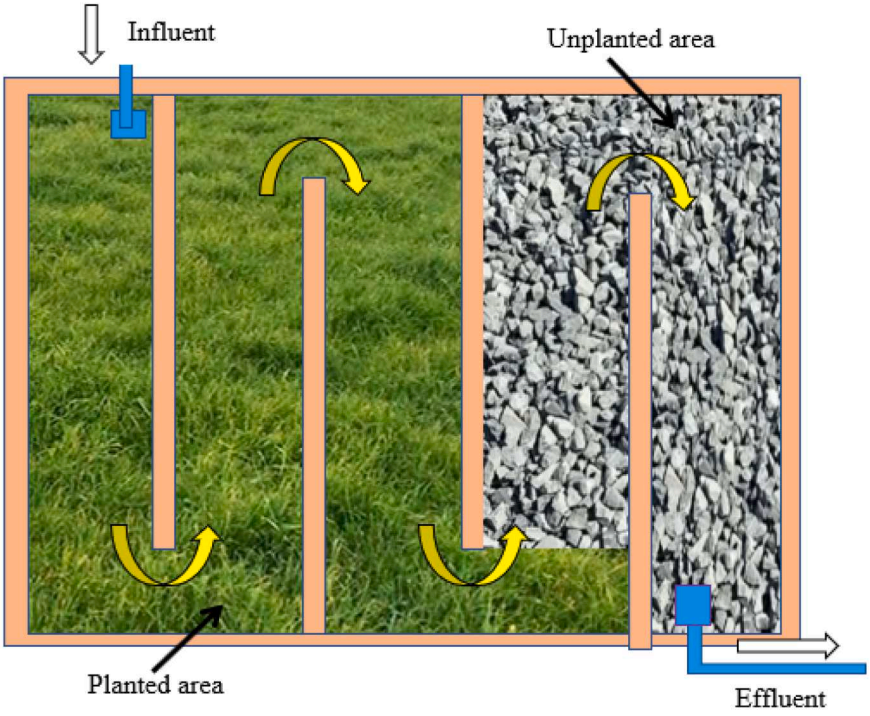

**Fig. 1.** Layout of the constructed wetland.

laboratory, and they were kept at 4 °C throughout the analysis time.

### Physico-chemical analysis of wastewater

Unless otherwise stated, all of the analyses were conducted using Standard Methods for the Examination of Water and Wastewater (APHA, 2017). A portable tester, the Hanna HI98129 Combo meter, was used to measure the temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) in-situ (Muriuki et al., 2020). A turbidity meter (HANNA, HI 93703-11) was used to measure the turbidity (Farid et al., 2014). The gravimetric method was employed to determine the total suspended solids (TSS) (Fahim et al., 2021). The phosphates concentration was determined by HACH test kit using the ascorbic acid method and PhosVer® (ascorbic acid) reagent pillows (Ge et al., 2020). Nitrate-nitrogen ($NO_3$-N) was measured using the HACH test kits (NitraVer 5 Nitrate Reagent Powder Pillows) (M. Wang et al., 2017). The Chemical oxygen demand (COD) was determined by Reflux Titrimetric Method (Part 5220 method C) (Fahim et al., 2021). The biochemical oxygen demand ($BOD_5$) was determined using the WTW OxiTop® measurement unit in accordance with the manufacturer's instructions (Punyapwar & Mutnuri, 2020).

### Enumeration of Escherichia coli

3M™ Petrifilm™ Select E. coli (SEC) Count Plates were used to count and isolate *E. coli* according to the manufacturer's instructions. In short, one milliliter of sample was inoculated onto SEC plates and incubated at 44 °C for 24 h after being diluted appropriately in 0.1% buffered peptone water. Regardless of size or color intensity, all blue *E. coli* colonies on the SEC plates with trapped gas were counted and identified as *E. coli*. If no colony was found on the SEC plates, the concentration was reported as less than 1 CFU/mL (detection limit), which is equivalent to 0 log CFU/mL (Medina & Jordano, 2019; Ofred et al., 2016).

### Wetland removal efficiency

The removal efficiency of CW was calculated by the percent difference in values denoted as the removal percentage (r %) for all the wetland settings and was calculated by using following equation (Eq. (1))

$$Removal\,\% = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \tag{1}$$

where $C_{in}$ = Concentration of a parameter in influent and $C_{out}$ = Concentration of parameter in effluent.

## Results

### Physicochemical parameters

The observed values of the physicochemical parameters are used as indicators of effluent quality in compliance with standards. The average concentrations of the physicochemical properties for the influent and effluent samples are shown in Table 1.

The comparison of the TSS, COD, BOD, turbidity, nitrate, and phosphate concentrations in relation to the standard values is shown in Fig. 2. Despite decreases in many parameters, only turbidity falls within the permitted levels of wastewater discharge.

### Biodegradability index

The $BOD_5$/COD ratio, also known as the Biodegradability Index (BI), was calculated to assess the biodegradability of pollutants in hospital wastewater (Lai et al., 2011). According to the results of this study (shown in Fig. 3), BI for influent ranges from 0.2 to 0.9 with an average of 0.5, while BI for effluent ranges from 0.3 to 0.7 with an average of 0.4. The findings indicate that there was a weekly fluctuation in the relative effluent biodegradability.

**Table 1**
Physicochemical characteristics of wastewater in this study.

| Parameter | Unit | Standards | Influent | | Effluent | |
|---|---|---|---|---|---|---|
| | | | Range | Mean ± SD | Range | Mean ± SD |
| pH | Numeric | 6.5–8.5 | 6.5–7.5 | 6.93 ± 0.59 | 6.9–8.1 | 7.48 ± 0.63 |
| EC | µS/cm | | 1566.8–3236.6 | 2360 ± 918 | 1918.4–3001.9 | 2441 ± 623 |
| Temp | °C | 20–35 | 23.9–26.6 | 25.2 ± 1.58 | 23.8–26.0 | 25.4 ± 1.64 |
| TDS | mg/L | 3000 | 776.6–1477.9 | 1218 ± 479 | 1057.8–1634.5 | 1305.5 ± 396 |
| TSS | mg/L | 100 | 224.5–324.7 | 270.38 ± 66.1 | 6.9–102.2 | 49.17 ± 53.11 |
| Turbidity | NTU | 300 | 98.5–200.9 | 150 ± 57.2 | 0.8–32.6 | 9.1 ± 14.83 |
| DO | mg/L | | 0.5–1.0 | 0.75 ± 0.34 | 6.0–7.4 | 6.8 ± 0.94 |
| COD | mg/L | 60 | 196.9–446.3 | 329.2 ± 135.6 | 132.7–208.6 | 170.4 ± 40.6 |
| $BOD_5$ | mg/L | 30 | 74.3–183 | 140.9 ± 66.8 | 47.4–96.7 | 74.8 ± 33.5 |
| $NO_3$-N | mg/L | 20 | 75.9–139.6 | 108.5 ± 36.8 | 10.9–84.7 | 45.4 ± 39.97 |
| $PO_4$-P | mg/L | 6 (TP) | 0.9–2.1 | 1.55 ± 0.66 | 2.3–6.7 | 2.30 |

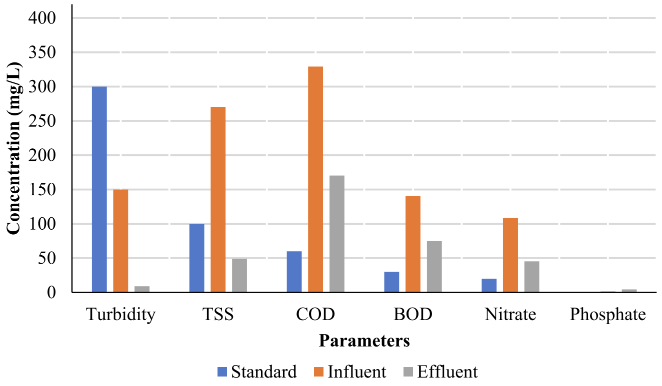

**Fig. 2.** Comparison between standard, influent and effluent parameters.

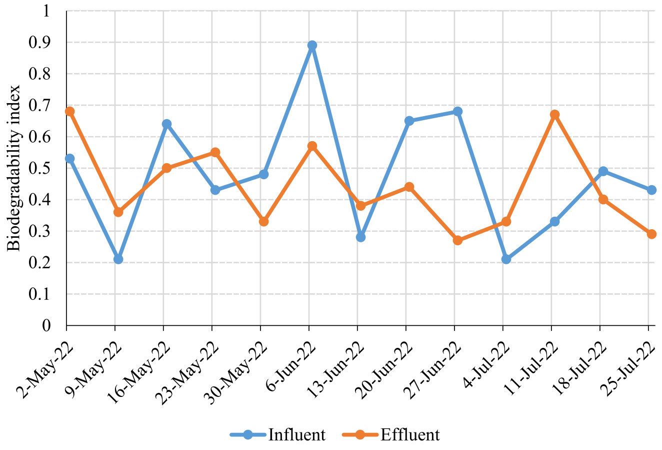

**Fig. 3.** Variation in biodegradability index (BOD5/COD ratio) of influent and effluent.

### *Enumeration of Escherichia coli*

Fig. 4 presents the results for the enumeration of *E. coli* in influent and effluent samples over a period of 13 weeks. *E. coli* concentration in the influent samples ranged from 2.5 × $10^4$ CFU/mL to 1.1 × $10^6$ CFU/mL, while concentration in the effluent samples ranged from 1.1 × $10^1$ CFU/mL to 1.1 × $10^2$ CFU/mL. For influent and effluent, the average values were 5.21logCFU/mL and 1.77logCFU/mL, respectively. These data demonstrate a significant decrease in *E. coli* following treatment in the CW. *E. coli* concentrations in wastewater were reduced by roughly 3.44log CFU/mL. The amount of E. coli in the effluent was almost within the acceptable level for disposal of effluent.

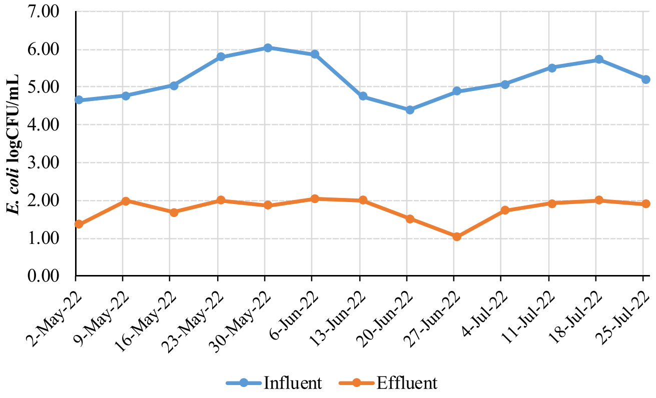

**Fig. 4.** *E. coli* enumeration in influent and effluent samples.

## Discussion

### *Physicochemical characterization*

The physicochemical characterization of hospital wastewater includes the evaluation of different parameters (Abd El-Gawad & Aly, 2011). The results of the physicochemical characteristics in our study revealed that some parameters, such as BOD, COD, TSS, Nitrates values, were higher than the Tanzanian standards established for wastewater discharge into the environment. pH is a basic characteristic that is incredibly essential since it controls the majority of chemical reactions in the aquatic environment. It is a measure of acidity or alkalinity of water. Anything very acidic or alkaline would be harmful to aquatic life. Aquatic organisms are sensitive to pH variations. Heavy metal toxicity is also increased at certain pH levels. This makes pH a critical parameter to determine for water and wastewater quality (Hassan et al., 2021; Lokhande et al., 2011). In the present study, the average values of pH were 6.93 ± 0.59 and 7.48 ± 0.63 for influent and effluents respectively. According to the results, the pH of the effluent has increased as compared to the pH of the influent. This can be explained by the production of ammonia gas during the anaerobic breakdown of organic nitrogen (Autlwetse & Kimwaga, 2022). Additionally, plants that engage in intensive photosynthesis raise the water pH (Kiflay et al., 2021). However, the pH of the influent and effluent both fall within the permissible range of 6.5–8.5, which is ideal for aerobic bacteria (Permatasari et al., 2018).

EC is a unit used to describe how well a liquid conducts an electric charge. EC is determined by the measurement temperature, ionic strength, and dissolved ion concentrations (Rusydi, 2018). Water's EC is a simple and accurate indication of salinity or total salt concentration (Patel et al., 2017). Results in Table 1 show that, the average EC of the effluent (2441 ± 623 µS/cm) is higher than that of the influent (2360 ± 918 µS/cm) by 3%. Similar results were reported at the University of Dar es Salaam in Tanzania, where wastewater effluent from the University's waste stabilization ponds was treated in a horizontal flow CW (Mashauri et al., 2000). This might be because plant decomposition releases nutrients back into the water, increasing the conductivity by raising the concentration of dissolved ions. It might also result from organic contaminants being degraded into less complex organic components (Kiflay et al., 2021).

Several chemical and physical properties of water, such as gases solubility, chemicals reactivity and toxicity, and microbiological activity are all strongly influenced by temperature (Wilson & Worrall, 2021). Higher temperatures make dissolved oxygen less soluble, lowering its concentration and, consequently, its availability to aquatic species (Dallas, 2008; Miller & Young, 2022). High microbial activity at the higher temperature speeds up oxygen depletion if the organic loading is high. The habitat temperature has also an impact on aquatic organisms' growth, reproduction, and distribution (Bhatia et al., 2018; Miller, 2021). The temperature of CW water is directly related to the temperature of the air and has an effect on total treatment efficiency (Udom et al., 2018). According Table 1, the temperature of influent during sampling ranged from 23.9 to 26.6 °C, while effluent temperatures ranged from 23.8 to 26.0 °C. There is no significant variation ($p > 0.05$) in temperature between the influent and effluent. Both influent and effluent temperature fall in the acceptable range (25–35 °C) which is suitable for high microbial activities (Mairi et al., 2001).

TDS is a measure of the total inorganic and organic content of a liquid in ionized, molecular or microgranular (colloidal sol) suspended form. TDS is made up of inorganic salts (mostly calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some organic matter that is dissolved in water (Gupta et al., 2016). A high TDS affects water density, gas solubility including oxygen, osmoregulation of freshwater in organisms, and the use of water for many applications including irrigation, drinking, and industrial (Lokhande et al., 2011). TDS results in the current study were 1218 ± 479 mg/L and 1305.5 ± 396 mg/L for influent and effluent respectively. The results show increase in TDS from influent to effluent by 7%. They both fall in the acceptable levels for effluent discharge. TDS and EC exhibit a correlation such that the TDS readings in each measurement were roughly half the EC values. The explanation for TDS observations is the same as the one provided for EC observations.

TSS are regarded as one of the main contaminants that lead to the decline in water quality (Verma et al., 2013). Increase in water suspended solids levels hinder the efficient exchange of oxygen between water and air. They have the potential to suppress aquatic animals from breathing. They cause an increase in turbidity, which causes oxygen level to decrease. Additionally, it may prevent the necessary light from entering the aquatic system, which would reduce the capacity of various algae and flora to produce food and oxygen. Because suspended solids can directly absorb sunlight, the water becomes warmer and has less dissolved oxygen (Wei et al., 2020). TSS removal in CWs is accomplished through a variety of mechanisms. This includes the deposition process that results from the interception of suspended solids due to the slower water flow through wetland substrate. Additionally, it comprises filtration and aggregation or flocculation (Rahmadyanti & Febriyanti, 2020). TSS results in the current study were 270.38 ± 66.1 mg/L and 49.17 ± 53.11 mg/L for influent and effluent respectively. This shows that the system is capable of removing up to 82 % of TSS.

Turbidity is a measurement of water clarity, how deep down the water column light can penetrate (Balaji et al., 2018; Scholz, 2016). Turbidity is the result of presence of suspended particles, which vary in size from large flocs to incredibly tiny colloidal particles. Infrared and visible electromagnetic radiation is scattered and absorbed by these particles (Fereja et al., 2020). High water turbidity lowers the amount of light available to photosynthetic organisms (Obinnaa & Ebere, 2019). The findings of the present study demonstrated the CW's outstanding effectiveness in removing turbidity from hospital wastewater. Around 94% of the wastewater turbidity was removed by the system, from influent with 150 ± 57.2 NTU to effluent with 9.1 ± 14.83 NTU.

DO is the amount of oxygen available in aquatic environment to aquatic organisms (Patel et al., 2017). DO is a state variable that regulates chemical oxidation, respiration, photosynthesis, and the exchange of oxygen between water masses (Carstensen et al., 2012). When there is little or no DO, oxidation occurs through the reduction of inorganic salts or the action of methane-forming bacteria that produce unpleasant end products (Muttamara, 1996). DO is generally a limiting factor in the removal of organic and inorganic contaminants such as nitrogen in CWs (Valipour & Ahn, 2017). The results from this study show that the hospital wastewater had DO of 0.75 ± 0.34 mg/L and 6.8 ± 0.94 mg/L for influent and effluent respectively. A combination of plant rhizospheric oxygen release and air–water interphase oxygen transfer from the atmosphere contribute to the increase in DO (Zhai et al., 2012).

COD is the quantity of oxygen equivalents spent during the oxidation of organic compounds by strong oxidizing agents like dichromate and permanganate (Silva et al., 2009). It is a sign of the presence of reducing agents in the water, such as organics, nitrite, sulfide, ferrous salts, etc., with organics predominating. The aquatic life suffers when the oxygen in the water system is reduced significantly due to a high COD content. A high COD value indicates that there is little microbial activity, which slows down the rate at which organic matter degrades (J. P. Patel & Parsania, 2017; Udom et al., 2018). The results from the current study shows removal of hospital wastewater COD by only 48 %. This is from 329.2 ± 135.6 mg/L to 170.4 ± 40.6 mg/L after the treatment process. In a similar study conducted to evaluate the efficiency of CW for hospital wastewater treatment the systems managed to remove COD by 64.9% in India (Parashar et al., 2022) and by 80% in Thailand (Vo et al., 2019).

The $BOD_5$ value is the amount of dissolved oxygen that aerobic biological organisms in a waterbody require to decompose organic matter present in a given water sample at a given temperature over a particular time period (Gupta et al., 2016) usually 5 days (Jouanneau et al., 2014; Kitalika et al., 2016). It is a method of indirectly quantifying existing organic or chemical pollutants that biodegrade in the presence of oxygen in water (Maddah and Ponnusamy, 2022). The degree of oxygen depletion in the water bodies increases with increasing $BOD_5$ content. High $BOD_5$ levels have comparable implications to low dissolved oxygen levels; aquatic organisms become stressed, suffocate, and die (Aniyikaiye et al., 2019). This decrease in $BOD_5$ can be driven by a range of mechanisms, including microbial degradation and physical processes such as settling, filtration, and predation of particulate organic matter (Kimwaga et al., 2004).The results in this study show that the CW system achieved $BOD_5$ reduction by only 47%. This is low performance when compared to a similar study done in India where 96% of BOD was removed from hospital wastewater in CW (Khan et al., 2020).

Water and wastewater contain four different types of nitrogen: nitrite, nitrate, organic nitrogen, and ammonia nitrogen. Most nitrogen in sewage-contaminated water is present as organic and ammonia compounds, which can be converted by microorganisms into nitrites and nitrates (APHA, 2017; Samer, 2015). Nitrate, a basic nutrient for plant growth, has the potential to be a growth-limiting nutrient factor. Too much nitrate in surface water can encourage eutrophication, which degrades the water's quality (Berkessa et al., 2019). Infants' health is immediately and seriously threatened by consuming water with an excessive nitrate concentration (greater than 10 mg/L) (Hassan Omer, 2020; Kitalika et al., 2016). So, discharge of nitrate into the environment should be controlled. In the current study the influent and effluent had 108.5 ± 36.8 mg/L and 45.4 ± 39.97 mg/L of nitrate respectively. This is around 58 % removal of nitrate. Despite this removal, the effluent has nitrate content above the discharge allowed level. Low nitrate removal may be explained by low denitrification process (Khan et al., 2020). The performance of the CW for removal of nutrients such as nitrogen can be increased by plants harvesting (Wang et al., 2021). This will reduce the release of nutrients from plants decomposition and the possibility of substrate clogging (Álvarez & Bécares, 2008; Tanaka et al., 2015, 2016).

High nutrients (nitrogen and phosphorus) content in wastewater has potentially adverse effects on the ecosystem. Similar to nitrogen, releasing wastewater that contains a lot of phosphorus promotes eutrophication in receiving water bodies (Autlwetse & Kimwaga, 2022; Balachandran et al., 2018; Kiflay et al., 2021). Water source eutrophication may also produce environmental conditions that encourage the growth of cyanobacteria that produce toxins, and human exposure to such toxins is dangerous (Edokpayi et al., 2017; Nayan et al., 2020). In addition, releasing organic-rich waste water into the environment causes a rapid decline in the amount of dissolved oxygen in the water bodies it enters, which has the unintended consequences of causing aquatic life to die and disturbing the balance of the ecosystem (Egbuikwem et al., 2021; Liang et al., 2017). Phosphorus removal in CWs is accomplished through precipitation, bacterial removal, adsorption and plant uptake (Albalawneh et al., 2016; Shukla et al., 2021) results in the current study shows that the average phosphorus in the influent and effluent were 1.55 ± 0.66 mg/L and 4.52 ± 2.30 mg/L respectively. This shows the general increase in phosphate in the wastewater after passing through the CW. This may be caused by the release of nutrients from decomposing plants. As explained for nitrates, the solution to this includes plant harvesting (Álvarez & Bécares, 2008; Vymazal, 2011).

### *Biodegradability index*

As described before, both influent and effluent high COD and BOD values beyond the established standards for effluent discharge. The $BOD_5$/COD ratio ranged from 0.2 to 0.9 for the influent which is a normal case and this waste is easily degradable by the biological processes. As for the effluent (treated sewage) the $BOD_5$/COD ratio varied from 0.3 to 0.7. Theoretically, for domestic wastewaters, the BI ranges from 0.4 to 0.8 (Al-Sulaiman & Khudair, 2018). If the $BOD_5$/COD ratio is between 0.3 and 0.6, seeding is required to treat it biologically, since the acclimation of the microorganisms that aid in the degradation process takes time due to the slow biodegradation process. $BOD_5$/COD ratio of less than 0.3 indicates the presence of organic compounds in the wastewater that are difficult to biodegrade, possibly toxic, and non-biodegradable. This wastewater cannot be treated biologically (Mesdaghinia et al., 2015; Rim-Rukeh & Agbozu, 2013). Results from this study shows that the average effluent's $BOD_5$/COD ratio is slightly low when compared to the ratios in the influent, giving clear evidence that the organic matter in the wastewater has undergone biological degradation (Zhao et al., 2018). Each stage of conventional wastewater treatment results in a decrease in the $BOD_5$/COD ratio. This happens mainly because the existing bacteria first breakdown the biodegradable component of organic matter, as measured by the $BOD_5$, while the more inert fraction of organic matter often remains constant throughout treatment (Abbas et al., 2022). Despite of the small difference in average values of $BOD_5$/COD ratio observed in this study, in both influent and effluent, the minimum values is below 0.4. This suggests that the wastewater contains non-biodegradable organic matter which may include xenobiotic compounds such as surfactants (Prokkola et al., 2022). This means that before influent can be treated via biological treatment, a pre-treatment procedure may be necessary to increase its biodegradability index.

### *Escherichia coli*

The reduction in *E. coli* concentration in this study was 3.44 log. As a result, the effluent was within the permitted values for discharge. Some studies have indicated a 4.5 log reduction in pathogens from domestic wastewater in CW (Vega De Lille et al., 2021). *Typha latifolia*-planted CW was reported to reduce *E. coli* from domestic wastewater by 3.9 log (Martinez-Guerra et al., 2018). In Egypt, the effectiveness of CW integrated with septic tanks on removing fecal coliform was examined. The findings demonstrate that the fecal coliform count was decreased by almost 5 log (Abdel-Shafy & El-Khateeb, 2013). A membrane bioreactor (MBR) and disinfection with either chlorine or ozone were used in another investigation to reduce *E coli* by more than 6 log from hospital effluent (Chiemchaisri et al., 2022). In a different study, carried out in Tanzania, the efficacy of fecal coliform bacteria removal from wastewater in waste stabilization ponds in the Morogoro, Mwanza, and Iringa regions was assessed. The largest reduction in fecal coliforms seen in this investigation was 3.8 log (Zacharia et al., 2019).

## Conclusion

This study investigated the physicochemical characteristics of wastewater from the Benjamin Mkapa Hospital in Dodoma Tanzania. The monitoring of the quality of the effluent from the wastewater treatment system is done to comply with the Tanzanian effluent quality discharge standards for municipal and industrial wastewaters. This study revealed a significant decline in the physicochemical characteristics of the discharged wastewater effluents and shows that the treatment processes seem to be ineffective at producing effluents of acceptable standard. *E. coli* concentration was decreased by 3.44 log which made the effluent be discharged with *E. coli* concentration ranging from 1.1 × $10^1$ CFU/mL to 1.1 × $10^2$ CFU/mL. The levels of COD, BOD, and nitrates were higher than the Tanzanian government's permitted discharge levels despite the observed decrease from influent to effluent. The system only effectively removed turbidity and TSS. The effluent contained higher levels of EC, TDS, and $PO_4$-P than the influent. Small difference in average values of $BOD_5$/COD ratio between influent and effluent, suggests presence of non-biodegradable organic matter which may include xenobiotic compounds such as surfactants. The performance of the system may be impacted by the substrate clogging, degradation of plants, and inadequate pretreatment of the wastewater. Improving the efficacy of wastewater treatment will require intervention in the wastewater treatment system.

## Author contribution statement

The authors confirm contribution to the paper as follows:

(a) Study conception and design: Petro Karungamye, Anita Rugaika, Kelvin Mtei, Revocatus Machunda
(b) Samples collection and analysis: Petro Karungamye,
(c) Data analysis and interpretation of results: Petro Karungamye, Anita Rugaika, Kelvin Mtei, Revocatus Machunda
(d) Draft manuscript preparation: Petro Karungamye.
(e) Review and manuscript finalization: Anita Rugaika, Kelvin Mtei, Revocatus Machunda
(f) Supervision: Anita Rugaika, Kelvin Mtei, Revocatus Machunda

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## References

Abbas, A.A., Yousif, Y.T., Almutter, H.H., 2022. Evaluation of Al-Thagher wastewater treatment plant. Period. Polytech. Civil Eng. 66 (1), 112–126. https://doi.org/10.3311/PPci.18513.

Abd El-Gawad, H.A., Aly, A.M., 2011. Assessment of aquatic environmental for wastewater management quality in the hospitals: A case study. Aust. J. Basic Appl. Sci. 5 (7), 474–482.

Abdel-Shafy, H.I., El-Khateeb, M.A., 2013. Integration of septic tank and constructed wetland for the treatment of wastewater in Egypt. Desalin. Water Treat. 51 (16–18), 3539–3546. https://doi.org/10.1080/19443994.2012.749585.

Albalawneh, A., Chang, T.K., Chou, C.S., Naoum, S., 2016. Efficiency of a horizontal subsurface flow constructedwetland treatment system in an arid area. Water (Switzerland) 8 (2). https://doi.org/10.3390/w8020051.

Ali, Z., Mohammad, A., Riaz, Y., Quraishi, U.M., Malik, R.N., 2018. Treatment efficiency of a hybrid constructed wetland system for municipal wastewater and its suitability for crop irrigation. Int. J. Phytorem. 20 (11), 1152–1161. https://doi.org/10.1080/15226514.2018.1460311.

Al-Sulaiman, A.M., Khudair, B.H., 2018. Correlation between BOD5 AND COD for Al-Diwaniyah wastewater treatment plants to obtain the biodigrability indices. J. Biotechnol. 15 (2), 423–427. www.pjbt.org.

Álvarez, J.A., Bécares, E., 2008. The effect of plant harvesting on the performance of a free water surface constructed wetland. Environ. Eng. Sci. 25 (8), 1115–1122. https://doi.org/10.1089/ees.2007.0080.

Amouei, A., Asgharnia, H., Fallah, H., Faraji, H., Barari, R., Dariush, N., 2015. Characteristics of effluent wastewater in hospitals of Babol University of Medical Sciences, Babol, Iran. Health Scope 4 (2), 4–7.

Aniyikaiye, T.E., Oluseyi, T., Odiyo, J.O., Edokpayi, J.N., 2019. Physico-chemical analysis of wastewater discharge from selected paint industries in Lagos, Nigeria. Int. J. Environ. Res. Public Health 16 (7). https://doi.org/10.3390/ijerph16071235.

APHA, 2017. Standard Methods for the Examination of Water and Wastewater, 23rd ed. American Public Health Association. https://doi.org/10.1016/B978-0-12-382165-2.00237-3.

Aukidy, M.A., Chalabi, S.A., Verlicchi, P., 2017. Hospital wastewater treatments adopted in Asia, Africa, and Australia. In: Hospital Wastewaters – Characteristics, Management, Treatment and Environmental Risks. https://doi.org/10.1007/698.

Autlwetse, B., Kimwaga, R., 2022. Effects of constructed wetlands plants on phosphorus removal from domestic wastewater in Gaborone, Botswana. Tanzania J. Eng. Technol. 40 (2), 82–96. https://doi.org/10.52339/tjet.v40i2.735.

Balachandran, T., Nanthakumaran, A., Devaisy, S., Sivanesan, K.S., 2018. Role of *Colocasia esculenta* in constructed wetlands for treating rice mill wastewater. AGRIEAST: J. Agric. Sci. 12 (2), 19. https://doi.org/10.4038/agrieast.v12i2.56.

Balaji, V., Anand Kumar Varma, S., Ashwin, R., 2018. Industrial effluent treatment by Moringa Oleifera as natural coagulant of different particle size. Asian J. Microbiol. Biotechnol. Environ. Exp. Sci. 20 (2), 550–556.

Bansal, S., Lishawa, S.C., Newman, S., Tangen, B.A., Wilcox, D., Albert, D., Anteau, M.J., Chimney, M.J., Cressey, R.L., DeKeyser, E., Elgersma, K.J., Finkelstein, S.A., Freeland, J., Grosshans, R., Klug, P.E., Larkin, D.J., Lawrence, B.A., Linz, G., Marburger, J., Noe, G., Otto, C., Reo, N., Richards, J., Richardson, C., Rodgers, L., Schrank, A.J., Svedarsky, D., Travis, S., Tuchman, N., Windham-Myers, L., 2019. Typha (Cattail) invasion in North American Wetlands: Biology, regional problems, impacts, ecosystem services, and management. Wetlands 39 (4), 645–684.

Barya, M.P., Gupta, D., Thakur, T.K., Shukla, R., Singh, G., Mishra, V.K., 2020. Phytoremediation performance of *Acorus calamus* and *Canna indica* for the treatment of primary treated domestic sewage through vertical subsurface flow constructed wetlands: A field-scale study. Water Pract. Technol. 15 (2), 528–539. https://doi.org/10.2166/wpt.2020.042.

Berkessa, Y.W., Mereta, S.T., Feyisa, F.F., 2019. Simultaneous removal of nitrate and phosphate from wastewater using solid waste from factory. Appl. Water Sci. 9 (2), 1–10. https://doi.org/10.1007/s13201-019-0906-z.

Bhatia, D., Sharma, N.R., Kanwar, R., Singh, J., 2018. Physicochemical assessment of industrial textile effluents of Punjab (India). Appl. Water Sci. 8 (3), 1–12. https://doi.org/10.1007/s13201-018-0728-4.

Camacho, A., Picazo, A., Rochera, C., Peña, M., Morant, D., Miralles-Lorenzo, J., Santamans, A.C., Estruch, H., Montoya, T., Fayos, G., Ferriol, C., 2018. Serial use of Helosciadum nodiflorum and Typha latifolia in mediterranean constructed wetlands to naturalize effluents of wastewater treatment plants. Water (Switzerland) 10 (6). https://doi.org/10.3390/w10060717.

Carstensen, J., Dahl, K., Henriksen, P., Hjorth, M., Josefson, A., Krause-Jensen, D., 2012. Coastal Monitoring Programs Vol. 7, 175–206. https://doi.org/10.1016/B978-0-12-374711-2.00712-9.

Chavan, R., Mutnuri, S., 2021. Domestic wastewater treatment by constructed wetland and microalgal treatment system for the production of value-added products. Environ. Technol. (United Kingdom) 42 (21), 3304–3317. https://doi.org/10.1080/09593330.2020.1726471.

Chiemchaisri, C., Chiemchaisri, W., Dachsrijan, S., Saengam, C., 2022. Coliform removal in membrane bioreactor and disinfection during hospital wastewater treatment. J. Eng. Technol. Sci. 54 (4) https://doi.org/10.5614/j.eng.technol.sci.2022.54.4.1.

Dallas, H., 2008. Water temperature and riverine ecosystems: An overview of knowledge and approaches for assessing biotic responses, with special reference to South Africa. Water SA 34 (3), 393–404. https://doi.org/10.4314/wsa.v34i3.180634.

Desta, A.F., Assefa, F., Leta, S., Stomeo, F., Wamalwa, M., Njahira, M., Appolinaire, D., 2014. Microbial community structure and diversity in an integrated system of anaerobic-aerobic reactors and a constructed wetland for the treatment of tannery wastewater in Modjo, Ethiopia. *PLoS ONE* 9 (12), 1–22. https://doi.org/10.1371/journal.pone.0115576.

Edokpayi, J.N., Odiyo, J.O., Durowoju, O.S., 2017. Household hazardous waste management in - impact of wastewater on surface water quality in sub-Saharan Africa developing countries: A case study of South Africa. Water Quality 18, 1–16.

Egbuikwem, P.N., Obiechefu, G.C., Hai, F.I., Devanadera, M.C.E., Saroj, D.P., 2021. Potential of suspended growth biological processes for mixed wastewater reclamation and reuse in agriculture: challenges and opportunities. Environ. Technol. Rev. 10 (1), 77–110. https://doi.org/10.1080/21622515.2021.1881829.

El Ghadraoui, A., Ouazzani, N., Ahmali, A., El Mansour, T.E.H., Aziz, F., Hejjaj, A., Del Bubba, M., Mandi, L., 2020. Treatment of olive mill and municipal wastewater mixture by pilot scale vertical flow constructed wetland. Desalin. Water Treat. 198, 126–139. https://doi.org/10.5004/dwt.2020.26009.

Fahim, R., Xiwu, L., Jilani, G., 2021. Feasibility of using divergent plantation to aggrandize the pollutants abatement from sewage and biomass production in treatment wetlands. Ecohydrol. Hydrobiol. 21 (4), 731–746. https://doi.org/10.1016/j.ecohyd.2021.05.003.

Farid, M., Irshad, M., Fawad, M., Ali, Z., Eneji, A.E., Aurangzeb, N., Mohammad, A., Ali, B., 2014. Effect of cyclic phytoremediation with different wetland plants on municipal wastewater. Int. J. Phytorem. 16 (6), 572–581.

Fatta-Kassinos, D., Meric, S., Nikolaou, A., 2011. Pharmaceutical residues in environmental waters and wastewater: Current state of knowledge and future research. Anal. Bioanal. Chem. 399 (1), 251–275. https://doi.org/10.1007/s00216-010-4300-9.

Fereja, W.M., Tagesse, W., Benti, G., Yildiz, F., 2020. Treatment of coffee processing wastewater using Moringa stenopetala seed powder: Removal of turbidity and chemical oxygen demand. Cog. Food Agric. 6 (1), 1816420.

Fitch, M.W., 2014. Constructed wetlands. In: Comprehensive Water Quality and Purification, 3. Elsevier Inc., pp. 268–295. https://doi.org/10.1016/B978-0-12-382182-9.00053-0

Ge, J., Guha, B., Lippincott, L., Cach, S., Wei, J., Su, T., Meng, X., 2020. Challenges of arsenic removal from municipal wastewater by coagulation with ferric chloride and alum. Sci. Total Environ. 725, 138351 https://doi.org/10.1016/j.scitotenv.2020.138351.

Gupta, P., Ann, T.W., Lee, S.M., 2016. Use of biochar to enhance constructed wetland performance in wastewater reclamation. Environ. Eng. Res. 21 (1), 36–44. https://doi.org/10.4491/eer.2015.067.

Hassan, I., Chowdhury, S.R., Prihartato, P.K., Razzak, S.A., 2021. Wastewater treatment using constructed wetland: Current trends and future potential. Processes 9 (11), 1–27. https://doi.org/10.3390/pr9111917.

Hassan Omer, N., 2020. Water quality parameters. In: Summers, K. (Ed.), Water Quality – Science, Assessments and Policy. IntechOpen.

Hdidou, M., Necibi, M.C., Labille, J., Hajjaji, S.E., Dhiba, D., Chechbouni, A., Roche, N., 2022. Potential use of constructed wetland systems for rural sanitation and wastewater reuse in agriculture in the moroccan context. Energies 15 (1). https://doi.org/10.3390/en15010156.

Hocaoglu, S.M., Celebi, M.D., Basturk, I., Partal, R., 2021. Treatment-based hospital wastewater characterization and fractionation of pollutants. J. Water Process Eng. 43 (February), 102205 https://doi.org/10.1016/j.jwpe.2021.102205.

Ilyas, H., van Hullebusch, E.D., 2019. Role of design and operational factors in the removal of pharmaceuticals by constructed wetlands. Water (Switzerland) 11 (11). https://doi.org/10.3390/w11112356.

Ilyas, H., van Hullebusch, E.D., 2020. Performance comparison of different types of constructed wetlands for the removal of pharmaceuticals and their transformation products: a review. Environ. Sci. Pollut. Res. 27 (13), 14342–14364. https://doi.org/10.1007/s11356-020-08165-w.

Irshad, S., Xie, Z., Kamran, M., Nawaz, A., Faheem, Mehmood, S., Gulzar, H., Saleem, M. H., Rizwan, M., Malik, Z., Parveen, A., Ali, S., 2021. Biochar composite with microbes enhanced arsenic biosorption and phytoextraction by Typha latifolia in hybrid vertical subsurface flow constructed wetland. Environ. Pollut. 291, 118269.

Ishii, S., Sadowsky, M.J., 2008. *Escherichia coli* in the environment: Implications for water quality and human health. Microbes Environ. 23 (2), 101–108. https://doi.org/10.1264/jsme2.23.101.

Jang, J., Hur, H.-G., Sadowsky, M.J., Byappanahalli, M.N., Yan, T., Ishii, S., 2017. Environmental *Escherichia coli*: Ecology and public health implications-a review. J. Appl. Microbiol. 123 (3), 570–581.

Jouanneau, S., Recoules, L., Durand, M.J., Boukabache, A., Picot, V., Primault, Y., Lakel, A., Sengelin, M., Barillon, B., Thouand, G., 2014. Methods for assessing biochemical oxygen demand (BOD): A review. Water Res. 49 (1), 62–82. https://doi.org/10.1016/j.watres.2013.10.066.

Kayombo, S., Ladegaard, N., 2004. Waste stabilization ponds and constructed wetlands design manual.

Khan, N.A., El Morabet, R., Khan, R.A., Ahmed, S., Dhingra, A., Alsubih, M., Khan, A.R., 2020. Horizontal sub surface flow Constructed Wetlands coupled with tubesettler for hospital wastewater treatment. J. Environ. Manage. 267 (February), 110627 https://doi.org/10.1016/j.jenvman.2020.110627.

Khan, M.T., Shah, I.A., Ihsanullah, I., Naushad, M., Ali, S., Shah, S.H.A., Mohammad, A. W., 2021. Hospital wastewater as a source of environmental contamination: An overview of management practices, environmental risks, and treatment processes. J. Water Process Eng. 41 (January), 101990 https://doi.org/10.1016/j.jwpe.2021.101990.

Kiflay, E., Selemani, J., Njau, K., 2021. Integrated constructed wetlands treating industrial wastewater from seed production. Water Pract. Technol. 16 (2), 504–515. https://doi.org/10.2166/wpt.2021.008.

Kimwaga, R., Mwegoha, W., Mahnge, A., Nyomora, A., & Lugali, L., 2013. Factors for success and failures of constructed wet? Lands in the sanitation service chains. In: VLIR UOS South Initiatives.

Kimwaga, R.J., Mashauri, D.A., Mbwette, T.S.A., Katima, J.H.Y., Jørgensen, S.E., 2004. Use of coupled dynamic roughing filters and subsurface horizontal flow constructed wetland system as appropriate technology for upgrading waste stabilisation ponds effluents in Tanzania. Phys. Chem. Earth Parts A/B/C 29 (15-18), 1243–1251.

Kitalika, A.J., Machunda, R.L., Komakech, H.C., Njau, K.N., 2016. Assessment of water quality variation in rivers through comparative index technique and its reliability for decision making. Tanzania J. Sci. 44 (3), 163–191.

Kumari, A., Maurya, N.S., Tiwari, B., 2020. Hospital wastewater treatment scenario around the globe. In: Current Developments in Biotechnology and Bioengineering. Elsevier, pp. 549–570.

Lee, Y., Kovalova, L., McArdell, C.S., von Gunten, U., 2014. Prediction of micropollutant elimination during ozonation of a hospital wastewater effluent. Water Res. 64, 134–148. https://doi.org/10.1016/j.watres.2014.06.027.

Liang, Y., Zhu, H., Bañuelos, G., Yan, B., Shutes, B., Cheng, X., Chen, X., 2017. Removal of nutrients in saline wastewater using constructed wetlands: Plant species, influent loads and salinity levels as influencing factors. Chemosphere 187 (August 2017), 52–61. https://doi.org/10.1016/j.chemosphere.2017.08.087.

Lokhande, R.S., Singare, P.U., Pimple, D.S., 2011. Study on physico-chemical parameters of waste water effluents from Taloja Industrial Area of Mumbai, India. *Int. J. Ecosyst.* 1 (1), 1–9.

Maddah, H.A., Ponnusamy, S.K., 2022. Predicting optimum dilution factors for BOD sampling and desired dissolved oxygen for controlling organic contamination in various wastewaters. Int. J. Chem. Eng. 2022, 1–14.

Mairi, J., Lyimo, T., Njau, K., 2001. Performance of a subsurface-flow constructed wetland for domestic wastewater treatment. Environ. Technol. (United Kingdom) 22 (5), 587–596. https://doi.org/10.1080/09593332208618260.

Majewsky, M., Gallé, T., Bayerle, M., Goel, R., Fischer, K., Vanrolleghem, P.A., 2011. Xenobiotic removal efficiencies in wastewater treatment plants: Residence time distributions as a guiding principle for sampling strategies. Water Res. 45 (18), 6152–6162. https://doi.org/10.1016/j.watres.2011.09.005.

Majumder, A., Gupta, A.K., Ghosal, P.S., Varma, M., 2020. A review on hospital wastewater treatment: A special emphasis on occurrence and removal of pharmaceutically active compounds, resistant microorganisms, and SARS-CoV-2. Journal of Environmental. Chem. Eng. 9 (January).

Martinez-Guerra, E., Castillo-Valenzuela, J., Gude, V.G., 2018. Wetlands for wastewater treatment. Water Environ. Res 90 (10), 1537–1562. https://doi.org/10.2175/106143018x15289915807281.

Mashauri, D.A., Mulungu, D.M.M., Abdulhussein, B.S., 2000. Constructed wetland at the University of Dar es Salaam. Water Res. 34 (4), 1135–1144. https://doi.org/10.1016/S0043-1354(99)00238-9.

Medina, L.M., Jordano, R., 2019. Petrifilm – A simplified technique for microbiological testing of foods and beverages. In: Reference Module in Food Science, October 2018. Elsevier. https://doi.org/10.1016/b978-0-08-100596-5.22933-8.

Mekonnen, A., Leta, S., Njau, K.N., 2015. Wastewater treatment performance efficiency of constructed wetlands in African countries: A review. Water Sci. Technol. 71 (1), 1–8. https://doi.org/10.2166/wst.2014.483.

Mesdaghinia, A., Nasseri, S., Mahvi, A.H., Tashauoei, H.R., Hadi, M., 2015. The estimation of per capita loadings of domestic wastewater in Tehran. J. Environ. Health Sci. Eng. 13 (1) https://doi.org/10.1186/s40201-015-0174-2.

Miller, R.L., 2021. Modeling response of water temperature to channelization in a coastal river network. River Res. Appl. 37 (3), 433–447. https://doi.org/10.1002/rra.3756.

Miller, R.L., Young, T.J., 2022. Reduced-complexity model of stream temperature. River Res. Appl. 38 (2), 267–279. https://doi.org/10.1002/rra.3909.

Mkude, I.T., Saria, J., 2014. Assessment of waste stabilization ponds (WSP) efficiency on wastewater treatment for agriculture reuse and other activities a case of Dodoma Municipality, Tanzania. Ethiopian J. Environ. Stud. Manage. 7 (3), 298–304. https://doi.org/10.1016/s1013-7025(09)70018-1.

Muriuki, C.W., Home, P.G., Raude, J.M., Ngumba, E.K., Munala, G.K., Kairigo, P.K., Gachanja, A.N., Tuhkanen, T.A., 2020. Occurrence, distribution, and risk assessment of pharmerciuticals in wastewater and open surface drains of peri-urban areas: Case study of Juja town, Kenya. Environ. Pollut. 267, 115503 https://doi.org/10.1016/j.envpol.2020.115503.

Mustapha, H.I., van Bruggen, H.J.J.A., Lens, P.N.L., 2018. Vertical subsurface flow constructed wetlands for the removal of petroleum contaminants from secondary refinery effluent at the Kaduna refining plant (Kaduna, Nigeria). Environ. Sci. Pollut. Res. 25 (30), 30451–30462. https://doi.org/10.1007/s11356-018-2996-9.

Muttamara, S., 1996. Wastewater characteristics. *Resour. Coserv. Recycl.* 16 (1-4), 145–159.

Nayan, S.B., Bari, Q.H., Debnath, P.K., Saju, J.A.S., 2020. Performance study of pilot-scale anaerobic-aerobic filter system for faecal sludge treatment. In: Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), February. https://www.researchgate.net/publication/339291807.

Njau, K.N., Mwegoha, W.J.S., Kimwaga, R.J., Katima, J.H.Y., 2011. Use of engineered wetlands for onsite treatment of wastewater by the local communities: Experiences from Tanzania. Water Pract. Technol. 6 (3) https://doi.org/10.2166/wpt.2011.047.

Obinnaa, I.B., Ebere, E.C., 2019. A review: Water pollution by heavy metal and organic pollutants: Brief review of sources, effects and progress on remediation with aquatic plants. Anal. Methods Environ. Chem. J. 2 (3), 5–38. https://doi.org/10.24200/amecj.v2.i03.66.

Ofred, J.M., Robinson, H.M., Lughano, J.M.K., Anita, F., Anders, D., 2016. Removal of *Escherichia coli* in treated wastewater used for food production in Morogoro, Tanzania. *Afr. J. Microbiol. Res.* 10 (33), 1344–1350. https://doi.org/10.5897/ajmr2016.8156.

Osińska, A., Korzeniewska, E., Korzeniowska-Kowal, A., Wzorek, A., Harnisz, M., Jachimowicz, P., Buta-Hubeny, M., Zieliński, W., 2022. The challenges in the identification of *Escherichia coli* from environmental samples and their genetic characterization. Environ. Sci. Pollut. Res. 30 (5), 11572–11583.

Otieno, A.O., Karuku, G.N., Raude, J.M., Koech, O., 2017. Effectiveness of the horizontal, vertical and hybrid subsurface flow constructed wetland systems in polishing municipal wastewater. Environ. Manage. Sustain. Dev. 6 (2), 158. https://doi.org/10.5296/emsd.v6i2.11486.

Paing, J., Guilbert, A., Gagnon, V., Chazarenc, F., 2015. Effect of climate, wastewater composition, loading rates, system age and design on performances of French vertical flow constructed wetlands: A survey based on 169 full scale systems. Ecol. Eng. 80, 46–52. https://doi.org/10.1016/j.ecoleng.2014.10.029.

Papadopoulos, N., Zalidis, G., 2019. The use of *Typha Latifolia* L. in constructed wetland microcosms for the remediation of herbicide terbuthylazine. Environ. Process. 6 (4), 985–1003. https://doi.org/10.1007/s40710-019-00398-3.

Parashar, V., Singh, S., Purohit, M.R., Tamhankar, A.J., Singh, D., Kalyanasundaram, M., 2022. Utility of constructed wetlands for treatment of hospital effluent and antibiotic resistant bacteria in resource limited settings: A case study in Ujjain, India. Water Environ. Res 94, 1–10. https://doi.org/10.1002/wer.10783.

Patel, S.B., Mehta, A., Solanki, H.A., 2017. Physiochemical analysis of treated industrial effluent collected from Ahmedabad mega pipeline. J. Environ. Anal. Toxicol. 07 (05) https://doi.org/10.4172/2161-0525.1000497.

Patel, J.P., Parsania, P.H., 2017. Characterization, testing, and reinforcing materials of biodegradable composites. In: Biodegradable and Biocompatible Polymer Composites: Processing, Properties and Applications. Elsevier Ltd., pp. 55–79. https://doi.org/10.1016/B978-0-08-100970-3.00003-1

Percival, S.L., Williams, D.W., 2013. *Escherichia coli*. In: Microbiology of Waterborne Diseases: Microbiological Aspects and Risks, Second Edition. Elsevier Ltd., pp. 89–117. https://doi.org/10.1016/B978-0-12-415846-7.00006-8

Permatasari, R., Rinanti, A., Ratnaningsih, R., 2018. Treating domestic effluent wastewater treatment by aerobic biofilter with bioballs medium. IOP Conf. Ser.: Earth Environ. Sci. 106 (1) https://doi.org/10.1088/1755-1315/106/1/012048.

Petersen, F., Hubbart, J.A., 2020. Physical factors impacting the survival and occurrence of *Escherichia coli* in secondary habitats. In: Water (Switzerland) (Vol. 12, Issue 6). MDPI AG. https://doi.org/10.3390/w12061796.

Pinninti, R., Kasi, V., Sallangi, L.K.S.V.P., Landa, S.R., Rathinasamy, M., Sangamreddi, C., Dandu Radha, P.R., 2022. Performance of Canna Indica based microscale vertical flow constructed wetland under tropical conditions for domestic wastewater treatment. Int. J. Phytorem. 24 (7), 684–694.

Pirsaheb, M., Mohamadi, M., Mansouri, A.M., Zinatizadeh, A.A.L., Sumathi, S., Sharafi, K., 2015. Process modeling and optimization of biological removal of carbon, nitrogen and phosphorus from hospital wastewater in a continuous feeding & intermittent discharge (CFID) bioreactor. Korean J. Chem. Eng. 32 (7), 1340–1353. https://doi.org/10.1007/s11814-014-0365-z.

Poolman, J.T., 2016. *Escherichia coli*. In: International Encyclopedia of Public Health. Elsevier Inc., pp. 585–593. https://doi.org/10.1016/B978-0-12-803678-5.00504-X

Prokkola, H., Heponiemi, A., Pesonen, J., Kuokkanen, T., Lassi, U., 2022. Reliability of biodegradation measurements for inhibitive industrial wastewaters. ChemEngineering 6 (1). https://doi.org/10.3390/chemengineering6010015.

Punyapwar, S., Mutnuri, S., 2020. Diversity and functional annotation of microorganisms in French vertical flow constructed wetland treating greywater. World J. Microbiol. Biotechnol. 36 (10) https://doi.org/10.1007/s11274-020-02923-1.

Rachman, T., 2018. Natural wetlands: A holistic overview towards its biomimicry for application in industrial effluent bioremediation. *Angew. Chem. Int. Ed.* 6 (11), 951–952.

Rahmadyanti, E., Febriyanti, C.P., 2020. Feasibility of constructed wetland using coagulation flocculation technology in batik wastewater treatment. J. Ecol. Eng. 21 (6), 67–77.

Rana, V., Maiti, S.K., 2018. Municipal wastewater treatment potential and metal accumulation strategies of *Colocasia esculenta* (L.) Schott and *Typha latifolia* L. in a constructed wetland. Environ. Monit. Assess. 190 (6), 1–15. https://doi.org/10.1007/s10661-018-6705-4.

Rani, N., Maheshwari, R.C., Kumar, V., Vijay, V.K., 2011. Purification of pulp and paper mill effluent through Typha and Canna using constructed wetlands technology. J. Water Reuse Desalin. 1 (4), 237–242. https://doi.org/10.2166/wrd.2011.045.

Reddy, M.V., Mauger, A., Julien, C.M., Paolella, A., Zaghib, K., 2020. Brief history of early lithium-battery development. Materials 13 (8), 1884. https://doi.org/10.3390/ma13081884.

Reungoat, J., Macova, M., Escher, B.I., Carswell, S., Mueller, J.F., Keller, J., 2010. Removal of micropollutants and reduction of biological activity in a full scale reclamation plant using ozonation and activated carbon filtration. Water Res. 44 (2), 625–637. https://doi.org/10.1016/j.watres.2009.09.048.

Rim-Rukeh, A., Agbozu, I.E., 2013. Impact of partially treated sewage effluent on the water quality of recipient Epie Creek Niger Delta, Nigeria using Malaysian Water Quality Index (WQI). J. Appl. Sci Environ. Manage. 17 (1), 5–12. www.bioline.org.br/ja.

Rusydi, A.F., 2018. Correlation between conductivity and total dissolved solid in various type of water: A review. IOP Conf. Ser.: Earth Environ. Sci. 118 (1) https://doi.org/10.1088/1755-1315/118/1/012019.

Samer, M., 2015. Biological and chemical wastewater treatment processes. In: Samer, M. (Ed.), Wastewater Treatment Engineering. InTech. https://doi.org/10.5772/61250.

Santoro, D.O., Cardoso, A.M., Coutinho, F.H., Pinto, L.H., Vieira, R.P., Albano, R.M., Clementino, M.M., 2015. Diversity and antibiotic resistance profiles of Pseudomonads from a hospital wastewater treatment plant. J. Appl. Microbiol. 119 (6), 1527–1540.

Santos, L.H.M.L.M., Gros, M., Rodriguez-Mozaz, S., Delerue-Matos, C., Pena, A., Barceló, D., Montenegro, M.C.B.S.M., 2013. Contribution of hospital effluents to the load of pharmaceuticals in urban wastewaters: Identification of ecologically relevant pharmaceuticals. Sci. Total Environ. 461–462, 302–316. https://doi.org/10.1016/j.scitotenv.2013.04.077.

Schaider, L.A., Rodgers, K.M., Rudel, R.A., 2017. Review of organic wastewater compound concentrations and removal in onsite wastewater treatment systems. Environ. Sci. Tech. 51 (13), 7304–7317. https://doi.org/10.1021/acs.est.6b04778.

Scholz, M., 2016. Constructed wetlands. In: Wetlands for Water Pollution Control. Elsevier, pp. 137–155. https://doi.org/10.1016/b978-0-444-63607-2.00020-4.

Shelef, O., Gross, A., Rachmilevitch, S., 2013. Role of plants in a constructed Wetland: Current and new perspectives. Water (Switzerland) 5 (2), 405–419. https://doi.org/10.3390/w5020405.

Shukla, R., Gupta, D., Singh, G., Mishra, V.K., 2021. Performance of horizontal flow constructed wetland for secondary treatment of domestic wastewater in a remote tribal area of Central India. Sustain. Environ. Res. 31 (1) https://doi.org/10.1186/s42834-021-00087-7.

Silva, C.R., Conceição, C.D.C., Bonifácio, V.G., Filho, O.F., Teixeira, M.F.S., 2009. Determination of the chemical oxygen demand (COD) using a copper electrode: A clean alternative method. J. Solid State Electrochem. 13 (5), 665–669. https://doi.org/10.1007/s10008-008-0580-9.

Swarnakar, A.K., Bajpai, S., Ahmad, I., 2022. Various types of constructed wetland for wastewater treatment-A review. IOP Conf. Ser.: Earth Environ. Sci. 1032 (1), 012026.

Tanaka, T.S.T., Irbis, C., Wang, P., Inamura, T., 2015. Impact of plant harvest management on function and community structure of nitrifiers and denitrifiers in a constructed wetland. FEMS Microbiol. Ecol. 91 (2), 1–10. https://doi.org/10.1093/femsec/fiu019.

Tanaka, T.S.T., Irbis, C., Kumagai, H., Inamura, T., 2016. Timing of harvest of Phragmites australis (CAV.) Trin. ex Steudel affects subsequent canopy structure and nutritive value of roughage in subtropical highland. J. Environ. Manage. 166, 420–428. https://doi.org/10.1016/j.jenvman.2015.10.055.

Udom, I.J., Mbajiorgu, C.C., Oboho, E.O., 2018. Development and evaluation of a constructed pilot-scale horizontal subsurface flow wetland treating piggery wastewater. Ain Shams Eng. J. 9 (4), 3179–3185. https://doi.org/10.1016/j.asej.2018.04.002.

Uluseker, C., Kaster, K.M., Thorsen, K., Basiry, D., Shobana, S., Jain, M., Kumar, G., Kommedal, R., Pala-Ozkok, I., 2021. A review on occurrence and spread of antibiotic resistance in wastewaters and in wastewater treatment plants: Mechanisms and perspectives. Front. Microbiol. 12, 1–19. https://doi.org/10.3389/fmicb.2021.717809.

Valipour, A., Ahn, Y.-H., 2017. A review and perspective of constructed wetlands as a green technology in decentralization practices. In: Singh, R., Kumar, S. (Eds.), Green Technologies and Environmental Sustainability. Springer International Publishing, pp. 1–492. https://doi.org/10.1007/978-3-319-50654-8.

Vega De Lille, M.I., Hernández Cardona, M.A., Tzakum Xicum, Y.A., Giácoman-Vallejos, G., Quintal-Franco, C.A., 2021. Hybrid constructed wetlands system for domestic wastewater treatment under tropical climate: Effect of recirculation strategies on nitrogen removal. Ecol. Eng. 166, 106243.

Verma, A., Wei, X., Kusiak, A., 2013. Predicting the total suspended solids in wastewater: A data-mining approach. Eng. Appl. Artif. Intel. 26 (4), 1366–1372. https://doi.org/10.1016/j.engappai.2012.08.015.

Vieira, Y., Pereira, H.A., Leichtweis, J., Mistura, C.M., Foletto, E.L., Oliveira, L.F.S., Dotto, G.L., 2021. Effective treatment of hospital wastewater with high-concentration diclofenac and ibuprofen using a promising technology based on degradation reaction catalyzed by Fe0 under microwave irradiation. Sci. Total Environ. 783, 146991 https://doi.org/10.1016/j.scitotenv.2021.146991.

Vo, H.N.P., Koottatep, T., Chapagain, S.K., Panuvatvanich, A., Polprasert, C., Nguyen, T. M.H., Chaiwong, C., Nguyen, N.L., 2019. Removal and monitoring acetaminophen-contaminated hospital wastewater by vertical flow constructed wetland and peroxidase enzymes. J. Environ. Manage. 250 (August), 109526 https://doi.org/10.1016/j.jenvman.2019.109526.

Vymaza, J., 2022. The historical development of constructed wetlands for wastewater treatment. Land 11 (2). https://doi.org/10.3390/land11020174.

Vymazal, J., 2011. Plants used in constructed wetlands with horizontal subsurface flow: a review. Hydrobiologia 674 (1), 133–156.

Wang, J., Chen, G., Fu, Z., Qiao, H., Liu, F., 2021. Assessing wetland nitrogen removal and reed (Phragmites australis) nutrient responses for the selection of optimal harvest time. J. Environ. Manage. 280 (November 2020), 111783 https://doi.org/10.1016/j.jenvman.2020.111783.

Wang, M., Shen, W., Yan, L., Wang, X.H., Xu, H., 2017. Stepwise impact of urban wastewater treatment on the bacterial community structure, antibiotic contents, and prevalence of antimicrobial resistance. Environ. Pollut. 231, 1578–1585. https://doi.org/10.1016/j.envpol.2017.09.055.

Wei, F., Shahid, M.J., Alnusairi, G.S.H., Afzal, M., Khan, A., El-Esawi, M.A., Abbas, Z., Wei, K., Zaheer, I.E., Rizwan, M., Ali, S., 2020. Implementation of floating treatment wetlands for textile wastewater management: A review. Sustainability (Switzerland) 12 (14), 1–29. https://doi.org/10.3390/su12145801.

Wilson, M.P., Worrall, F., 2021. The heat recovery potential of "wastewater": A national analysis of sewage effluent discharge temperatures. Environ. Sci. Water Res. Technol. 7 (10), 1760–1777. https://doi.org/10.1039/d1ew00411e.

Wu, S., Carvalho, P.N., Müller, J.A., Manoj, V.R., Dong, R., 2016. Sanitation in constructed wetlands: A review on the removal of human pathogens and fecal indicators. Sci. Total Environ. 541, 8–22. https://doi.org/10.1016/j.scitotenv.2015.09.047.

Yalçuk, A., Ugurlu, A., 2020. Treatment of landfill leachate with laboratory scale vertical flow constructed wetlands: plant growth modeling. Int. J. Phytorem. 22 (2), 157–166. https://doi.org/10.1080/15226514.2019.1652562.

Yang, Y., Ok, Y.S., Kim, K.H., Kwon, E.E., Tsang, Y.F., 2017. Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: A review. Sci. Total Environ. 596–597, 303–320. https://doi.org/10.1016/j.scitotenv.2017.04.102.

Yuan, T., Pian, Y., 2023. Hospital wastewater as hotspots for pathogenic microorganisms spread into aquatic environment: A review. Front. Environ. Sci. 10 (January), 1–10. https://doi.org/10.3389/fenvs.2022.1091734.

Zacharia, A., Ahmada, W., Outwater, A.H., Ngasala, B., Van Deun, R., 2019. Evaluation of occurrence, concentration, and removal of pathogenic parasites and fecal coliforms in three waste stabilization pond systems in Tanzania. Sci. World J. 2019, 1–12.

Zhai, J., Zou, J., He, Q., Ning, K., Xiao, H., 2012. Variation of dissolved oxygen and redox potential and their correlation with microbial population along a novel horizontal subsurface flow wetland. Environ. Technol. 33 (17), 1999–2006. https://doi.org/10.1080/09593330.2012.655320.

Zhao, X., Hu, Y., Zhao, Y., Kumar, L., 2018. Achieving an extraordinary high organic and hydraulic loadings with good performance via an alternative operation strategy in a multi-stage constructed wetland system. Environ. Sci. Pollut. Res. 25 (12), 11841–11853. https://doi.org/10.1007/s11356-018-1464-x.

Lai, T.M., Shin, J.-K., Hur, J., 2011. Estimating the biodegradability of treated sewage samples using synchronous fluorescence spectra. Sensors 11 (8), 7382–7394. MDPI AG. Retrieved from https://doi.org/10.3390/s110807382.