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Investigation of functional performance of treatment systems for textile wastewater in selected textile industries in Tanzania

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ABSTRACT

Textile industrialization is an integral part of the economic growth in Tanzania. However, the corresponding wastewater from textile treatment processes consists of dyes and auxiliaries associated with acute toxicological impacts. This necessitates an investigation of the functional performance of the industrial treatment systems used before effluent discharge. The study primarily accesses the catalog of industrial dyes and the functionality of the treatment system at Arusha, Morogoro and Dar es Salaam vis-à-vis the effluent physicochemical properties. The analytical study reveals disperse (42%), vat (34%) and reactive (26%) as the most used industrial dyes. The physicochemical properties of the quantified wastewater reveal a significant amount of and phosphorus which was consequent to the high turbidity, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) apart from the color at the different sampling points. Although the treatability of the wastewater was 90% efficient using an activated carbon system (237.33 $\pm$ 0.67 mg/L). Similarly, the use of aerated constructed wetlands shows efficiency in the remediation of the recalcitrant having a value of 12.13 $\pm$ 0.89^{b} mg/L (90%) and 13.22 $\pm$ 0.15^{a} mg/L (94%). Thereafter, needful recommendations were suggested based on the physicochemical properties of the textile wastewater and to improve the functionality of the treatment systems in the respective industries.

Key words: dyes, functionality, performance, textile, treatment systems

HIGHLIGHTS

- Treatment systems.
- Performance assessment.
- Improved constructed wetlands.
- Integrated coupled treatment system.
- Industrial Azo dyes.

GRAPHICAL ABSTRACT

1. INTRODUCTION

Textile industries are globally known for various industrial unit operations that are associated with large volumes of water consumption (Dasgupta *et al.* 2015; Oyetade *et al.* 2022). This high amount of water consumption accounts for the large volume of corresponding wastewater generated (Dasgupta *et al.* 2015). The quantitative properties of textile wastewater are in tandem with various unit processes such as resizing, scouring, bleaching, mercerization, dyeing, printing and pigmentation of textile substrates (Ghaly *et al.* 2014). An approximate value of 10,000 chemicals such as dyes, pigments and dyeing auxiliaries are industrially used in these unit processes and the resulting wastewater is characterized by 5–35% constituents of these chemicals on discharge (Khataee & Kasiri 2010; Verma *et al.* 2012). The wastewater discharged significantly holds an appreciable amount of these dyes of which $<$40% are biodegradable (Chacko & Subramaniam 2011). The chromophores, chromogens and auxochromes present in the dye structure in collaboration with dyeing axillaries account for the coloration and physicochemical properties of the wastewater (Chaube *et al.* 2010; Chung 2016; Amin *et al.* 2020). Among these dyes, the dominance of the azo group is rated 70% due to its unique fastness rating. However, poses great toxicity when discharged as effluent (Ventura-Camargo & Marin-Morales 2013). Also, the constituents of effluent from the process line of pigmentation, dyeing, printing and finishing are associated with extreme environmental toxicological impacts (Lu & Liu 2010; Abayomi *et al.* 2020). Effluent within this process line significantly alters the physicochemical parameters of waterbodies after indiscriminate discharge (Shindhal *et al.* 2021). Textile industries in Tanzania conventionally undergo treatment actions as remedial mitigation against environmental pollution resulting from discharged effluent (Bidu *et al.* 2021). These treatment processes are broadly classified as physical, chemical and biological with examples such as screening, neutralization, sedimentation, coagulation, flocculation, filtration, oxidation, adsorption, reverse osmosis, biological decolonization, ion exchange, phytoremediation (Bhatia *et al.* 2018; Roy *et al.* 2020; Oyetade *et al.* 2022). The physicochemical properties of generated wastewater are commonly measured in compliance with the standards set by the Tanzanian Bureau of Standards (TBS) and World Health Organization (WHO) before (influent) and after treatment (effluent). However, many industries seldom measure effluent from each treatment section to access its functionality and the efficiency of the system. Hence, it becomes imperative to quantitatively access the functionality of each treatment system through the quantitative physicochemical assay of the corresponding effluent. The study carried out a comprehensive assessment of the functional performance of various treatment systems for textile wastewater in selected textile industries in Tanzania and proffer logical scientific recommendations to achieve better treatment efficiency of textile wastewater.

2. MATERIALS

2.1. Glassware, chemicals and instruments

Calibrated glassware was used for the experiment and all the chemicals for analysis were analytical grade. Chemicals such as HACH powdered pillows (HR) for determination of dissolved chemical compounds and HACH COD HR reagent vials for chemical oxygen demand (COD), respectively. Also, analytical grade deionized water was used throughout the experimental process. The instruments used include multiparameter kit HACH: HQ40d, Eppendorf Centurifuge:8810, portable UV spectrophotometer HACH: DR900, BOD machine: Oxitop^{R} IS 12 and COD reactor Hanna Instruments: H1839800.

2.2. Study area and survey

The study was in Dar es Salam (−6.7924° S, 39.2083° E), Morogoro (−6.8278° S, 37.6591° E) and Arusha (−3.3869° S, 36.6830° E). Arusha region is geographically situated in the northeastern part of Tanzania, having 4.3% covered with lakes such as Eyasi, Manyara, Babati and Natron. Its land mass generally occupies 9.2% of Tanzania's mainland. Dar es Salaam is a low-level coastal elevation city having the highest localized industries and inhabiting the major port of Tanzania. It occupies about 0.2% of Tanzania's mainland and borders the Indian Ocean. Morogoro is the third largest region after Arusha and Tabora having an approximate value of 8.2% of the total area of Tanzania mainland. Four textile industries were selected for effluent sampling within this locale, with one in Dar es Salaam, one in Morogoro and two in Arusha. For the selected textile industries, a qualitative survey was carried out on the catalog of industrial dyes commonly used by these industries and the corresponding input and outputs of wastewater vis-à-vis the treatment system were monitored from 7 am to 9 am daily. Also, the process line involving the wet and dry treatment process was surveyed and the corresponding effluent from the respective treatment plant of each industry was quantitatively evaluated.

2.3. Sample collection

The textile wastewater sample was obtained from the influent (wastewater after the wet treatment process of textile material) and wastewater after each treatment system (effluent). The sample collection vial was labeled accordingly for the onsite quantitative determination of physicochemical parameters. Another analysis was carried out in the laboratory of Nelson Mandela African Institution of Science and Technology (NM-AIST) Arusha, Tanzania. The transported samples were kept in an ice bag and transferred into the refrigerator below 4 °C before analysis. The techniques and methods followed for collection, preservation, analysis and interpretation are those given by APHA (2012).

2.4. Analysis of physicochemical parameters of sampled wastewater

2.4.1. Onsite analysis

The quantitative determination of the physicochemical parameters such as pH, temperature, total dissolved solids (TDSs), total suspended solids (TSSs) turbidity, dissolved oxygen (DO) and conductivity of the influent and the effluent at each sampling point were done onsite using the multiparameter kit instrument, following APHA (2012). For the analysis of the color (Pt-Co) at 420 nm, an aliquot of the samples was centrifuged (4,000 r/min) for 15 min and then quantified with the multiparameter kit (Laizer *et al.* 2022).

2.4.2. Laboratory analysis

The quantitative analysis of the COD and dissolved compounds such NO_3, NH_3, NH_3-N, PO_3, PO^{4-}, P_2O_5 and P was done using HACH pillow reagents for each compound and quantified via colorimetric technique at NM-AIST Arusha, Tanzania.

2.4.2.1. Determination of COD. COD quantification is used to measure the oxygen required for the oxidized organic matter in wastewater by the action of strong oxidizing agents under acidic conditions (Equation (1)). This parameter was determined using the colorimetric technique. The COD reactor was preheated to 150 °C before the addition of 1 ml of deionized water into the COD reagent vial (blank) and was repeated for 1 ml of the sampled wastewater. It was shaken and then inserted into the reactor for refluxing for 2 h, cooled and analyzed using the portable UV spectrophotometer (Bidu *et al.* 2021; Laizer *et al.* 2022).

$$C_nH_aO_bN_c + O_2 \xrightarrow[H^+]{Cr_2O_7^{2-}} CO_2 + H_2O + NH_3 \quad (1)$$

2.4.2.2. Determination of biochemical oxygen demand. The biochemical oxygen demand (BOD) measures the amount of oxygen consumed by heterotrophic bacteria for the oxidation of organic matter (Equations (2) and (3)). The quantitative difference in the DO levels of water samples before incubation (BOD_0) and after 5 days of incubation (BOD_5) was carried out using manometric techniques at 20 °C with stirring in dark BOD bottles tightly closed by a manometric cap (Bhatia *et al.* 2018; Laizer *et al.* 2022). The BOD measurement was then determined using Equation (4).

$$\text{Organic matter} + \text{Microorganism} + O_2 + \text{Nutrients} \rightarrow CO_2 + H_2O + \text{Microorganism} \quad (2)$$

$$[BOD_5] = \frac{mgO_2}{L} \quad (3)$$

$$[BOD_5] = \frac{mgO_2}{L} = \text{Value} \times \text{factor} \quad (4)$$

where value indicates the manometric cap reading on day 5 and factor indicates the value of the BOD Instrument.

2.5. Statistical analysis

The data generated from the experimental processes were statistically analyzed using IBM SPSS version 16.0 (Chicago, USA) computer software programs. The experimental data are presented as the mean ± SE of the replicate experiment at $^*p \leq 0.05$.

3. RESULTS

3.1. Analysis of commonly used industrial dyes

The results in Figure 1(a) and 1(b) show the comprehensive catalog of commonly used industrial dyes in the selected textile industries. The dyes were analytically separated based on respective applications (Figure 1(a)) and chromophoric types (Figure 1(b)). Figure 1(a) reveals that dispersed dyes (42%), reactive dyes (26%) and vat dyes (14%) are the most commonly used industrially. Also, the lowest industrially used dyes are the inorganic (2%) and the basic dyes (5%). However, the distinct classification of these industrial dyes based on the chromophoric types shows azo linkage (N = N) of 65.91% followed by 15.91% of anthraquinone and 11.36% of tetraphenyl dyes, respectively. On the other hand, the least recorded percentage is indigoid (1.51%) and chlorobenzoyl (5.30%). Benkhaya *et al.* (2020) and Mahmoodi *et al.* (2010) affirmed that vat and reactive dyes are the most commonly used industrial dyes. This frequent use is due to their excellent fastness in washing and the unique formation of brilliant hues on synthesis (Islam & Mostafa 2019; Oyetade *et al.* 2021). Also, the strong dye–fiber interaction of the reactive groups with the textile substrate justified their stability to subsequent washing, ironing, crocking and bleeding (Abayomi *et al.* 2020; Oyetade *et al.* 2022). In addition to this, the characteristic color of the dye molecules imparted to the textile substrate is in tandem with the absorption and excitation of electromagnetic waves of the azo chromophoric system (Laurent *et al.* 2010). Also, the figures agree with the study carried out by Bunjes & Kuntsche (2016) and Qiu *et al.* (2020), which suggests that dispersed azo dyes take up more than 50% of industrial usage among other synthetic dyes. However, they exhibit a high level of hydrophobicity due to their non-ionic (Ozyurt & Ataçag 2003; Islam & Mostafa 2019). They are commonly applied via dispersion to nylon, cellulose acetate and acrylic fibers which are the most predominant textile materials around Tanzania (Coulson 2016). However, their corresponding effluent has a significant amount of these dye molecules which are most persistent in the environment and can undergo chemo-transformative behavior to toxic aromatic amine (Jamil *et al.* 2020; Oyetade *et al.* 2022).

3.2. Effluent properties from Morogoro textile industry

The results in Figure 2 show the physicochemical analysis of raw textile influent and effluent after treatment from the coagulation and filtration system together with the final treated outputs going into the environment (Morogoro). Furthermore, Figure 3(a) and 3(b) gives the quantitative evaluation of the COD, BOD and dissolved compounds in textile wastewater. The results are compared to the TBS and WHO/Environmental Protection Agency (EPA) as shown in Table 1. From the results (Figure 2), the pH for raw, coagulation and filtration are within tolerable limits, with the lowest recorded value for the output (7.46 ± 0.01). The situation of a high pH value above the tolerable limit significantly affects soil permeability and accounts for groundwater pollution water (Rajendran 2018). Also, the results of color Pt-Co were higher than the tolerable limit with the highest value of 4,042.67 ± 1.76 in raw effluent and the lowest color value of 1,800 ± 0.00 for the filtered

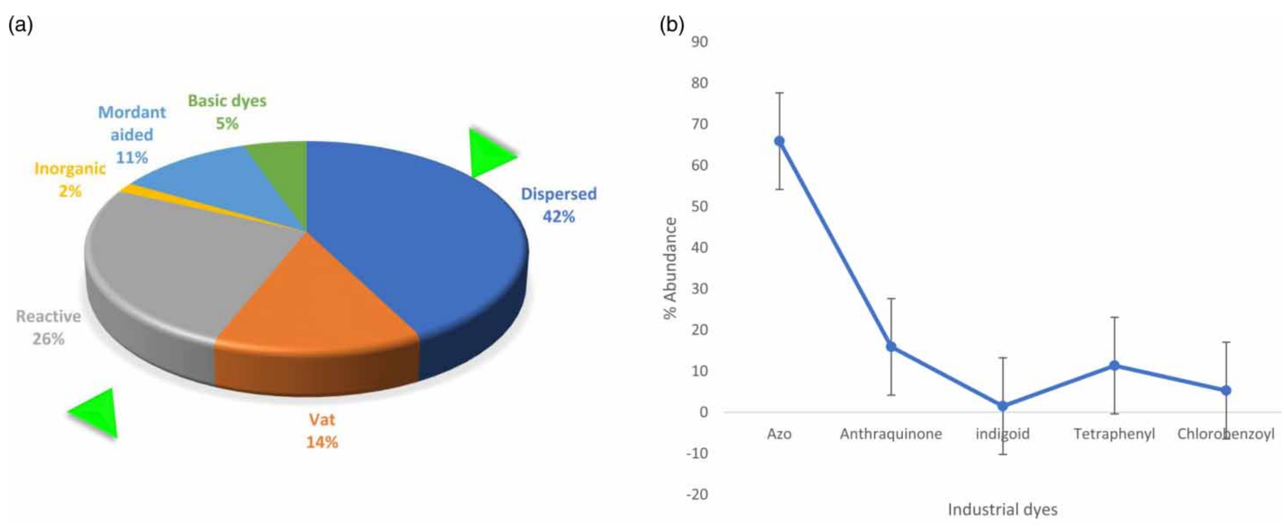

Figure 1 | (a) Industrial dyes based on classification. (b) Industrial dyes based on the chromophoric type.

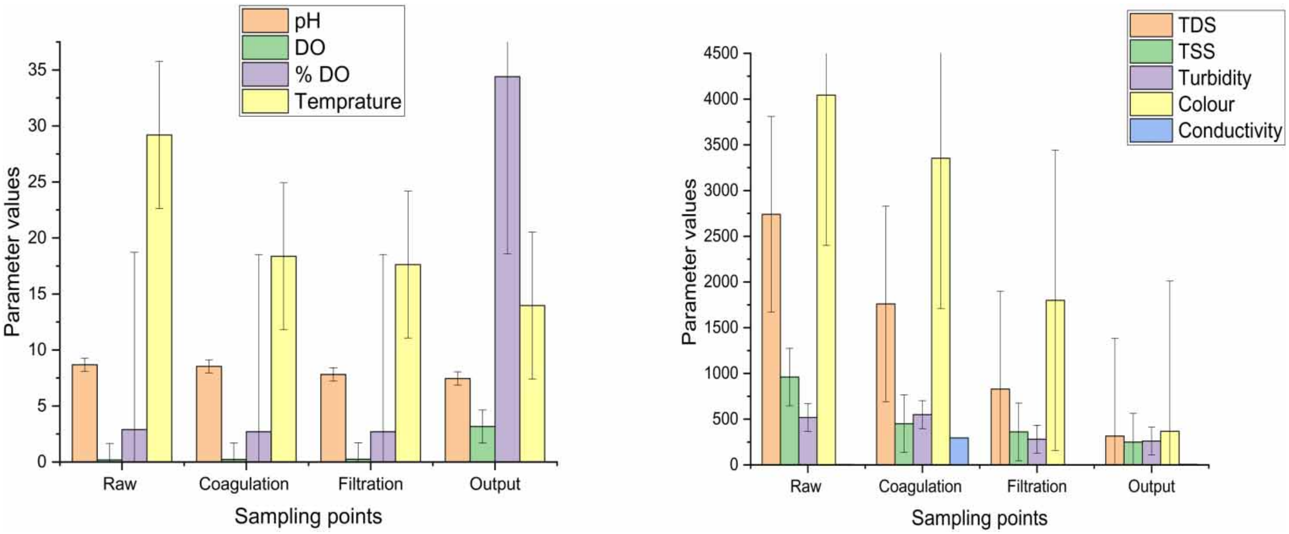

Figure 2 | Physicochemical parameter values of effluent from each treatment system in Morogoro.

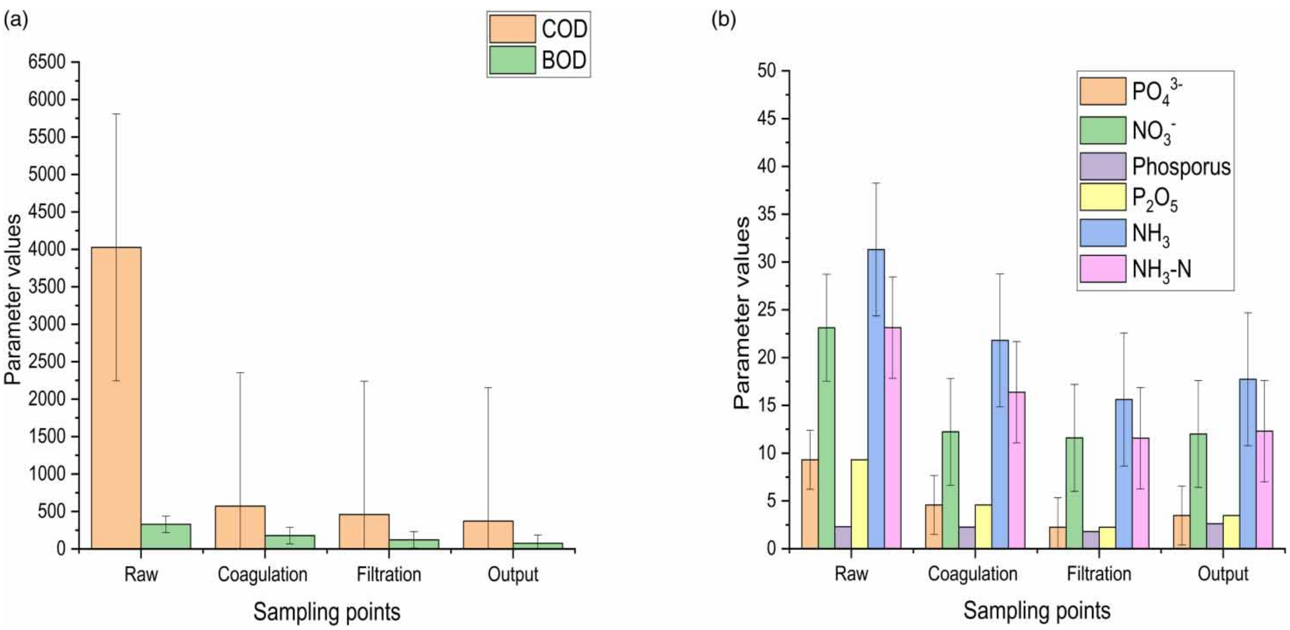

Figure 3 | (a) COD and BOD analysis of textile wastewater. (b) Chemical constituents of textile wastewater.

stream. Although the value was higher than the report by Jangid *et al.* (2021) for raw and filtered stream effluent, however, comparable results were reported by Bidu *et al.* (2021). The lowest recorded color value was 368.267 $\pm$ 2.67 (90.8%) for the output which is still higher than the TBS standards (300) although within the WHO limit (500). The high value of the raw effluent before treatment suggests the significant presence of dye molecules in the wastewater which was agglomerated to settle as flocs during coagulation and filtered to remove the suspended solids (Sarkar *et al.* 2017).

Similar, observation was made for the TSS value in Figure 2 having the highest value of 960.67 $\pm$ 0.67 mg/L was recorded for the raw while 361 $\pm$ 0.58 mg/L (62.46%) was reported for the filtered stream, respectively. The high amount in the color and TSS values equally reflect in the turbidity of the raw effluent (518.33 $\pm$ 1.00 NTU) which is eventually below the tolerable limits (281.33 $\pm$ 0.88 NTU) after the filtration system. Generally, a high amount of TSS results in high turbidity which has

Table 1 | Parameter limits for the wastewater

S/N	Parameters	Unit	TBS (TZS 860:201)	WHO/EPA
1	pH	1–14	6.5–8.5	6.5–8.5
2	TDS	mg/L	100	2,000
3	Conductivity	μs/cm	N/A	7,000
4	DO	mg/L	100	>2.0
5	% DO	%	N/A	N/A
6	Temperature	°C	20–35	≤40
7	Color Pt-Co	Pt-Co	300	500
8	TSS	mg/L	100	140
9	Turbidity	NTU	300	300
10	NO_{3-}	mg/L	20	45
11	Phosphorus (P)	mg/L	6	33
12	PO_4^{3-}	mg/L	N/A	15
13	P_2O_5	mg/L	N/A	N/A
14	NH_3	mg/L	N/A	15
15	NH_3-N	mg/L	N/A	10
16	COD	mg/L	60	150
17	BOD	mg/L	30	60

Note: WHO (2006), EPA (2012). TBS, Tanzania Bureau of Standards; WHO, World Health Organization; EPA, Environmental Protection Agency.

deleterious effects on discharged water bodies and greatly maligns the porosity and texture of soil (Saini 2017; Slama *et al.* 2021). Although, the value of dissolved chemical species such as PO_4^{3-}, P_2O_5, phosphorus NO^{3-} in mg/L are within the tolerable limits after treatment (Figure 3(b)). However, the high amount of NH_3 (31.30 $\pm$ 0.00 and 21.80 $\pm$ 0.06 mg/L) and NH_3-N (23.14 $\pm$ 0.03 and 16.37 $\pm$ 0.1 mg/L) in raw and coagulated stream accounts for high BOD and COD values (Figure 3(b)). However, the slight increase 17.73 $\pm$ 0.03 mg/L in the value of NH_3– can be due to contamination of the effluent discharged by nomadic grazing and discharges of animal feces. The result in Figure 3(a) reported an extreme amount of COD and BOD of 4,025.73 $\pm$ 0.10 and 329 $\pm$ 0.00 mg/L, respectively, in raw effluent which is similar to a study carried out by Rajendran (2018) with appreciable amount of statistical significant difference from other respective point of discharge. However, significant reduction of 459.07 $\pm$ 0.03, 122.00 $\pm$ 0.00 mg/L and 371.2 $\pm$ 0.07, 75.00 $\pm$ 0.00 mg/L was recorded for the BOD and COD of filtered stream and final output, respectively.

Although 75.00 $\pm$ 0.00 mg/L was lower than the limits by WHO and TBS, values of other section based on TBS limits were beyond the tolerable limits. These high-reported values of COD and BOD pose great toxicological impacts on the environment and indicate a high amount of bio-resistant chemical compounds in the textile wastewater (Halim *et al.* 2018).

3.3. Effluent properties from Dar es Salam textile industry

Figure 4 shows the results of the physicochemical quantification of textile effluent treated via bioreactor (TB) inductively coupled aerated (CWA) and non-aerated constructed wetlands (CWs), respectively. Similarly, Figure 5(a) and 5(b) quantitatively accesses the COD, BOD and the dissolved ion constituents of the textile wastewater vis-à-vis the coupled treatment technologies. From Figure 4, the peak value of color Pt-Co accessed was in the raw textile wastewater (4,812.67 $\pm$ 0.52), however, after treatment with the bioreactor it decreases by 51.26% (2,346.33 $\pm$ 1.33). As a corollary, the turbidity of the effluent reduces from 238 $\pm$ 0.33 NTU to 171.67 $\pm$ 0.88 NTU and 160.00 $\pm$ 0.58 NTU for non-aerated and aerated CWs, respectively. The significant reduction agrees with the observed trend of biological treatment of textile wastewater by Laizer *et al.* (2022) using an improved biological treatment system. However, the percentage color reduction from Figure 4 was still below the tolerable limits described in Table 1 for TBS and WHO. This shows the recalcitrant activities of the dye molecules and auxiliaries to microbial decolorization and degradation (Bafana *et al.* 2011; Chacko & Subramaniam 2011). Furthermore, the highest value of TDS observed (4,461.67 $\pm$ 0.88 mg/L) was for the raw effluent while an appreciable stability in the value

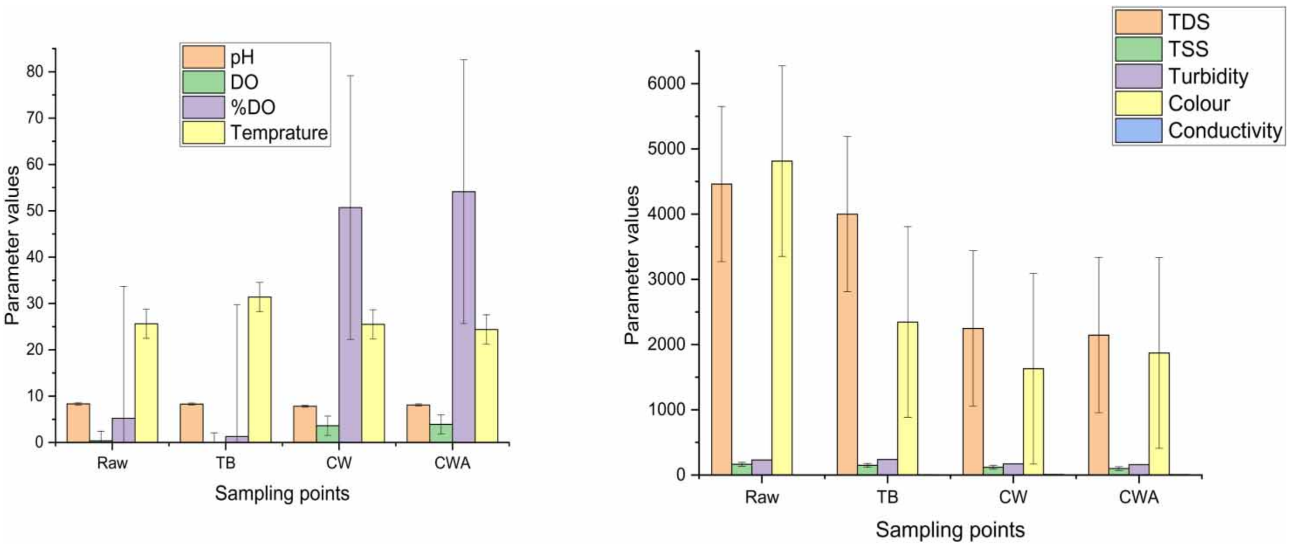

Figure 4 | Analysis of industrial effluent treated with a bioreactor system and constructed wetland in Dar es Salam. TB, treated via bioreactor; CW, constructed wetlands without aeration; CWA, constructed wetlands with aeration; TBS, Tanzanian Bureaus of Standards; WHO, World Health Organization.

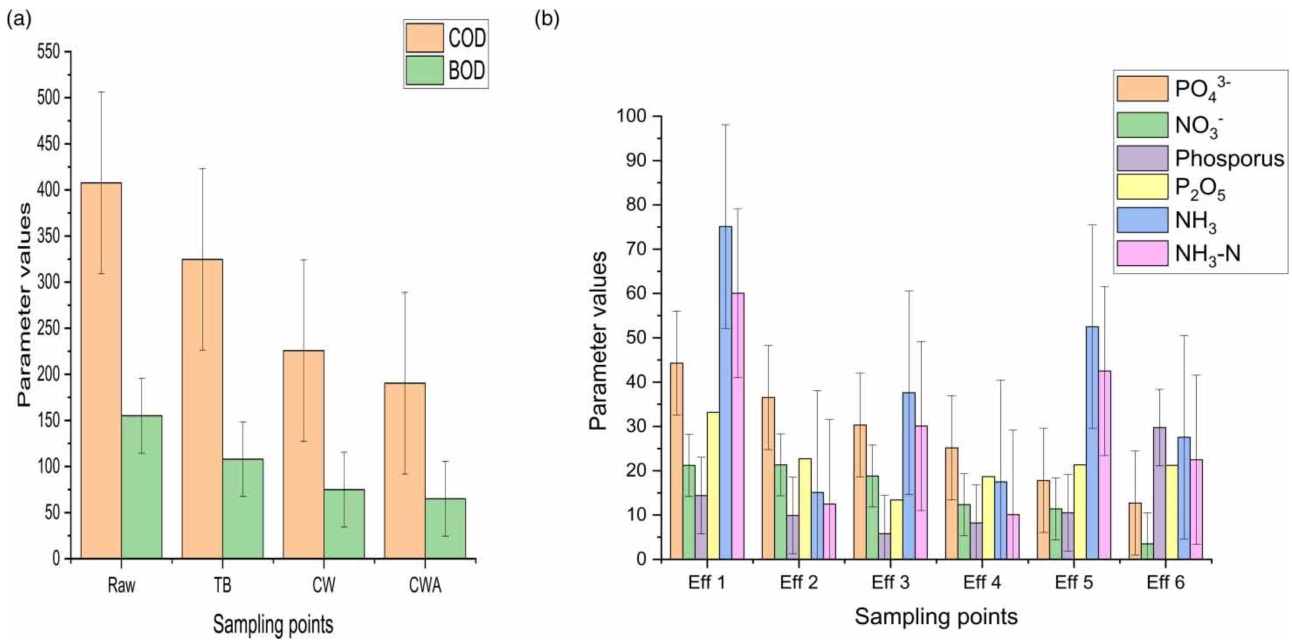

Figure 5 | (a) COD and BOD analysis of textile wastewater. (b) Chemical constituent of textile wastewater.

was observed after treatment in the bioreactor (4,000.33 ± 0.33 mg/L) before treated in the non-aerated CW (2,248.33 ± 1.67 mg/L) and aerated CW (2,145.33 ± 0.33 mg/L). Results by Paul *et al.* (2012) revealed a similar case having a value range from 7,072 to 2,264 mg/L. The low reduction in value after biological treatment (TB) may be due to the stability mechanism, persistent nature of the dye molecules to microbial action which can lead to the formation of toxic aromatic amine derivates (Chung 2016; Ventura-Camargo & Marin-Morales 2013). Despite the appreciate reduction after CW (49.61%) and CWA (51.92%) respective treatment, the eventual respective value was still higher than the tolerable limit (2,000 mg/L) in Table 1. This results reflects the attendant limitations of bioreactors and CWs which are mainly its inconsistency in treatment and potential generation of NH_3 and NH_3-N due to long retention time required (Correia *et al.* 2020; Wei *et al.* 2020). Also, the type of flow design and maintenance offered especially during stringent weather conditions accounts for their treatment inconsistencies Hassan *et al.* (2021), Brovelli *et al.* (2011) and Vymazal *et al.* (2021) added that during cold temperature, the treatment process of CWs is slow, while during droughts and high temperatures the plants involved are damaged which may constitute low efficiency in treatment. Kimambo *et al.* (2019) reported Morogoro has one of the most frequently affected regions by flood in Tanzania. This implies that the heavy rainfall and flood can result in the overloading of the CW system leading to inefficient treatment performance of the system. Also, from Figure 5(a) and 5(b), the observed value of NH_3 and NH_3-N increases to 123.67 ± 0.33 and 230.17 ± 3.35[d] mg/L from an initial value of 64.00 ± 0.58 and 66.00 ± 0.58 mg/L, respectively. Bidu *et al.* (2021) and Yang *et al.* (2018) suggest that microbial activities and increasing resident often led to increase in ammonia, ammoniacal nitrogen and nitrate. However, when integrated with aerated CW it falls to 12.13 ± 0.89 mg/L (90%) and 13.22 ± 0.15 mg/L (94%). It is noteworthy to add that the high amount of these chemical species in water pollution accounts for algae blooms and consequent death of aquatic life (Yang *et al.* 2018).

After treatment of the textile wastewater in the biological reactor, the BOD value of 108.00 ± 0.00 mg/L was recorded which was initially 155.00 ± 0.00 mg/L. However, 75.00 ± 0.00 mg/L was quantified with continuous treatment in non-aerated CWs, while 65.00 ± 0.00 mg/L was recorded for aerated CWs (lower than the limits). Similarly, the TSS value of 165.07 ± 0.06 mg/L was observed for the raw effluent which reduces significantly to 99.51 ± 0.82 mg/L after passing through the bioreactor system coupled with a aerated CW. This significant reduction in the aerated CW shows improved microbial growth that aids dye decolorization thereby reducing the suspended solutes in the effluent (Bidu *et al.* 2021). Furthermore, the vital importance of the integration of CW enhance the removal of heavy metals pollutants via phytoremediation alongside microbial decolorization of dye molecules (Masi *et al.* 2019; Tara *et al.* 2019). However, the situation of extreme bioaccumulation due to high organic loading from the effluent consequently lowers the functional efficiency of the treatment system (Wu *et al.* 2015). Technically, these CWs are engineered systems which uses soil, plants and microorganism to remediate toxic pollutants in wastewater. The textile wastewater treated via these technology uses the process of biodegradation and phytoremediation to naturally attenuate toxic pollutants for subsequent removal and mineralization (Truu *et al.* 2015).

The mechanism CWs involves the use of soil with large surface area and plant roots as biofilm layers which separate out the large, suspended solids from the effluent by the action of filtration, sedimentation, adsorption and precipitation (Qin & Chen 2016). The treatment process involves organic matter decomposition via aerobic or anerobic action with the end products of CO_2 and H_2O or CO_2 and CH_4, respectively, to achieve the reduction in effluent parameters (Qin & Chen 2016; Barik 2018).

3.4. Effluent properties from Arusha textile industries

The result in Figure 6 reveals the quantified physicochemical parameters of effluent from Arusha industries. Eff 1 represents the raw textile effluent while Eff 2, 3, 4, 5 and 6 represent effluent treated after coagulation with NaOCl, secondary settling tank and aeration, polymer dosing chamber, pressurized sand filtration system and activated carbon system, respectively. Figure 7(a) and 7(b) describes the efficiency of the treatment system in tandem with the measured parameters such as COD, BOD and dissolved chemical compounds. From Figure 6, the value of conductivity of the coagulating section was extremely higher (7,955.00 ± 2.89 NTU) than in other treatment sections. Furthermore, during the continuous treatment process, the dissolved solid reduces from the highest value of 10,335.03 ± 0.09 mg/L (raw wastewater) to 6,051.67 ± 0.88 mg/L (wastewater after sand filtration system). Reports by Laizer *et al.* (2022) and Suriyaprabha & Fulekar (2018) shows the significant reduction of physicochemical parameters of textile wastewater with this continuous treatment system. Although, high amounts of these parameters were equally reported among textile industries in Tanzania by Bidu *et al.* (2021). The TSS reported was extremely higher at Eff 2 (800.13 ± 0.07 mg/L) which may be a result of the addition of the coagulants before moving to the settling tank. However, the value was reduced by 59.4% (324.75 ± 0.26) after activated carbon treatment. The observed reduction is due to the adsorption of the dye molecules and dyeing axillaries unto the active site of the adsorbents.

However, the low absorption capacity of the treatment system may be due to the oversaturation of the binding site available during treatment processes (Zare *et al.* 2018; Khan *et al.* 2021). Also, the color of the raw effluent was reported higher (2,051.00 ± 0.58), however, it undergoes a significant reduction of 90% (237.33 ± 0.67) at Eff 6 (activated carbon filtration system), which is below the tolerable limits. Effective dye-adsorbent interaction account for the significant color reduction of the resulting effluent (Nassar *et al.* 2015). From Figure 7(a) and 7(b), the dissolved ions such as PO_4^{3-}, NO_3^- phosphorus (mg/L) reduces with continuous treatment below the tolerable limits.

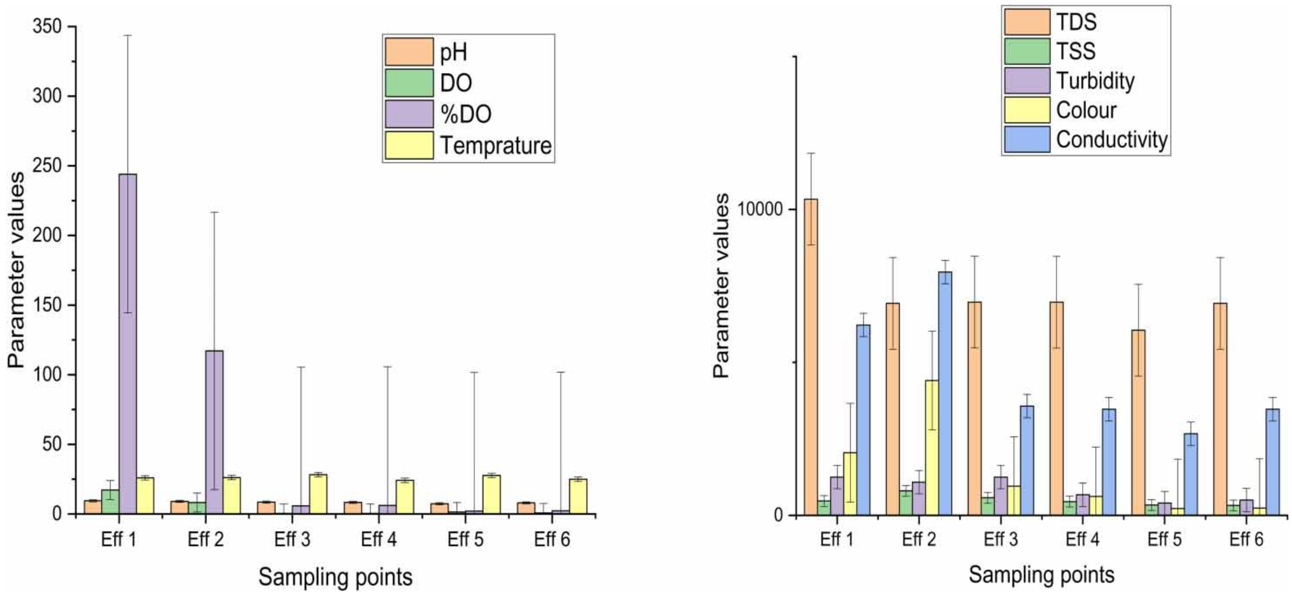

Figure 6 | Analysis of industrial effluent at each treatment system in Arusha Textile Industry 1. Eff 1, raw textile effluent; Eff 2, effluent after coagulation with NaOCl; Eff 3, effluent after secondary settling tank and aeration; Eff 4, effluent after polymer dosing; Eff 5, effluent after the pressurized sand filtration system; Eff 6, effluent after activated carbon system.

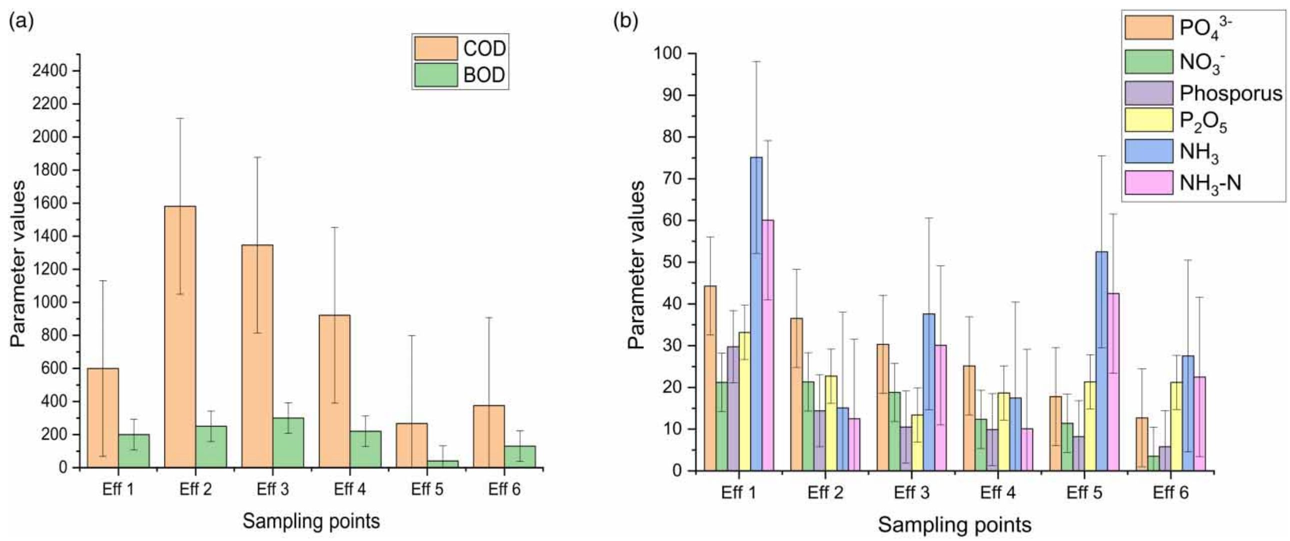

Figure 7 | (a) COD and BOD analysis of textile wastewater. (b) Chemical constituents of textile wastewater.

However, a significant amount of P_2O_5, NH_3, NH_3-N observed was similar to the study carried out by Singh *et al.* (2013) on the remediation of textile wastewater. The highest COD reflected in Eff 2 having a value of 1,580.67 $\pm$ 0.67 mg/L but decreases considerably to the value of 267.33 $\pm$ 0.33 mg/L (83%) and 375.67 $\pm$ 0.09 mg/L Eff5 and Eff 6, respectively. Furthermore, the sand filtration system (Eff 5) proves effective due to the resulting value of the BOD (40 $\pm$ 0.00 mg/L) which is within the tolerable limit of WHO. The BOD, COD and BOD/COD often give indications of the extent of the organic pollution and biodegradable index, respectively, in wastewater (Paul *et al.* 2012). It is noteworthy to add that increase in BOD causes depletion in oxygen levels which has an impaired effect on aquatic life (Tishmack & Jones 2003). The hydrolysis and reaction of azo dyes with other pollutants results in the generation of carcinogenic byproducts (Ventura-Camargo & Marin-morales 2013). Generally, one of the limitations of the conventional treatment for textile effluent is the challenges of removing pollutants by transferring them from one phase to another or to more toxic secondary pollutants (Martí *et al.*

2010). This is because only 45–47% of dyestuff has been reported biodegradable while others are characterized as recalcitrant to treatment (Rauf *et al.* 2011; Zubair *et al.* 2017).

The result in Figures 8, 9(a) and 9(b) described the quantified parameters after treatment of textile location 2 in Arusha. S1 represents raw textile wastewater, S5 is the final output going to the community while S2, S3 and S4 are treated after coagulation with calcium hypochlorite, filtration and trickling filter system, respectively. Comparing the pH value of Figure 6 with Figure 8. The textile effluent in Figure 8 exhibits pH value within the tolerable limits compared to Figure 6 which is above the tolerable limit (9.46 ± 0.00). Although the pH range correlates with the study carried out by Aniyikaiye *et al.* (2019) and Eremektar *et al.* (2006).

However, the observed dispersity is due to the effluent constituents and different treatment technologies used for the generated wastewater (Aniyikaiye *et al.* 2019). Also, the TDS results in Figure 8 are extremely higher with a value of

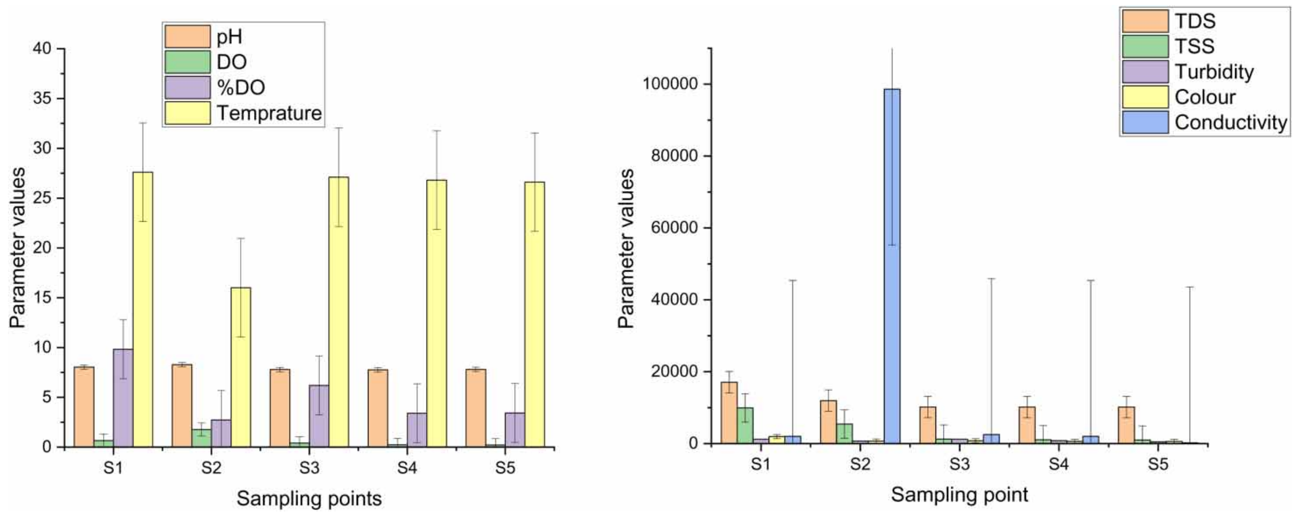

Figure 8 | Analysis of industrial effluent at each treatment system in Arusha Textile Industry 2. S1, raw textile wastewater; S2, effluent after treatment via coagulation with calcium hypochlorite; S3, effluent after filtration; S4, trickling filter system; S5, final output effluent going to the community.

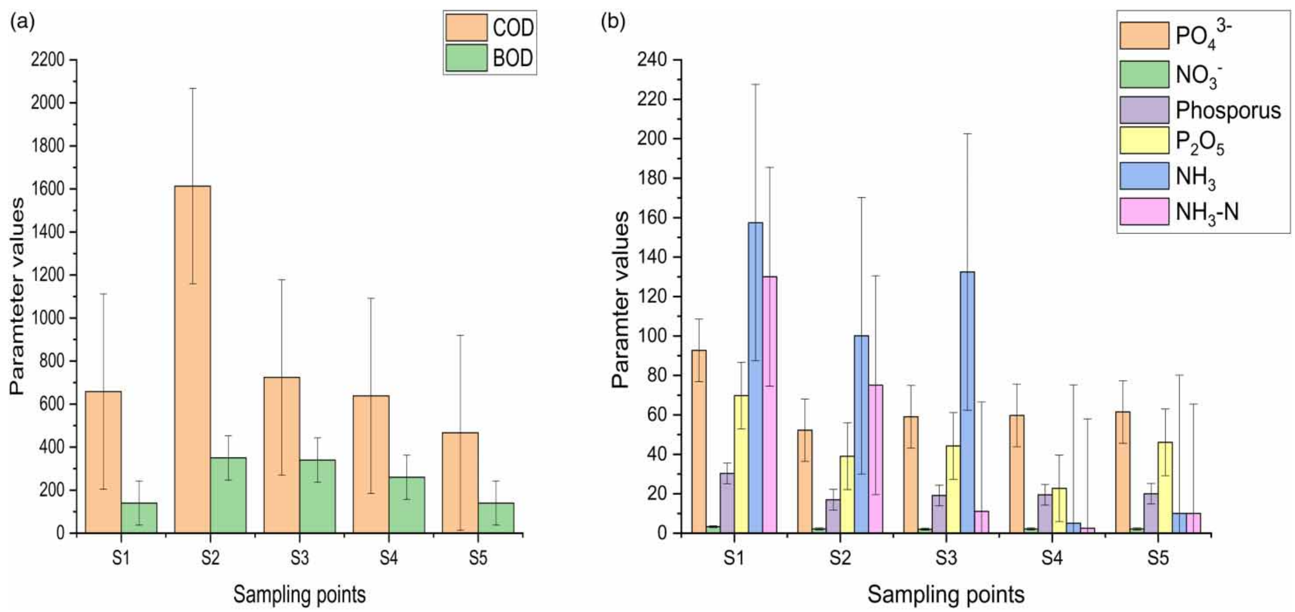

Figure 9 | (a) COD and BOD analysis of textile wastewater. (b) Chemical constituents of textile wastewater.

(11,950 ± 5,100 mg/L) after coagulation with CaOCl and exhibit no statistical difference concerning continuous treatment. However, in Figure 6, it was 7,955.00 ± 2.89 mg/L in value with statistical significance with respect to continuous treatment. Aboulhassan *et al.* (2014) added that the high TDS value is a direct determinant of the conductivity value of the effluent. The TSS value of the effluent was reported to be 5,450.10 ± 0.06, 1,065.03 ± 0.33, 9,924.00 ± 0.58 1,239.33 ± 0.33 mg/L for S2, S3, S4, respectively, which is similar to the influent and effluent analysis of textile wastewater by Aniyikaiye *et al.* (2019). Similarly, the level of TSS indicates the level of turbidity, which was considerably high above the tolerable limits in Figure 8 (Alrumman *et al.* 2016). Furthermore, only NO_3^- was reported below the tolerable limits in Figure 9(a) and 9(b), but the value of other dissolved ions is considerably high. It is expected that high values of the quantified ions is consequent of the increase in COD and the BOD textile wastewater (Ghaly *et al.* 2014). Additionally, Figure 9(b) describes NH_3 and NH_3-N has the highest among compounds quantified. Their reported value was 100.13 ± 0.88 and 75.06 ± 0.07 mg/L, respectively, after coagulation treatment and their persistence through the treatment process were shown in Figure 9(b). Although the value of NH_3 increases to 132.5 ± 0.06 mg/L, the filtered stream reduces to 5.10 ± 0.06 mg/L. The high amount of the compounds with other ions is suggestive of the low DO reported in Figure 8. Generally, the value of DO is the main determinant in an aquatic ecosystem as it indicates the survival of aquatic life (Trick *et al.* 2008; Edokpayi *et al.* 2015; Aniyikaiye *et al.* 2019). Also, persistency of ammoniacal nitrogen and NH_3 is a characteristic feature of effluent laden with recalcitrant azo. The transformative behavior of these dyes and auxiliaries in effluent can result in the generation of excessive biomass and non-biodegradable substances on discharge (Asia *et al.* 2006; Smith *et al.* 2007).

4. CONCLUSION

The study shows that reactive, vat and dispersed dyes are the most commonly used dyes in these selected textile industries having a predominant class of the azo chromophoric system. The analyzed performance of the respective treatment system regarding their corresponding wastewater exhibited a high amount of quantified parameters when compared with the set standard by TBS and WHO. Among the measured parameters BOD, COD, Color, TSS, TDS, Turbidity and dissolved chemical compounds were significantly higher than the tolerable limits. Among the dissolved chemical species, the highest recorded were phosphorus, NH_3 and NH_3-N which were above the tolerable limits for all the sample effluents. However, the use of an activated carbon system and sand filtration proffer a significant remedial action for the color and corresponding turbidity of the effluent. Also, aerated CW exhibited significant functional performance in the remediation of NH_3, NH_3-N which was significantly persisting in the treated effluent. The study noted the recalcitrant behavior of these industrial synthetic dyes to continuous treatment and indicated susceptibility of land and many riverine areas to increasing algae blooms and consequent toxicological allergies in man.

RECOMMENDATIONS

Based on the reported findings of functional efficiency of the current treatment technologies within the selected textile industries, it is needful to recommend the following:

- The need for prompt and proactive measures on the general maintenance of the treatment plants of respective textile industries with strict monitoring of the quality of discharged effluent in compliance with set standards.
- The incorporation of the continuous integrated system with high selectivity to lower vital parameters such as color, TDS, TSS, COD and BOD which are considerably higher than the tolerable limits from the report.
- The used of modern design CWs such as the floating treatment wetlands (FTWs) and implementation of effective control of seepage and oversaturation of water during flood and heavy rain in coastal region like Morogoro and Dar es Salaam.
- The introduction of more effective bioorganisms such as *Trametes versicolor* and *Aspergillus luchuensis* into the CWs and bioreactor to completely remove persisting dissolved ions such as NH_3 and NH_3-N, phosphorus and PO_4^{3-} pollutants.
- Monitoring of influence concentration to reduce oversaturation and constant maintenance of the filter cartridges of the filtration system.
- Adoption of durable and highly selective nano textile filters used in modern sequencing batch reactor.
- Adoption of the flow rate and concentration control system to reduce oversaturation and overloading of the sorbent system.
- The use of improved and impregnated nanosorbents with effective selectivity in the removal of persisting and toxic pollutants from the wastewater.

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DECLARATION OF COMPETING INTEREST

The authors declare an absence of competing financial interests in personal relationships that could influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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