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Current status of textile wastewater management practices and effluent characteristics in Tanzania

J. M. Bidu, B. Van der Bruggen, M. J. Rwiza and K. N. Njau

ABSTRACT

Textile wastewater from wet processing units is a major environmental problem. Most chemicals, including dyes, are only partly consumed, resulting in highly colored wastewater containing a variety of chemicals released into the environment. This paper gives information on the current management of textile wastewater in Tanzania. A semiquantitative analysis was done to identify the main types of chemicals used in wet processing units, wastewater characteristics and existing wastewater treatment methods in the textile industry. The performance evaluation of the existing wastewater treatment plants is also discussed. The advantages of integrating constructed wetlands with the existing treatment facilities for textile wastewater are explained. It has been observed that pretreatment and dyeing/printing of the fabrics are the main two processes that produce wastewater in many textile companies. Main pollutants are chemicals used from pretreatment and materials removed from de-sizing, bleaching and scouring processes. Dyes, printing pigments and dye auxiliaries are the main pollutants from the dyeing/printing process. Most of the textile companies in Tanzania are equipped with effluent treatment plants. Wastewater treatment plants have basically similar units, which are coagulation-flocculation, sedimentation through clarifiers and aerobic reactor. However, their effluents do not meet discharge limits stipulated by the Tanzania Bureau of Standards (TBS).

Key words | dyeing, printing, textile wastewater, textile wastewater treatment, textile wet processing

HIGHLIGHTS

- Characteristics of textile wastewater effluents in Tanzania.
- Textile wastewater treatment technologies used in Tanzania.
- Performance of textile wastewater treatment plants in Tanzania.
- Main pollutants in textile wastewater in Tanzania.
- Use of constructed wetland for tertiary treatment of textile wastewater.

INTRODUCTION

Textile industries generate huge quantities of wastewater with complex chemical substances from different processing units as unused materials (Dasgupta *et al.* 2015). The

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chemical substances are released with wastewater generated from different textile processing units (Verma *et al.* 2012). Some of the companies do not have a wastewater treatment plant and hence discharge untreated wastewater into the environment. The discharged untreated wastewater causes undesirable changes to the environment, affecting its ecological status (Verma *et al.* 2012). The

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number of textile companies is expected to increase due to the rise in demand of textiles products proportional to the increase in middle class population (Ministry of Industry Trade and Investment 2020). The Tanzanian government is also promoting industrialization, which includes the textile industry (Ministry of Industry Trade and Investment 2020). Textile wet processing consumes a large amount of fresh water. An increase of textile processing plants will cause a substantial increase in water pollution if their wastewater is not well managed.

The textile industry is very important in providing people with clothing as a basic need. Moreover, it positively affects the economic development of countries and the world as a whole (Scholz & Yaseen 2018). However, the textile industry is one of the main producers of highly polluted wastewater (Holkar *et al.* 2016). Textile plants discharge wastewater with various pollutants such as dyes, sizing agents, salts and other dyeing auxiliaries (Scholz & Yaseen 2018). In general, the discharge of textile wastewater is characterized by a complex mixture of chemicals and coloring agents with low biodegradability and high salinity (Vajnhandl & Valh 2014). Textile wastewater constituents include acids and alkalis, dyes, print pigments, hydrogen peroxide, starch, surfactants, dispersing agents and soaps of metals (Vajnhandl & Valh 2014). The average consumption of water by textile mills is about 100–200 L per kg of fabric processed per day (Vajnhandl & Valh 2014; Holkar *et al.* 2016). Just like other industries, the textile industry is obliged to act more sustainably, and discharge wastewater within standard limitations (Vajnhandl & Valh 2014; Kumar & Saravanan 2017). Color has been the first concern in textile wastewater due to its harmfulness to the environment (Kumar & Saravanan 2017). The main units responsible for the generation of a huge amount of highly polluted textile wastewater are sizing and de-sizing, bleaching, scouring, mercerization, dyeing, printing and finishing.

Effects of sizing and de-sizing

In order to ensure weaving of the fabrics and reduce yarn breakage, the yarns are sized using different sizing agents, most of which are starch materials. To enable good dyeing and printing, the size materials must be removed from the yarns by a process known as de-sizing. Typical wastewater from the de-sizing section is characterized by a high biological oxygen demand (BOD) (Magdum *et al.* 2013; Meng *et al.* 2014; Holkar *et al.* 2016).

Effects of bleaching

The matter that causes natural color is removed by a bleaching process by the use of bleaching agents such as hypochlorite, peroxide and peracetic acid (Abdel-halim & Al-deyab 2013; Holkar *et al.* 2016). Peracetic acid is mostly used as it is considered an environmentally friendly option compared with hypochlorite, which has a slightly harmful effect on the environment (Holkar *et al.* 2016). Usually, these bleaching agents are carried along with the wastewater, thus becoming part of the pollution sources in textile wastewater (Abdel-halim & Al-deyab 2013; Liang & Wang 2015; Holkar *et al.* 2016).

Effects of mercerization

The cotton fabrics are mercerized to give shine and enhance the dye uptake of the cotton fabric. Mercerization is done by treating cotton fabric with 18–24% by weight of sodium hydroxide (Holkar *et al.* 2016). The fabrics are washed after mercerization to remove sodium hydroxide, which is carried in the wastewater.

Effects of dyeing and printing

Dyeing is a process in which a yarn or a fabric is treated to impart color (Holkar *et al.* 2016). A chemical structure responsible for color from dyes is called a chromophore group (Scholz & Yaseen 2018). Chromophore groups include azo ($N=N$), carbonyl ($C=O$), and quinoid groups. In addition, there are auxochrome groups such as amine, carboxyl, sulfonate and hydroxyl (Scholz & Yaseen 2018). The commonly used dyes have azo or anthraquinone chromophore groups (Holkar *et al.* 2016; Scholz & Yaseen 2018). The printing process involves the use of dyes in the form of a thick printing paste while dyeing is applied in the form of a solution. However, the most important reactions in both dyeing and printing are the same (Holkar *et al.* 2016). To enable sorption of dyes on the fibers of the yarn or fabrics, many other chemicals are used (Scholz & Yaseen 2018). Dyes and auxiliary chemicals used during dyeing and printing process become part of textile wastewater effluents (Scholz & Yaseen 2018). Dyes, dyeing auxiliaries and other chemicals are the cause of the unacceptable appearance and toxic effect in wastewater (Scholz & Yaseen 2018).

Effects of finishing processes

Fabrics with certain specific functional properties are treated with specific chemicals. Functional properties of some

of the fabrics are crease recovery, waterproofing, antibacterial and UV protection (Holkar *et al.* 2016). Finishing chemicals are released in water and hence constitute the pollution load of textile wastewater (Holkar *et al.* 2016).

Methods of textile wastewater treatment

There are several methods employed in textile wastewater treatment. To ensure complete treatment, several methods are employed in sequence. The descriptions of the different methods existing in textile wastewater treatment are shown in Table 1.

Textile wastewater treatment methods include coagulation and adsorption process, biological process and chemical oxidation (Gosavi & Sharma 2014). However, individually these methods are not enough to remove all the pollutants from textile wastewater. In real applications, a combination of methods is efficient in treating textile wastewater (Gosavi & Sharma 2014). A description of textile wastewater treatment methods is given in Figure 1.

This paper provides a comprehensive overview of different wet processing steps in textile industry and their corresponding sources of pollutants and characteristics of wastewater generated. This article also gives an overview of the main methods currently used in textile wastewater treatment in Tanzania. To illustrate the wastewater treatment capacity of the existing treatment plants, this study gives an analysis of the performance of wastewater treatment plants existing in textile industries in Tanzania. It also suggests alternative methods that can bring the wastewater released to the environment within standard limits.

MATERIALS AND METHODS

Survey

To accomplish the study, a survey was conducted in six textile processing plants from four different cities in Tanzania. A semiquantitative analysis was done to investigate the wastewater producing units, wastewater treatment plants and characteristics of treated and untreated textile wastewater. In each visited plant the main wet processing units were studied. The chemicals used in each process were also identified. A tentative water characteristic profile from each process was established depending on the characteristics of the chemicals used in each process. The physico-chemical characteristics of wastewater effluent were also determined. The existing wastewater treatment plants were also identified and analyzed for their performance.

Textile wastewater treatment in Tanzania

From the survey, qualitative and quantitative information was gathered. For the quantitative information, wastewater quality parameters were measured for the sake of characterizing textile wastewater effluents and evaluating the performance of the treatment systems. The parameters monitored in textile wastewater treatment are suspended solids, color, dissolved solids, nitrates and phosphates, and chemical oxygen demand (COD) and biological oxygen demand (BOD). Other parameters include pH, electrical conductivity, and turbidity and dissolved oxygen.

Several treatment steps are involved in most of the visited textile plants (Figure 2). The first steps are primary treatment, which involves use of bar screens for grit and large solids removal, equalization units for flow and

Table 1 | Combined treatment methods on textile wastewater

Treatment sequence	Reported Efficiency	References
Coagulation-flocculation-sedimentation-aerobic – advanced oxidation process	95%	Verma <i>et al.</i> (2012); Huang <i>et al.</i> (2014); Pan <i>et al.</i> (2017); Silva <i>et al.</i> (2018)
Anaerobic-aerobic-ozonation	70%	Sandhya & Sarayu (2012)
Anaerobic-aerobic sequential treatment system	85%	Bonakdarpour <i>et al.</i> (2011)
Ozone-membrane ultrafiltration-reverse osmosis	84%	Sandhya & Sarayu (2012); Chang <i>et al.</i> (2009)
Sand filtration-ozone aeration-ultrafiltration-reverse osmosis	74%	Yin <i>et al.</i> (2019)
Membrane -advanced oxidation processes	97%	Jegatheesan <i>et al.</i> (2016), Gao <i>et al.</i> (2010)
Ozone- anoxic-anaerobic activated sludge method	86%	Suryawan <i>et al.</i> (2019)

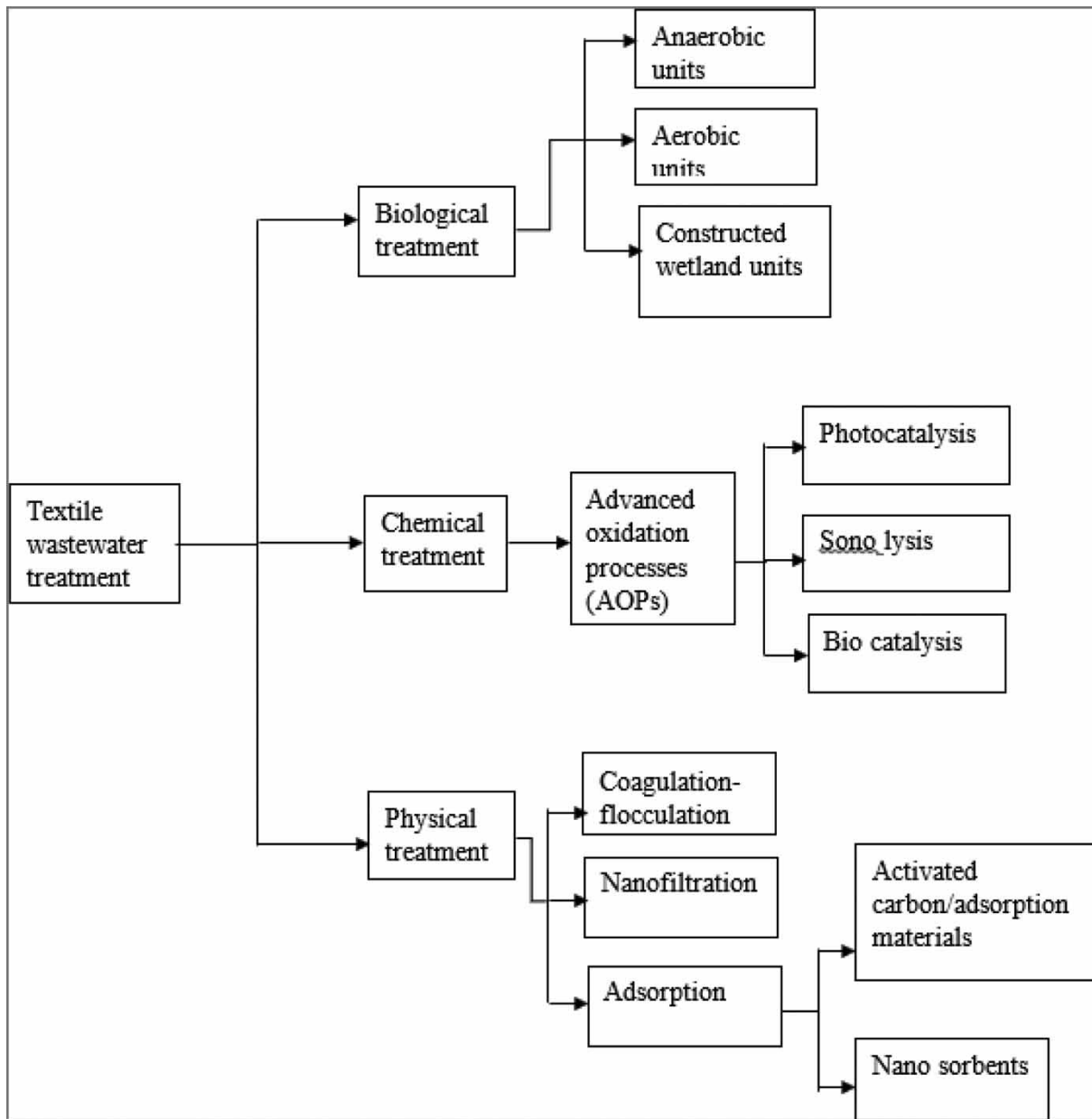


Figure 1 | Overview of textile wastewater treatment techniques.

composition normalization, and coagulation-flocculation and sedimentation in the coagulation and clarifying units for dyes and other colloidal particles removal. The secondary treatment is a biological process under aerobic conditions followed by secondary clarifier. Secondary treatment is aimed at reducing BOD and COD (Ghaly *et al.* 2014). Activated carbon units are used in a few plants for polishing treated water by adsorbing dyes and other pollutants from textile wastewater (Jin *et al.* 2013).

Physico-chemical analysis of the samples

Physical parameters like pH, temperature, dissolved oxygen (DO), electrical conductivity (EC) and total dissolved solids (TDS) were determined onsite by a Hanna Multiparameter (HI 9829), whereas turbidity was determined by Hanna Turbidometer (HI 93703). Color, COD, Nitrate, phosphorus, ammonia, and total suspended solids (TSS) were determined by use of DR2800 spectrophotometer from the

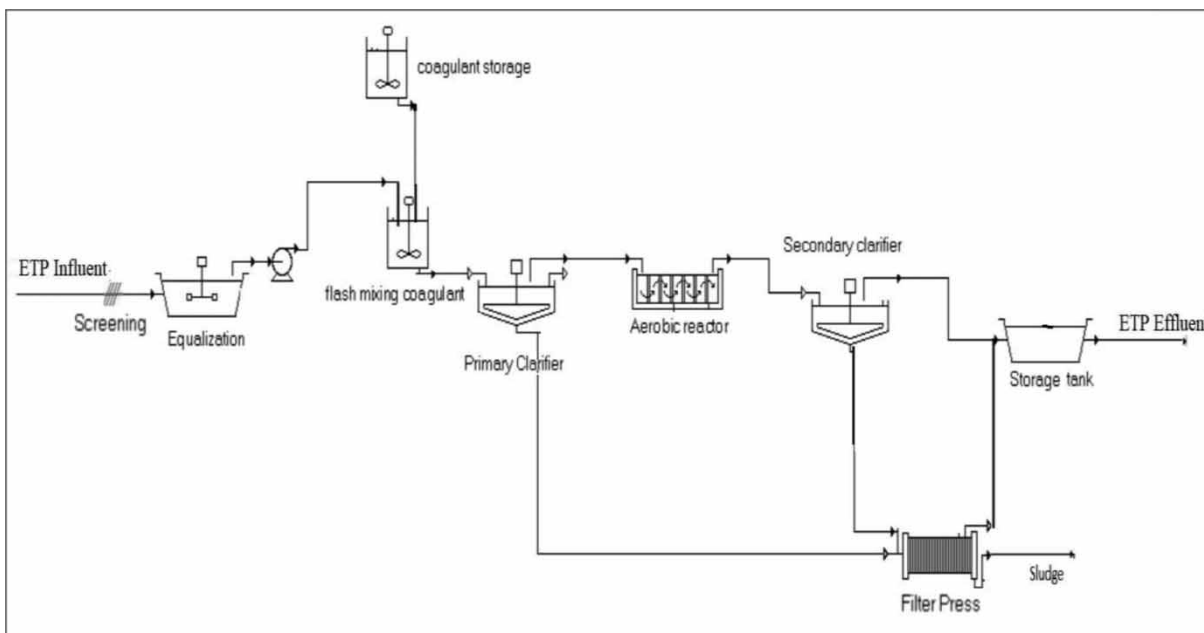


Figure 2 | Common process flow sheet for textile wastewater effluent treatment plants.

Nelson Mandela African Institution of Science and Technology (NM-AIST) laboratory in Arusha, Tanzania.

Biological oxygen demand (BOD) analysis

For BOD determination, the respirometry method was used using OxiTop pressure measuring heads equipment/respirometer at the NM-AIST laboratory.

RESULTS AND DISCUSSION

Pollutant source and wastewater characteristics

There are several unit processes which a textile product goes through during production. The process units may include fiber preparation, transformation of fibers into yarn and alteration of the yarn into fabric. The fabric also goes through several stages of unit processing (Holkar *et al.* 2016). Several units in fabric preparation involve wet processes, which use a considerable quantity of potable water, thus releasing highly polluted wastewater (Scholz & Yaseen 2018). The unit processes observed in wet processing in the present study were sizing, de-sizing, scouring, bleaching, mercerizing, dyeing/printing and finishing technique (Scholz & Yaseen 2018). These processes are usually responsible for the wastewater produced in most textile plants. The

sources of pollutants and wastewater characteristics from each process unit are summarized in Table 2.

In the visited companies, all have similar wet processing units except the small-scale company. The most used dyes from the visited plants are azo reactive dyes and azo disperse dyes.

Physical characteristics of textile wastewater treatment plants

Most of the visited textile companies with wet processing units were equipped with wastewater treatment plants. The process steps and physical characteristics of the visited textile wastewater treatment plants were found to have important similar treatment units. These units are bar screen, equalization tank, coagulation-flocculation and clarification unit for primary treatment. Bar screen was responsible for removal of grit and other large solid particles such as bottles, sticks, fabrics and rags. In each visited plant, the collected materials from bar screens were disposed to municipal landfills or landfills owned by the textile companies. Equalization units were used for flow normalization and homogenizing wastewater before subsequent treatment. It was important to use equalization units as the efficiency of the treatment systems has been reported to increase for the homogenized wastewater (Raji *et al.* 2018). Most of the observed equalization units in textile companies are mechanically mixed to prevent settling

Table 2 | Typical chemicals used and characteristics of wastewater from different units of textile wet processing

Process step	General chemicals used/sources of pollutants from literature	Chemicals used in textile industries surveyed	Wastewater characteristics resulting
1. De-sizing	Acetic acid, starch, water soluble polyvinyl alcohol, water soluble sizes, synthetic sizes, enzymes, wax, ammonia lubricants	Sodium hydroxide, enzymes, scetic acid, starch, desizol THL, seraquest, wettanol DBL (sodium ethyl hexyl sulfate), OT paste	High BOD and COD from sizes
2. Scouring process	Sodium hydroxide, pectinase, disinfectant, insecticide residue, detergents/surfactant, fats, oils, wax, lubricants	Sodium hydroxide, ethoxylate, wetting agent (Wettanol), NaHSO ₄ , stabilizer, Serafile, soda ash, acetic acid, hydrose	High COD, High pH
3. Bleaching	Sodium hypochlorite, hydrogen peroxide, sodium silicate, organic stabilizer	Seraquest, hydrogen peroxide	High pH, COD
4. Mercerization	Sodium hydroxide, liquid ammonia	Wettanol DBL (sodium ethyl hexyl sulfate), NaOH	High pH
5. Dye auxiliaries	Salt, alkali, Thickening agents: kerosene, water based polyacrylate copolymer Hydrotropic agent: Urea, dicyanamide Water repellent: fluorocarbons Wetting agent: Alkyl phenol ethoxylates, fatty alcohol phenol ethoxylates Reducing agent; Sodium sulfide, glucose, acetyl acetone, glucose Organic acid carriers Oxidizing agents	Bicarbonate (Na ₂ CO ₃), sodium hydroxide (NaOH), sodium chloride (NaCl), sodium sulfate (Na ₂ SO ₄), ammonia, sodium alginate, sodium bicarbonate, Resist salts, urea, Seraquest M-USP, OT paste	Heavy metals, BOD, color, COD, acidity/alkalinity, dissolved solids
6. Dyeing	Reactive dyes Vat dyes Disperse dyes Direct dyes Sulfur dyes	Reactive dyes, disperse dyes, vat dyes	Color, COD, dissolved solids, suspended solids
7. Printing	Binder: Formaldehyde Print paste: Urea, suspended particles, dyes, complex metals Solvents: oils, thickeners, and surfactants	Ammonia, sodium alginate, sodium bicarbonate, Resist salts, urea, Seraquest M-USP	Suspended solids, urea, solvent, color, metals, COD
8. Finishing	Unimul APV, Resin AA, Amino (Silicon), sodium alginate, Seraquest, sodium bicarbonate, urea, Soft white, Kunal White	Unimul APV, Resin AA, Amino (Silicon), sodium alginate, Seraquest, sodium bicarbonate, urea, Soft white, Kunal White	Suspended solids, solvents, BOD, COD, resins, waxes, chlorinated compound, acetate

of the solid particles to the bottom of the tank. In the visited companies, the pH regulation was done by dosing acid in an equalization unit. pH was regulated to ensure smooth functioning of the subsequent treatment units (Mekuriaw Manderso 2018; Raji *et al.* 2018).

From the equalization units, coagulation-flocculation and sedimentation in the primary clarifiers followed. It was observed that after coagulation-flocculation and sedimentation in clarifiers, color was highly reduced. This

means that, these were the main process units in dyes removal from wastewater. Flocs formed were observed to be gelatinous precipitates, and the same was reported by other researchers (Abdulkareem *et al.* 2016). Most coagulants used in the surveyed companies were aluminum sulfate, ferrous sulfate, and poly aluminum chloride (PAC) as commonly used in textile wastewater treatments as reported (Seneviratne 2018). However, the major limitation of coagulation-flocculation processes in textile wastewater

is the generation of a large amount of sludge and the ineffective removal of some soluble dyes (Nawaz & Ahsan 2014).

Secondary treatment involved an aerated unit (Figure 3) for removal of biodegradable organics, hence reducing COD and BOD in the wastewater. After the aeration unit, there was a secondary clarifier responsible for the removal of biomass sludge formed in the aeration unit.

Activated carbon (Figure 4) as an adsorption unit was used as a polishing unit after secondary clarifying. Effluents from the activated carbon unit were found to have less color compared to their influents. Turbidity was also highly reduced after passing activated carbon units. Therefore, it can be said that the activated carbon helped in reducing color and turbidity of wastewater as a final treatment step. However, there is still a challenge on how to dispose the concentrated stream from the backwash of the activated carbon unit.

Sludge management

High volumes of sludge are produced by the existing textile wastewater treatment methods in Tanzanian textile companies, as seen in Figure 5. Basically, dyes present in wastewater are converted to sludge, the majority in primary and the remaining in the secondary clarifier. Disposal of sludge remains a key challenge for textile wastewater treatment plants (Ghaly *et al.* 2014). In the surveyed plants, sludge was dried in drying chambers and sent to the municipal solid waste disposal facilities. The solid waste municipal landfills are not designed to degrade the dyes; some anaerobic degradation might be occurring, which might produce carcinogenic compounds such as aromatic amines (Sandhya & Sarayu 2012). Aromatic amines can only be degraded under aerobic conditions (Shi *et al.* 2014; Maqbool *et al.* 2020). Thus, the sludge as dyes might be ending up in the environment through leaching, posing a risk to human and ecological health. In one of the plants, the sludge was



Figure 4 | Activated carbon filters.

used as a raw material for making building bricks. However, the quality and safety of the bricks made was not established.

Analysis of the existing treatment systems

The disadvantages of the physio-chemical treatment process of textile wastewater are the formation of sludge and its disposal (Ghaly *et al.* 2014). This was observed in the surveyed plants, where much sludge was observed at the sites. The disposal of this sludge added running costs, as companies were supposed to pay for disposing in municipal landfills. There was also no evidence of how these dyes were handled after the landfills were abandoned. The disadvantages of aerobic degradation in the visited industries were the presence of toxic substances and the high pH of the effluent; these were unfavorable conditions for microbial growth. For example, in one textile plant, effluent from the wastewater treatment plant had a pH of 12. Therefore, the observed pH in the effluent strongly inhibited the growth of microorganisms. Most of the effluent wastewater from treatment plants was observed to have a pH above 9, as shown in Table 4. Therefore, complete treatment of the wastewater effluent by the observed treatment processes was difficult due to the high pH (Ghaly *et al.* 2014).



Figure 3 | Aerated biological units.



Figure 5 | Sludge produced after coagulation-flocculation process in primary clarifier.

Wastewater effluent characteristics

Typical characteristics of textile effluents

The dye effluents are characterized by a strong color, high pH, suspended solids (SS), high total suspended solids, COD, BOD, heavy metals, and different types of salts (Scholz & Yaseen 2018). Thus, textile wastewater treatment must consider monitoring all those properties before discharging to the receiving water bodies (Scholz & Yaseen 2018). Other parameters that need to be monitored include total organic carbon (TOC), ammonia (NH_3), nitrate (NO_3) and phosphorus (P, P_2O_5) (Vajnhandl & Valh 2014; Scholz & Yaseen 2018).

The actual values of parameters of textile wastewater are reported by different researchers (Scholz & Yaseen 2018). The main difference in textile wastewater characteristics is related to the type of the fibers and unit processes (Scholz & Yaseen 2018). Textile wastewater also has metal contamination due to the use of metal complex dyes. It has been reported that the main metals found within the dye chromophores in textile effluents are cobalt, copper and chromium (Scholz & Yaseen 2018).

The main fiber used in textile industries to produce fabrics in Tanzania is cotton. In that regard, most textile mills surveyed have similar production steps that produce wastewater. Apart from the normal process units, other units that produce wastewater are washing and noncontact cooling wastewater (Dasgupta *et al.* 2015). The amount of wastewater and its pollutants varies depending on the specific processes and the equipment used as well as the water management practices in a specific textile mill (Verma *et al.* 2012). Due to the many processes with various chemicals involved in textile wet processing, textile

wastewater contains a complex mixture of pollutants (Verma *et al.* 2012; Dasgupta *et al.* 2015).

Textile wastewater from the surveyed textile companies in Tanzania

Dissolved oxygen (DO) and pH. The pH values were observed to be higher than 8.5, therefore above the allowable limit according to the Tanzania Bureau of Standards (TBS) (Tanzania Bureau of Standards 2005). For the plants with wastewater treatment facilities, the pH of effluent treatment plant (ETP) effluents was also high, which suggests that biological degradation in the aerated ponds was not working well. This is because the microorganism activity has the highest rate at pH range 6.5–8.5. The DO values of wastewater were found at an average of 2 mg/L. For treated wastewater, DO slightly increased at an average of 3 mg/L.

Biochemical oxygen demand (BOD_5). The results for BOD_5 obtained from this measurement show that the minimum BOD_5 from one company was 200 and maximum 550. In most of the facilities, BOD_5 measured was at an average of 400. For the plants with wastewater treatment facilities, the ETP effluent had a BOD_5 of 100 being the lowest while the maximum was 500. However, the values were still above the allowable limit as stipulated in the TBS standard, which is 30 mg/L (Tanzania Bureau of Standards 2005). Textile wastewater contains toxic substances and a high pH, which inhibited the growth of microorganisms. BOD_5 values were low because most textile wastewater contained compounds which are not biodegradable (Bilińska *et al.* 2016). The only sources of BOD came from the desizing process and the biomass from aeration ponds.

Chemical oxygen demand (COD). For most surveyed plants, the COD of the wastewater effluents was above 2,000. The highest was 3,750 mg/L and lowest was 2,020 mg/L. The COD reduction by wastewater treatment plants was not very efficient, because the average performance was around 20%. This means that the efficiency of the systems in reducing COD was very low. The values of COD measured were high compared to the TBS standard limit, which is 60 mg/L for industrial and domestic wastewater (Tanzania Bureau of Standards 2005). COD measurement cannot be used solely as a measure of the removal of all organic carbon. This is because COD does not measure certain aromatics which can be found in textile wastewater, such as benzene, toluene, phenol, etc., which are not completely oxidized in the reaction (Dasgupta et al. 2015).

Nitrate and phosphorus. Other parameters measured were nitrate as NO_3^- and NO_3^- -N and phosphorus as PO_4^{3-} , P and P_2O_5 . The values were found to be just above the permissible TBS limits (Tanzania Bureau of Standards 2005). In some plants the values were even within the effluent permissible limits. After wastewater treatment, the values for most of the industries were found to be low. For the case of phosphorus, it can be noted that there were no sources of phosphorus in textile wastewater.

Conductivity. EC was observed to be above 8 mS/cm for most effluent wastewater. This is typical for many textile wastewater effluents as identified from the literature (Kamal et al. 2016). For the surveyed plants, the highest observed electrical conductivity was 13.46 mS/cm and the minimum was 2.9 mS/cm. This minimum was observed at a small-scale fabric dyeing, where few chemicals were used compared to large-scale textile industries. Small-scale industries used fewer chemicals because some of the processes such as scouring and mercerization were not skipped. For the wastewater treatment plants, the reduction, of electrical conductivity is by 25%. This is not a significant reduction, and thus the system performance for EC reduction was poor.

Total suspended solids (TSS) and color. The total suspended solids for most of the industries were above 100 mg/L and below 400 mg/L. There were two extremes for two industries, one being 65 mg/L and the other 2,435 mg/L. For the highest value of TSS measured, this was a small-scale industry without heating facilities to ensure dyes are dissolved. Thus, this can be the reason for high TSS due to undissolved dyes. For ETP effluent, there was a significant decrease in TSS, true color and apparent color. This

means that for most of the industrial wastewater treatment plants, coagulation-flocculation and sedimentation processes were working well. For some of the industries the results were within the disposal limit from TBS standards for industrial wastewater effluent disposed to the surface land and water bodies (Tanzania Bureau of Standards 2005). The inlet to ETP was colored mostly due to dyes present in wastewater. Coagulation-flocculation removed dyes and hence decreased color.

Total dissolved solids. TDS were observed to be 10,160 mg/L and 2,680 mg/L as maximum and minimum, respectively. The plant with minimum total dissolved solids was a small-scale dyeing, and this plant does not have heating facilities for dissolving enough dyes. Furthermore, fewer chemicals were used for pretreatment; thus less dissolved solids are found. There was a small decrease in TDS after wastewater treatment. Thus, the effectiveness of the ETP to remove dissolved solids is low. In some plants TDS was found to increase after treatment; this may be due to mineralization of organic and inorganic materials in the biological tank.

Wastewater effluents from company I

For a period of four months, the wastewater effluent characteristics from company I were studied, as shown in Table 5. The aim was to determine if there was a significant difference on values of the parameters over a given period. The results showed that the average values of different parameters did not have a significant change. Thus, the properties of textile wastewater effluents obtained from an equalization tank from a textile company did not have significant differences. This means that the wastewater influents into treatment plants have more or less the same properties on different days despite some changes in the processes.

CONCLUSION

Textile wastewater pollutant sources

According to the surveyed textile industries, wastewater was produced mainly from two process steps. The first was a pre-treatment step which included sizing and de-sizing, scouring, bleaching and mercerization processes. Pollutants from these steps were the chemicals used in these steps and the materials or waste from fabrics removed by those processes. The main chemicals used were starch materials, sodium hydroxide, hydrogen peroxide, sodium hypochlorite,

and in addition, fats, oils, insecticide residues, pectin, wax, spin finishes and detergents/surfactant. Second were the dyeing and printing processes. The chemicals used in dyeing and printing processes were dyes, dye pigments and dyeing auxiliaries. Reactive dyes were commonly used by all textile industries for dyeing cotton fabrics. They were azo reactive dyes because of their versatility in dye shade and low price. Other dyes are typically used in small quantities, such as vat dyes on cotton fabrics and disperse dyes on polyester fabrics. Disperse dyes were used in small quantities because they were used to dye polyester fabrics, which were produced in small quantities. Most of these dyes are azo dyes characterized by the azo group $-N=N-$ producing the color in the dye molecule.

Wastewater management in textile plants

For the textile processing plants visited, it was observed that they were equipped with wastewater treatment plants. Four out of six had wastewater effluents treatment plants. One of these companies was releasing wastewater to municipal ponds and is paying money as a charge to release their wastewater. One company was just spilling wastewater in the ground. This company produced little wastewater

because it was a small-scale company. The other four had more or less similar treatment plants. They consisted of primary and secondary treatment systems. Primary included equalization, coagulation-flocculation and sedimentation with the use of clarifiers. The secondary used method is biodegradation using the aerated ponds. Some other units involved are activated carbon and sand filters for some industries. The performance of these plants was evaluated, and it was found that all plants were not able to remove the pollutants to the TBS effluents limits. Only nutrients such as nitrates and phosphorus for some plants were reduced to the acceptable levels.

Wastewater characteristics

Most of the parameters were observed to be higher than the limits as per TBS standards. Thus, it is to say that there is a need for improvement to rescue the situation by improving some process units in the ETP and include the process unit of the effluent treatment plants. The performance of the effluent treatment plants was good for some parameters, especially nitrates. The wastewater effluents from company I was monitored for the period of four months to see if there were changes in characteristics of effluents. The results

Table 3 | Characteristic parameters recorded from the textile wastewater effluents before treatment

Parameter	Textile Company						Minimum	Maximum	Average	TBS Limits	SI Unit
	I	II	III	IV	V	VI					
Color Apparent	950.0	5,080.0	2,050.0	2,630.0	2,100.0	13,000.0	950.0	13,000.0	4,301.7	N/A	Pt Co
Color True	785.0	4,090.0	1,410.0	1,812.0	1,787.5	231.0	231.0	4,090.0	1,685.9	300	Pt Co
Total Suspended Solids (TSS)	394.0	195.0	131.0	187.0	65.0	2,435.0	65.0	2,435.0	567.8	100	mg/L
Total Dissolved Solids (TDS)	8,630.0	10,160.0	8,520.0	9,220.0	5,669.0	2,680.0	2,680.0	10,160.0	7,479.8	100	mg/L
Dissolved oxygen (DO)	1.3	1.2	1.8	1.4	3.9	7.7	1.2	7.7	2.9	100	mg/L
Turbidity	72.5	153.0	144.0	161.0	9.4	450.0	9.4	450.0	165.0	300	NTU
EC	13,460.0	10,390.0	8,290.0	8,920.0	534.4	2,900.0	534.4	13,460.0	7,415.7	N/A	$\mu\text{S/cm}$
pH	7.5	12.3	10.6	11.1	9.5	8.5	7.5	12.3	9.9	6.5–8.5	
Temperature	32.8	32.0	28.9	29.1	30.0	30.1	28.9	52.8	33.8	20–35	$^{\circ}\text{C}$
Redox potential	-220.5	-314.2		-210.1	-146.6	216.8	-314.2	216.8	-134.9	N/A	mV
COD	3,750.0	2,020.0	2,190.0	2,113.0	480.0	2,250.0	480.0	3,750.0	2,133.8	60	mg/L
BOD ₅	550.0	400.0	200.0	475.0	125.0	450.0	125.0	550.0	366.7	30	mg/L
Nitrate (NO ₃ ⁻ -N)	12.5	170.0	11.0	31.3	1.0	0.0	0.0	170.0	37.6	N/A	mg/L
Nitrate (NO ₃ ⁻)	50.0	74.0	48.0	52.0	10.0	0.0	0.0	74.0	39.0	20	mg/L
Phosphorus (PO ₄ ³⁻)	9.2	3.8	6.1	7.8	0.6	0.0	0.0	9.2	4.6	N/A	mg/L
Phosphorus (P)	3.0	1.4	2.0	2.4	0.2	0.0	0.0	3.0	1.5	6	mg/L
Phosphorus (P ₂ O ₅)	6.9	3.2	4.5	3.3	0.4	0.0	0.0	6.9	3.1	N/A	mg/L
Sodium Chloride	13.0	12.4	10.1	9.0	11.0	2.9	2.9	13.0	9.7	N/A	mg/L

Table 4 | Characteristic parameters recorded from textile wastewater effluent treatment plants (ETPs)

Parameter	Textile Companies						VI	TBS Limits	SI Unit	
	I	II	III	IV	Minimum	Maximum				
Color Apparent	2,350.0	420.0	2,125.0	1,803.0	420.0	2,350.0	No Treatment	No Treatment	N/A	Pt Co
Color True	505.0	185.0	224.0	301.0	185.0	505.0	plant	plant	300.00	Pt Co
Total Suspended Solids (TSS)	871.0	44.0	19.0	72.0	19.0	871.0			100	mg/L
Total Dissolved Solids (TDS)	14,280.0	7,562.0	6,130.0	7,860.0	6,130.0	14,280.0			100	mg/L
Dissolved oxygen (DO)	1.6	2.6	2.5	3.0	1.6	3.0			100.00	mg/L
Turbidity	172.5	96.0	12.2	132.0	12.2	172.5			300.00	NTU
EC	21.9	7.7	5.8	5.7	5.7	21.9			N/A	μS/cm
pH	7.9	9.4	8.1	9.2	7.9	9.4			6.5–8.5	
Temperature	38.1	27.7	24.3	30.1	24.3	38.1			20–35	°C
Redox potential	−85.3	−152.1	−650.0	−433.0	−650.0	−152.1			N/A	mV
COD	4,000.0	1,640.0	330.0	1,404.0	330.0	4,000.0			60	mg/L
BOD ₅	500.0	100.0	125.0	236.0	100.0	500.0			30	mg/L
Nitrate (NO ₃ ⁻ -N)	45.0	4.6	31.5	47.0	4.6	47.0			N/A	mg/L
Nitrate (NO ₃ ⁻)	202.5	20.3	7.1	196.4	7.1	202.5			20	mg/L
Phosphorus (PO ₄ ³⁻)	22.6	0.5	0.2	1.5	0.2	22.6			N/A	mg/L
Phosphorus (P)	7.4	0.2	0.1	0.6	0.1	7.4			6	mg/L
Phosphorus (P ₂ O ₅)	16.9	0.4	0.2	1.0	0.2	16.9			N/A	mg/L
Sodium chloride		8.9	7.08	9.7	8.9	9.7			N/A	mg/L

Table 5 | Wastewater effluent characteristic parameters monitored for four months from textile company I

Parameter	June 2020	July 2020	August 2020	September 2020	Average
Color (Ptco)	2,800	2,022.9	2,250	6,925	3,499.5
TSS (mg/L)	120	167	1,124	141	388.0
TDS	5,376	4,861	3,928	4,590	4,688.8
Dissolved Oxygen (mg/L)	1.9	1.15	2.04	3.75	2.2
Turbidity	32.66	43.74	562	50.56	172.2
Conductivity	10,180	9,738	7,858	9,173	9,237.3
pH	9.66	10.72	9.5	9.64	9.9
Temperature	41	30.36	20.3	16.56	27.1
COD (mg/L)	1,415	1,060	935	685	1,023.8
BOD ₅	335	220	350	200	276.3
NO ₃ ⁻ (mg/L)	66	155	62	118	100.3
NO ₃ -N (mg/L)	16	35	16	31	24.5
PO ₄ ³⁻ (mg/L)	31.75	7.8	40	11.9	22.9
P (mg/L)	10.25	3	14	3.9	7.8
P ₂ O ₅ (mg/L)	23.75	6.8	26	8.9	16.4
Practical Salinity Unity (Psu)	5.6	5.45	4.37	5.8	5.3

obtained in Table 3 showed that there was no significant difference in wastewater characteristics. Therefore, the characteristics of textile wastewater from the surveyed companies represented the real situation of wastewater in textile companies in Tanzania. In general, the wastewater characteristics of surveyed textile companies were in the range of typical characteristics of textile wastewater worldwide (Scholz & Yaseen 2018).

RECOMMENDATION

There are several recommendations to ensure that textile mills release the wastewater within standards. Furthermore, the effluent can be used for other economic activities and reused for other processes within the companies. Textile wastewater contains dyes which are made to resist biological degradation (Masi *et al.* 2019; Tara *et al.* 2019). The existing physical methods had proved to be inefficient to remove all the dyes. There is a need to incorporate other methods for complete treatment of wastewater. As observed from the dyes used, most of them were azo dyes, which can only be degraded under anaerobic conditions to form aromatic amines. The aromatic amines produced need aerobic conditions for their degradation into simple compounds. Therefore, there is a need to incorporate anaerobic and then aerobic steps for complete degradation of dye molecules.

On the other hand, nanotechnology can be used as alternative methods for textile wastewater treatment. Researchers have reported nanoparticles as alternative efficient and cost-effective methods (Bora & Dutta 2014). Nanotechnology in textile wastewater treatment includes photocatalysis, nanofiltration and nanosorbents (Bora & Dutta 2014; Baruah *et al.* 2018). Al-Mamun *et al.* studied the effect of electrochemically assisted TiO₂ nanoparticles in photocatalytic degradation of Rhodamine 6G dye. They reported that the maximum degradation efficiency of Rhodamine 6G was about 90% (Al-Mamun *et al.* 2019). Jaafarzadeh *et al.* reported ultrasound irradiation as an energy source for creating the positive holes and free radicals in the use of Fe₃O₄ nanoparticles. Fe₃O₄ nanoparticles were reported to catalyze H₂O₂ to produce hydroxyl radicals for decomposing organic pollutants (Jaafarzadeh *et al.* 2018). Ultrasonic power influenced the degradation rate of RO107 dye in the heterogeneous Fenton-like system. With increase of ultrasonic power from 100 to 300 W, RO107 removal efficiency improved from 6% to 100% (Jaafarzadeh *et al.* 2018). Nanoparticles have been used also in influencing biodegradation of dyes.

Fouda *et al.* synthesized maghemite nanoparticles (γ -Fe₂O₃-NPs) using *Penicillium expansum* (K-w), which was used in textile wastewater biotreatment. Nanoparticles showed decolorization and degradation of dyes with efficiency of 89–90% (Fouda *et al.* 2021). Nanofiltration membranes have a range of 1–5 nm pore sizes, in which almost all the solutes are efficiently rejected by the membrane (Bora & Dutta 2014). Magnetic iron oxide nanoparticles have been investigated for dye removal from synthetic and real textile wastewater through adsorption. The research reported fast adsorption of dyes with the adsorption equilibrium data fitting the Langmuir adsorption isotherm model (Nassar *et al.* 2015).

Polishing can be done by use of constructed wetland, as constructed wetland will provide aerobic and anaerobic regions with which bacteria will degrade the remaining dyes into simple compounds (Tara *et al.* 2019). A constructed wetland will also help in acting as a heavy metals sink; this is because heavy metals will be absorbed by plants within the system. Studies have shown that constructed wetland can degrade dyes in textile wastewater when the specific bacteria for dye degradation are present (Masi *et al.* 2019; Tara *et al.* 2019). Thus, a tertiary phase of a constructed wetland is necessary to further improve the quality of the effluent from both ETP. However, textile wet processing is chemical intensive and therefore unfriendly to the environment. Co-digestion of textile wastewater and domestic waste can be applied to dilute toxic concentration, improve the pH, and seed and increase carbon and nitrogen sources for microorganisms to degrade dyes. This will increase efficiency of treatment and wastewater effluent quality.

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COMPLIANCE WITH ETHICAL STANDARDS CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

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

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