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Improving biological treatment of textile wastewater

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ABSTRACT

Textile industries are among the primary contributors of water pollution. Treatment of textile wastewater is very important before discharging it to the environment. In the present study, laboratory-scale anaerobic batch reactors were used for co-treatment of a mixture of textile and domestic wastewater at 37 °C. The objective of this work was to investigate optimum conditions for the anaerobic co-digestion of textile wastewater and domestic wastewater. Domestic wastewater as a carbon source to enhance treatment of textile wastewater in color and other pollutants removal was examined. Textile and domestic wastewater were mixed at different proportions to make a total volume of 500 mL. Proportions of domestic wastewater and retention time were two main factors studied in influencing pollutant removal efficiency. Optimum conditions for removal of pollutants were 18 days' residence time at 60 and 40% textile and domestic wastewater respectively. The removal efficiencies were 52.8, 58.3 and 51.6% for Color, BOD and COD, respectively. Phosphorus (PO_4^{3-}), Ammonium (NH_3-N) and Nitrate (NO_3-) increased at 78.5, 49 and 87% respectively. However, the concentration levels were above Tanzania Bureau of Standards (TBS) discharge limits. Post treatment is suggested to achieve standard discharge limits.

Key words: anaerobic treatment, biological oxygen demand (BOD_5), chemical oxygen demand (COD), domestic wastewater, dyes, textile wastewater

HIGHLIGHTS

- Degradation of dyes in textile wastewater.
- Co-digestion of textile and domestic wastewater.
- Degradation of organic matter in textile wastewater.
- Reduce water pollution from textile wastewater effluents.
- Ecological protection of water bodies.

INTRODUCTION

Increasing industrial activities and urbanization lead to the increasing discharge of organic and inorganic contaminants to the environment. Textile industry is the primary contributor of water pollution among industries (Punzi 2015). Textile wastewater consist of colors, pigments, surfactants, grease, oil, metals, sulfate, chloride, and starch; all of these have impact on water quality. Dyes in water impede the passage of light and eventually reduce photosynthetic activities and oxygen level in water (Bafana *et al.* 2009). Heavy metals, particularly Lead (Pb), Chromium (Cr), Cadmium (Cd) and Copper (Cu) are widely used for the production of color pigments of textile dyes. High concentrations of heavy metals affect microbial activity in the system and impede the biological wastewater process (Kumar & Mudhoo 2013). However, a recent study reported that the concentration of heavy metals in textile wastewater from textile companies in Tanzania are below the recommended limit by Tanzania Bureau of standards (Bidu *et al.* 2021). Additionally, one of the impacts of textile effluents is that they have carcinogenic and mutagenic effects that are toxic to all forms of life. Textile industries consume huge quantities of water and yield huge amount of wastewater from different stages of production processes. For example, it is estimated that about 0.08–0.15 m^3 of water is used to produce 1 kg of fabrics (Ghaly *et al.* 2014). Therefore, wastewater from textile industries is a global problem and they need appropriate treatment before discharging to the environment. There are several technologies available for the treatment of wastewater from textile industries. The selection of a suitable type of technology depends on various factors such as production process, chemical used, constituents of effluent, discharge standards, location, capital, operating costs, availability of land area, options of reusing/recycling the treated wastewater, skills and expertise available (Jegatheesan *et al.* 2016). During the past two decades, different treatment technologies have been studied to evaluate the sustainable treatment of textile wastewater. The studies showed that there are various wastewater treatment technologies but most of them are expensive, not environmentally friendly, require large space and produce much biological sludge (Wei *et al.* 2020). One of the alternative approaches for the treatment of textile wastewater is by means of anaerobic treatment. Anaerobic treatment uses less energy, produces less biological sludge and require no aeration as compared to aerobic treatment. In addition to that, anaerobic biological treatments are considered as cheap and environmentally friendly (Tapsoba *et al.* 2020). Among the best anaerobic treatment of textile wastewater is co-digestion of textile and domestic wastewater. The term co-digestion means the anaerobic digestion of two effluents, whereby a readily biodegradable stream is mixed with a more recalcitrant one in order to enhance the digestibility of the latter. Co-digestion of textile and domestic wastewater is used to reduce toxicity, increase dilution during treatment and provide a carbon source to enhance dye degradation (Tapsoba *et al.* 2020). Bacterial methods can be useful in degrading dyes, including azo dyes. The use of microorganisms for biodegradation is suitable because it is multipurpose, has active metabolisms, and has potential machinery of enzymes. The use of microbes not only ensures a non-toxic process but also has the ability to decolorize very complex synthetic dyes (Ferraz *et al.* 2014).

The method is an efficient way of degrading textile dyes and most preferred due to its effectiveness in improving the quality of wastewater (i.e. BOD, COD, pH, and suspended solids) (Ferraz *et al.* 2014). Domestic wastewater is used as a carbon source, which normally improves de-nitrification and microbial mediated processes causing degradation of wastewater pollutants (Ferraz *et al.* 2014). The composition and amount of dissolved organic carbon entering anaerobic treatment system may significantly affect the level of enzyme activity.

As was noted, textile wastewaters are often rich in color and chemicals and therefore need suitable handling before being released to the environment (Khatri *et al.* 2015). Even though co-digestion is considered as among the best methods for treating textile wastewater, due to the contents of pollutants such as toxic compounds in which some have low biodegradability, treatment of textile wastewater is still very challenging (Punzi 2015). Toxicity of textile wastewater to essential micro-organisms is another challenge in anaerobic treatment. Mercury, Antimony, Lead, and Arsenic are some metals present in textile wastewater that are very toxic and limit micro-organisms activities (Kumar & Mudhoo 2013).

Several researchers investigated the optimum condition by using various techniques for improving anaerobic treatment of textile wastewater. For example, Gnanapragasama *et al.* (2011) used tapioca sago wastewater rich in starch to treat textile wastewater. It was found that 30/70 was the optimum ratio of textile and starch wastewaters to reduce color and COD by 87.3 and 81%, respectively. Another method was the use of an anaerobic biofilm reactor with 3 days retention time; the optimum condition was able to reduce COD by 70% (Punzi 2015).

C/N ratio of the substrates is a crucial factor in the decolorization process because an appropriate nutrient balance is required by anaerobic microorganism for their growth as well as for maintaining a stable environment. Generally, a C/N ratio of 20–30 is considered optimal for bacterial growth in an anaerobic digestion system (Kumar *et al.* 2020).

C/N ratio, pretreatment, retention time and pH variation are some of the factors regulating efficiency of co-digestion. Therefore, this study was conducted with an objective of investigating optimum conditions for the treatment of textile wastewater through anaerobic co-digestion in which textile and domestic wastewaters inoculated with cow dung. Cow dung has several groups of microorganisms such as *Acinetobacter, Pseudomonas, Serratia, Bacillus* and *Alcaligenes* spp., which makes it fit for microbial degradation of pollutant (Gupta *et al.* 2016). The study used domestic wastewater at different ratios as the source of nutrients to improve micro-organism activities. Even though this study was conducted at laboratory scale, the identified optimum condition can easily be applied at industrial scale since domestic wastewater can be cheaply obtained and used.

MATERIAL AND METHODS

The experimental setup was done in a tropical region at the Nelson Mandela African Institution of Science and Technology (NM-AIST)'s laboratory located at −3.400905 latitude and 36.795659 longitude, Arusha-Tanzania.

Textile wastewater was collected from the equalization tank of the A-to-Z textile mill located at −3.38442 latitude and 36.59465 longitude. Domestic wastewater was collected from the Nelson Mandela African Institution of Science and Technology (NM-AIST). Physiochemical parameters were determined in-situ for both textile and domestic wastewaters.

A laboratory-scale reactor (Figure 1) was set up as follows: Four bottles containing domestic and textile wastewater at different ratios of 4:1, 3:2, 2:3 and 1:4 together with two bottles of pure textile and domestic wastewaters, which were used as control experiments (Table 1). It should be noted that 100 and 0% textile wastewater represent pure textile and pure domestic wastewater, respectively. A total of six bottles were sealed and incubated in a water bath, which was maintained at a constant temperature of 37 °C. This is the temperature at which microbial enzymes are most active, when enzymes are active the rate of biological reaction increases (Hance 2020). The reactor was constructed using an Erlenmeyer flask bottle (0.5 L) connected to a measuring cylinder (1 L). A plastic pipe was used to connect the reactor to the gas collector and parafilm was used to seal the Erlenmeyer flask's outlet to prevent gas leakage. The water displacement method was used to collect the biogas produced. According to Sharma (2017) for better inoculation, 1 g of cow dung needs to be added in 50 mL of wastewater.

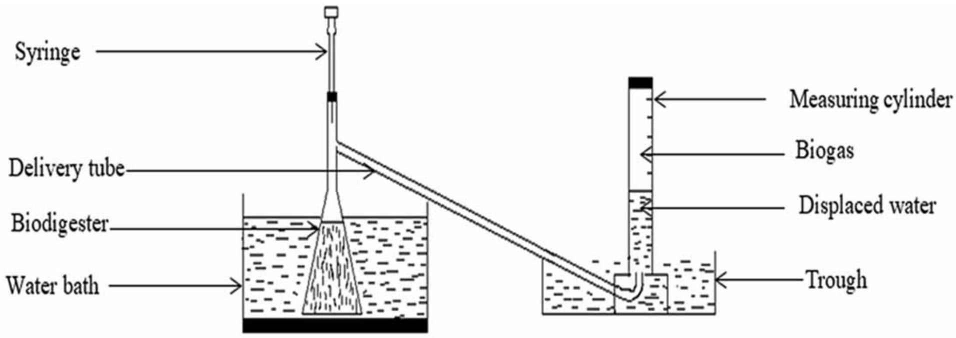

Figure 1 | A sketch of the laboratory set up for the anaerobic digestion (Hance 2020).

Table 1 | Amount of textile and domestic wastewaters mixed at different proportions

Fraction of textile wastewater (%)	Textile wastewater (mL)	Domestic wastewater (mL)	Cow dung (g)
100	500	0	10
80	400	100	10
60	300	200	10
40	200	300	10
20	100	400	10
0	0	500	10

The present study used 10 g of cow dung in 500 mL of wastewater, the initial parameters were determined after introducing a cow dung. Cow dung was used to introduce microorganisms in the mixture. Anaerobic treatment was conducted in batches for 3, 6, 12 and 18 days. According to Passos *et al.* (2015), the average time that the impact of anaerobic digestion can be observed or noticed is 15–20 days. The pH of the wastewater during system operation was adjusted to be 7.0. It is reported that pH in the range of 6.5–7.5 is effective and favorable for microbial growth rate involved in anaerobic digestion. Physiochemical parameters were measured before and after mixing the two wastewaters and are displayed in Table 2. Thereafter, physiochemical parameters were measured after treatment of 3, 6, 12, and 18 days and the results were compared with the initial readings.

Analytical procedures

Wastewater samples were collected as per standard method for water and wastewater sampling procedures (APHA 2012). The samples were stored tightly in 20-liter plastic cans of high-density polyethylene for further

Table 2 | Initial characteristics of wastewater

	Textile wastewater (%)						
	0	20	40	60	80	100	TBS (TZS 860:2019)
P_20_5 (mg/l)	19.6	18.9	13.7	9.7	8.6	3	
P (mg/l)	8.6	8.2	5.8	4.2	3.8	1.3	5
PO_4^{3-} (mg/l)	26.3	25.2	17.8	13	11.5	4	
Color (Ptco)	199	710	1,240	1,840	2,410	2,800	300
NO_3^- (mg/l)	16	32	46.8	55.6	63.2	72.4	45
NO_3-N (mg/l)	3.7	7.2	10.4	12.5	14.5	16.6	
NH_3-N (mg/l)	44.5	36.5	28.25	25.5	22.2.5	16.5	
NH_3 (mg/l)	57.25	48.25	42	27.25	25.5	23.75	
NH_4^+N(mg/l)	4.7	4.5	4.3	4.1	3.9	3.5	5
NH_4^+ (mg/l)	62	52.5	47.75	33.5	30.5	27.5	
TSS (mg/l)	120	190	270	307	390	450	100
COD (mg/l)	993	1,203	1,281	1,357	1,597	1,415	60
BOD (mg/l)	500	500	550	600	650	500	30
Turbidity (NTU)	32.66	104	118	160	200	243	300
DO (mg/L)	2.98	2.9	2.84	2.6	2.2	1.9	
Conductivity (mS/cm)	994	2,032	4,975	7,018	8,476	10,180	
TDS (mg/L)	476	1,028	2,494	3,511	4,246	5,276	
pH	8.1	8.4	8.7	9.2	9.6	10.4	6.5–8.5

analysis. Parameters measured in-situ by Multiparameter (HI 9,829) were temperature, electrical conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO) and pH.

Parameters analyzed in the laboratory by Hach spectrophotometer DR2800 according to standard methods described in APHA (2012) were: Chemical Oxygen Demand (COD), nutrients (Nitrate (NO_3–N), Ammonia (NH_3–N), Phosphate (PO_4–P), color and Suspended Solids (SS). Oxitop pressure was used for determination of Biological Oxygen Demand (BOD) while turbidity was measured by using a turbidity meter.

To determine color, samples were centrifuged (4,000 r/min) for 15 min then measured. Measurement of each parameter was done before mixing, after mixing and after anaerobic reaction of 3, 6, 12, and 18 days. To ensure quality of data measured, the equipments were calibrated before use. Measurements were also done twice for quality control of the values obtained in each measurment.

Data analysis

Origin Pro version 9.0 (Origin lab 2012) and Microsoft Excel were used for data analysis. The removal efficiency in each parameter were obtained through Equation (1) except for the Nitrate, Nitrate – Ammonium and Ammonium, which were calculated by Equation (2). C/N ratio was determined by Equation (3);

$$\text{Percent removal} = \frac{\text{Initial reading} - \text{Final reading}}{\text{Initial reading}} \times 100\% \tag{1}$$

Percent increase was determined by this formula;

$$\text{Percent increase} = \frac{\text{Final reading} - \text{Initial reading}}{\text{Initial reading}} \times 100\% \tag{2}$$

$$\frac{C}{N}\text{ratio} = \frac{\text{Carbon content}}{\text{Nitrogen content}} \tag{3}$$

RESULTS AND DISCUSSION

Characteristics of wastewaters before treatment

Characteristics of wastewater after mixing textile and domestic wastewaters at different proportions are displayed in Table 2. Pure textile wastewater had higher concentrations of almost all measured parameters compared to that of domestic wastewater. High nutrients, TDS, TSS in pure textile wastewater possibly contributed to decrease amount of dissolved Oxygen. Concentration of dissolved Oxygen was lower in textile wastewater (1.9 mg/L) than domestic wastewater (2.98 mg/L). Color was higher in pure textile wastewater and the amount decreased with the increasing amount of domestic wastewater. For example, color was 2,800 Ptco in pure textile wastewater but an additional of 80% domestic wastewater color decreased to 710 Ptco. Both textile and domestic wastewaters had basic pH, but textile wastewater was more basic than domestic wastewater. Generally, in this co-digestion treatment, domestic wastewater diluted textile wastewater, see Table 2.

Level of almost all pollutants in the mixture before treatment were above all available Tanzania Bureau of Standards (TBS) recommended levels for discharging wastewater except nitrate and turbidity (Table 2).

Characteristics of wastewater after treatment

Color removal

Figure 2 shows that color removal varied when the experiment was set for different retention times and at different ratios of textile wastewater. As can be seen, some of the values obtained were positive indicating color removal while others were negative indicating color increase. In general, color changed based on duration of the treatment and the composition of the mixture. There was increase in color for samples with 0% to 20% textile wastewater over all the days of anaerobic treatment. This might be caused by the addition of inoculum to the system, which contains a number of natural dissolved organic matters. These organic carbons include humic acid, fulvic acids and natural tannins (Yap *et al.* 2018). The 0–20% color increase was significantly affected by natural dissolved organic Carbon, as the number of days increased it continues to decay and the natural tannins tend to increase color to the domestic wastewater. For the case of 40–100% the effect was not seen due to strong color in textile wastewater. However, color reduction was observed for samples with 40–100% of textile wastewater. This is because at these proportions the contribution of the color of textile wastewater was high, bearing in mind that textile wastewater was rich in color (Table 2). Therefore, the effect of color due to natural colorants from cow dung became negligible. In this case, availability of domestic wastewater played a part in reducing toxicity and provided a carbon source to enhance dye degradation (Ferraz *et al.* 2014).

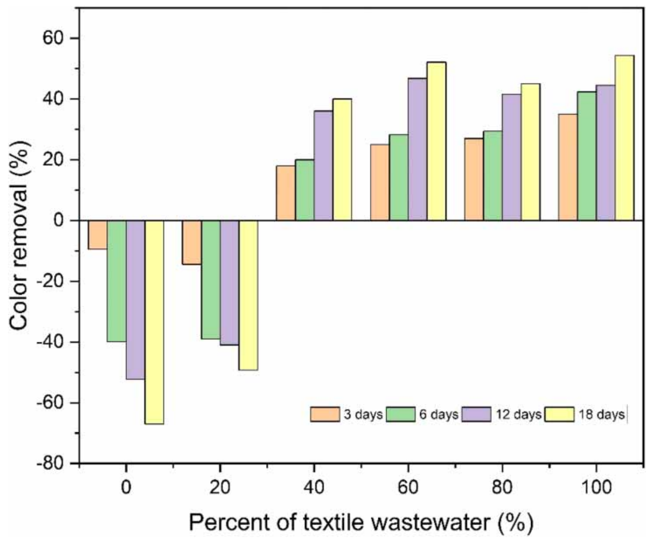

Figure 2 | Color removal with proportion of textile wastewater.

For all textile water proportions above 20%, the removal efficiency increased significantly with textile wastewater proportion to 60%, above which the increase became insignificant for all retention times tested. There was insignificant difference between graphs of retention time of 12 and 18 days especially for the textile

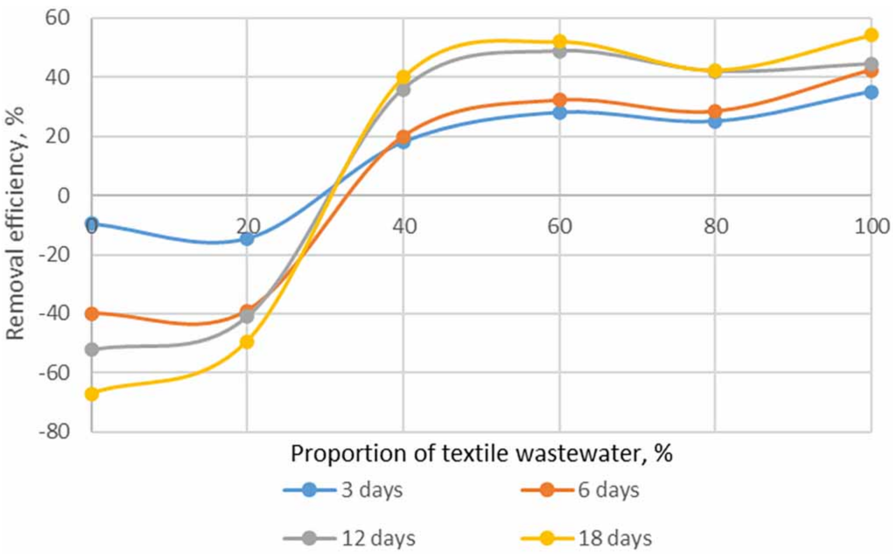

Figure 3 | Line graph for color removal with proportion of textile wastewater.

wastewater proportion of 60% (Figure 3). At 60, 80 and 100% of textile wastewater for 18- and 12-days color removal was fairly ranging from 42 to 54%. The optimum removal occurred after 18 days of anaerobic treatment with a mixture consisting of 60% textile wastewater and 40% domestic wastewater in which removal efficiency was 52.8%. This improvement was due to the addition of an external Carbon source, which helps to establish a reducing environment and possibly increased the concentration of enzyme co-factors, such as F430 and Vitamin B12 in the reactor that could also potentially reduce azo bonds and hence resulted in better color removal (Razo-flores *et al.* 1997). Color removal increased with an increasing HRT in anaerobic process (Figure 2). Another factor influencing anaerobic reaction was the amount of domestic wastewater for example at 80% of textile wastewater, removal efficiency was 42.5 and 45% for 12 and 18 days, respectively. In this case, color removal from an additional 20% domestic wastewater was lower than an additional 40% domestic wastewater. Domestic wastewater not only helped for dilution and dye degradation but also acted as an electron donor for azo bond reductive cleavage (Ferraz *et al.* 2014). At optimum condition (60% textile wastewater in 18 days) the amount of color decreased from 1,840 to 868 Ptco but still the final amount of color was higher than the recommended level for discharging wastewater (Table 2). Post treatment such as constructed wetlands can be used to remove color to the recommended level for discharging wastewater.

Chemical oxygen demand (COD) and biological oxygen demand (BOD_5) removal

The efficiency of anaerobic digestion can also be evaluated by using COD and BOD removal, which reflects the amount of degradation taking place (Van Lier 2008). Figure 4(a) shows that COD removal varied when the experiment was set for different number of days and at different ratios of textile wastewater. There was high removal of COD in pure domestic wastewater (0%) for 18 and 12 days, which was 82.6 and 60%, respectively (Figure 4(a)) This removal was due to high microbial degradation of organic matter found in domestic wastewater. Since the aim of this experiment was the treatment of textile wastewater, even though removal of COD was maximum the conditions were not considered as optimum because no textile wastewater was included. Furthermore, COD removal decreased with the increasing textile wastewater. Maximum COD removal efficiency of 51.6% occurred after 18 days of treatment at 60% textile wastewater. Therefore, the results suggest that optimum condition for COD and color removal occurred at 60% textile wastewater (Figures 2 and 4). Generally, time has a significant effect on COD removal efficiency: as the number of days increases in the anaerobic system, the more COD will be removed in the system. This was because as the time increased, more micro-organisms were produced and more organic matter was consumed, which decreased COD.

BOD removal decreased with increasing textile wastewater. The optimum condition for BOD removal that coincides with COD and color removal was at 60% textile wastewater after 18 days of treatment (Figures 2 and 4). As was observed in COD removal, time also has a significant effect on BOD removal: as the number of days increased in the anaerobic system the more BOD was removed (Figure 4(b)). High BOD in the untreated

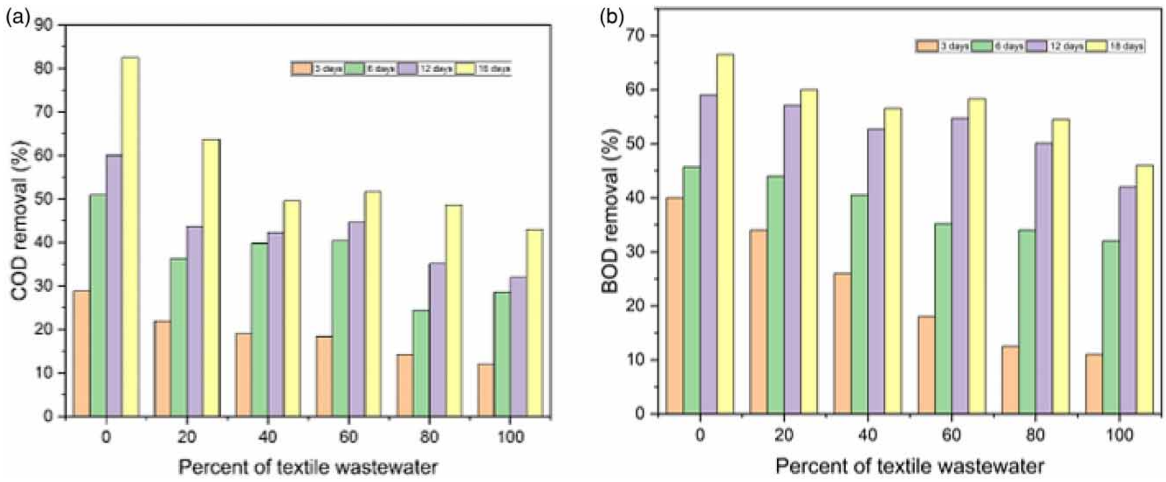

Figure 4 | COD and BOD removal with textile wastewater.

textile wastewater can cause rapid depletion of dissolved Oxygen if it is directly discharged into the surface water sources. Thus, as the residence time increased, more BOD removal was observed but the removal was low when the ratio of textile wastewater was 80 and 100%. This is because textile effluents are highly toxic, containing heavy metals, and most of them are non-degradable (Aslam *et al.* 2010).

After treatment in optimum conditions, COD and BOD decreased from 1,357 mg/L to 706 mg/L and 600 mg/L to 350 mg/L, respectively. The levels of COD and BOD after treatment were above the recommended TBS level for effluent discharge, which is 60 mg/L for COD and 30 mg/L for BOD_5 (Table 2). In order to meet the TBS discharge standards, this study recommends post treatment such as an aerobic process by means of constructed wetlands.

There was production of biogas during anaerobic digestion when microorganisms break down (eat) organic materials in the absence of air (Tapsoba *et al.* 2020). Methane yield was efficient, and its production increased exponentially during the first 12 days of the experiments. Biogas is mostly methane (CH_4) and carbon dioxide (CO_2), with very small amounts of water vapor and other gases (Tapsoba *et al.* 2020).

CN ratio

There was a gradual decrease in the COD and BOD_5 removal with a decrease in C/N ratio and retention time whereas the opposite was the case for color removal (Figure 5). The results concur with Kumar *et al.* (2020), who suggested that the low C/N ratio (<20) imbalances the anaerobic digestion and the releases of excess Ammonia in the digester and also inhibits the growth of methanogens. Maximum removal for both COD and BOD occurred after 18 days of anaerobic treatment with a C/N ratio of 11.92, in which removal efficiency was 82.6 and 66.5% respectively (Figure 5(a) and 5(b)). This removal was due to a high amount of Carbon, low Nitrogen content and high microbial degradation of organic matter found in domestic wastewater. The functions of Carbon in microbial processes are as substrates for microbial enzyme synthesis and enzyme action.

At C/N ratios of 9.52, 9.12 and 8.46, color removal was 52.8%, 46.5% and 54.3% respectively for 18 days and 48.8%, 42% and 40.5% respectively for 12 days. Color removal increased with increasing retention time. Minimum color removal occurred at CN ratio of 11.92 in which the removal efficiency was −67% (this means the color of domestic wastewater has increased by 67 percent). Color increase was significantly affected by natural dissolved organic matter, as the number of days increased it continues to decay and the natural tannins tend to increase color in the domestic wastewater (Yap *et al.* 2018).

From Figure 5(a)–5(c), both COD, BOD_5 and color optimum removal occurred after 18 days of anaerobic treatment with a C/N ratio of 9.52. These results indicated that decolorization of textile wastewater and the biological toxicity of textile wastewater significantly decreased after mixing with domestic wastewater due to availability of easily biodegradable Carbon

Therefore, the anaerobic co-digestion of textile wastewater and domestic wastewater at certain ratios producing appropriate C/N ratio is possible for increasing the efficiency of color removal, also causing a remarkable BOD_5 and COD removal.

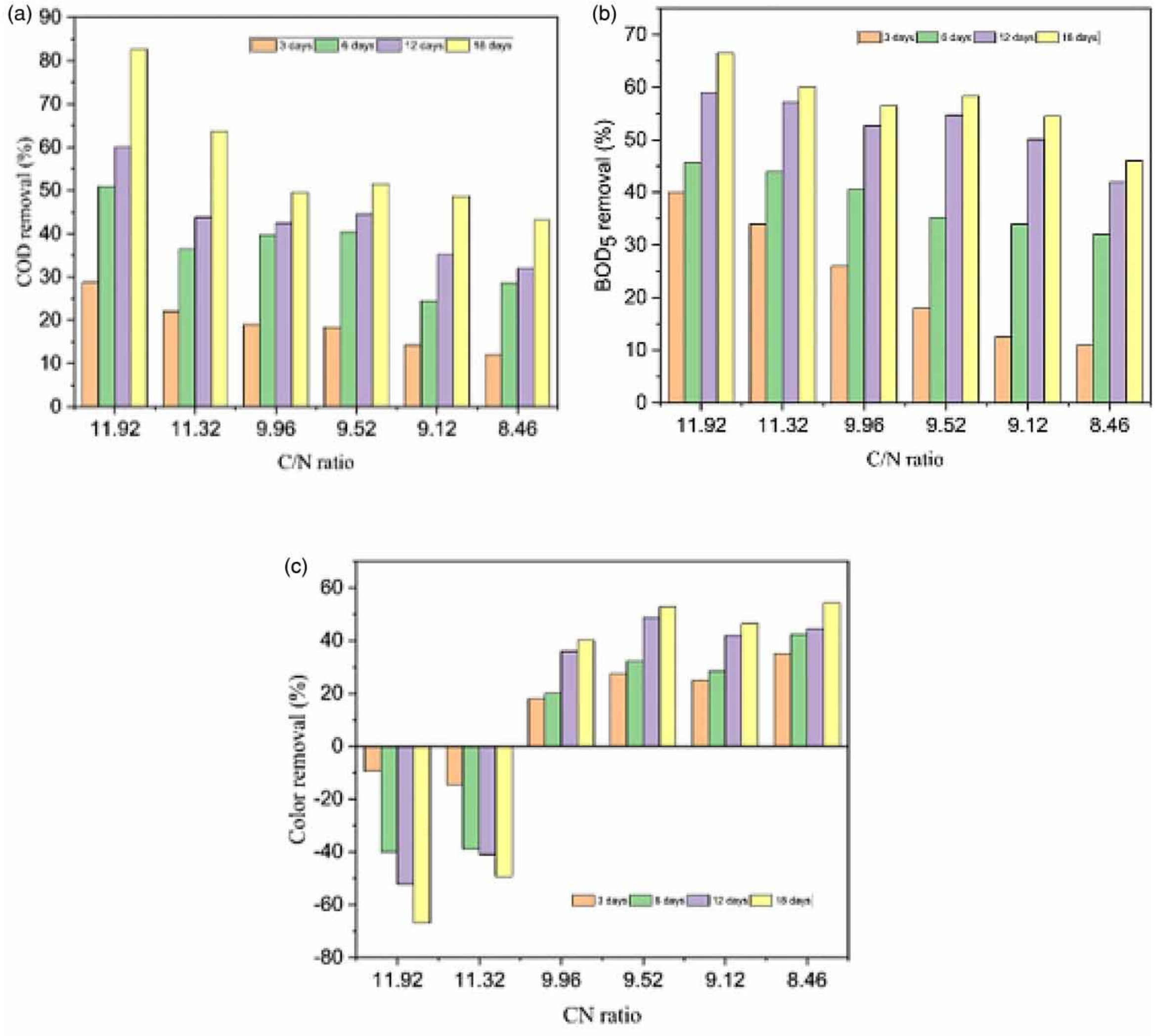

Figure 5 | (a) COD, (b) BOD_5 and (c) color removal with change in C/N ratios.

Variation of pH

The pH of the reaction mixture initially was 7.0 when the experiment was set for 18, 12, 6, and 3 days of anaerobic reaction. The pH of the mixture increased from pure domestic wastewater to pure textile wastewater (Figure 6). The pH of textile effluent was generally high because of the use of many alkaline substances in textile processing (Khatmode & Thakare 2015). Anaerobic digestion of the organic substances produces Ammonia, the increase in Ammonia to the system will lead to the increase of pH, most anaerobic bacteria grow best around neutral pH (6.5–7.5) (Dai *et al.* 2017). The pH at optimum condition (60% of textile wastewater in 18 days of treatment) was 8.3, which was under the recommended TBS level for discharging wastewater (Table 2). Extreme value of pH has to be avoided in order to maintain good reactor performance in biological systems, thus pH adjustment necessary.

Removal of total dissolved solids (TDS) and conductivity

For 3 days of treatment, TDS and conductivity was observed to increase. When graphs deviate to the negative side it means that there was an increase in TDS and conductivity to the system and vice versa on positive side. However, the increase of TDS and conductivity decreased with increasing textile wastewater and increase in retention time (Figure 7). Therefore, the increase in TDS and conductivity in 3 days might be caused by the addition of inoculum to the system and low retention time, which limits the time for reaction (Peng *et al.* 2020). The increase in TDS and EC might also arise from mineralization; that is, the conversion of organic Carbon into smaller and simpler organic compounds. TDS and conductivity decreased with increased retention time, which is why in

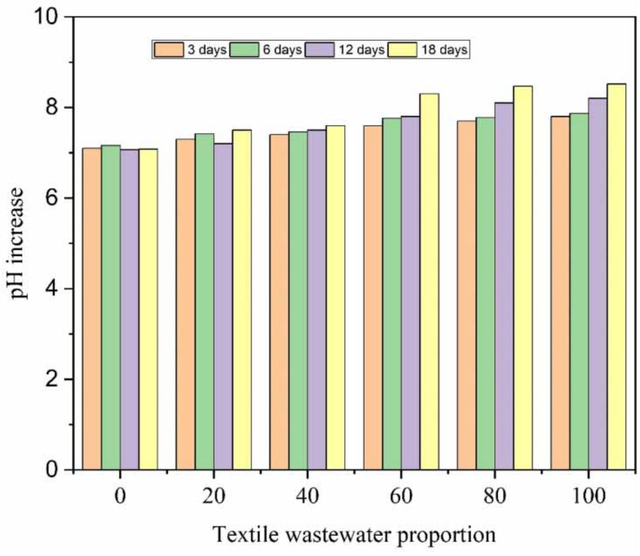

Figure 6 | pH increases with textile wastewater proportion.

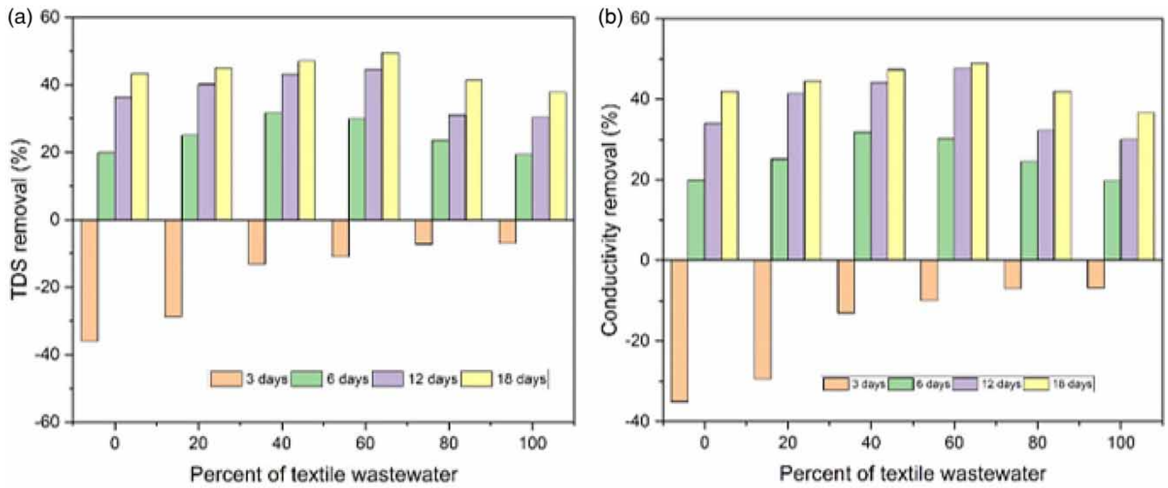

Figure 7 | variation of TDS (a) and conductivity (b) with time and proportions of textile wastewater.

3 days TDS and EC increased (Peng *et al.* 2020). Maximum increase of TDS and conductivity occurred in pure domestic wastewater whereas optimum removal occurred at 60% textile wastewater when the treatment was conducted for 18 days. Level of TDS at 60% textile wastewater before treatment was 3,511 mg/L whereas after 18 days of treatment level of TDS decreased to 1,305 mg/L. The concentration of TDS after treatment was still higher than 1,000 mg/L recommended WHO for discharging wastewater, therefore post treatment is highly recommended such as activated Carbon, reverse osmosis, that can further improve effluents to attain WHO standard for discharging wastewater.

Phosphorus

Phosphorus in all forms increased with increasing textile wastewater for 18, 12, 6 and 3 days (Figure 8). In general, Phosphorus increased with increasing domestic wastewater and increase in retention time. This is because Phosphorus enters the wastewater stream primarily in the form of excreted human metabolic products (urine, feces), food residues, and detergents (Egle *et al.* 2015).

The driving forces for the increase in Phosphorus might also be caused by the presence of Phosphorus Accumulating Organisms (PAOs). These organisms can keep excess amounts of Phosphorus as polyphosphates in their cells under aerobic conditions, and secondly they can accumulate organic material in the anaerobic stage

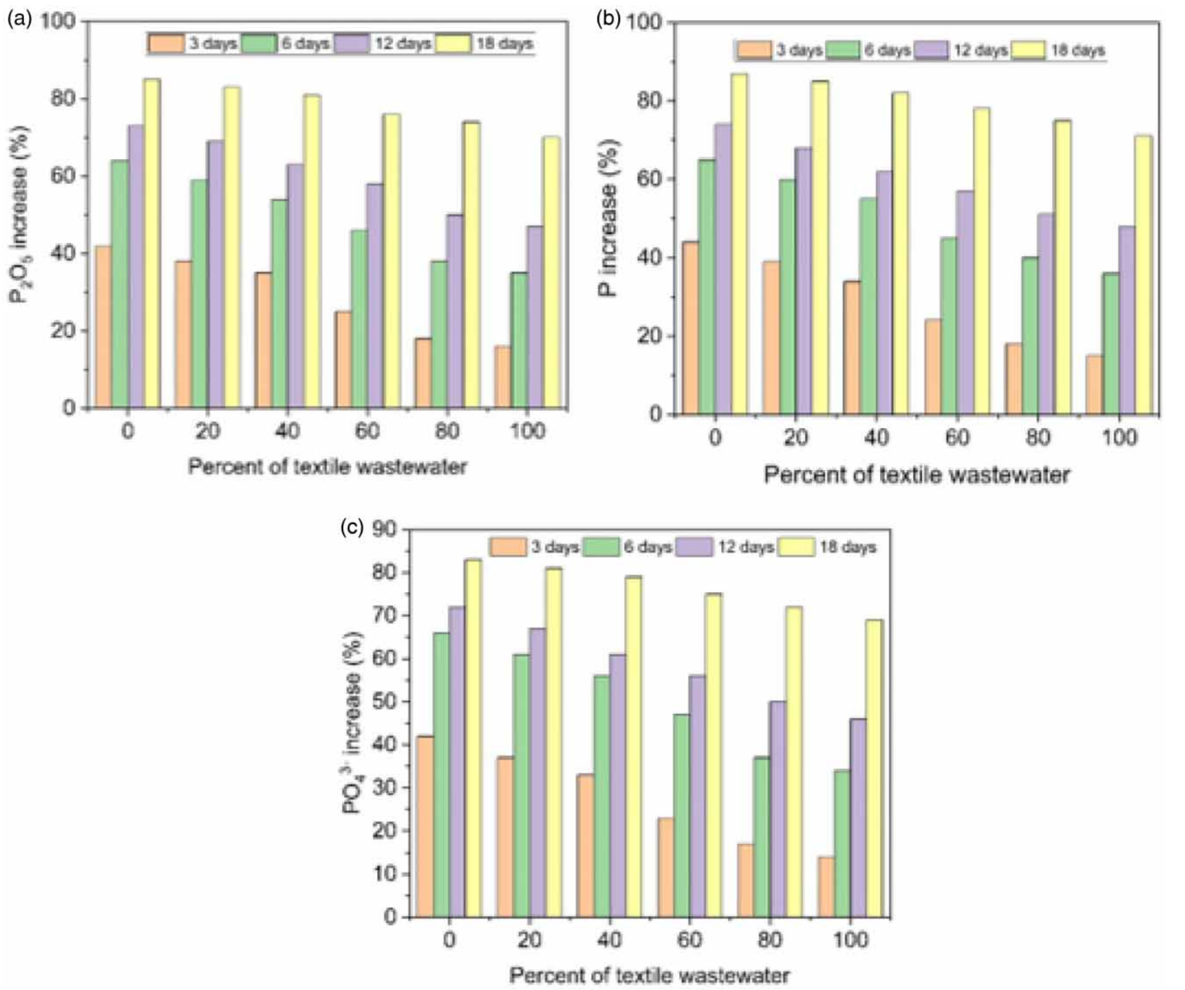

Figure 8 | Phosphorus P_20_5 (a), P (b) and PO_4^{3-} (c) change with textile wastewater.

(Nieminen 2010). When exposed to anaerobic conditions, PAOs start using their intracellular polyphosphates as an energy source to assimilate fermentation products from water. As retention time increases, the energy supply for the PAOs will become depleted leading to secondary release of phosphorus (Metcalf and Eddy 2003).

It should be noted that anaerobic treatment can be effective in the removal of organic compounds, such as COD, but it is unable to remove mineralized compounds such as PO_4^{3-} (Van Lier 2008). Concentration of PO_4^{3-} after treatment at 60% textile wastewater was 31.7 mg/L compared to 13 mg/L before treatment at 60% textile wastewater (Table 2).

After treatment, the level of Phosphorus was above the recommended TBS level for effluent discharge (6 mg/L). Post treatment is recommended, such as aerobic treatment (microbial biofilms of PAOs), which can further remove Phosphorus from wastewater to attain TBS standards.

Ammonium and nitrate

Both Nitrate-Nitrogen and Nitrate increased with increased textile wastewater and with increase in residence time (Figure 9(a) and 9(b)). Possibly there was a presence of iron in the textile wastewater, which might cause a feammox reaction. In a feammox reaction, ferric iron [Fe(III)] is reduced, coupled with anaerobic Ammonium oxidation. Fe(III) is reduced to Fe(II), accompanied with oxidation of NH_4^+ to N_2, NO_2^- and NO_3^- (Yang *et al.* 2018). This may lead to increase in nitrate, which might be further denitrified to form Nitrogen gas (N_2) (Yang *et al.* 2018).

It was observed that Ammonium in all forms increased with textile wastewater and with increased retention time (Figure 10(a)–10(c)). The increase is due to anaerobic degradation of organic matter in the anaerobic environment, which increases the release of Ammonium (Mahenge & Malabeja 2018). Also, Nitrate can be converted into Ammonium in a dissimilatory process called Nitrate ammonification. Domestic wastewater urea or

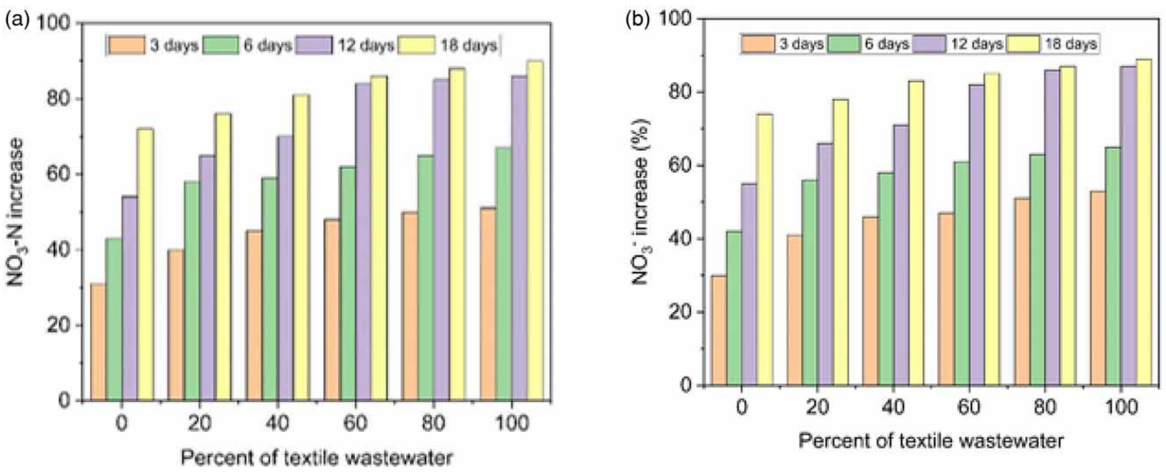

Figure 9 | Nitrate NO_3-N (a) and NO_3^- (b) increase with textile wastewater.

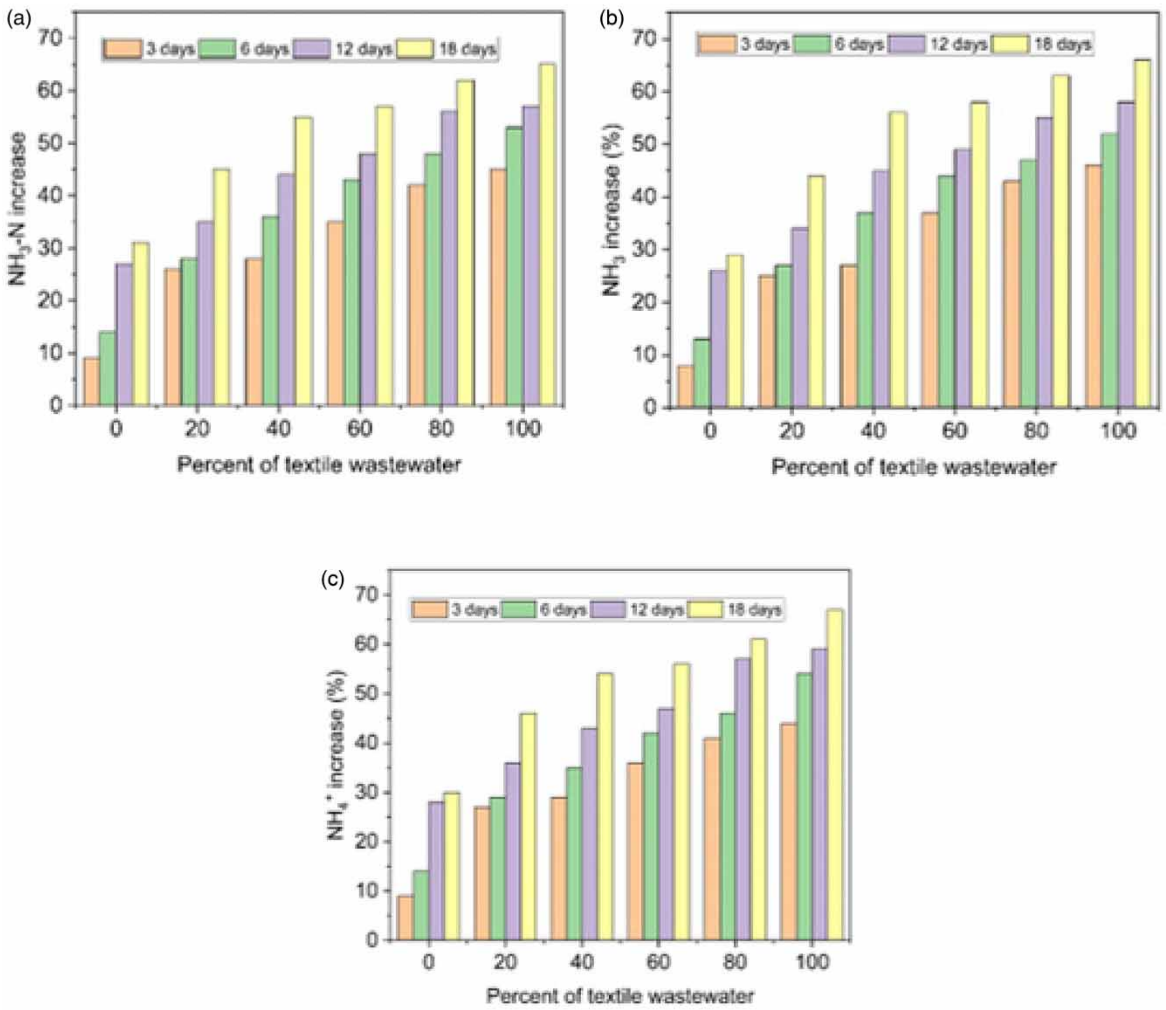

Figure 10 | Ammonia NH_3-N (a), NH_3 (b) and NH_4^+(c) increase with textile wastewater.

uric acid in their Nitrogen-containing urine, along with diverse organic Nitrogen compounds in their feces (Bidu *et al.* 2021). The urea, uric acid, and organic Nitrogen of feces are all substrates for ammonification. It was observed that there was increase in Ammonia with increase in textile wastewater, which might be due to the presence of urea as dying auxiliaries in the dying step (Bidu *et al.* 2021).

Various processes enable the removal of NH_4^+ in anoxic sediments, but in any potential interaction with Fe(III) the removal remains largely unknown (Clement *et al.* 2005). If there was presence of Iron in wastewater, it may lead to an increase in Ammonia when treated in anaerobic system. Fe (III) may accelerate the release of Ammonia from the decomposition of protein, which is the major organic component of wastewater sludge (Yang *et al.* 2018).

Biological Nitrogen removal involves two successive processes; that is, nitrification and denitrification. The nitrification transforms Ammonia to a more oxidized Nitrogen compound such as Nitrite or Nitrate, which is then converted to Nitrogen gas in the subsequent denitrification process (Ahmed *et al.* 2005). Without the availability of a ready source of biodegradable Carbon, denitrification will not occur, or will occur at a slow rate because of the absence of a readily biodegradable Carbon source that can be used as an effective substrate by denitrifying bacteria during the denitrification process (EPA 2013). The concentration of Nitrate (NO_3^-) at 60% textile and 40% domestic wastewater in 18 days increased from 55 mg/L before treatment to 108 mg/L after treatment. Concentration of Nitrate after treatment was above recommended TBS levels for effluents discharge (Table 2). Post treatment is recommended that can further improve effluents to attain TBS standards.

For the case of Ammonium, the trend was as follows (Figure 10).

CONCLUSION

This study investigated how domestic wastewater and cow dung can be used to improve treatment of textile wastewater. Domestic and textile wastewater were mixed at different proportions and co-digestion was allowed to take place over different days to identify the optimum condition for the treatment of textile wastewater. It was observed that a mixture of 60% textile and 40% domestic wastewater in 18 days gave optimum results for the treatment of Color, COD and BOD. Though the level of Color, COD, and BOD_5 after treatment were above recommended the TBS level for effluent discharge. Post treatment such as constructed wetland can be used to remove Color, COD and BOD_5 to the recommended level for discharging wastewater. The importance of domestic wastewater was as a co-substrate in removing Color, COD and BOD_5 by means of an anaerobic system, which seems to be of great importance due to its effectiveness in treatment of those mentioned pollutants. The outcomes evidently displayed that a small addition of domestic wastewater as a Carbon source and 10 g of cow dung as inoculate are the appropriate co-substrates for the bacterial dye decolorization process. Meanwhile, the levels of Phosphorus, Nitrate and Ammonium increased after treatment, suggesting that there was a need to come up with an integrated technology that can remove Phosphorus, Nitrate and Ammonium from the system. From this study it is concluded that the use of domestic wastewater in treating textile wastewater is a promising technology in removing color, COD and BOD_5 from textile wastewater.

DATA AVAILABILITY STATEMENT

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

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