Quantification of Physiochemical Characteristic Wastewater Effluents: A Case Study of Bata Tanneries, Kenya

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Abstract

The tanning industry is well developed in Kenya and has been identified as one of the most important sectors in economic development. However, depending on the leather process, it generates large quantities of wastewater with ammonium, sulphates, surfactants, acids, dyes, sulphonated oils and organic substances, heavy metals Cr, Pb and natural or synthetic tannins. Bata leather industries in Kenya have been discharging effluent to nearby rivers leading to human and environmental pollution. The current study sought to carry out quantification of physicochemical characteristics of tannery wastewater effluents involving Bata Tanneries. Water samples from four sampling points (S1 – Pre-tanning Stage, S2 – Tanning Stage, S3 – Post-tanning Stage and S4 – Drainage to the river) were collected using a clean grab sampler. The samples were transported in cool box to the chemistry laboratory of the Kenya Tea research foundation, Kericho for analysis. Physiochemical parameters were determined from the collected samples and results were compared with NEMA, KEBS and WHO set standards. The mean range levels obtained from (S_1-S_4) were total dissolved solids (TDS) 137.7 and 270 mg/L, DO 8.4 and 10.6 mg/L, pH concentrations ranged between 1.52 and 8.2. EC 1348.8 and 1385 mS/cm at S3, temperature 22.7 and 27.9 ^{o}, biological oxygen demand (BOD) 3141.2 and 5477.7 mg/L, total suspended solids (TSS) 148 mg/L to 284 mg/L, total solids (TS) 286 and 554 mg/L. Chemical oxygen demand (COD) 5986.7 to 9093.2 mg/L, colour (Pt-Co) 488.5 and 787.2 Pt-Co. All values of physicochemical parameters exceeded KEBS, NEMA and WHO standards except for temperature which was within the range. The Ministry of Environment should therefore, enforce the law concerning water pollution and prosecute those who are found culpable. Polluter pay principle should be applied to the company.

Keywords : Industralization, development policy, chronium salts, toxic, dyes, treatment, raw materials

INTRODUCTION

The tannery industry in East Africa is a significant contributor to the economy and provides significant employment opportunities for members of society who are poor (Cassano *et al.,* 2001). Since independence on 12 December 1963, Kenya has pursued an 'industrialization first' development policy as the key to economic growth (Mwinyihija *et al.,* 2006). Kenya's tanning business is one of the largest in East and Central Africa (Muchie, 2001). The main tanneries get raw materials from several infrastructure entities. These facilities in Kenya have led to the processing of hides and skins from neighbouring countries, with tanning enterprises expanding to meet demand (Onyango *et al.,* 2019).

Industrial waste is typically generated because of various industrial processes. As a result, the amount and toxicity of waste generated by industrial processes varies (Alvarez-Bernal *et al.,* 2006). The tanning process requires a lot of water and generates 90% effluent. Tannery effluents comprise chrome salts, sodium chloride and sulphate, organic and inorganic pollutants, toxic metallic compounds, physiologically oxidizable tanning materials, and putrefying floating detritus, ammonium, surfactants, acids and dyes (Chowdhury *et al.*, 2015; Nyabaro *et al.*, 2013). These chemical substances are used to convert animal skin into dye-resistant products and to increase their mechanical and hydrothermal resistance. Because most of these organic compounds are believed to be resistant to conventional chemical and biological treatments, wastes dumped into natural waters contribute to environmental pollution and associated health risks (Srivastava *et al.*, 2018).

The treatment of this type of solid waste and wastewater is extremely complicated, owing to the large number of chemical products added in varying concentrations (Kurt *et al.*, 2007). The discharge of untreated or inadequately treated tannery effluents into the river can cause environmental and human harm. High levels of pollutants in river water causes an increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), toxic metals such as Cd, Cr, Ni and Pb and fecal coliform and hence make such water unsuitable for drinking, irrigation and aquatic life (Chowdhury *et al.*, 2015).

Therefore, determination of River Ndurumo water pollution loads caused by Bata tannery is a prerequisite for rational decision-making and management of the river Ndurumo and its public utility. Specifically, the research also sought to determine level of pollution loads in effluents from Bata Company, based on pH, temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), colour and compare actual wastewater pollution loads with the expected national and international standards.

METHODOLOGY

Study Area

Limuru is a settlement located at 1°16'S latitude and 36°48'E longitude on the eastern rim of the Great Rift Valley, approximately 30 miles north of Nairobi, Kenya's capital city. Limuru locals are primarily employed in agriculture and a shoe industry. Limuru is a settlement in Kenya's central region. Additionally, it is the name of a legislative constituency and a division of government. The town's population was approximately 4,800 in 2004 but had climbed to 159,314 in a 2019 census (KNBS, 2019). Limuru's year-round temperature ranges between 10 and 28 degrees Celsius. Limuru's industry is well-known in Kenya for the quantity of tea it produces. Bata Shoe Company is headquartered in Limuru. It is East and Central Africa's largest. Limuru is served by the Uganda Railway.

Study Design

The effluent samples were collected from four strategic sites in the tannery and the surrounding area. Discrete grab sampling method was used. Spot samples were collected using a sterilized grab sampler once per week for one month. Normal collection was done during operations.

The pre-tanning stage was the first sample point; that is, the effluents released following all soaking, liming, and de-liming operations. S1 is a 500-mL sample taken from this point. The second sample location was at the tanning processes, namely at the effluents following chrome and vegetable tanning. A 500-mL sample was taken from this location and labelled S2. The third sampling location was just prior to the water being discharged to the river (at the point of entry into the treatment plant) during the post-tanning/finishing stage (influent). S3 was a 500 mL sample taken from this point. The final sample location is the Ndurumo River, where wastewater is pumped (at the treatment plant's departure, when it is ready to be discharged into the environment following primary treatment) (effluent). S4 was a 500 mL sample taken from this moment. To avoid chromium ion absorption on glass bottles, 500 mL Teflon bottles were utilized for sampling.

Sample preservation

After collection, the samples were kept in cool box to inhibit any biological activity of samples. They were then preserved with concentrated nitric acid (1 mL/L) and kept in the cool box at 4^{o}C for further preservation before analysiswas done. After which they were kept in 500 mL air tight Teflon containers. Finally, they were transported to the laboratory.

Physicochemical Analysis

The physicochemical parameters included pH, temperature, BOD_5, COD, TDS, conductivity, TSS, Colour. These parameters were selected because they are considered to be deleterious on the receiving environment and they were included in the discharge limit. Temperature, pH, conductivity and TDS were measured in situ using combined pH/T$^{\circ}$/TDS and conductivity meter. In the laboratory, BOD_5 and COD were measured according to standard methods (APHA, 1998).

Data Analysis

The obtained data were was analysed using the Statistical Package for Social Science (SPSS) version 17. The data and results given in graphs and tables were summarized using descriptive statistics (frequency, mean, and standard deviation). To determine the significance of a difference between two or more groups, one way analysis of variance and the T-test were utilized.

RESULTS

The mean levels of physicochemical parameters in the samples of tannery effluent from Bata tannery at different sites

The mean values of the physicochemical parameters in the samples of wastewater Bata leather tanneries in Kenya at different sites are shown in Table 1.

Table 4: Results showing mean values of Physicochemical Parameters of Treated and Untreated Tannery Effluents Samples in comparison with NEMA, KEBS and WHO standards

Physicochemical parameters	N	Mean	Std. Error	Std. Deviation	NEMA standards	KEBS standards	WHO standards
DO (mg/l)	24	9.17	0.275	1.347	7.0	7.0	7.0
pH	24	5.03	.530	2.597	6.0-8.0	6.5-8.5	6.5 – 9.5
EC (mS/cm)	24	1363.38	2.827	13.850	25	25	25
Temperature(^{0}C)	24	25.59	0.503	2.466	20-35	20-35	≤37°C
BOD_5(mg/l)	24	4721.34	130.473	639.184	50	30	6
TSS (mg/l)	24	213.50	10.111	49.532	100	30	30
TDS (mg/l)	24	201.46	9.8	47.906	1200	1200	1000
TS (mg/l)	24	413.58	19.877	97.376			
COD (mg/l)	24	7772.92	234.631	1149.453	100	50	10
Colour (TCU)	24	667.00	23.137	113.348	300	<40	15

Total Dissolved Solids (TDS)
Total Dissolved Solids (TDS) is the measure of total inorganic salts and other dissolved substances in water. Results from wastewater Bata leather tanneries in Kenya indicated that, the TDS was found much lower than the prescribed limit of NEMA, KBS and WHO (201.46 ±9.8 mgL^{-1}). Results are presented in figure 1 below.

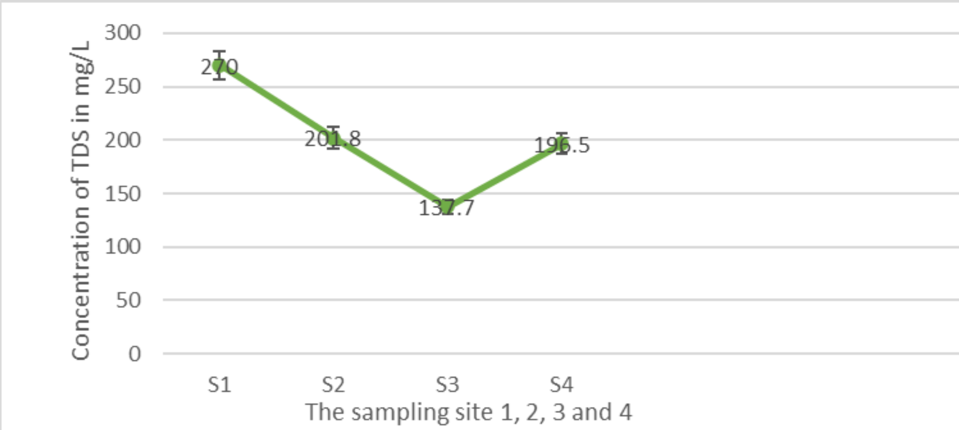

Figure 1: The mean levels of total dissolved solid in sites 1, 2, 3 and 4

The mean levels of TDS from each of the four sites indicate that it ranged from 137.7 – 270 mg/L with site 1 having the highest value. All amounts from the four sites were below the KEBS, NEMA and WHO standards.

To determine if there were any spatial significant differences in total dissolved solid, One-Way analysis of variance was conducted. The mean TDS level recorded was ($p < 0.05$ mg/L) significantly different among the four sites (P=0.000, df= 3, F=10930.0).

pH
The average pH level for all four sites from wastewater of Bata leather tanneries in Kenya was 5.03±0.5 which implies it was slightly acidic and not within the recommended levels of NEMA, KEBS and WHO. Results are presented in Figure 2 below.

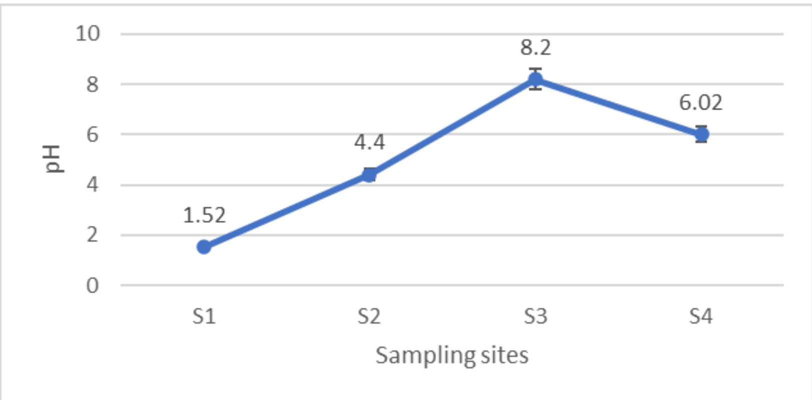

Figure *2*: The pH levels for S1, S2, S3 and S4

The mean levels of pH from each of the four sites indicate that it ranged from 1.52 – 8.2 with site 3 having the highest pH of 8.2 as indicated in Figure 2. The pH level for sites 1 and S2 were not within the recommended levels for KEBS, NEMA and WHO standards.

ANOVA was then used to determine if there was a significant difference in pH values in effluent samples across the four sites.

Table 2: ANOVA for the pH across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	142.577	3	47.526	75.7	.000
Within Groups	12.557	20	.628		

*. The mean difference is significant at the 0.05 level.

The pH values shown in Table 4.2 reported that there was ($p < 0.05$) significantly different among the four sites (P=0.000, df= 3, F=75.7).

Dissolved Oxygen

The overall mean DO level for all the four sites from wastewater of Bata leather tanneries in Kenya was 9.17 ± 0.275 which was slightly higher than the NEMA, KEBS and WHO standards recommended level.

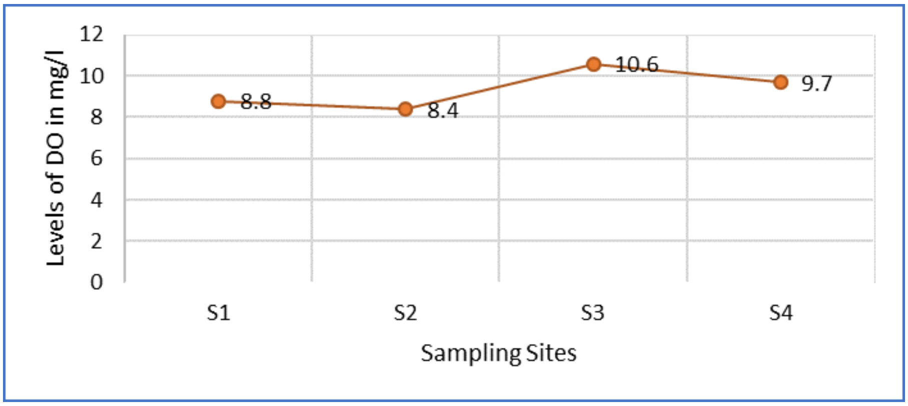

Figure 3: The mean levels of Dissolved oxygen for Site 1, 2, 3 and 4

According to Figure 3, the mean concentrations of DO from each of the four sites ranged from 8.4 to 10.6 mg/L with S3 recording the highest amountn of 10.6 mg/L. The DO levels for all the four sites were above the recommended levels of 7 mg/L for KEBS, NEMA and WHO standards.

To determine if there was any significant difference between the sites, ANOVA was calculated and the results are presented in Table 3 below.

Table 3: ANOVA for the BOD across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	26.788	3	8.929	11.940	.000
Within Groups	14.957	20	.748		

**. The mean difference was significant at the 0.05 level.*

According to ANOVA and from the results above, the p- values of BOD was 0.000 which was ≤ 0.05 significance level indicating significance at 95 %.

Electrical Conductivity (EC)

The ability of a solution to conduct an electrical current is governed by the migration of solutions and is dependent on the nature and numbers of the ionic species in that solution. This property is called electrical conductivity. It is a useful tool to assess the purity of effluent. The overall mean levels for EC from all four sites from wastewater of Bata leather tanneries in Kenya was 1363.38 ± 2.83 mS/cm which was well above the recommended level of 25 mS/cm for NEMA, KEBS and WHO. Figure 4 shows the mean levels of EC for the sites S1-S4.

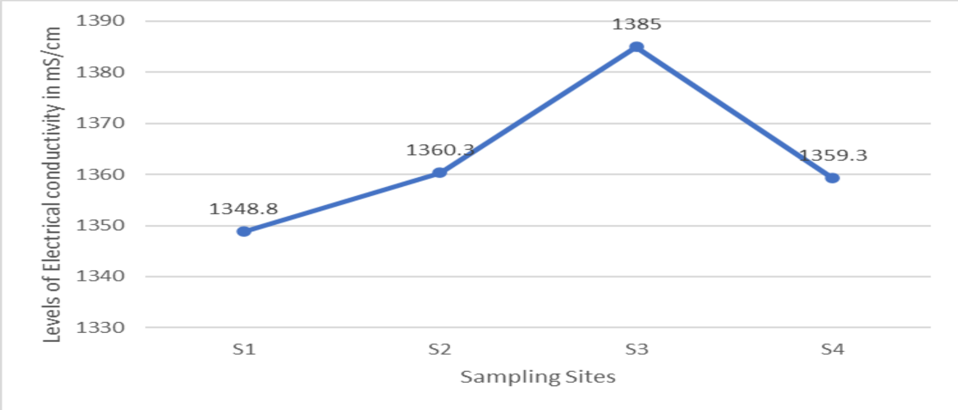

Figure 4: The mean levels of electrical conductivity for sites 1, 2, 3 and 4

The results from Figure 4 indicate that the mean values of EC from each of the four sites ranged between 1348.8 and 1385 mS/cm with S3 recording the highest amount of 1385 mS/cm. Electrical Conductivity levels for all the four sites were way above the recommended levels of 25 mS/cm for KEBS, NEMA and WHO standards.

To determine if there were any spatial significant differences in electrical conductivity, One-Way analysis of variance was conducted. The mean EC level recorded was ($p < 0.05$) significantly different among the four sites (P=0.000, df= 3, F=153.61).

Temperature (^{0}C)

The average temperature level for all four sites from wastewater Bata leather tanneries in Kenya was 25.59±0.5 which means it was within the recommended levels of 20-35°C for both NEMA and KEBS and ≤37°C for WHO.The results of mean level of temperature for sites 1-4 are shown in Figure 5.

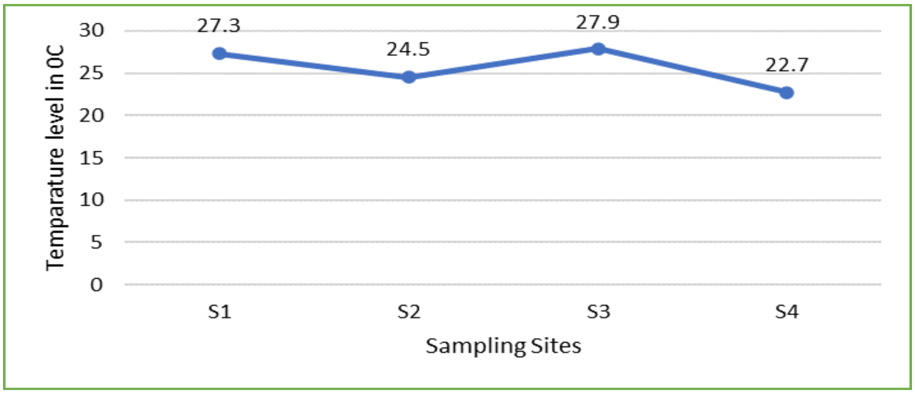

Figure 5: The mean levels of temperature for sites 1, 2, 3 and 4

According to Figure 5, the mean levels of temperature from each of the four sites ranged between 22.7 and 27.9 ^{0}C with S3 recording the highest temperature of 27.9 ^{0}C. The temperature levels for all the four sites were however, within the recommended levels set by KEBS, NEMA and WHO standards.

To determine if there was any significant difference between the sites, ANOVA was calculated and the results are presented in Table 4 below.

Table 4: ANOVA for the temperature across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	107.946	3	35.982	22.554	.000
Within Groups	31.908	20	1.595		

*. *The mean difference was significant at the 0.05 level.*

According to ANOVA results above, the p- value of temperature was 0.000 which was above 0.05 significance level indicating there was significance at 95 % in the values of temperature across the four sites.

Biological Oxygen Demand (BOD)

The results presented in table 5 indicate that biological oxygen demand from wastewater of Bata leather tanneries in Kenya was 4721.34 ± 130.5 mg/L and it was found to be way higher than KEBS, NEMA and WHO standards of 50, 30 and 6 mg/L respectively. The Figure 5 below shows the mean levels for each site.

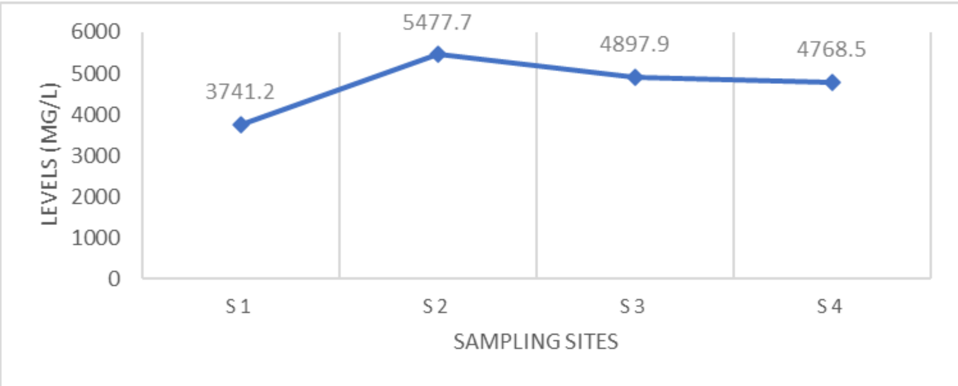

Figure 5: The mean levels of biological oxygen demand for sites 1, 2, 3 and 4

It is apparent from the results from Figure 5 that the BOD for the four sites ranged between 3141.2 and 5477.7 mg/L with site 2 recording the highest amount of 5477.7 mg/L. The BOD levels for all the four sites were above the recommended levels set by KEBS, NEMA and WHO standards.

To determine if there were any spatial significant differences in biological oxygen demand, One-Way analysis of variance was conducted, and results presented in Table 6.

Table 6: ANOVA for the BOD across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9396779.776	3	3132259.925	25100	.000
Within Groups	24.957	20	1.248		

*. *The mean difference is significant at the 0.05 level.*

The mean BOD level recorded was ($p < 0.05$) significantly different among the four sites ($P=0.000$, df= 3, $F=25100$).

Total Suspended Solids (TSS)

In the present study, the Total Suspended Solids (TSS) overall mean levels from wastewater Bata leather tanneries in Kenya was 213.50± 10.1 mg/L which was well above the recommended levels of 100, 30 and 30 mg/L for NEMA, KEBS and WHO standards respectively. Figure 6 below shows the mean values for each site.

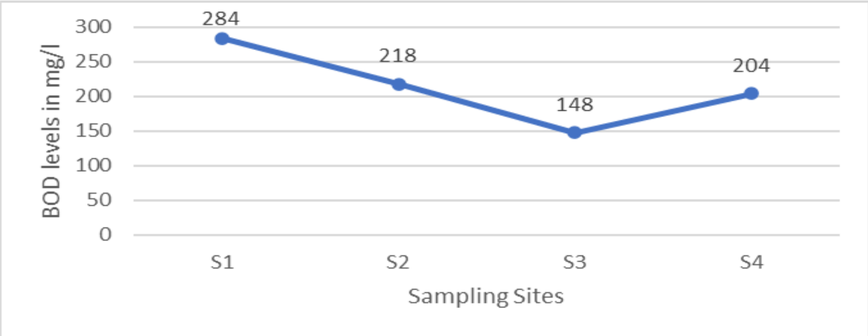

Figure 6: The mean levels of Total Suspended Solids for Site 1, 2, 3 and 4

Regarding the values of TSS for each of the four sites, all the effluent samples showed more presence of contaminants, as the values ranged from 148 mg/lLto 284 mg/l with S1 recording the highest value of 284 mg/L. The TSS values for all the four sites were above the recommended levels set by KEBS, NEMA and WHO standards.

To determine if there was any significant difference between the sites, ANOVA was calculated. The results are presented in Table 7 below.

Table 7: ANOVA for the TSS across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	56226.000	3	18742.000	1856	.000
Within Groups	202.000	20	10.100		

*. The mean difference is significant at the 0.05 level.

The mean TSS level recorded was ($p < 0.05$) significantly different among the four sites (P=0.000, df= 3, F=1856).

Total Solids (TS)

The results presented in table 4.1 indicate that total solids values from wastewater of Bata leather tanneries in Kenya was 413.58 ± 11.87 mg/L and it was found to be above than KEBS, NEMA and WHO standards of 50, 30 and 6 mg/L respectively. Figure 7 below shows the mean values for each site.

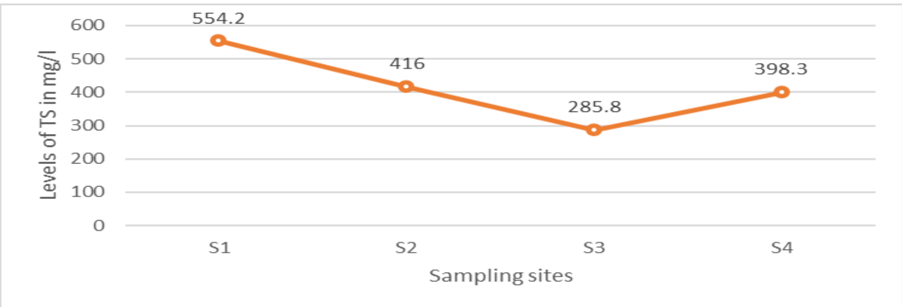

Figure 7: The mean levels of total solids for sites 1, 2, 3 and 4

The TS values of effluent samples ranged from 286 to 554 mg/L. All these measured values were also above the WHO guideline value which is 500 mg/L.

To determine if there were any spatial significant differences in biological oxygen demand, One-Way analysis of variance was conducted, and the results presented in Table 8.

Table 8: ANOVA for the TS across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	217932.833	3	72644.278	9254	.000
Within Groups	157.000	20	7.850		

**. The mean difference is significant at the 0.05 level.*

The mean TS level recorded was ($p < 0.05$) significantly different among the four sites ($P=0.000$, df= 3, $F=9254$).

Chemical Oxygen Demand (COD)

COD test is commonly used to measure the number of organic compounds in water which is not degraded by microbial activity. The mean value for COD for the four sites from wastewater of Bata leather tanneries in Kenya was 7772.92 ± 234.63 mg/L which was also well above the recommended level of 100, 50 and 10 mg/L for NEMA, KEBS and WHO standards, respectively. Figure 8 below shows the mean values for each site.

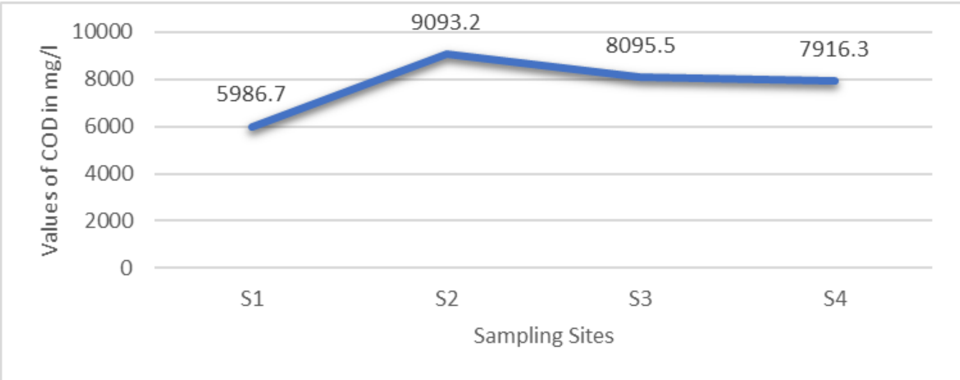

Figure 8: The mean values of chemical oxygen demand for sites 1, 2, 3 and 4

The results presented in Figure 8 indicate high values of COD of the effluent samples which ranged between 5986.7 and 9093.2 mg/L with site 2 reporting the highest value of 9093.2 mg/L. All these measured values were also above the KEBS, NEMA and WHO standards of 500 mg/L.

To determine if there was any significant difference between the sites, ANOVA was calculated and the results are presented in Table 9 below.

Table 9: ANOVA for the COD across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	30350007	3	1012000	5286	.000
Within Groups	38281.000	20	1914.050		

**. The mean difference is significant at the 0.05 level.*

According to ANOVA results above, the p- value of chemical oxygen demand was 0.000 which was above 0.05 significance level indicating there was significance at 95 % in the values of temperature across the four sites.

Colour (TCU)

According to the results presented in Table 9, the mean value for colour (TCU) for the four sites from wastewater of Bata leather tanneries in Kenya was 667 ± 23.12 Pt-Co which was also well above the recommended level of 300, < 40 and 15 Pt-Co for NEMA, KEBS and WHO standards, respectively. Figure 9 below shows the mean levels for each site.

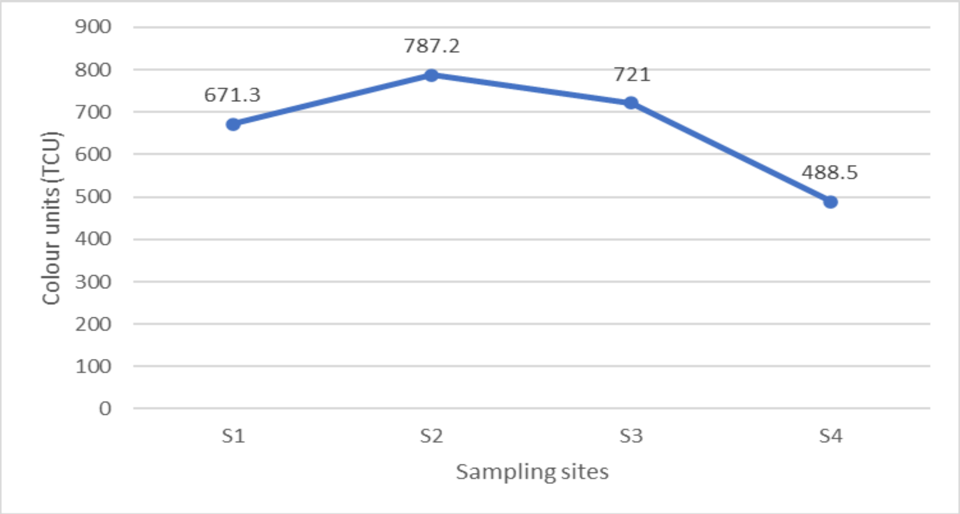

Figure 9: The mean levels of colour units for sites 1, 2, 3 and 4

The colour values of effluent samples ranged from 488.5 to 787.2 Pt-Co with S2 recording the highest value of 787.2 Pt-Co. The colour values for all the four sites were above the recommended levels set by KEBS, NEMA and WHO standards.

To determine if there was any significant difference between the sites, ANOVA was calculated and the results are presented in Table 10 below.

Table 10: ANOVA for the colour across the four effluent sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	295422.333	3	98474.111	25360	.000
Within Groups	77.667	20	3.883		

*. The mean difference is significant at the 0.05 level.

The mean colour level recorded was ($p < 0.05$) significantly different among the four sites (P=0.000, df= 3, F=25360) at 95% confidence limit.

DISCUSSION

Total Dissolved Solids (TDS)

Carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, nitrogen, calcium, sodium, potassium, and iron all contribute to total dissolved solids (Singh *et al.*, 2012). The overall value for this study was (201.46 mg/L), while the mean value for each of the four sites varied between 137.7 and 270 mg/L, with site 1 having the highest value. All the four sites had values that fell below the KEBS, NEMA, and WHO standards. The presence of elevated TSS and TDS levels may be due to the presence of insoluble organic and inorganic compounds in the effluent (Aniyikaiye *et al.*, 2019). Sugasini and Rajagopal (2015) reported values of 318.5 mg/L in untreated effluent, slightly higher than those in this study, while Smrithi *et al.* (2012) reported a much higher value of 600 mg/L.The significant difference between sampling points was attributed to the tanning process's various stages of treatment.

Dissolved Oxygen (Do)

The amount of oxygen dissolved in water is referred to as dissolved oxygen (DO). The overall level of DO was 9.17 mg/L, with mean values ranging between 8.4 and 10.6 mg/L at each of the four sites, with S3 recording the highest concentration of 10.6 mg/L. All values exceeded the KEBS, NEMA, and WHO permissible limits of 7 mg/L. The presence of a high organic content in tannery waste water results in an increase in microbial activity, which consumes dissolved oxygen as organic matter biologically discomposes. Similarly, Noorjahan *et al.* (2004) and Sugasini and Rajgopal (2015) reported similar findings. Parveen *et al.* (2017) also reported that the maximum DO levels was 6.96 mg/L in the control group while the minimum DO amount ranged between 5.09 and 5.76 mg/L during an assessment of the physico-chemical properties of tannery waste water and its impact on fresh water quality. The significant difference between sampling points was attributed to the tanning various stages of treatment process.

pH

The average pH value for all the four sites was 5.03 for wastewater from Bata leather tanneries in Kenya. The mean pH levels at each of the four sites ranged between 1.52 and 8.2, with site 3 having the highest pH of 8.2. The pH levels at sites 1 and S2 exceeded those recommended by KEBS, NEMA and WHO. The higher pH indicates that the tannery wastewater was both alkaline and acidic in nature, exceeding or exceeding the permissible limit of 5.0 to 9.0 set by NEMA, KEBS and WHO. Chrome tanning effluents had the lowest pH, 3.8, which was significantly less than the prescribed standard limits. The low pH of the chrome tanning effluents may be due to the addition of sulphuric acid during the pickling stage used to prepare the pickled pelt. The liming effluents had the highest mean pH (12.5), owing to the excessive use of lime and sodium sulphide in the production of lime pelt.

The pH of this basic effluent was significantly higher than the established limits. A large pH value fluctuation stresses the aquatic environment and may have a detrimental effect on some sensitive species of aquatic flora and fauna (Welker *et al.*, 2013), Navaraj and Yasmin (2012) reported similar findings. Discharge of such alkaline effluent into ponds, rivers, and other bodies of water for irrigation purposes may be detrimental to aquatic biota such as zooplankton and fishes. According to Saxena *et al.,* (2002), the tannery effluent's alkaline nature may be due to the presence of carbonates and bicarbonates. A spatially significant difference in pH was attributed to the use of various types of acidic or basic salts in the various stages of leather tanning. The pH of the pre-tanning/preparatory process effluents was alkaline. This means that the liming section uses $CaCO_3$, Na_2S, and NaHS, which are all basic in nature and thus cause an increase in the pH of the effluent.

Electrical Conductivity (EC)

Electrical conductivity is a numerical representation of a water sample's ability to conduct an electric current. The value is dependent on the total concentrations of dissolved ionized substances in water and the temperature at which the measurement is taken. It is an effective tool for determining the effluent's purity. The mean values of EC across all the four sites from wastewater of Bata leather tanneries in Kenya was 1363.38 mS/cm, with mean levels ranging between 1348.8 and 1385 mS/cm at S3. The pickling and chrome tanning effluents had the highest mean value of EC. This was primarily because significant amounts of sodium and chromium salts are added during the pickling and tanning processes. The high EC values of the effluents indicated that they contained a high concentration of salts. EC levels at all the four sites were significantly greater than the 25 mS/cm recommended by KEBS, NEMA, and WHO standards.

Conductivity could be increased due to the presence of chloride ions and inorganic salt cations (Na^+, K^+, Ca^{2+}, and Fe^{3+}), which increased the salinity of the water. Murali *et al.* (2013) reported similar results of increased conductivity in untreated and treated tannery effluents, indicating a greater amount of chemicals in wastewater as cations and anions. The increased conductivity is dependent on the chelating properties of water bodies and results in an imbalance of available free metals to flora and fauna (Akan *et al.*, 2008).

Temperature (ºC)

The average temperature for all the four sites from waste water of Bata leather tanneries in Kenya was 25.59 ºC, with the mean temperatures for each site ranging between 22.7 and 27.9 ºC with S3 recording the highest temperature of 27.9 ºC. Temperatures at all the four locations were within the recommended ranges established by KEBS, NEMA, and WHO standards. Temperature is a critical indicator of water quality in terms of aquatic organism survival. Wosnie and Wondie (2014) made a similar observation, stating that the effluents were 25.5 °C.

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand is a critical parameter in water pollution studies because it is used to determine the impact of wastewaters on receiving waters. The present study established that the biological oxygen demand in the effluents of the Bata leather tanneries in Kenya was high at 4721.34 mg/L, and that the BOD levels for the four sites ranged between 3141.2 and 5477.7 mg/L, with site 2 having the highest value at 5477.7 mg/L. The BOD levels at all four sites exceeded the levels recommended by KEBS, NEMA, and WHO standards.

The presence of organic substances (skins and hides) used as raw materials in the tannery industry is reflected in the results. A high amount of dissolved organic matter depletes oxygen and raises the BOD level, which undergoes anaerobic processes that result in the formation of ammonia and organic acids (acetic acids and butyric acid). The primary issue with BOD is the depletion of dissolved oxygen in stream waters caused by microbial decomposition, which promotes anaerobic activity and results in the release of noxious gases (Song *et al.*, 2000). Mwinyihija *et al.* (2006) reported similar findings.

Total Suspended Solids (TSS)

The mean values of total suspended solids (TSS) in wastewater from Bata leather tanneries in Kenya was 213.50 mg/L, with values ranging from 148 mg/L to 284 mg/L, with S1 recording the highest concentration of 284 mg/L. TSS values were found to be greater than 100, 30 and 30 mg/L for NEMA, KEBS, and WHO standards, respectively. The high levels of total suspended solids in tannery effluent could be attributed to their accumulation during finished leather processing. Additionally, the presence of total suspended solids results in turbidity, which reduces light penetration into the aquatic system, impairing photosynthetic activity (Anantnarayan *et al.*, 2018). Furthermore, the settling of suspended particles on soil and soil fauna may result in a variety of adverse effects, including changes in soil porosity, texture, and water holding capacity on the one hand, and clogging of fish gills and respiratory surfaces on the other (Chowdhary *et al.*, 2020). Chowdhury *et al.* (2015) analysed the effluents from leather processing businesses and found that the total suspended solid (TSS) ranged from 820 90 to 11000 10 mg/L which were higher levels as compared to this study.

Total Solids (TS)

Total solids in wastewater from Bata leather tanneries in Kenya was 413.58 mg/L and ranged between 286 and 554 mg/L. All these values were also greater than the WHO guideline value of 500 mg/L. The TS results indicated that the tannery's effluents require additional or additional effort to be purified prior to release to water sources. The total alkalinity of the sample is dependent on its high carbonate and bicarbonate values, indicating that the effluents contain a high amount of dissolved salts. Chowdhury *et al.,* (2015) discovered that the alkalinity levels at all sampling points exceeded the standard permissible limits.

Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) test is the most accurate method for estimating organic matter and the quickest method for determining the total oxygen demand of organic matter present in a sample. COD levels were found to be elevated in the present investigation, with an overall mean of 7772.92 mg/L and a mean range of 5986.7 to 9093.2 mg/L at the four sampling sites. The results were significantly greater than the respective recommended NEMA, KEBS, and WHO standards of 100, 50, and 10 mg/L. Additionally, Noorjahan (2014) observed COD values ranging from 2286 to 9600 mg/L. Increased COD levels could be as a result of a high concentration of organic compounds that are unaffected by bacterial decomposition (Nagarajan and Ramachandramoorthy, 2002). These findings corroborate previous research by Alvarez-Bernal *et al.* (2006).

Colour (Pt-Co)

There was a variation in colour of effluents at various stages. The mean value for colour (Pt-Co) for the four sites of wastewater from Bata leather tanneries in Kenya was 667 Pt-Co and ranged between 488.5 and 787.2 Pt-Co, with S2 recording the highest value of 787.2 Pt-Co due to its yellowish-brown colour. These values were significantly higher than the corresponding NEMA, KEBS, and WHO recommended levels of 300, 40, and 15 Pt-Co. At monitoring points S1, S3, and S4, the colour unit was lower. The effluent's colour could be due to the presence of biodegradable and non-biodegradable high molecular weight organic compounds, as well as a high concentration of inorganic chemicals such as sodium and chromium used during processing. Odour could be due to putrefaction of organic residues from processed skin and hides (Smrithi *et al.,* 2010). According to Verma *et al.* (2008), the yellowish-brown colour may impede sunlight penetration, resulting in a decrease in the rate of oxidation of pollutants. The findings of this study are also consistent with those of Dhungana and Yadav (2009).

CONCLUSION

Pollution from the Bata leather industries' effluents is a major environmental and social concern in Kenya. This study's findings reported elevated levels of TSS, TDS, TS, BOD5, COD, colour, DO and pH, as compared to NEMA, KEBS, and WHO standards were detected in effluents collected from four strategic locations throughout the tannery and surrounding area. At four different monitoring points (S1, S2, S3, and S4), the major physio-chemical parameters of all composite effluents exceeded the standard disposal limits except for temperature. Water quality results indicated poor water quality, implying that untreated leather industrial effluents were unfit for discharge into surface water and adjacent fields. These practices endanger humans, aquatic life, and the entire ecosystem.

RECOMMENDATIONS

The following recommendations were drawn based on the results:

1. Care should be taken to monitor the quality of tannery effluents on a regular basis and to treat them appropriately to prevent pollutants from entering the environment.

2. Bioremediation is an option that offers the possibility to destroy or render harmless various contaminants of tannery effluent using natural biological activity, and therefore, further study should be undertaken using greener bio-method.
3. The company should therefore take immediate counteractive actions to lower these levels of the toxicants to avert the associated effects to human and environment.
4. The ministry of Environment should enforce the law concerning water pollution and prosecute those who are found culpable.
5. Future studies should be considered on short- and long-term impacts of pollution on aquatic ecosystem and also on human health.

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