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Full Length Research Paper

Performance Aspects of Tannery Wastewater Treatment Plants in the Vicinity of Addis Ababa, Ethiopia:A Case Study

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Abstract
The performance of tannery wastewater treatment plants in the vicinity of Addis Ababa, Ethiopia was evaluated through a case study of a selected industry called China Africa Tannery located in Sululta town of the Oromia regional state. Treatment system wastewater samples were collected and analyzed as per the standard procedure for the dry (End of January-February, 2014) and wet (end of June-July, 2014) seasons for the parameters of BOD_5, TSS, TDS, NH_3-N and pH. The dry season COD, chromium, sulfide and reactive phosphate and the wet season total phosphorous were also analyzed. Design Expert Software Version 7.0.0 and MS-Excel 2007 were the used for statistical data analysis. For the overall treatment plant, the dry season mean daily removal efficiencies were 56.3%, 74.9%, 89.5% and 99.7% for BOD_5, COD, TSS and sulfide respectively while the figures for the wet season were 37.4% for BOD_5, 80.5% for TSS and 28.3% for total phosphorous. No statistically significant day-to-day (ANOVA; $p > 0.05$) and seasonal-except in few cases (t-test; $p > 0.05$) treatment efficiency variations were observed. The national tannery effluent release standard was well achieved for BOD_5, COD, sulfide, total phosphorous, pH and temperature while it was significantly exceeded for TSS, NH_3-N and total nitrogen.

Keywords: *Ethiopia, Tannery Wastewater, Treatment Performance, Seasonal variation, Day-to-day Variation*

Introduction

Although highly beneficial, tanneries are among the manufacturing industries that are notorious for their impact on the environment. Their production process involves hide and skin storage, beam house, tanyard, post tanning and finishing, most of those sections generating huge amount of BOD, COD, TSS, TDS, nitrogen and toxic substances in their wastewater (WBG, 2007; UNIDO, 2011). Huge chemicals including toxic substances are also associated with tanning industries (UNEP, 1996). Effluent treatment plants are employed as end-of-pipe solutions to protect water bodies from damaging pollutants (Flores-Alsina et al., 2010). To this end, a number of available in-use tannery effluent treatment technologies exist in the world (Durai and Rajasimman, 2011). Preliminary treatment removes large particles such as sand, grit and grease in addition to chrome and sulfides reduction. Coarse and fine screens, equalization tanks, sulfide oxidation system, chrome recovery system, floater remover and wastewater stream segregation are performed as standard pretreatment. Primary treatment removes organic and inorganic solids, floating materials being also removed through skimming operation. Removal of 25-50% of BOD_5, 50-70% of TSS and 65% of the oil and grease can be achieved during primary treatment (UNIDO, 2011). Secondary treatment is the next step in the treatment of industrial wastewater, both aerobic and anaerobic biological systems being used with different efficiencies across the world (Chan et al., 2009; Durai and Rajasimman, 2011). Advanced technologies such as membrane processes, membrane bioreactors and advanced oxidation processes have also been tried in the treatment of tannery effluents (Lofrano et al., 2013).

A number of studies were conducted on the performance of tannery effluent treatment plants operational in different places in the world (Shanmugasundaram and Murthy, 2000; Tadesse et al., 2003; Govindasamy et al., 2006; Ezike et al., 2012; Dejene and Tenalem, 2012). Typical efficiency values being also determined based on experience (IUE of IULTCS, 2008). Pollution of water bodies from tanneries is a serious concern in Ethiopia in general and in Addis Ababa area in particular (Itanna, 1998; Mersha, 2008; Gebre and Van Rooijen, 2009; Degefu et al., 2013). As the sector is one of the top development priorities in the country, the pollution problem is expected to get exacerbated in the future. Despite the practice in some cases of using effluent treatment plants, serious concern exists on their performance leading to their inability to comply with national and international effluent release standards to surface waters (e.g. Table 1).

Thus, the general objective of the paper was to evaluate the performance of the selected tannery wastewater treatment system. The specific objectives are therefore to determine treatment efficiencies of major units in the treatment line; to check daily & seasonal treatment performance variations; to compare actual efficiencies with the results of other studies and to compare the overall effluent quality with national and international tannery effluent release standards to surface waters.

Table 1. National (Ethiopian) and World Bank tannery effluent discharge limit to surface water

Parameter	Unit	National (FEPA and UNIDO, 2003)	World Bank (WBG, 2007)
Temperature	^{o}C	40	
pH	pH units	6-9	6-9
BOD_5 at 20^{o}c	mg/l	200 (or 90% removal)	50
COD	mg/l	500	250
SS	mg/l	50	50
Total ammonia (as N)	mg/l	30	10
Total nitrogen (as N)	mg/l	60 (or 80% removal)	10
Total phosphorous (as P)	mg/l	10 (or 80% removal)	2
Total chromium	mg/l	2	0.5
Sulfide (as S^{2-})	mg/l	1	1

Materials and Methods

Description of the Study Area

The effluent treatment plant selected for the case study is China Africa tannery located in Sululta, Oromoia region (9° 09' 39" N and 38° 45' 03" E) at 32km north of Addis Ababa. The industry has a well established, secondary level, operational effluent treatment plant that led to its selection for the case study. The national (Ethiopian) Leather Industry Development Institute (LIDI) and the Environmental Protection Authorities of the Oromia region and the Addis Ababa city were consulted in the selection process. The industry used to process sheep and goat skin (mostly sheep skin) during the study period though trial scale hide and skin processing was also commenced at the latter stage of the study. Daily skin soaking capacity was 9.1 ton (7000 pieces) with a daily production of 2.6-2.8 ton (6500-7000 pieces) while the corresponding soaking capacity for the hide and skin was around 200 pieces. The final product was finished leather for the sheep/goat skin and crust for the hide and skin. The industry uses ground water for all its needs.

The Selected Wastewater Treatment Plant

The actual wastewater treatment plant diagram is shown in Figure 1. Accordingly, the chrome separation supernatant is mixed with the beamhouse and re-tanning sections effluent to be cleaned with three major manually cleaned screens of mesh size 5-10mm before being collected into three rectangular tanks (2*) each with storage capacity of 108m^3. Those three containers were also found to be used as pre-sedimentation tanks. The wastewater then goes to a two-compartment in-line equalization tank of volume 180m^3 for organic and hydraulic loading homogenization (3*), the second compartment (3**) also serving as coagulation basin and sulfide removal by chemical precipitation. Clarification takes place in a circular clarification tank (4) of volume = 152.4m^3 followed by activated sludge treatment (5: aeration tank = 700m^3; 6: secondary clarifier of = 181m^3). The primary and secondary sludge is handled by a sludge drying bed (SBD) of plane area size 200m^2 with four compartments of 50m^2. (Some of the sizing data were also taken from the treatment plant design document)

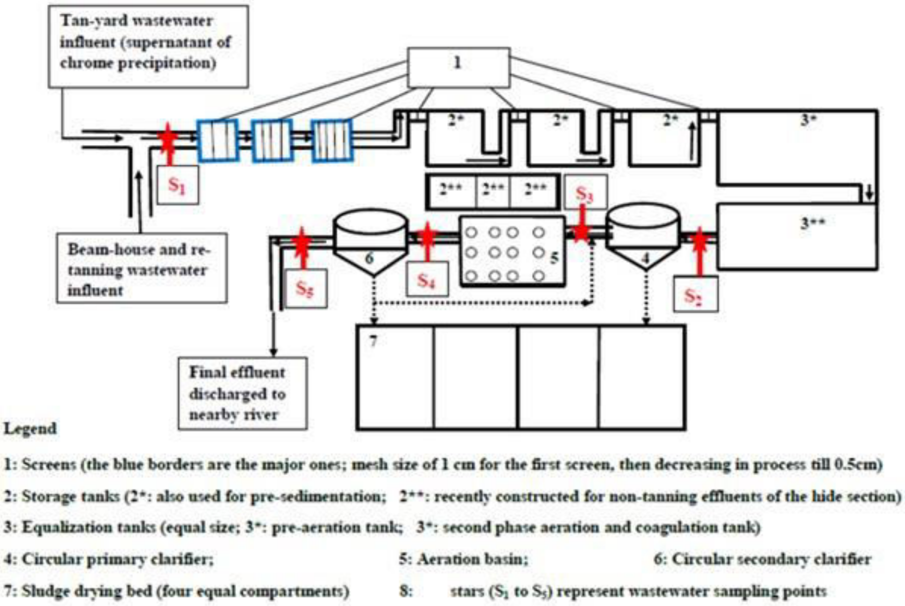

Fig 1. The actual effluent treatment plant with wastewater sampling sites of S_1 to S_5

Wastewater Sample Collection and Laboratory Analysis

Treatment system wastewater samples were collected for the dry (end-of-January to February, 2014) and wet (end-of-June to July, 2014) seasons in morning hours (10:00-12:00 A.M) over a maximum of five days at five selected sites (S1: at the raw influent: S2: before primary treatment; S3: after primary treatment; S4: after the activated sludge (AS) aeration tank and S5: after the secondary clarifier) for laboratory analysis of BOD_5, TSS, TDS, NH_3-N and pH while COD, chromium, sulfide and R-PO_4 for the dry season and total phosphorous for the wet season were also analyzed apart from onsite measurements of DO (in the AS reactor) for both seasons. Some of these parameters (particularly BOD, COD, TDS and SS) were also used as tannery effluent treatment plant performance indicators in other studies (Shanmugasundaram and Murthy, 2000; Govindasamy et al., 2006; Dejene and Tenalem, 2012; Ezike et al., 2012).

Wastewater samples were collected in plastic bottles cleaned with hydrochloric acid solution followed by repeated washing by distilled water. They were taken at the well mixed (turbulent) section of the wastewater. After sampling, they were preserved at appropriate temperature (around 4^{o}C) using ice blocks till laboratory analysis which was conducted as quickly as possible. The samples were analyzed in the environmental laboratory of the Addis Ababa Environmental Protection Authority (AAEPA) with standard methods for the examination of water and wastewater (APHA, 1995). Samples were analyzed as quickly as possible with regular and required calibration conducted in the process.

Treatment Efficiency Determination

The treatment efficiency of individual unit operations and the whole treatment plant was determined using the following equation:

$$\eta\ (\%) = \frac{(IC-EC)}{IC} \times 100$$

Where η = efficiency; IC = Influent concentration and EC =Effluent concentration

Statistical Data Analysis

The efficiency data were analyzed using Design Expert Software Version 7.0.0 for ANOVA and LSD tests based on randomness and normality assumptions to check the significance of day-to-day treatment efficiency variations. MS-Excel 2007 was also used for T-tests (for seasonal efficiency analysis) and other statistical analysis.

Results and Discussion

Wastewater Pollutant Concentration

Wastewater pollutant concentrations (mean ± standard deviation) at different stages from entrance to exit of the treatment plant for the two seasons are shown in Table 2 and Table 3.

Table 2. Laboratory analysis results of wastewater samples for the dry season (mg/l)

Parameter	Statistics	S1	S2	S3	S4	S5
	No of samples	5	5	5	5	5
BOD_5	*Mean ± STD*	353.3 ± 139.8	742.1 ± 237.2	356.0 ± 169.4	600.0 ± 201.5	136.8 ± 23.2
COD	*Mean ± STD*	1761.1 ± 944.8	3366.7 ± 1051.6	1575.5 ± 619.0	3160.0 ± 1285.7	337.6 ± 69.6
TDS	*Mean ± STD*	1590.1 ± 507.5	3277.5 ± 488.5	3182.0 ± 414.1	3278.0 ± 175.7	2960.0 ± 222.6
pH	*Mean ± STD*	11.2 ± 0.8	7.8 ± 0.7	6.9 ± 0.5	7.8 ± 0.4	7.8 ± 0.2
NH_3-N	*Mean ± STD*	33.8 ± 22.5	69.7 ± 15.9	65.6 ± 23.3	82.1 ± 20.2	79.4 ± 25.7
TSS	*No of samples*	4	5	4	4	5
	Mean ± STD	1039.5 ± 437.8	5789.4 ± 2365.6	1014.0 ± 564.6	5249.9 ± 1602.8	89.5 ± 9.1
Sulfide	*No of samples*	4	5	5	4	4
	Mean ± STD	92.1 ± 53.7	82.9 ± 56.9	14.6 ± 8.5	4.9 ± 4.1	0.3 ± 0.3
R-PO_4	*No of samples*	4	4	4	4	4
	Mean ± STD	62.7 ± 31.3	170.8 ± 61.8	40.3 ± 14.4	188.9 ± 115.6	11.5 ± 4.2
Chromium	*No of samples*	5	5	5	5	4
	Mean ± STD	14.6 ± 14.0	27.7 ± 25.9	1.0 ± 0.6	30.6 ± 29.3	0.6 ± 1.3
Temp. (^{O}c)	*No of samples*	3	4	3	4	3
	Mean ± STD	20.3 ± 1.9	18.4 ± 0.8	19.2 ± 1.1	18.0 ± 0.6	18.0± 1.2
Parameter	Statistics	S1	S2	S3	S4	S5
	No of samples	5	5	5	5	5
BOD_5	*Mean ± STD*	353.3 ± 139.8	742.1 ± 237.2	356.0 ± 169.4	600.0 ± 201.5	136.8 ± 23.2
COD	*Mean ± STD*	1761.1 ± 944.8	3366.7 ± 1051.6	1575.5 ± 619.0	3160.0 ± 1285.7	337.6 ± 69.6
TDS	*Mean ± STD*	1590.1 ± 507.5	3277.5 ± 488.5	3182.0 ± 414.1	3278.0 ± 175.7	2960.0 ± 222.6
pH	*Mean ± STD*	11.2 ± 0.8	7.8 ± 0.7	6.9 ± 0.5	7.8 ± 0.4	7.8 ± 0.2
NH_3-N	*Mean ± STD*	33.8 ± 22.5	69.7 ± 15.9	65.6 ± 23.3	82.1 ± 20.2	79.4 ± 25.7
TSS	*No of samples*	4	5	4	4	5
	Mean ± STD	1039.5 ± 437.8	5789.4 ± 2365.6	1014.0 ± 564.6	5249.9 ± 1602.8	89.5 ± 9.1
Sulfide	*No of samples*	4	5	5	4	4
	Mean ± STD	92.1 ± 53.7	82.9 ± 56.9	14.6 ± 8.5	4.9 ± 4.1	0.3 ± 0.3
R-PO_4	*No of samples*	4	4	4	4	4
	Mean ± STD	62.7 ± 31.3	170.8 ± 61.8	40.3 ± 14.4	188.9 ± 115.6	11.5 ± 4.2
Chromium	*No of samples*	5	5	5	5	4
	Mean ± STD	14.6 ± 14.0	27.7 ± 25.9	1.0 ± 0.6	30.6 ± 29.3	0.6 ± 1.3
Temp. (^{O}c)	*No of samples*	3	4	3	4	3
	Mean ± STD	20.3 ± 1.9	18.4 ± 0.8	19.2 ± 1.1	18.0 ± 0.6	19.0± 1.2

Significant day-to-day variation of pollutant concentrations was observed for parameters such as SS, NH_3-N and temperature especially in dry season which could be due to factors such as poor housekeeping in the treatment plant area causing re-entrance of pollutants; operational inconsistencies of leather production and wastewater treatment; occasional failure of treatment units, power interruption; discontinuous operation of energy-intensive units such as the AS and variation in daily production capacity.

Table 3. Laboratory analysis results of wastewater samples for the wet season (mg/l)

Parameter	Statistics	S1	S2	S3	S4	S5
	No of samples	4	4	4	4	4
TDS	*Mean ± STD*	1963.5 ±983.6	4207.5 ±480.1	4087.5 ±180.8	3927.5 ±589.0	3950.0 ±686.3
pH	*Mean ± STD*	9.6 ±1.2	5.8 ±0.8	6.2 ±1.0	7.5 ±0.2	7.8±0.1
NH_3-N	*Mean ± STD*	61.4 ±45.3	204.1 ±23.0	184.0 ±36.0	175.5 ±20.1	161.0 ±16.3
TSS	*Mean ± STD*	1073.8 ±735.2	6178.3 ±2079.1	637.8 ±427.6	7096.9 ±898.9	132.0 ±19.7
TP	*Mean ± STD*	6.6 ±3.7	7.0 ±0.9	2.9 ±1.1	16.4 ±4.6	4.4 ±2.4
Temp. (^{O}c)	*Mean ± STD*	20.7 ±0.8	18.2 ±0.6	18.7 ±0.5	18.0 ±0.8	18.5 ±0.9
BOD_5	*No of samples*	3	3	3	3	3
	Mean ± STD	289.3 ±139.6	178.7 ±92.5	89.3 ±80.1	568.0 ±115.4	149.3 ±13.3

Treatment Plant Removal Efficiencies

The treatment efficiencies of the actual treatment plant are summarized in Table 4 and Table 5.

Table 4. Actual treatment plant pollutant removal efficiencies (%) (Wet season)

Parameter	Day Operation	Day1	Day2	Day3	Day4	Mean daily ± STD
BOD_5	**PRT**	87.7	16.7	23.7	-	**42.7 ± 39.1**
	SCT	-378.6	-160.0	12.2	-	**-175.4 ± 195.9**
	Overall	69.3	43.1	0.0	-	**37.4 ± 35.0**
TSS	**PRT**	96.8	90.4	93.8	67.1	**87.0 ± 13.5**
	SCT	40.3	75.1	72.5	90.5	**69.6 ± 21.1**
	Overall	91.9	69.1	67.0	94.1	**80.5 ± 14.4**
Total phosphorous	**PRT**	76.0	59.4	65.4	30.7	**57.9 ± 19.4**
	SCT	-44.4	-46.2	-22.2	-80.9	**-48.4 ± 24.2**
	Overall	54.8	19.1	4.3	34.9	**28.3 ± 21.6**
TDS	**PRT**	12.7	2.5	5.6	-12.9	**2.0 ± 10.8**
	SCT	0.3	-14.9	17.4	11.4	**3.5 ± 14.2**
	Overall	-59.3	-254.7	-274.5	-13.3	**-150.4 ± 133.4**
NH_3-N	**PRT**	29.0	-23.0	10.3	18.9	**8.8 ± 22.5**
	SCT	-19.7	20.9	14.3	24.7	**10.0 ± 20.3**
	Overall	-475.1	-56.5	-700.0	-75.8	**-326.9 ± 314.8**

Note that PRT: primary treatment; SCT: Secondary treatment; Negative values: Pollutants enhanced

The dry season primary treatment removal efficiencies were 40-65.5% for BOD_5, 36.7-60.2% for COD, 76.9-96.6% for TSS, 55.1-96.9% for sulfide and 57.6-87.1% for R-PO_4. For the wet season, they were 16.7-87.7% for BOD_5 and 67.1-96.8% for TSS. For the secondary treatment, the dry season efficiencies were 32-71.1% for BOD_5, 72.9-83.3% for COD, 64.1-94.6% for TSS, 75-99.7% for sulfide and 56.3-83% for R-PO_4. On the other hand, efficiencies of -378.6-12.2% for BOD_5 (enhanced for possible reasons such as re-entry of waste due to the observed poor house-keeping in the treatment area) and 40.3-90.5% for TSS were found for the wet season. The dry season overall efficiencies of the plant were 39.1-79.3% for BOD_5, 46.9-89.8% for COD, 82.9-94.3% for TSS, 99.4-99.8% for sulfide and 39.3-91.1% for R-PO_4.

Table 5. Actual treatment plant pollutant removal efficiencies (%) (Dry season)

Parameter	Day / Treatment	Day1	Day2	Day3	Day4	Day5	Mean daily ± STD
BOD_5	PRT	50.0	40.0	48.1	65.5	62.7	**53.3 ± 10.6**
	SCT	53.3	71.1	69.6	55.4	32.0	**56.3 ± 15.8**
	Overall	46.7	39.1	48.8	79.3	67.6	**56.3 ± 16.6**
COD	PRT	51.0	36.7	60.2	59.2	58.6	**53.1 ± 9.9**
	SCT	72.9	83.3	78.8	76.8	74.8	**77.3 ± 4.0**
	Overall	74.2	46.9	78.0	85.4	89.8	**74.9 ± 16.8**
TSS	PRT	-	79.2	85.3	76.9	96.6	**84.5 ± 8.8**
	SCT	-	91.1	91.4	94.6	64.1	**85.3 ± 14.2**
	Overall	-	82.9	87.0	93.8	94.3	**89.5 ± 5.5**
Sulfide (S^{2-})	PRT	-	55.1	84.3	81.2	96.9	**79.4 ± 17.5**
	SCT	-	98.9	99.7	98.8	75.0	**93.1 ± 12.1**
	Overall	-	99.6	99.8	99.8	99.4	**99.7 ± 0.2**
R-PO_4	PRT	-	73.0	57.6	77.3	87.1	**73.8 ± 12.3**
	SCT	-	83.0	70.3	56.3	70.4	**70.0 ± 10.9**
	Overall		39.3	86.1	75.9	91.1	**73.1 ± 23.4**
TDS	PRT	-11.7	12.3	2.5	11.6	-3.3	**2.3 ± 10.2**
	SCT	8.2	-4.8	19.9	-1.8	9.3	**6.2 ± 9.8**
	Overall	-81.5	-48.2	-260.1	-90.4	-51.9	**-106.4 ± 87.8**
NH_3-N	PRT	41.4	-10.7	-22.2	-6.9	23.1	**4.9 ± 26.4**
	SCT	-89.4	-20.4	22.7	5.9	-57.6	**-27.8 ± 45.9**
	Overall	-108.0	-2698.3	-142.9	-45.5	-46.6	**-608.3 ± 1169.1**
Chromium (the freely available, not the total)	PRT	96.8	100.0	-51.5	96.9	97.9	**68.0 ± 66.8**
	SCT	100.0	0.0	16.8	100.0	-104.0	**22.6 ± 84.5**
	Overall	100.0	0.0	-	100.0	87.5	**71.9 ± 48.3**

The corresponding wet season values were 0-69.3% for BOD_5 and 67.0-94.1% for TSS. Mean daily total phosphorous removal efficiencies of 57.9%, -48.4% and 28.3% were found for the primary, secondary and overall plant respectively. The whole plant dry season mean daily removal efficiencies were -106.8% for TDS and -608.3% for NH_3-N, the corresponding values for the wet season being -150.4% for TDS and -326.9% for NH_3-N. One major reason for the significant enhancement and erratic removal efficiencies of TDS and NH_3-N by the overall treatment plant is the fact that the reduction of those pollutants was not considered in the design and operation of the treatment plant, the main objective being to reduce BOD_5, COD, TSS, sulfide and chromium. The assessment of the treatment system removal efficiencies of TDS and NH_3-N was conducted in this paper (though the system was not designed for that purpose) to check how the already existing system is responding to those parameters thereby generating useful data based on which to recommend future actions in this regard. The enhancement of chromium in some cases may be explained by the re-entrance of chrome sludge damped in the area, among others.

As for comparison of treatment units (Figure 2 and Figure 3), for the dry season, the secondary treatment had higher efficiencies than the primary treatment for BOD_5, COD, TSS and sulfide. For the wet season, however, the primary treatment gave much better efficiencies than the secondary treatment for BOD_5, TSS and total phosphorous. The variation of chemicals used in the enhanced primary clarification along with improper dosing and inadequate process monitoring and control might have contributed to the day-to-day treatment efficiency variations (though not statistically significant) of the enhanced primary treatment as well as other subsequent processes of the treatment plant.

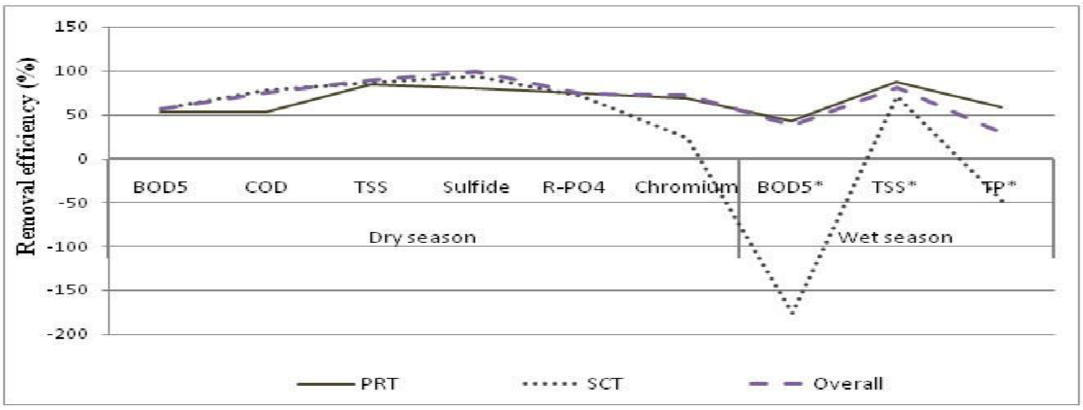

Fig 2. Actual mean treatment efficiencies of major parameters

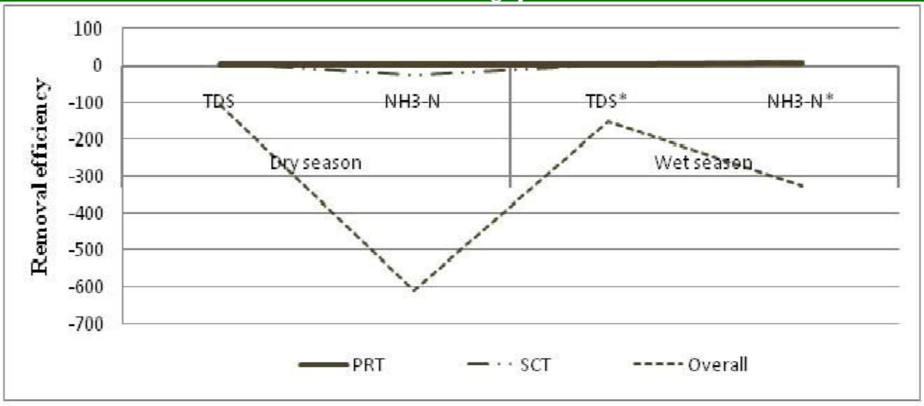

Fig 3. Actual mean treatment efficiencies of parameters with erratic values

Seasonal and Daily Treatment Efficiency Variations

The seasonal variation of removal efficiencies was also assessed (Figure 4). End-of- June to July was considered wet season while end-of-January to February was considered dry season. The year 2014 monthly rainfall data for Sululta town were 0.0mm for January; 25.2mm for February; 60.4mm for June and 252.1mm for July (National Meteorological Agency of Ethiopia).

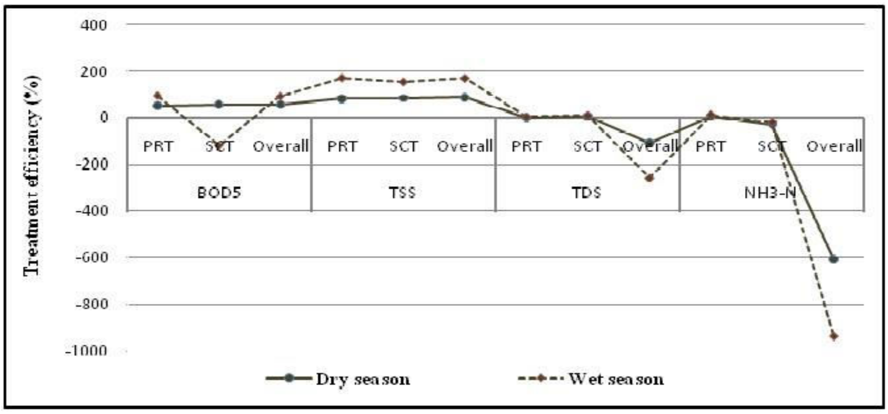

Fig 4. Seasonal variation of actual mean-daily removal efficiencies of treatment units

The pollutant removal efficiencies of the treatment plant were greater in the dry season than in the wet season for BOD_5, TSS and TDS for all treatment units except for that of primary clarifier in TSS removal and the overall plant in TDS removal. This might be due to the relatively high temperature in the dry season possibly enhancing the chemical (coagulation process) and the biochemical (in the biological reactor of the AS) reaction enhancing the removal efficiencies of BOD_5 and TSS. On the other hand, the wet season removal efficiency exceeded that of the dry season for all the treatment units including for the overall treatment for NH_3-N, which might be due to increased nitrification in the biological system owing to high dissolved oxygen in the bioreactor of the AS system. However, the seasonal efficiency differences were not statistically significant ($p > 0.05$) in all cases except for the TSS and NH_3-N removal of the combined primary-secondary treatment unit. At other significant levels, however, the variations start to be significant. For example, the secondary and the primary-secondary combined treatment units had significant seasonal variation in removing BOD_5 ($p < 0.2$), the same being true for the removal of NH_3-N by the secondary treatment unit.

The statistical insignificance of seasonal efficiency variations ($p > 0.05$) could be partly explained by the neutralizing effect of efficiency enhancers and reducers. For example, the wet season might have caused turbulence in clarifiers reducing efficiency; the dissolved oxygen in the biological reactor did, however, increase that was good for secondary treatment efficiency.

There were no statistically significant differences of day-to-day treatment efficiencies of the treatment plant in both the dry and wet seasons for all the parameters considered in the study (ANOVA test; $p > 0.05$). Similarly, no two compared days (for most parameters) had statistically significant efficiency differences (LSD test; $p > 0.05$). Normal probability plot of residuals indicates that there is no as such non-normality of efficiency data distribution for the parameters of BOD_5, COD, TSS, R-PO_4 and total phosphorous. Neither are there significant outliers (those that significantly deviate from the normal probability line) for those parameters. However, for the parameters of sulfide, TDS, NH_3-N and chromium, one can't ascertain the normality of the efficiency data from the normal probability plot leading to the limitations of statistical data analysis such as ANOVA for those parameters. Plus, there are many outliers from the normal probability line for those parameters especially in the dry season.

Comparative Analysis

A comparison was made between the actual treatment plant efficiencies and international benchmark efficiencies (Table 6). Light shaded cells indicate values within the benchmark. Consequently, the dry season mean daily pollutant removal efficiency of the actual primary treatment unit was within the range of the benchmark for BOD_5, COD, TSS and chromium. In the wet season, the mean daily removal efficiency of BOD_5 was outside (less than) the benchmark value whereas that of TSS was well within the range. The combined primary secondary treatment mean daily efficiency in the dry season was well within the benchmark for COD, TSS, sulfide and chromium while that of BOD_5 was below the benchmark. For the wet season, all the daily and mean daily removal efficiencies were well within the benchmark for TSS removal while they were below the benchmark for BOD_5 removal.

Table 6. A comparison of actual efficiencies in both seasons with international benchmark (IUE IULTCS, 2008) (*wet season)

Parameter	Unit	Day1	Day2	Day3	Day4	Day5	Mean	IUE IULTCS (IUE IULTCS; 2008)
BOD_5 (%)	PRT	50	40	48.1	65.5	62.7	**53.3**	**50-65**
	PRSCT	76.7	82.7	84.2	84.6	74.6	**80.6**	**90-97**
BOD_5* (%)	PRT	87.7	16.7	23.7	-	-	42.7	**50-65**
	PRSCT	41.2	-116.7	33.1	-	-	-14.1	**90-97**
COD (%)	PRT	51	36.7	60.2	59.2	58.6	**53.1**	**50-65**
	PRSCT	86.7	89.4	91.5	90.5	89.6	**89.5**	**85-95**
TSS (%)	PRT	-	79.2	85.3	76.9	96.6	**84.5**	**80-90**
	PRSCT	-	98.2	98.7	98.8	98.8	**98.6**	**90-98**
TSS* (%)	PRT	96.8	90.4	93.8	67.1	-	**87**	**80-90**
	PRSCT	98.1	97.6	98.3	96.9	-	**97.7**	**90-98**
Sulfide (mg/l)	PRT	10.25	15.375	25.45	19.06	3	**14.6**	**2-10**
	PRSCT		0.175	0.085	0.225	0.75	**0.3**	**<1**
Chromium (mg/l)	PRT	1.281	<0.0001	1.306	1.196	1.248	**1**	**2-5**
	PRSCT	<0.0001	<0.0001	1.0861	<0.0001	2.546	**0.7**	**<1**

Some design efficiencies of the plant were also compared with the actual efficiencies (Table 7). Accordingly, the overall efficiency of the treatment plant at design was in such a way to comply with the national effluent release standard to surface water, which was well achieved for COD, BOD_5, sulfide and chromium. The primary-secondary combined treatment efficiencies at design, which were 87-95% for COD and 99% for sulfide were achieved by the treatment plant whose mean daily efficiencies were 89.5% for COD and 99.6% for sulfide. Nevertheless, the design removal efficiency for BOD_5 which is 95% was not achieved by the plant in both seasons. Among the reasons for the low BOD_5 removal efficiencies of the secondary and the primary-secondary combined treatment units could be the very high MLSS (with high dead microorganisms) within the AS aeration tank and the variable organic loading to the aeration tank of the AS.

Table 7. A comparison of actual efficiencies with some design efficiencies of the plant

Parameter	Preliminary treatment		Primary-secondary treatment		Overall treatment	
	Design Value (mg/l)	Actual mean daily value (mg/l)	Design efficiency (%)	Actual mean daily efficiency (%)	Design (objective)	Actual
COD	**1500***	**3366.7 ***	**87-95**	**89.5**	Compliance with national standard for release to surface waters	Compliance well achieved
BOD5	**600***	**742.1***	**95**	**80.6**		
BOD5*	**600***	**178.7***	**95**	**-14.1**		
Sulfide	**40***	**82.9***	**99**	**99.6**		
Cr (total)	**20****	**9.43****	**NA**	**73.9**		

** Before primary clarifier ** Chromium precipitation supernatant value; NA: not available; *wet season*

The actual final effluent quality at the outlet of the treatment plant was compared with national (Ethiopian) and international (World Bank) tannery effluent release standards for discharge to surface waters (see Table 1 for the standards). Accordingly, the final effluent daily and mean daily qualities were much below (within) the national standard for BOD_5, COD, sulfide, temperature and pH while they well exceeded the national standard for TSS and NH_3-N and obviously for total nitrogen. The final effluent daily and mean daily sulfide and pH values were also below (within) the World Bank standard though it was not the case for BOD_5, COD (except for one day), TSS and NH_3-N. The dry season daily and mean daily PO_4-P values were above the world bank total phosphorous release standard to surface waters, which is 2 mg/l. In the wet season, all the final effluent daily and mean daily total phosphorous values were below the national release standard, though they somehow exceeded the world bank standard. The dry season final effluent mean daily chromium (the freely available which is only part of the total chromium) amount (0.6mg/l) already exceeded the world bank total chromium release standard of 0.5mg/l.

The dry season treatment efficiency of the primary clarifier of the actual treatment plant was much better than those reported by other studies for BOD_5, COD and TSS (Shanmugasundaram and Murthy, 2000; Ezike et al., 2012). However, its TDS removal efficiency was much below that reported by Ezike et al. (2012), being almost equal to that of Shanmugasundaram and Murthy (2000). The COD and TSS removal of a primary clarifier as reported by Govindasamy et al. (2006) was, however, somehow better than that found in the actual study. Its wet season TSS removal efficiency was also much better than those of Shanmugasundaram and Murthy (2000) and and Ezike et al. (2012) whereas that of TDS was much lower than that reported by Ezike et al. (2012). Similarly, its BOD_5 removal efficiency in wet season was a little better than those of Shanmugasundaram and Murthy (2000) and Ezike et al. (2012).

The dry season secondary treatment was much more efficient than that of Govindasamy et al. (2006) and Shanmugasundaram and Murthy (2000) for COD and TSS removal. Its TDS removal was also better than that reported by Shanmugasundaram and Murthy (2000). On the other hand, it was by far less efficient than that of Govindasamy et al. (2006) and Shanmugasundaram and Murthy (2000) in terms of BOD_5 removal. Its wet season TSS removal efficiency was somewhat better than that reported by Govindasamy et al. (2006) and Shanmugasundaram and Murthy (2000) while its TDS removal efficiency was a bit better than that of Shanmugasundaram and Murthy (2000).

One major difference between the actual study and the other studies is the low BOD_5 removal efficiency of the actual secondary treatment which could be due to the very high MLSS (with high dead microorganisms) within the AS aeration tank and the varying organic loading to the aeration tank of the AS, among others. The actual plant primary and secondary treatment units TSS removal efficiency is found to be better than others in most cases may be due to differences in the design of primary and secondary clarifiers and coagulation efficiencies among others.

Conclusion

The treatment performance of tannery wastewater treatment plants in Addis Ababa Area, Ethiopia was evaluated through a case study of a selected industry. Accordingly, the actual treatment plant is well functional, reasonably efficient and attained the national tannery effluent discharge standard for major parameters such as BOD_5, COD, sulfide, chromium and total phosphorous. No seasonal (except for the combined primary-secondary treatment in removing NH_3-N and TSS) and day-to-day treatment efficiency variations were observed though further research is essential in this regard. Actual plant design and international bench mark treatment efficiencies were also well achieved for some parameters. However, big limitation was found to exist in terms of nitrogen and dissolved solids removal as well as sludge management.

Recommendation

Better cleaner production must be practiced to aid end-of-pipe treatment of pollutants, mainly NH_3-N and TDS. Incorporation of nutrient (mainly nitrogen) removal systems in to the existing plant is recommended either through intermittent aeration or pre-anoxic tank approaches. Enhanced phosphorous removal may also be implemented through incorporation of anaerobic tank in the system before the pre-anoxic tank. Adequate monitoring and control of process variables such as pH, temperature, OLR, F/M, MLSS and toxic substances is also strongly recommended. Chrome must be recovered for reuse rather than simply precipitated and disposed of openly in the factory compound as chrome reuse can significantly reduce chrome associated cost. Finally, further research needs to be conducted especially on the seasonal variation of treatment system efficiency to complement the finding of the current study.

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