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PHYSICOCHEMICAL CHARACTERIZATION OF ASMARA BREWERY EFFLUENTS

Aremanda Ramesh Babu*, ORCID: 0000-0002-6609-8640,
Tekle Arsiema, ORCID: 0000-0003-0239-0834,
Daniel Heaven, ORCID: 0000-0003-4064-038X,
Berhane Filmon, ORCID: 0000-0003-4601-4128,
Mehari Abiel, ORCID: 0000-0002-8891-4805

Department of Chemical Engineering, Mai Nefhi College of Engineering & Technology (MCOETEC), P.O. Box 344, Asmara, Eritrea.
*Corresponding author: Ramesh Babu Aremanda, *ramesh.nitrkl@gmail.com*

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Abstract. Brewing industry is water intensive and consequently generates huge volumes of wastes. Bottle washing and brewing operations recognized as the major effluent sources of Asmara Brewery Corporation Share Company (ABCSC), Eritrea. Effluents of bottle cleaning and brewing sections and their mix of 2:1 characterized on weekly basis for the resemblance of national and international effluent standards. DO levels of wastes detected as low as 2.14 mg/L, which does not support any life and eventually poses severe environmental issues. TSS, COD and BOD_5 levels have exceeded EU and EPA effluents standards. COD and BOD_5 concentrations estimated were higher than other reported breweries and beyond the benchmarks of Brewer's Association, USA. Brewery wastewater has a mean COD of 83240 mg/L and BOD_5 of 11066 mg/L and highly contaminated than bottle cleaning and mixed effluents. Therefore, in order to reuse voluminous wastewater and to curb excessive COD levels, effluents from ABCSC require special attention prior to their discharge into the public sewer line.

Keywords: *Industrial wastewater, characterization, breweries, environmental pollution, chemical oxygen demand, biological oxygen demand.*

Rezumat. Industria berii este consumatoare de apă și, în consecință, generează volume uriașe de deșeuri. Spălarea sticlelor și operațiunile de fabricare a berii sunt recunoscute ca surse majore de efluent ale Asmara Brewery Corporation Share Company (ABCSC), Eritreea. Efluenții secțiilor de curățare a sticlelor și de preparare a berii și amestecul lor de 2:1 sunt caracterizați săptămânal privitor la corespunderea lor standardelor naționale și internaționale pentru efluenți. Nivelurile de DO ale deșeurilor detectate variază până la 2,14 mg/L, ceea ce nu susține nicio formă de viață și în cele din urmă ridică probleme grave de mediu. Nivelurile TSS, COD și BOD_5 au depășit standardele UE și EPA privind efluenții. Concentrațiile de COD și BOD_5 estimate au fost mai mari decât pentru alte fabrici de bere raportate și dincolo de criteriile de referință ale Asociației Berarii, SUA. Apa uzată a fabricii de bere are un COD mediu de 83240 mg/L și BOD_5 de 11066 mg/L și sunt contaminate la curățarea sticlelor și amestecarea efluenților. Prin urmare, pentru a reutiliza volumele mari de ape uzate și pentru a reduce nivelurile excesive de COD, efluenții din ABCSC necesită o atenție deosebită înainte de deversarea lor în canalizarea publică.

Cuvinte cheie: *Ape uzate industriale, caracterizare, fabrici de bere, poluare a mediului, necesar chimic de oxigen, necesar biologic de oxigen.*

1. Introduction

Water usage has been increasing globally by 1% every year since 1980's and is expected to accelerate at similar rate in future due to continuous growth of population and socio-economic development activities [1]. Prudent utilization of fresh water resources accompanied with promising protection of natural ecosystems is one of the most prominent issues of today's world. Plenty of research has been done or in progress emphasizing optimization of fresh water consumption in domestic, agricultural and industrial applications. Furthermore, there have also been reported the utilization of wastewater with innovative treatment technologies which, at the same time reduces environmental pollution significantly. Different types of chemicals discharged into the aquatic systems through industrial activities pose risk to human health and environment. Some of them are persistent, toxic and partly biodegradable; hence, they do not easily removed in conventional wastewater treatment plants and need a special attention to develop an eco-efficient method for the treatment of a specific pollutant [2].

The brewing industry is water intensive and consequently produces huge volumes of wastewater despite of the beer is fifth most consuming alcoholic beverage in the world and brewing is a multibillion-dollar industry that creates jobs, generates taxes, supports agriculture and attracts tourism [3, 4]. Beer brewing also characterized by the use of high-quality fresh water due to public perception about the deterioration in quality of beer [3, 5]. It was mentioned in several reports that for every 1 L of beer production, approximately 6 to 10 L of water is used [3, 6, 7]. Water in any brewery used typically for brewing, cleaning and cooling processes [7]. Usually, wastewater is pre-treated within the brewery before being discharged into the waterway or municipal sewer system [3]. However, most of them dispose their effluents without adequate characterization, quantification and pre-treatment due to economic and technological constraints, which may have adverse effects on the municipal treatment plant by reducing the efficiency of waste treatment plant and overloading the system [6]. In recent years, a considerable number of environmental issues includes water and soil pollution problems such as eutrophication of rivers and dams [6], inhibition of seed germination, reduction of soil alkalinity and damage of agricultural crops have been reported due to high inorganic and organic matters from industrial effluents [2].

The quantity and characteristics of brewery wastewater can differ significantly from time to time and location to location as it depends on several different processes that occur within a brewery such as malting, mashing, wort processing, fermentation, filtration, bottle cleaning and packaging. [3, 7]. Commonly, the effluents of the brewery are characterized by high organic load and high acidic content [3, 6, 7]. It consists of soluble sugar, soluble starch, carbohydrates, ethanol, volatile fatty acid, suspended solids, yeast etc. [7]. However, the major component of brewery effluents is organic material, as evidenced by high chemical oxygen demand (COD) and biological oxygen demand (BOD) [3, 8]. Both of these parameters (i.e. COD and BOD) are imperative diagnostic parameters for determining the quality of water in natural waterways and waste streams [3, 9].

Case Studied

Asmara Brewery Corporation Share Company (ABCSC) originally known as "MELOTTI BREWERY" established in 1939 and currently it is the only brewery in Eritrea, located in the southern region of Asmara city in central region of the country. The plant's water consumption rates fluctuates from 8.12 to 19.80 L with an average value of 10.76 L for every 1 L of beer produced against 3.5 L, an average water use by the international best practices. Due to the poor design of water supply infrastructure with lack of awareness of water management policies, the water usage rates are very high in the plant [10]. The total average daily available process water is about 870 m^3/day, which is slightly less than the planned water demand of 882.38 m^3/day on average, regardless of the status of water quality and water use and management. Hence, ABCSC system manufacturing operations are vulnerable to the scarcity of process water and it is essential to adopt the best practices of water use minimization, and it is mandate to develop wastewater reuse and recycle technologies as early as possible. Because of voluminous water usage, brewery industry discharges large volumes of highly polluting effluents the year [11]. Noted that effluents from individual process steps are variable. For example, bottle-washing results in a large wastewater volume, but it contains only a minor part of the total organics discharged from the brewery processes. On the other hand, effluents from fermentation and filtering are high in organics/biochemical oxygen demand (BOD), but generally low in volume, accounting for about 3% of the total wastewater volume but 97% of the BOD [11]. Therefore, the present study mainly intensive on identification of major manufacturing operations of the plant that generates higher volumes of wastewater and assessment of effluent compositions to facilitate necessary data for further development of appropriate treatment methods for wastewater recycling. In addition, this may serve as database for the industry and local authority as well to assess the degree of compliance by the industries to the legislative guidelines for effluent disposal.

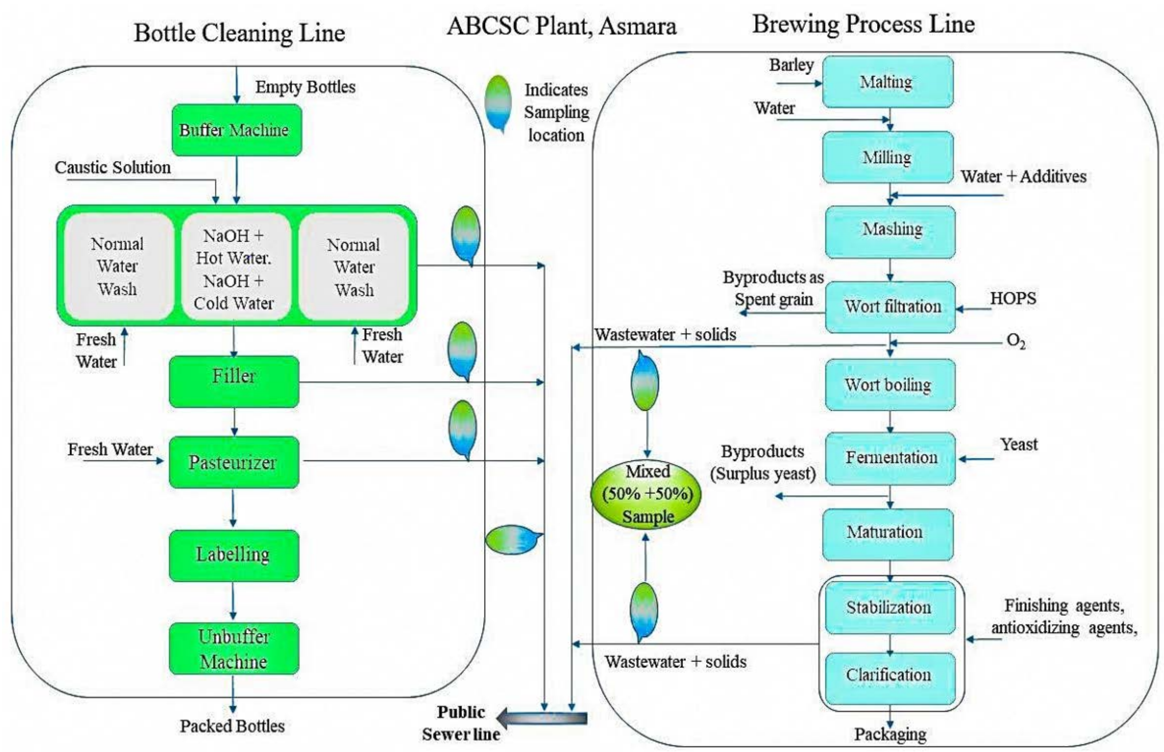

Figure 1. Bottle cleaning and brewing process lines of ABCSC with specified sampling location.

2. Materials and Methods

2.1. Wastewater Sample Collection

Effluent water samples collected from the pre-screened independent sewer exit points of bottle cleaning and brewing sections, two major wastewater-generating units of Asmara Brewery Corporation Share Company (ABCSC) for every week during April and May months, 2021. Samples also collected for one time from Washer, filler and pasteurizer units of bottle cleaning section.

2.2. Characterization of wastewater

Wastewater samples analyzed for physicochemical parameters such as pH, temperature, total alkalinity, salinity, electric conductivity (EC), turbidity, total suspended solids (TSS), Dissolved Oxygen (DO). They were also tested to know the presence of cations such as Sodium (Na^{+}), Potassium (K^{+}), Manganese (Mn^{2+}), Total Iron (Fe) and Chromium (Cr^{6+}). Anions such as Sulphate (SO_4^{2-}), Chlorine (Cl), Nitrate (NO_3^{-}), Nitrite (NO_2^{-}), Phosphate (PO_4^{3-}),) were also measured. Chemical contaminants were determined by quantifying Chemical Oxygen Demand (COD) and Biological Oxygen Demand for five days (BOD_5).

2.3. Conventional and Instrumental Testing Methods

Salinity, Electric Conductivity (EC) and Temperature measured by using calibrated electrode (WTW Multi 197i, USA). Although pH does not have direct impact, usually it act as an indicator of the process stability and it was read by using a pH meter (HANNA instruments, UK), while the conductivity display the presence of total dissolved solids (TDS) and palatability of water [12]. The dissolved oxygen (DO) content of water determines the activation of biological processes, measured by using a DO meter in mg/L. Total alkalinity, Chloride, total hardness and $CaCO_3$ were measured using digital titration procedures followed by the laboratory of Ministry of Water, Land and Environment of Eritrea.

To measure total alkalinity, 25 mL of a sample titrated with 0.02N H_2SO_4 in presence of Bromcresol Green – methyl red pillow powder (BCG) reagent has turned the solution from green color to pink. Turbidity describes the cloudiness of water caused by suspended particles, chemical precipitates, organic particles and organisms. Turbidity typically expressed as nephelometric turbidity units (NTU) and measured by using Eutech TN-100 instrument made by Thermoscientific, UK. The BOD_5 measurement accomplished using the respirometric method for five days (WAGTECH, FTC 90 system, UK). The COD concentration in the wastewater determined by close refluxing according to the standard method 5220D. Block heater (Stuart, SBH 200D, UK) was first used to digest the samples at 150°C for 2 h in COD vials containing the digestion solution (0−15,000 mg COD/L, acquired from HACH, Germany). Then, COD concentration quantified using a discrete auto-analyzer (HACH, Germany).

Spectrophotometer applied to know the presence of various chemicals in the sample of wastewater tested. System was calibrated at corresponding wavelengths to measure nitrogen in nitrites and nitrates, manganese, iron, sulfates, phosphates and chromium as shown in Table 1. After calibrating the equipment, a bottle of 25ml filled by the sample and appropriate reagent was added and mixed for specified reaction time and measured corresponding absorbance on spectrophotometer. Nitrate and nitrite ions not found from the spectrophotometer reading directly. Instead, nitrogen in nitrates and nitrites found from the spectrophotometer reading, later Nitrates and Nitrites are calculated as:

$$NO_3^{\,-} = N - NO_3^{\,-} \times 4.429$$
$$NO_2^{\,-} = N - NO_2^{\,-} \times 3.286$$

The amount of sodium and potassium present in the wastewater sample measured using the flame photometer shown in fig 2B. The function of this instrument is similar to spectrophotometer except that it uses flame rather than light. Initiation step takes some time once it turned on, then system calibrated prior to read the values for actual samples. After that, by taking the sample in a small measuring cup and inserting aspiration tube in to the cup of the sample, and supplied into the flame photometer to read its absorbance.

Table 1

Characterization methodology using spectrophotometry

Test	Code	Wave length (nm)	Reagent	Mixing method	Reaction time (min)
Manganese(Mn^{+2})	295	525	Buffer, citrate type Sodium Periodate	Invert to mix Invert to mix	2
Total Iron (Fe)	265	510	FerroVer	Swirl to mix	3
Sulfates (SO_4^{2-})	680	450	SulfaVer 4	Swirl vigorously to mix	5
Nitrates (N-NO_3^-)	355	500	NitraVer 5	1min vigorous shake	5
Nitrites (N-NO_2^-)	371	507	NitriVer 3	Swirl to mix	15
Phosphates (PO_4^{3-})	490	890	PhosVer 3	30sec vigorous shake	2
Chromium (Cr^{+6})	90	540	ChromaVer 3	Swirl to mix	5

2.4. Statistical Analysis

Compositions of bottling line wastewater and mixed streams of 2:1 of bottling and brewery lines wastewater samples are analyzed and the results are verified with analysis of variance (ANOVA) study using Microsoft Excel®, 2016 software.

Figure 2. a) Spectrophotometer b) Flame Photometer.

The variance and mean values of characterized parameters are determined for the comparison with the reported values for other breweries and other industrial effluents from the literature and also with national and international industrial effluent standards.

3. Results and Discussion

According to the informants of ABCSC, approximately 8.455 L of wastewater discharges per every L of beer produced and it is mainly comprised of two major process lines i.e., bottle cleaning (BC) line and brewing line. Despite of the water consumed in BC line discharged totally into the sewer a basis for the wastewater treatment set by assuming that BC line alone contribute 2/3rd of the total wastewater generated from the ABCSC plant and the remaining by the brewing line. To identify the qualitative nature of the BC wastewater, samples tested once from each cleaning equipment for physicochemical characteristics as given in Table 2. Wastewater from filler and pasteurizer units have low pH values whereas in washer shown significantly higher values and which resulted a further higher value of the BC line sample collected from a single exit point source just before it discharges into public sewer line. Filler and pasteurizer wastes have shown greater variation from washer operations. Higher COD values recorded for filler and pasteurizer discharges.

Table 2

Physicochemical Properties of Wastewater from Bottle Cleaning Operations in ABCSC

Parameter	Point Sources Wastewater from Bottle Cleaning Section					
	Filler	**Pasteurizer**	**Washer 1**	**Washer 2**	**Washer 3**	**Bottle Cleaning**
Temperature (°C)	17.3	17.4	16.9	16.3	17.7	19
pH	5.72	5.91	11	10.81	11.04	12.36
EC (µs/cm)	499	566	1696	1350	1290	3840
Turbidity (NTU)	5.85	83.8	94.5	382	1400	112
Salinity (mg/L)	0	0	0.7	0.5	0.4	3.5
Sodium Na^+(mg/L)	37.5	38.4	269	209.7	210	526.5
Potassium K^+ (mg/L)	16.1	14.5	3	17.1	3	12.2
DO (mg/L)	2.43	0.67	5.66	5.85	5.87	3.28
COD (mg/L)	4700	1350	30	42	90	4800
BOD_5 (mg/L)	1926.7	806.7	8.9	10	11.1	2310

Note: DO-dissolved oxygen; COD-chemical oxygen demand; BOD_5 - biological oxygen demand for five days.

Brewing line has two major discharge streams from wort filtration and clarification units, hence samples of mixed (50 % of wort filtration waste and 50 % of clarification wastewater) stream have considered as brewery wastewater. Samples were collected for five consecutive weeks, from the both BC line (BCWW) and brewery lines (BRWW) and mixed wastewater (MWW) samples of 2/3rd of BC line discharge and 1/3rd of brewery line discharge were also prepared. Weekly samples characterized for physicochemical parameters and their analysis revealed that they possess greater diversity in COD values and the samples collected during first two weeks have recorded with higher COD values as shown in Figure 3, whereas BRWW samples have shown higher BOD_5 than BCWW and MWW samples in Figure 4.

BOD_5/COD values were higher for BRWW samples; a value of 0.547 was observed as greater than any other sample and recorded by 4th sample of BRWW as in Figure 5.

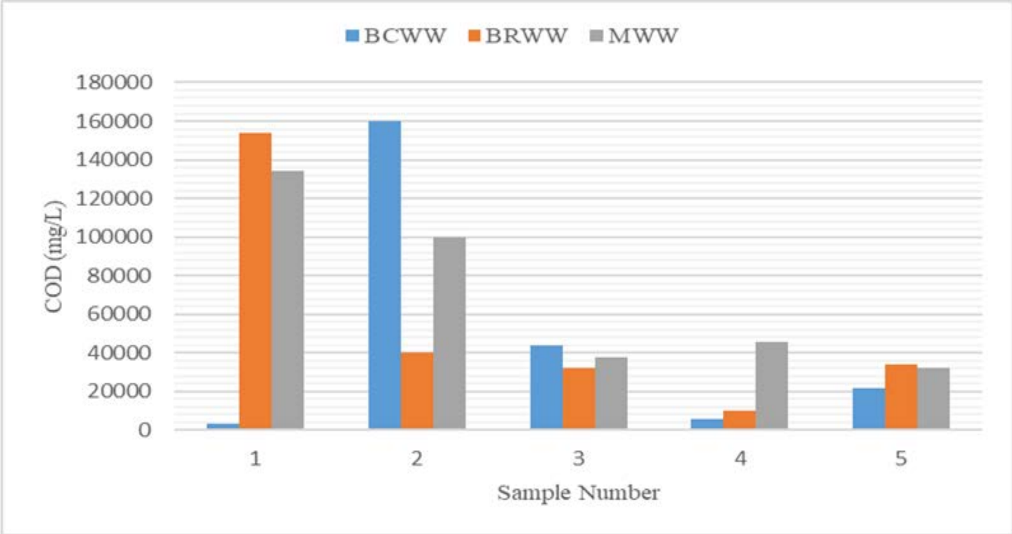

Figure 3. Weekly estimated chemical oxygen demands of Asmara brewery waste samples.

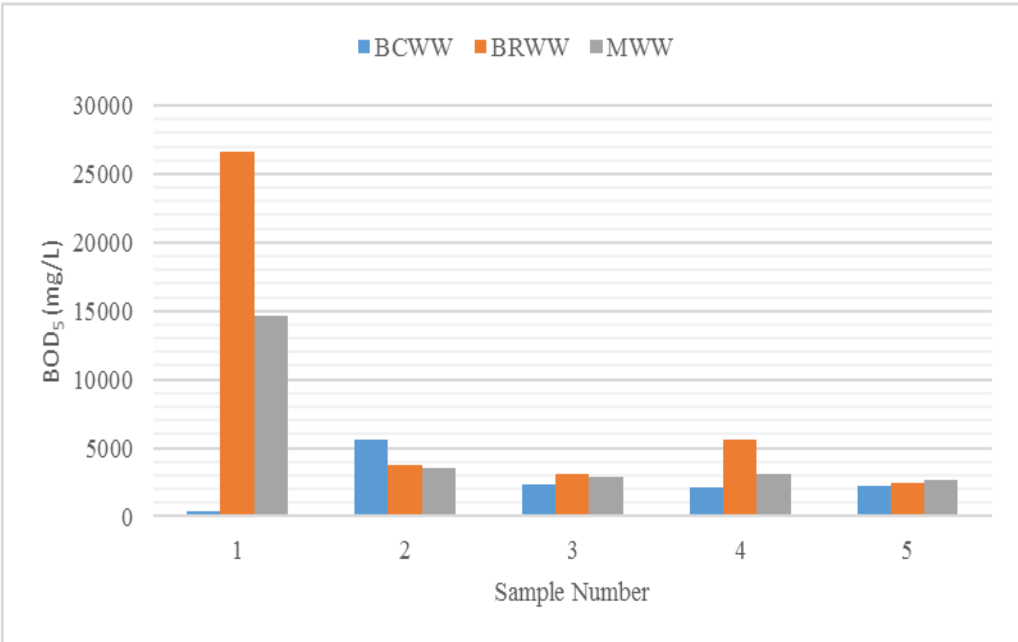

Figure 4. Weekly estimated biological oxygen demands of Asmara Brewery waste samples.

Although pH usually has no direct impact on environment, it is one of the most important operational water quality parameters and plays key role in controlling minimization of corrosion of water carrying systems. pH values of all the samples studied hold relatively higher pH values except for the samples collected during 2nd week. Bottle washer consumes chemicals such as caustic soda, it caused for higher pH values of BCWW samples.

However, lower- pH (approximately pH -7 or less) water is more likely to be corrosive. BRWW samples shown lower pH values than BCWW and MWW samples and a pH of 2.62 was noted in the sample collected during 1st week as the lower than any other samples as shown in Figure 5(a).

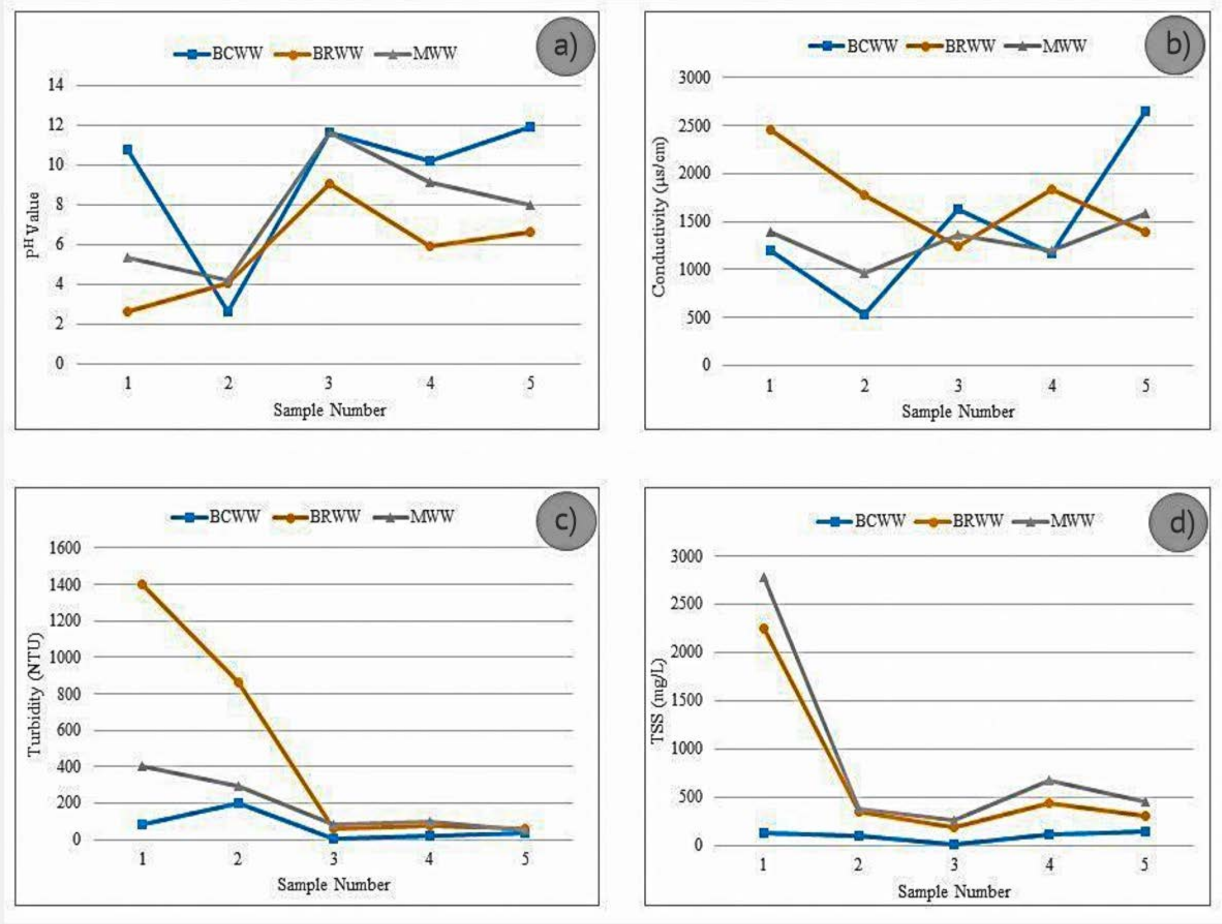

Figure 5. Weekly estimated pH (a), electric conductivity (b), turbidity (c) and total suspended solids (d) values of Asmara Brewery effluents.

Dissolved oxygen (DO) levels in the water indicate the potential existence of aquatic life. Nevertheless, a value of DO less than 4.5 mg/L can't support any life in water [13]. Figure 6 depicts that BRWW samples has lower DO levels than any other samples and it was also seen a lowest value of 0.39 mg/L for BRWW sample collected during 2nd week of our study. Thus, BRWW and MWW samples doesn't support any aquatic life but BCWW has comparatively higher DO levels, yet they are far lower than 9.5 mg/L above which a healthy life could be identified in water bodies [13].

The palatability of water is determined with the presence of total dissolved solids (TDS) which can be estimated through electric conductivity. Higher levels of TDS, greater than about 1000 mg/L may objectionable to handle, owing excessive scaling in pipes, heaters, boilers and household appliances [12]. Higher conductivity has seen for BRWW samples collected during 1st week and also for the BCWW samples collected in 5th week. MWW samples have shown less deviation among the conductivity values measured as described by the Figure 5(b). Turbidity describes the cloudiness of water, increasing turbidity reduces the clarity of water to transmitted light. Brewery wastewater samples have recorded with higher turbidity values than BCWW and MWW whilst BCWW has lower turbidity than both MWW and BRWW for all the samples. Turbidity also indicate the presence of physical, chemical and biological contaminants. Presence of total suspended solids (TSS) indicate the direct measure pollutants in the wastewater, and higher TSS values were noticed in the first week samples of MWW and BRWW. MWW samples have shown higher TSS levels than any other samples collected in every week as shown in Figure 5(d) whereas BCWW samples were observed with lower TSS values.

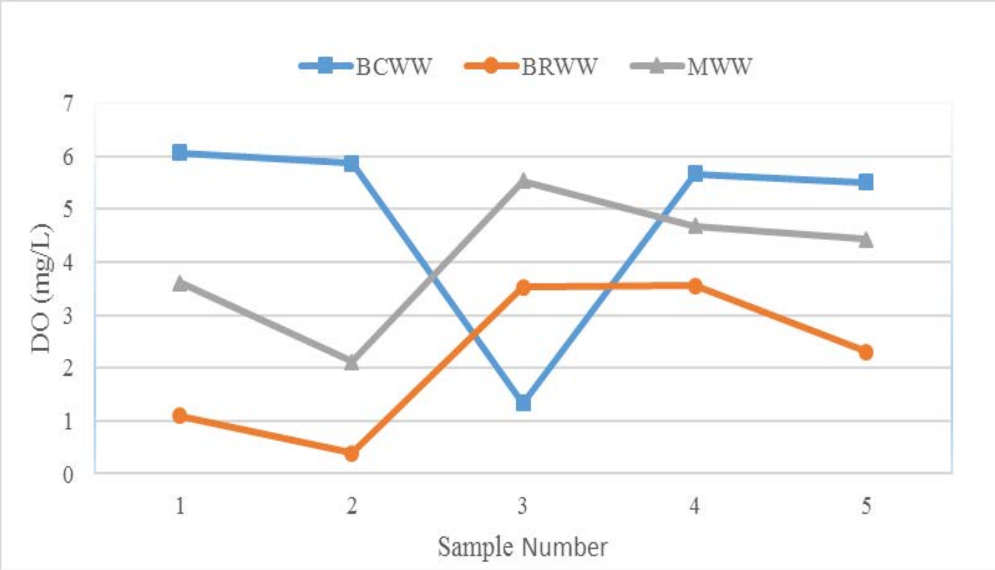

Figure 6. Weekly estimated dissolved oxygen levels of Asmara Brewery discharges.

Table 3

ANOVA Study of ABCSC Brewery and Bottle Cleaning and Mixed wastewater characteristics

Parameters	Bottle cleaning wastewater		Brewery Wastewater		Mixed Wastewater	
	Range	Mean	Range	Mean	Range	Mean
Temperature (°C)	19-34.4	28.36	26.3-34.4	29.6	24-31.2	27.94
pH	2.62-12.36	9.41	2.62-9.03	5.6	4.22-11.59	7.8
EC (μs/cm)	538-3840	1432.6	1244-2450	1740.2	968-1578	1297.2
Turbidity (NTU)	5.03-112	83.366	58.9-1400	599.8	51.3-400	218.3
Salinity (mg/L)	0-3.5	1.01	0.4-1.1	0.7	0.3-0.6	0.46
Sodium Na^+ (mg/L)	29.8-526.5	246	26.7-199.4	108	39.5-185	122.27
Potassium K^+ (mg/L)	2.1-184.8	52.12	6.7-64.5	24.8	6.3-41.1	17.77
DO (mg/L)	1.33-6.06	3.84	0.39-3.55	2.14	2.12-5.53	3.98
COD (mg/L)	3500-160000	43560	10200-154000	83240	32000-134000	70000
BOD_5 (mg/L)	357-5633	3594	3133-26667	11066	2856-14667	6641
COD/BOD_5	2.57-28.41	13.9	1.83-14.08	8.51	9.17-27.9	15.44
Total hardness	40-400	166.67	400-900	709.33	68-392	273.33

Note: EC - electric conductivity; DO - dissolved oxygen; COD - chemical oxygen demand; BOD_5 - biological oxygen demand for five days; NTU - nephelometric turbidity units.

A single factor analysis of variance (ANOVA) study was performed to determine the mean and variance values of all characteristic parameters and the results are listed in Table 3. COD and BOD_5 values were deviated highly for BCWW, BRWW and MWW samples. The highest mean of COD has seen as 83240 mg/L for BRWW samples with a range of 10200-154000mg/L. Although BCWW samples have shown less mean value, a significant range of COD, 3500-160000 mg/L was noted. The mean COD values of all BRWW, BCWW and MWW samples were too far from the benchmarks of Brewers Association, USA (Table 4). The variations in the COD concentrations for each week could be as a result of variation in the activities and housekeeping practices of the brewery plant, which could cause serious environmental impact and closure of the production plant by the municipal authority, if not checked.

Table 4

Comparison of brewery wastewater with Eritrean Effluent standards and Effluent benchmarks of BA

Parameter	Bottle Cleaning line Effluent Composition	Brewing line Effluent Composition	Mixed (2:1) Effluent Composition	Industrial Effluent standards entering Public Sewers in Eritrea [15]	Brewers Association (USA) Benchmarks for Effluent [14]
Temperature (°C)	28.36	29.6	27.94	< 43	NA
pH	9.41	5.6	7.8	6-10	3-12
TDS	1228.67	1166	869	< 3000	< 3000
TSS	98.2	606.8	203	< 600	200-1500
Sulphate (mg/L)	50.5	236.75	95	< 1500	NA
Fe (mg/L)	0.714	1.466	0.896	< 25	NA
Mn (mg/L)	2.03	7.13	3.325	< 25	NA
COD (mg/L)	43560	83240	70000	NA	1800-5500
BOD_5 (mg/L)	3594	11066	6641	NA	600-5000
COD/BOD_5	12.12	7.522	10.54	NA	NA

Note: TDS - total dissolved solids; TSS - total suspended solids; COD - chemical oxygen demand; BOD_5 - biological oxygen demand for five days.

Physicochemical characteristics of BCWW, BRWW and MWW were analyzed to compare with industrial effluent quality standards that permit into public sewers of Eritrea as shown in Table 4. Mean values of Temperature, pH, TDS, TSS, Sulphate, Iron, Manganese were observed as within permissible limits of national industrial effluent standards, Eritrea. Average concentration of pH, TDS and TSS were also notified as within the limits of effluent benchmarks set by the Brewer's Association, USA. BOD5 is an indicator of organic loading in the effluent streams, brewery operations have showed 4 times greater BOD_5 than bottle washer line. Mix of 1/3rd of brewery effluent with 2/3rd of BCWW, has doubled the levels of BOD_5. Brewery discharges also shown doubled COD loadings than bottle cleaning wastes. BOD_5 & COD levels of wastewater from bottle cleaning line were comparatively lower and BOD_5 concentration was also dwell within the limitations of Brewer's Association, benchmarks. In all other cases, COD and BOD_5 levels were very much higher than usual brewery effluents which indicates greater chemical and biological contamination of ABCSC effluents. As COD/BOD_5 is 12.12 for BCWW, it has loaded with high levels of chemical contaminants than BRWW and MWW, whereas COD/BOD_5 is 7.522 for BRWW, it contains higher organic loadings.

Table 5

Comparison of ABCSC wastewater characteristics with other reported parameters in the literature

Parameter	This work	Gemeda et al. [16]	Akunan et al. [17]	Enitan et al. [18]	Brito et al. [19]	Driessen & Vereijken, [20]
Temperature (°C)	24-31.2	20.9	ND	27.9	30-35	18-40
pH	4.22-11.59	6.55	5-11	6.0	6.5-7.9	4.5-12
EC (µS/cm)	968-1578	5425	ND	1516	ND	ND
TSS (mg/L)	154-520	140.15	ND	1826.74	ND	200-1000
TN (mg/L)	0.004-14.7	166.5	20-600	13.29	12-31	25-80
TP (mg/L)	0-19.45	11.55	4-103	23.71	9-15	10-50
Total COD (mg/L)	32000-134000	210.9	1800-50000	5341	800-3500	2000-6000
BOD_5 (mg/L)	2700-14667	209	2700-38,000	3215.27	520-2300	1200-3600

Note: EC - electric conductivity; TSS - total suspended solids; TN - total nitrogen; TP - total phosphorous; COD - chemical oxygen demand; BOD_5 - biological oxygen demand for five days.

Quality of ABCSC mixed wastewater (MWW) composition was comparable with other reported parameters in the literature as in Table 5.

Table 6

Comparison of brewery wastewater with other industrial and municipal wastewater

Parameter	Brewery	Dairy (Milk-cheese) plants	Tannery	Textile Mills	Municipal
pH	4.22-11.59	5.2-11.3	8-11	4.5-10.1	6-8
Salinity (g/L)	0.3-0.6	0.5	6-40	0.5-0.9	<0.5
TSS (mg/L)	154-520	350-1082	2070-4320	20-210	100-350
TN (mg/L)	0.004-14.7	14-450	250-1000	14-72	20-85
TP (mg/L)	0-19.45	37-78	4-107	1-18	4-15
Total COD (mg/L)	32000-134000	189-20000	3500-13500	1900-100000	250-1000
BOD_5 (mg/L)	2700-14667	709-10000	1000-7200	700-1650	110-400
Reference	This Work	Bielefeldt, 2017 [21]	Bielefeldt, 2017 [21]	Bielefeldt, 2017 [21]	Bielefeldt, 2017[21]

Note: TSS - total suspended solids, TN - total nitrogen; TP - total phosphorous; COD - chemical oxygen demand; BOD_5 - biological oxygen demand for five days.

The range of pH was similar with Driessen and Vereijken study in 2003 [20]. Enitan et al. [18] has reported a conductivity of 1516 μS/cm, which dwell in the range of this study. TSS concentrations of this report are moderate when it compared with Enitan et al. [18], F.T. Gemeda et al. [16], and Akunan et al. [17], have reported higher range of total nitrogen (TN) values, but this study is comparable with Enitan et al. [18], and Brito et al. [19]. Total Phosphates (TP) are comparable with all the reports with slight deviation. COD concentrations are too higher than any other reported values, which indicate the presence of high levels of chemical contaminants in ABCSC wastewater. BOD_5 levels also higher than all reported values except Akunan et al. However, these quantitative comparisons made a clear conclusion that all the characteristics are case specific and have greater diversity in their values.

The study also considered brewery industry to compare with other relevant process industries in Eritrea concerning their effluent compositions. Dairy, tannery, textile mills and domestic wastewater were comparable with brewery effluents as shown in Table 6. Chemical loadings of ABCSC effluents are competitive with effluents of textile mills. BOD_5 concentrations are approximately in the rage of dairy wastes, pH values are as high as dairy and tannery wastes and nutrients such as nitrogen and phosphorous are typically in the rage of textile wastes. Noted that most of the parameters of brewery industry wastes are different from municipal wastewater. Brewery wastes cannot be treated usually with municipal wastewater treatment plant, as they require special attention.

Table 7

Assessment of ABCSC effluent quality with EU and EPA effluents standards

Parameter	Bottle Cleaning line Effluent Composition	Brewing line Effluent Composition	Mixed (2:1) Effluent Composition	EU, Effluent Limits [22]	EPA, Effluent Standards [23]
TSS	98.2	606.8	203	35	50
COD (mg/L)	43560	83240	70000	125	150
BOD_5 (mg/L)	3594	11066	6641	25	50
COD/BOD_5	12.12	7.522	10.54	5.0	3.0

Note: TSS - total suspended solids; COD - chemical oxygen demand; BOD_5 - biological oxygen demand for five days.

TSS, COD and BOD_5 levels of ABCSC discharges are beyond international limits such as EU discharge limits EPA, USA effluents standards as shown in table 7. Suspended solid are more in brewery effluent than bottle cleaning wastewater, and it is 17 times and 12 times of EU and EPA standards. COD concentration of mixed effluent is 560 and 467 times of EU and EPA effluents limits respectively, which indirectly warns the company to take immediate action to control such higher chemical contaminants in the effluents. In other words, organic loadings of mixed effluent exceed 256 and 133 times the permitted values of EU and EPA. COD/ BOD_5 estimated as twice the EU limit and thrice the EPA regulated value that specifies more presence of chemicals than organics.

4. Conclusions

According to the informants of ABCSC, approximately 8.455 L of wastewater discharges per every L of beer produced and it is mainly comprised of two major process lines i.e., bottle cleaning (BC) line and brewing line. Thus, samples of bottle cleaning and brewery effluents were collected weekly and their physicochemical characteristics were analyzed. Mean values of dissolved oxygen (DO) of all wastewater samples were found lower than 4.5 mg/L. Thus, it indicates no life in such effluents and subsequently causes for severe environmental issues. The results of this study showed that COD and BOD_5 concentrations of wastewater from ABCSC are higher than other brewery industries reported in the literature and they are also beyond the benchmarks set by Brewer's Association, USA. TSS, COD and BOD_5 levels have exceeded the international standards such as EU and EPA effluents standards, which indicate an immediate action by the company to prevent the cost of penalties. Therefore, there is a need to treat the brewery wastewater in order to protect the environment and to reduce the use of fresh water sources.

The levels of pH, TSS, COD and BOD_5 of brewery effluents are beyond the ranges of municipal waste water, hence they can't be treated together. Instead, brewery wastewater might be treated separately with a special attention to remove higher COD levels. As the characteristics of bottling and brewery effluents are distinct, treatment technologies can be developed based on their significant variation in characteristics. As COD/BOD_5 is 12.12 for BCWW, it contains high levels of chemical contaminants than BRWW and MWW, whereas COD/BOD_5 is 7.522 for BRWW, it has higher organic loadings. Characteristics of mixed wastewater were determined to develop a suitable pretreatment plant for the potential reuse of water through an existing RO plant in ABCSC.

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Conflicts of Interest. The authors declare no conflict of interest.

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Submission of manuscripts: jes@meridian.utm.md