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Brewery Effluent Treatment with Conventional and Natural Coagulants

Aremanda Ramesh Babu[a*], Filmon Berhane[a], Heaven Daniel[a], Abiel Mehari[a], Arsiema Tekle[a]
[a]*Department of Chemical Engineering, Mai Nefhi College of Engineering & Technology (MCOETEC), Asmara, Eritrea.*
[*]Corresponding author: *ramesh.nitrkl@gmail.com*

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ABSTRACT. In water scarce countries such as Eritrea, maintaining brewery industry remain ever challenging task. Currently, Asmara breweries is the only beer producing factory consuming 8.46 L of water per every L of beer produced which is notably higher than Brewer's Association (BA) benchmark and consequently generates 7.53 L of wastewater/L of beer. Bottle cleaning and brewery activities ascertain ample effluent bases. Wastewater from bottle cleaning (BCWW), brewery (BWW) and mixed (MWW) have attributed a wide spectrum of 3500-160000 mg/L of COD and 327-26667 mg/L of BOD_5, which are significantly overtops other reported brewery effluents. Physicochemical treatments including coagulation with conventional (alum) and natural (MO seed) flocculants have tested to remove higher COD and BOD_5 concentrations of brewery effluents. Optimal coagulant dosage determined by accounting turbidity as a key performance indicator. Alum treatment of BCWW and MO seed flocculation of MWW have resulted in lower turbidity levels of 0.49 and 6.17 NTU at 60 mg/L of dosages respectively. The optimal quantities of 92.2 % and 86.6% (by weight) of water recovered from alum treatment of BCWW and MO seed coagulation of MWW respectively. Higher sludge volumes recorded as a major disadvantage in alum coagulation whereas natural coagulant, MO seed manifested competitive results in removal of COD, BOD_5, Chlorine, Nitrogen, Sulphate, Sodium, TDS and TSS along with P^H stabilization. In addition, 97.2% of influent turbidity removed through MO seed coagulation treatment, an equipollent to alum despite of four fold increment in potassium levels.

1. INTRODUCTION

Ever raising demand for water paid special attention to recycle wastewater streams from domestic and industrial effluent sources. In connection, the brewery industry consume high quantities of water for producing beer, cleaning, washing, and sterilizing. Despite of the fact that the beer is the fifth most consumed beverage globally [1], beer brewing is one of the water-intensive processes with an average water use rate ranges from 3.5 L to 10 L per one L of beer produced. The aforementioned range covers a plant that adopted the best water management practices to the plant where the staff does not have least knowledge about water usage policies [2]-[4]. Thus, many researchers have focused on the brewery industry for several years to develop various methods targeting water usage minimization, reuse of processed water for a suitable application and treatment of wastewater to produce primary or secondary quality water.

Cleaner production and waste minimization initiatives in industries are usually slow, especially in developing countries due to mental barriers of employees. 'Justification' barrier which defends the reason why waste minimization exercise cannot be done, 'Done that before' barrier which keeps referring to previous programs of similar nature, and 'it is not my job' barrier which prevents workers from taking other additional responsibilities, geared towards waste minimization [5, 6]. Water pinch analysis, Mathematical and multi objective optimization are among some of the technologies reported by several researchers for wastewater minimization [7]. The key factors contributing to the success of the water minimization program include employee awareness of the importance of water conservation and a commitment of employees to save water [5].

The major component of brewery effluent 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 important diagnostic components for determining the quality of water in natural waterways and waste streams [3, 9]. Wastewater treatment is a process that involves protecting human health by removing wastewater away from populated areas and transforming it into a harmless form. Properly treated wastewater and then be discharged back to the aqueous environment contributing to the global natural water reserve or recycled for domestic and industrial use to ease the demand for freshwater [10]. For a typical wastewater treatment, system facilities are required to undertake three levels of treatment processes, namely primary, secondary, and tertiary [10-12].

Typically, brewery wastewater treatment has aerobic, anaerobic and combined treatment technologies. In addition, many different methods such as nanofiltration [4], quenched plasma [13], activated sludge process, aerated lagoon, Trickling filter process, Bifiltration towers [12], upflow anaerobic sludge blanket (UASB) [12], [14-17] have been studied. Membrane technology [14], electrochemical method [17], anaerobic fluidized bed reactors [14], Microbial fuel cell [18] and reverse osmosis [19] have been tested. These various methods reported to remove 73-98% of the nutrients in brewery wastewater. After treatment, BOD, COD, and suspended solids (SS) of treated brewery wastewater have shown markedly reduced by the methods cited above. However, searching of more reliable and economical methods be continued for every specific scenario.

1.1 Case Study

Asmara Brewery Corporation Share Company (ABCSC) originally known as “MELOTTI BREWERY” is one of the leading brewing industry in Eritrea with annual capacity of beer production of 60 million bottles of 300cc, Liquors of 1.5 million bottles of 880cc, Pure Alcohol of 600,000 liters and Denatured alcohol of 60,000 liters. Nevertheless, the company has been facing the problem of water scarcity in the country, and trying to get new well water sources. The plant’s water consumption rates are also very high with an average water consumption of 10.76 L per L of Beer produced, which is remarkably far from 3.5 L of the plant which follows the best water usage policies. Hence, ABCSC system manufacturing operations are vulnerable to the scarcity of process water and it is essential to adopt either the best practices of water use minimization, or best technology for recycling of water or both. Therefore, the purpose of this work is to develop a suitable method for ABCSC brewery wastewater treatment that shall regenerate water for reuse in the plant. Two sections of the plant, bottle rinsing and brewery effluent were identified as major wastewater sources consist approximately 90 % of wastewater from the entire plant operations.

This work primarily conducted to facilitate a fundamental study on physicochemical treatment of ABCSC effluents through simple conventional approaches. The objective of the work includes physicochemical examination of wastewater samples and selection of suitable pre-treatment method to recycle water through already existing RO plant along with other fresh water sources for ABCSC plant operations. P^H neutralization, coagulation, activated carbon contact and chlorination have chosen as chemical treatment stages along with other physical separation techniques such as sedimentation, aeration, centrifugation and filtration.

Over the years, coagulation and flocculation have remained as widely used methods for solid-liquid separation in wastewater treatment. Effective coagulant dosage has become one of the most challenging issue despite of coagulation and flocculation are the prominent processes and unit operations in water treatment plants. Coagulation and flocculation consist of three sequential steps, i.e., coagulant formation, colloid/particle destabilization, and inter-particle collisions and aggregation. The most frequently used synthetic coagulants in coagulation and flocculation processes around the world are aluminum polychloride and aluminum sulfate [20, 22] despite health issues in relation to Alzhiemer’s disease (Lilian et al 2017). Since naturally originated coagulants are efficient, cost effective, readily available and non-toxic, their demand increasing in raw water and wastewater treatments. Moringa Oleifera (MO) is a plant whose seed applied as potential natural coagulant in comparison with conventional coagulants for the treatment of wastewater in several studies [20]. MO Seed powder, which is not harmful to human and does not have significant drawbacks, has been applied for variety of industrial wastewaters as a competitive natural coagulant with other commercial coagulants such as alum and reported significant results in the reduction of turbidity, alkalinity, TDS, hardness, BOD, COD, DO, and EC [21]. MO Seed contains water-soluble, positively charged proteins that act as an effective coagulant for water and wastewater treatments. The performance of MO seed extract in textile wastewater treatment towards the removal of color, alkalinity, turbidity and COD were reported with high efficiency [23]. Turbidity removal efficiency reported between 75.29 per cent to 85.88 per cent, BOD removal 60.17 per cent and COD removal 40.15 per cent by Moringa oleifera seed coagulant in dairy wasteswater treatment in another study [24]. However, the ability of MO Seed as a natural coagulant in brewery wastewater treatment was not examined yet. Alum $(Al_2(SO_4)_3.14H_2O)$ and Moringa Oleifera (MO) seed were chosen as chemical and natural coagulants for the treatment of bottle cleaning wastewater (BCWW) and mixed wastewater (MWW) samples of bottle cleaning and brewery effluents at 2:1 proportions. The lab scale experimentations performed to quantify suitable dosages of coagulants to cut off excessive turbidity, COD and BOD_5 concentrations and a comparative study of the resultant water characteristics with WHO drinking water quality standards along with other fresh water sources of Eritrea were conducted. Results analyzed to determine the quality of treated water for the safe disposal to curb national and international environmental pollution issues.

2. MATERIALS AND METHODS

2.1 Sample Collection

Wastewater samples from the bottle cleaning and brewery operations of ABCSC collected in 1 L capacity of clean glass bottles for physicochemical characterization conducted at Chemical laboratory of Ministry of Water, Land and Environment (MoWLE), Eritrea. 10 L plastic bottles were used to collect samples for the treatment at Chemical Reaction Engineering laboratory, Department of Chemical Engineering, Mai Nefhi College of Engineering & Technology (MCOETEC), Eritrea. Characterization tests were conducted separately for bottle cleaning wastewater (BCWW), brewery effluents (BRWW) and mixed sample (MWW) of both at 2:1 ratio. Treatment methods were employed only for BCWW and MWW samples but not for BRWW, because of their discharges were comparatively less and hence they were mixed with bottle rinsing effluents for the development of suitable treatment method.

2.2 Characterization of Wastewater and Treated Water

Wastewater and treated water samples analyzed for physicochemical parameters such as pH, temperature, total alkalinity, and 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 analyzed. Chemical contaminants were determined by measuring Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD_5).

Salinity, Electric Conductivity (EC) and Temperature were assessed with calibrated electrode (WTW Multi 197i, USA). P^{H} of the samples read from a pH meter (HANNA instruments, UK) using proxy method. The dissolved oxygen (DO) content of the water determines the activation of biological processes in the water and measured it 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. 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 it by using Eutech TN-100 instrument made by Thermoscientific, UK. The BOD_5 was estimated 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 was measured using a discrete auto-analyzer (HACH, Germany). Spectrophotometer used to test the presence of various chemicals such as nitrogen in nitrites and nitrates, manganese, iron, sulfates, phosphates and chromium. The amount of sodium and potassium present in the wastewater sample was measured using a flame photometer.

Mean values of different parameters of BCWW, BRWW and MWW samples were calculated by performing a single factor ANOVA (analysis of variance) study using Microsoft Excel®, 2016 software.

2.3 Chemicals and Coagulants

Alum in lumps of ½ to 1 inch size provided by the nearby water treatment plant, 'Mai-nefhi Water Treatment Plant' and powdered sample of dry Aluminum Sulphate, $Al_2(SO_4)_3\ 14H_2O$ (Alum) of 1 mm size on average was prepared by crushing manually and stored in airtight polyethylene bags for further usage in coagulation process. Dried Moringa Oleifera (MO) known as drumsticks collected from a town, Keren, Eritrea and extracted their seeds. The outer shells of the seeds removed manually and applied for sun drying about two days, and crushed into a fine powder of 0.1 to 1 mm size. Powdered sample packed in a polyethylene bag and stored for further usage. For carbonation of coagulated water, activated carbon prepared in the lab applied and Calcium hypochlorite from chemical laboratory of Ministry of Water, Land and Environment (MoWLE), Eritrea used for the chlorination process.

2.4 Experimental Methodology

Pre-screened effluent water samples of BCWW and MWW initially allowed to primary sedimentation in 1 L measuring jar for two hrs. Settled sludge separated in to a 500 ml glass beaker, the clear water decanted to 1 L glass beaker and allowed for aeration by using compressed air at 1.5 bar for 15 min for the removal of any floating contaminants. Consequently, pH value measured and adjusted to 7.5 with the aid of 37 % HCl solution and caustic soda pellets. A magnetic stirrer provided to maintain uniform P^H value of the solution in the neutralizer as shown in figure 1. Later, coagulation with Aluminium Sulphate (Alum) and Moringa Oleifera (MO) seeds applied at optimum dosage rates of 60 mg/L for both BCWW and MWW samples. Coagulation process carried out in a continuous stirred tank vessel facilitated with a magnetic stirrer to confirm uniformity of the solution about 30 min followed by allowed for 1 hr to settle. Clear water decanted and centrifuged for a very short time of 5 min at 100 rpm. Then the process water sent to an activation carbon contact for 15 min and filtered it through $43\mu m$ Whatman filter paper. Subsequently, the filtrate treated with calcium hypochlorite to facilitate chlorine at a rate of 2 mg/L as a disinfectant. Finally, collected water characterized to compare the parameters with the process water uses in ABCSC plant along with WHO drinking water quality standards.

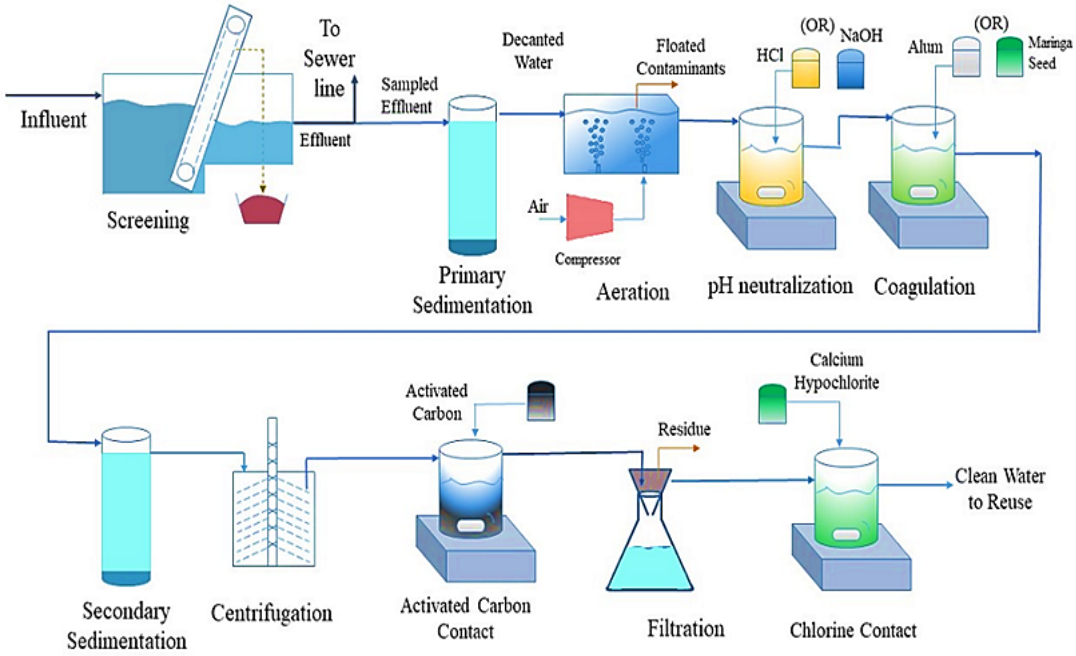

Figure 1. Schematic diagram of experimental process

3. RESULTS AND DISCUSSION

3.1 Wastewater Characteristics

ANOVA study performed on weekly reports of BCWW, BRWW and MWW samples for five consecutive weeks to estimate mean values of characteristic parameters such as pH, conductivity, turbidity, COD and BOD_5 as listed in table 1. The range of pH measured for the samples have greatly diverse from each other, some of the samples were highly acidic with a pH of 2.62 or highly alkaline with a pH of 12.36 and others dwell in between. Brewery effluents were noticed with high mean turbidity of 600 NTU. Average DO levels of all samples fall under 4.5 mg/L, which indicates that it cannot support any life. Chemical and biological contaminants are generally measured by COD and BOD_5 concentrations. Brewery wastewater typically has higher COD from all organic (sugars, soluble starch, ethanol, volatile fatty acids, etc) in the range of 2000-6000 mg/L [12].

In contrast, highest mean COD levels were observed in brewery wastes studied as figured in Table 1. BWW, BCWW and their mix of 1:2 (MWW) were noted with higher COD to BOD5 ratios in the rage of 1.83 to 28.41 against a typical ratio of 1.667 [12]. Since the bottle cleaning sections uses chemicals and sanitizing agents (e.g., caustic soda, phosphoric acid, nitric acid, etc) [12], identified with higher COD levels and frequent changes in daily operations caused for high variance in COD and BOD_5. Organic pollutants are 3 times higher in BRWW than in BCWW with an average BOD_5 of 11066 mg/L. MWW samples have shown unique characteristics with moderate pollutant levels. One-third of brewery wastes mixed with two-third of bottle cleaning waste have showed significant changes in the resultant solution. 33.3 % of brewery effluent caused for 60.64 % rise in COD levels, and 84.78 % increment in BOD_5 concentrations.

3.2 Effect of Coagulant Dosage

In determining the best dosages of both synthetic and natural coagulant, turbidity levels have chosen as performance indicators. Alum and MO seed coagulants were first applied at different dosages of 10, 20, 30, 40, 50 and 60 mg/L for both BCWW and MWW samples and an optimum dosage rate was determined as 60 mg/L for both chemical and natural coagulation processes, with low turbidity values of 0.49 and 6.17 NTU respectively. In both cases, turbidity increased to maximum at 20 mg/L of dosage, later it has reduced gradually to a minimum value at 60 mg/L as shown in figure 2. Turbidity levels measured lower at 10 mg/L of coagulant dosages in both cases comparable with the turbidity values at 20 mg/L of dosages. This must be caused due to an experimental error incurred due to random sampling while collecting the first sample used for 10 mg/L dosages, which might be collected without proper agitation. Thus the influent sample initial turbidity levels must be lowered than all other samples used for other higher dosages and eventually resulted in lower turbidity than the 20 mg/L dosage. But in later dosages the turbidity levels have shown gradual fall in both cases. Lilian et al [20] has measured optimum turbidity values using MO seed at 20 mg/L in the Maringa river water treatment. Therefore, it was clear that optimum dosages depend on original turbidity in addition to most effective parameters such as temperature, agitation, influent turbidity and P^H. Study considering several sets of experiments ensure the improvement in consistent optimal coagulant dosage levels.

Table 1. ANOVA Study of 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
P^H	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^{+1} (mg/L)	29.8-526.5	246	26.7-199.4	108	39.5-185	122.27
Potassium K^{+1} (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

3.3 Treatment of Bottle Cleaning Wastewater (BCWW)

According to the informants of ABCSC, approximately 50-60 % of wastewater discharges from packing section that includes operations such as bottle rinsing, filling and pasteurization. Bottling line effluents identified with high pH values due to alkaline chemicals such as caustic soda used in cleaning process. In other words, bottling discharges characterized with low turbidity, COD and BOD_5 levels in comparison with brewery and mixed wastes as shown in Table 1. A primary trial treatment of BCWW with both Alum and MO seed powder provided an assessment on selection of best choice out of chemical and natural processes as shown in Table 2.

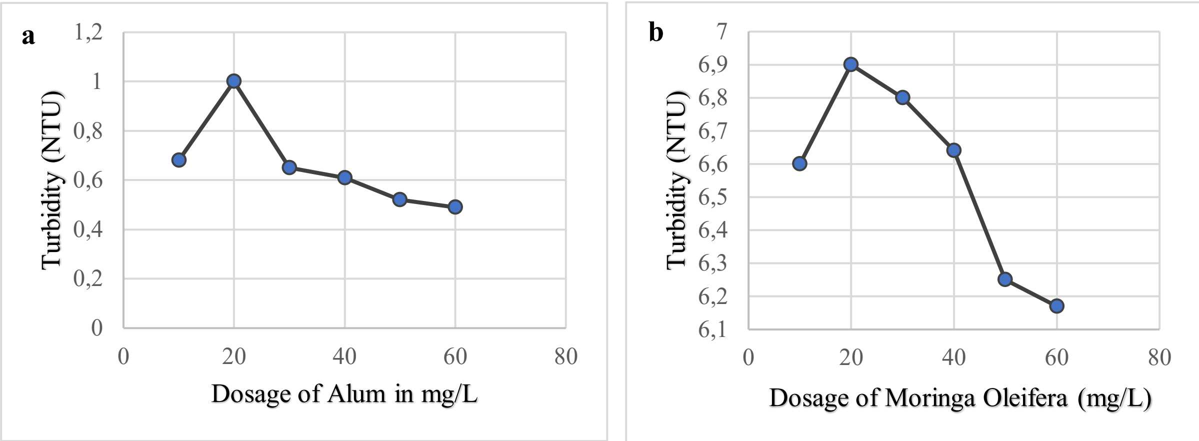

Figure 2. (a) Effect of Alum dosage on BCWW; (b) MO dosage effect on MWW

MO seed treatment resulted in slightly higher COD and turbidity values when compared with alum treated one but Sulphate, potassium and TDS reduced to appreciably low levels. Since COD levels chosen as the performance index for the treatment, Alum opted as better choice for further study of bottle cleaning wastes. Nevertheless, MO Seed treatment proved better performance levels in removal of Sulphate and Potassium concentrations and have shown a competitive performance in reducing COD concentrations and Turbidity levels to notable ones as depicted in Table 2. MO seeds reported with rich crude protein content of 40.34% and a crude lipid of 39.12 % and its content of macroelements such as sodium, potassium, and magnesium is much higher than other metals and K content is 2537.71 mg/kg of MO Seed [27]. Further the composition analysis of MO seeds has reported MO Seed contains 38-54% edible oil with rich unsaturated fatty acids and dominant saturated fatty acids such as palmitic, lauric acid, stearic acid, oleic and linoleic acid which non-toxic and biocompatible with human body and they act as a cleaning agent with a polar head group that can bind metal cations and nonpolar chains that confers solubility in organic solvents [34]. Sulphates and potassium together must be existing as potassium Sulphate in the wastewater samples which reacts with fatty acids, stearic acid in particular to form potassium stearate and sulphuric acid. Thus the Sulphate and potassium contents removed well in MO seed coagulation. In other words, Sulaiman et al. 2019 has mentioned that MO seeds removed maximum turbidity and suspended materials and the powdered seeds generate less sludge volume and promotes COD removal [25]. Alum coagulation of BCWW have shown an effective removal of turbidity to 51% in between the dosages of 20 mg/l to 60 mg/l.

Table 2. Composition of Treated BCWW

Parameters	Alum treated water	MO seed treated water	Guide Values of DOE, Eritrea	WHO drinking water Standards
Temperature (ºC)	22.7	22.6	10<T<40 C	10<T<40 C
P^H	8.61	8.13	6.5-9.2	6.5-8
EC (µs/cm)	1451	1256	2000 us/cm	NA
Turbidity (NTU)	0.54	2.77	<5 NTU	5 NTU
Nitrogen (NO_3) (mg/L)	3	3.3	50 mg/L	50 mg/L
Chlorine (Cl^{2--}) (mg/L)	0.38	0.09	600 mg/L	0.6-1 mg/L
Sulphate (SO^{2-}) (mg/L)	215	47.5	400 mg/L	250 mg/L
Sodium (Na^{+1}) (mg/L)	233.9	235.6	200 mg/L	200 mg/L
Potassium (K^{+1}) (mg/L)	46.3	15.6	12 mg/	12 mg/L
COD (mg/L)	50	78	69.5*	0.1 - 2 mg/L
TDS (mg/L)	972.17	841.52	1500 mg/L	1000 mg/L

Treatment of BCWW with conventional coagulant (Alum) at optimized dosage of 0.6 g/L carried out at laboratory scale of 1 L (0.986 kg) of waste discharge that consist 4.31 % of solids by weight. From the material balance displayed in figure 3, confirmed that the bottle-cleaning waste contains significant setteable solids and primary sedimentation separates 53.33 % of total solids from the wastewater. Coagulation with synthetic alum primarily aid in removal of suspended solids through secondary sedimentation followed by centrifugation, which contributes approximately 42 % of total solids. The results of the P^H measurements have shown stable values for both cases and slightly higher values noted for the case of alum treatment. However, the recorded values for all the treated samples remained in the range of P^H within the specifications of Portaria 2914 [20], which range between 6.0 and 9.5.

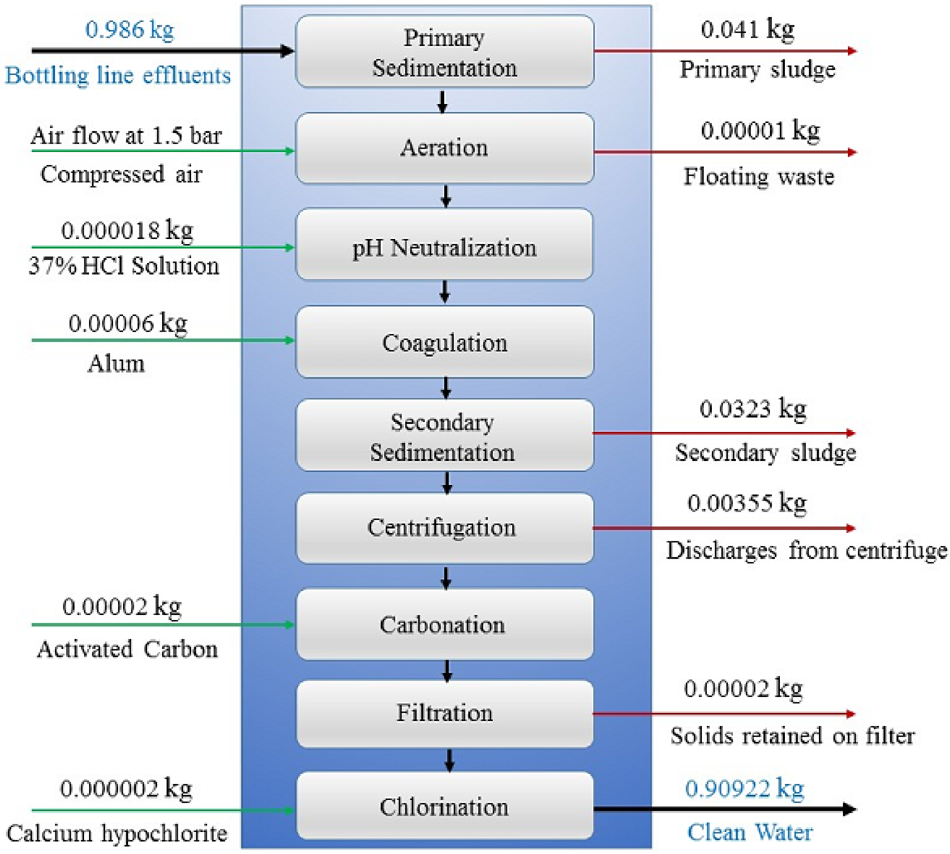

Figure 3. Mass balance on Alum treatment of bottling line effluents (BCWW) from ABCSC

3.4 Mixed Wastewater (MWW) Treatment

Coagulation and sedimentation of MWW with alum and MO seed powder examined at various dosages as stated earlier and determined that at 60 mg/L, optimum turbidity levels attained. In view of commercial adaptation of natural coagulation process at larger scale, huge volumes of mixed effluent streams from the breweries invigorated to study the potential application of natural substances in removal of higher COD levels for the sake of development of eco-friendly process. A detailed material balance on several stages of treatment process have shown in figure 4 to understand that 86.6 % of wastewater is possible to recover with a simple primary coagulation treatment at the expense of 60 mg of MO seed per litre of MWW. In addition, more than 10 % of MWW separated as setteable sludge from the primary sedimentation followed by aeration to rid of any oily contaminants. P^H neutralization step was remained insignificant in the treatment of MWW as it was neutralized successively from the removal of primary sludge and floating wastes.

MO seed coagulation resulted in 21 % of total solids removal by secondary sedimentation whereas in case of alum coagulation of BCWW it was 42 %. Although MWW has higher solid contaminants, as mentioned by Simate GS. 2012 [24], one of the major disadvantage of alum coagulation is a very large sludge volume generation, double than MO seed coagulation noted for alum treatment of BCWW from both secondary sludge and centrifuge discharges. MO seed treatment stabilized P^H value of samples to 7.72, a lower value than the alum case but retained with slightly higher turbidity values than WHO standards and Eritrean guide values. MO seed usually rich in potassium [25], which consequently resulted in higher potassium residues the treated samples as shown in Table3. The most important parameter of brewery wastes is COD, which has effected immensely to a very lower level in the study of both alum and MO seed powder treatments. Despite of the fact that they could not attain the WHO drinking water standards, tremendously reduced COD levels from a mean value of 70000 mg/L to 180 and 195 mg/L in case of alum and MO seed tests respectively. Alum coagulation also notified with higher TDS values than MO seed treatment, which has left TDS values within national and WHO standards.

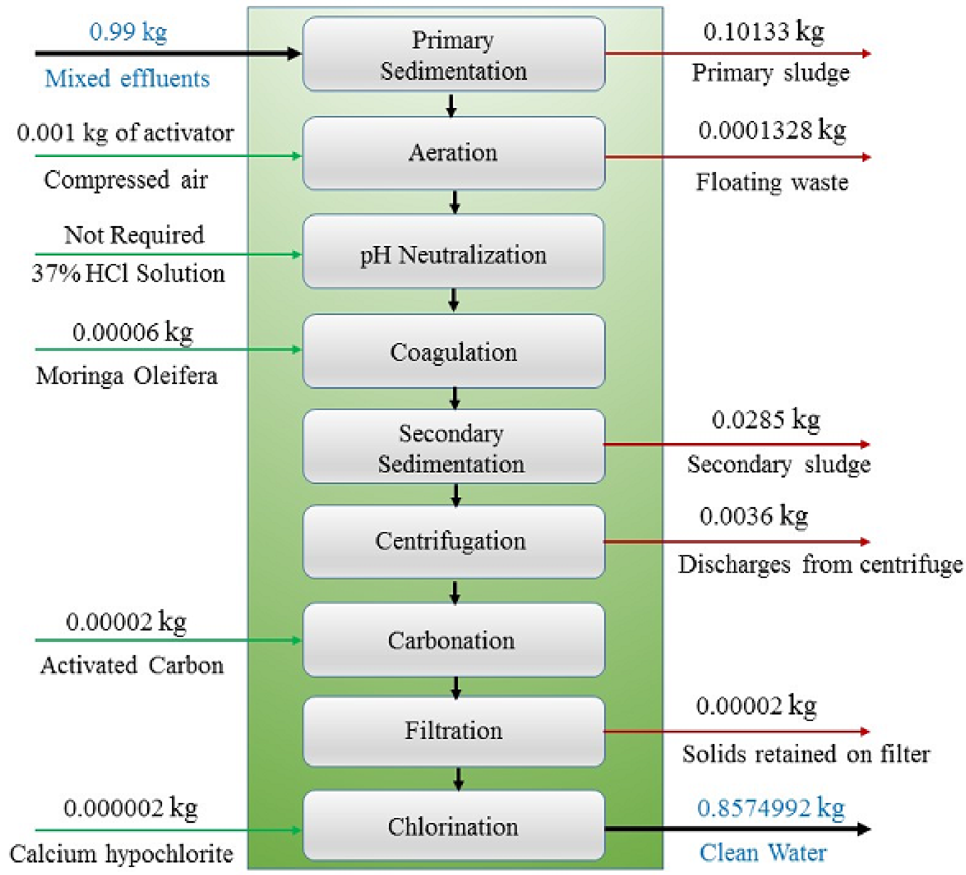

Figure 4. Mass balance on MO Seed treatment of mixed effluents (MWW) from ABCSC

Table 3. Composition of Treated MWW

Parameters	Alum treated water	MO seed treated water	Guide Values of DOE, Eritrea[28]	WHO drinking water Standards[29]
Temperature (°C)	22.8	22.8	10<T<40 C	10<T<40 C
P^H	8.23	7.72	6.5-9.2	6.5-8
EC µs/cm	1568	1427	2000 µs/cm	NA
Turbidity NTU	0.62	6.12	<5 NTU	5 NTU
Nitrogen (NO_3) (mg/L)	8.2	7.2	50 mg/L	50 mg/L
Chlorine (Cl^{2-})	0.5	0.35	600 mg/L	0.6-1 mg/L
Sulphate SO_4^{2-}) (mg/L)	237.5	92.5	400 mg/L	250 mg/L
Sodium (Na^{+1}) (mg/L)	193.4	188.9	200 mg/L	200 mg/L
Potassium (K^{+1})(mg/L)	50.8	195	12 mg/L	12 mg/L
COD (mg/L)	180	195	69.5*	0.1 - 2 mg/L
TDS (mg/L)	1050.56	908.52	1500 mg/L	1000 mg/L

The extent of coagulant dosage was decided to stop at 60 mg/L in view of keeping the turbidity levels within or very close the WHO drinking water guidelines and other economic concerns. In the case of Alum dosages applied for BCWW treatment, the influent samples were not possessed with any higher turbidity levels, but when it was studied in between 20 mg/l to 60 mg/l, approximately 51% of turbidity was removed. But in case of MWW treatment with MO seed powder coagulation 11 % of turbidity removed from 20 mg/l-60 mg/l dosages and attained

6.17 NTU which was close to WHO guideline and yet it can be further studied to lower the values using higher dosage levels.

3.5 Role of Physical Operations in Treatment

Physical methods encompass all processes in which contaminants are removed by means of or through the application of physical forces. In most cases, preliminary treatment consists of flow equalisation, screening, grit removal and gravity sedimentation [30]. In this study, sedimentation applied before (primary) and after (secondary) coagulation to remove setteable particulates. Primary sedimentation of BCWW calculated with more than 50% of total solids as setteable content from the balance sheet depicted in figure 3, whereas setteable in MWW estimated as 75.8 % as shown in figure 4. Flotation considered eliminating any greasy contaminants with the aid of compressed air circulation. Immediate to coagulation a secondary sedimentation allowed which was accounted to separate 42 % and 21% of total solids from BCWW and MWW samples respectively. Chemical or natural coagulation retain with suspended substances, most of the dangling matter separated using centrifuges, which are relatively energy intensive. Centrifugation has stood as third significant physical separation technique with 4.6% and 2.7% of total solids separation from BCWW and MWW respectively. After carbon effect on water, filtration applied to set out carbon residues prior to chlorination.

3.6 Comparison of Treated Water with Local Water Sources and International Benchmarks

Water shortage is a major constraint in sub Saharan countries, especially in Eritrea with gradually decreasing per capita resources to a value of 2119 m^3/year in 2018 from 2948 m^3/year in 2002 [31] which was accounted for approximately 28 % fall. Mai Nefhi, Toker dam, Mai Sirwa and Adi Sheka are some of the major fresh water reservoirs that depends on seasonal rain falls. Water use ratio estimated in ABCSC was almost double than the BA benchmark [32] as compared in the Table 5, whereas wastewater assessed was 7.53 liters per one liter of beer against a benchmark value of 2.52. Hence, it is crucial for the company to decide on wise water management practices, which includes finding a better technology with the available resources.

Table 4. Comparison of treated water with Fresh water sources in Eritrea

Parameters	Alum treated BCWW	MO Seed treated MWW	Toker Dam [33]	Mai Nefhi [33]	Mai-Sirwa [33]	Adi-Sheka [33]
Temperature (°C)	22.8	22.8	20.3	20.2	20.2	19.2
P^H	8.61	8.13	8.66	8.03	7.68	8.03
EC (µs/cm)	1568	1356	218	341	241	181.2
Nitrogen (NO_3) (mg/L)	8.2	7.2	5.32	7.53	6.65	12.4
Chlorine (Cl^{2-})	0.5	0.35	12	34	12	10
Sulphate (SO_4^{2-}) (mg/L)	237.5	92.5	10	42	4	8
Sodium (Na^{+1}) (mg/L)	193.4	188.9	10.26	14.68	8.72	4.96
Potassium (K^{+1}) (mg/L)	50.8	195	2.9	4.48	2.11	3.29
TDS (mg/L)	1050.56	908.52	102.88	177.82	116.7	97.72
COD (mg/L)	180	195	NA	NA	NA	NA

However, pre-treatment methods such as simple physicochemical methods also helps in reuse of water or safe disposal of effluents in to the sewer lines. Optimized treatment methods applied for both BCWW and MWW effluents have compared with fresh water sources as shown in Table 4. P^H values were stabilized between 7.6 and 8.6 in all cases. As Sodium, Sulphate and Potassium values of treated BCWW and MWW were higher than fresh water sources, conductivity noticed with much higher levels while MO seed treatment has shown lesser than alum case as it consists lower dissolved solids.

As aforementioned, COD levels are primary performance indicators and COD removal efficiency has measured more than 99 percent in all treatment cases tested with alum and MO seed coagulations followed by centrifugation despite of that the mixing in coagulation and centrifugation are quite energy intensive comparable with other operations involved. In fact, alum has shown slightly better performance in terms of COD removal and comparable with BA benchmarks as shown in Table 5 while leaving higher volumes of sludge. Consequently, BOD_5 concentrations decreased to acceptable levels. Alum is an effective flocculent in PH range of 4 to 7, in which tetravalent aluminum hydroxo complex is dominant [26].

Table 5. Comparison of the study with the benchmarks of BA, USA

	Untreated Water			Pre-treated Water		
Parameter	BCWW	MWW	BA benchmark	BCWW	MWW	BA benchmark
Water to Beer (L/L)	5.12	8.46	4.58	NA	NA	NA
Wastewater to beer (L/L)	5.12	7.53	2.52	NA	NA	NA
COD (mg/L)	3500-160000	32000-134000	1800-5500	50	180	175
BOD_5 (mg/L)	357-5633	2856-14667	600-5000	40	140	100-400
P^H	2.62-12.36	4.22-11.59	3-12	8.61	8.3	6-9
TSS (mg/L)	14-139	29-520	200-1500	150	448	50-500

However, the lower end of P^H levels favoured for alum coagulation of BCWW to reduce colloidal particles concentration to a mean value of 150 mg/L whereas in case of MO Seed treatment of MWW resulted slightly higher TSS of 448 mg/L. The total suspended solids levels are well adjusted by the process to correlate with BA limits. MO seed flocculation of MWW using 60 mg/L of dosage has reduced 97.2% of turbidity, whereas Lilian et al [20] has removed 94.9% turbidity and 92.5 % of colour using MO seed at 20 mg/L of river water.

4. CONCLUSION

Breweries consumes huge volumes of fresh water sources and consequently discharges higher amounts of effluents. In the countries, where public striving hardly to access water for their survival, brewery industry has to pay special attention at wastewater minimization or recovery of reusable water to survive for longer in business. Asmara breweries, the only brewery in Eritrea, estimated with higher volumes of waste generations. Bottle cleaning section and brewery line are two major departments, where significant amounts of wastewater discharges into sewer lines without any pre-treatment methods. BCWW, BWW and MWW samples characterized with a wide range of 3500-160000 mg/L of COD and 327-26667 mg/L of BOD_5, which are absolutely higher when compared with typical brewery effluents of 2000-6000 mg/L of COD and 1200-3600 mg/L of BOD_5. Simple physicochemical treatments such as sedimentation, air flotation, coagulation, centrifugation, carbon contact and chlorination steps using conventional coagulant (alum) and natural substance (MO seed) have tested for the first time successfully to remove higher COD and BOD_5 concentrations from brewery effluents. Optimal dosages of coagulants determined by accounting turbidity as key performance indicator. Alum treatment of BCWW and MO seed flocculation of MWW have resulted in lower turbidity levels of 0.49 and 6.17 NTU at 60 mg/L of dosages respectively. MO seed flocculation of MWW using 60 mg/L of dosage has reduced 97.2% of turbidity.

The optimal amounts of water recovered from the alum treatment of BCWW and MO seed coagulation of MWW are 92.2% (weight) and 86.6 % (weight) respectively. Higher sludge volumes recorded as a major disadvantage of alum coagulation. In other words, natural coagulant, MO seed manifested competitive results in removal of COD, BOD_5, Chlorine, Nitrogen, Sulphate, Sodium, TDS and TSS along with PH stabilization. In addition to slightly turbid nature of MO seed treated water, potassium levels found four fold increment comparative to alum treated water. However, MO seed seems a better substitute for the alum to avoid excessive sludge volumes, higher toxicity of sludge and Alzheimer's disease causes from alum coagulation, detailed economical assessment of MO seed cultivation and preparation along process development is necessary to consider for further study.

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CONFLICT OF INTEREST

The authors of this report declares that there is now any kind of confliction in regard with the publication of this manuscript.

REFERENCES

[1] F. Luc, B.A. Pascal, D. Georges. "Water, wastewater and waste management in brewing industries", *J. of Cleaner Production,* Vol 14, pp. 463-471, 2006. doi:10.1016/j.jclepro.2005.01.002

[2] R. Akbarzadeh, J.A. Adeniran, M. Lototskyy, A. Asadi. "Simultaneous brewery wastewater treatment and hydrogen generation via hydrolysis using Mg waste scraps". *J. of Cleaner Production,* S0959-6526(20), 2020. https://doi.org/10.1016/j.jclepro.2020.123198

[3] G.S. Simate. "Water treatment and resuse in breweries" *Brewing Microbiology*, 1st ed, Annie E. Hill, Woodhead Publishing,Swaston, UK, pp.425-456, 2015. http://dx.doi.org/10.1016/B978-1-78242-331-7.00020-4

[4] L.Braeken, B.Van der Bruggen, C.Vandecasteele. "Regeneration of brewery waste water using nanofiltration". *Water Reserach*, Vol *38*, no.13, pp. 3075–3082, 2004.

[5] P.Emmanuel, S. Maarten. "Minimisation of water use in a Ghanaian brewery: effects of personnel practices". *J. of Cleaner Production,* Vol 13, pp. 1139-1143, 2005. doi:10.1016/j.jclepro.2004.06.002

[6] J.W. Davis. "Fast track to waste-free manufacturing: straight talk from a plant manager". *Portland (OR): Productivity Press*; pp. 23-60, 1999.

[7] J.K. Jiri. "Industrial water recycle/reuse", *Cur.Opinion in Chemical Engineering*, Vol 1, pp. 238-245, 2012. http://dx.doi.org/10.1016/j.coche.2012.03.010

[8] Brewers of Europe. "Guidance note for establishing BAT in the brewing industry". *Brussels: Brewers of Europe*, 2002. Available online: http://www.brewersofeurope.org/docs/ publications/ guidance.pdf. (Accessed: 12th Feb 2022)

[9] Mantech. "PeCOD application note # 1" *Ontario: Mantech Inc.* 2011. Available online: http://www. titralo.hu/WEBSET_DOWNLOADS/613/PeCOD-Wastewater%20Industry.pdf. (Accessed: 5th Oct 2021)

[10] G.K.C.Ding. "Wastewater Treatment and ReusedThe Future Source of Water Supply", *Encyclopedia of Sustainable Technologies,* Vol 4, pp. 43-52, 2017. http://dx.doi.org/10.1016/B978-0-12-409548-9.10170-8

[11] M. Meshksar, R. Tayebe, R.R Mohammad. "Membrane technology for brewery wastewater treatment", *Current Trends and Future Developments on (Bio-) Membranes*, pp. 289-303, 2020. https://doi.org/10.1016/B978-0-12-816823-3.00010-1

[12] G.S. Simate, J. Cluett, S.E. Iyuke, E.T. Musapatika, S. Ndlovu, L.F. Walubita, A.E. Alvarez. "The treatment of brewery wastewater for reuse: State of the art", *Desalination,* Vol 273, pp. 235-247, 2011. doi:10.1016/j.desal.2011.02.035

[13] A.Doubla, S.Laminsi, S.Nzali, E.Njoyim, J.Kamsu-Kom, J.L.Brisset. "Organic pollutants abatement and biodecontamination of brewery effluents by a non-thermal quenched plasma at atmospheric pressure", *Chemosphere*, Vol 69, pp. 332–337, 2007.

[14] P. Mullai, S. Vishali, M.K. Yogeswari1, M. Estefanı´a Lo´pez, Eldon R. Rene. "Methane production and recovery from wastewater", *Cur Trends and Fut Dev. on (Bio-) Membranes,* pp. 17-36, 2020. https://doi.org/10.1016/B978-0-444-64321-6.00002-1

[15] R. Pachiega, M.F. Rodrigues, C.V. Rodrigues, I.K. Sakamoto, M.B.A. Varesche, J.E. De Oliveira , S.I.

Maintinguer. “Hydrogen bioproduction with anaerobic bacteria consortium from brewery wastewater”, *Int. J. of Hydrogen Energy*, pp. 1-9, 2018. https://doi.org/10.1016/j.ijhydene.2018.02.107
[16] C.-Y. Lin, C.-H. Lay, C.-C. Chen (2017). High-Strength Wastewater Treatment Using Anaerobic Processes, Current Developments in Biotechnology and Bioengineering: Biological Treatment of Industrial Effluents, 321-357. http://dx.doi.org/10.1016/B978-0-444-63665-2.00013-8
[17] H.J. Choi. ”Parametric study of brewery wastewater effluent treatment using Chlorella vulgaris microalgae”, *Environ. Eng. Res.* Vol 21, no.4, pp. 401-408, 2016. http://dx.doi.org/10.4491/eer.2016.024
[18] Li He, Peng Du, Yizhong Chen, Hongwei Lu, Xi Cheng, Bei Chang, Zheng Wang. ”Advances in microbial fuel cells for wastewater treatment”, *Ren. and Sust. Energy Reviews*, Vol 71, pp. 388–403, 2017. http://dx.doi.org/10.1016/j.rser.2016.12.069
[19] S.S. Madaeni, Y. Mansourpanah. “Screening membranes for COD removal from dilute wastewater”. *Desalination*, Vol 197, pp. 23–32, 2006.
[20] L.D.S. Fermino, A.D.C.S. Pedrangelo, P.K.D.M. Silva, R.E.C.D. Azevedo, N.U. Yamaguchi, R.M. Ribeiro. “Water Treatment with Conventional and Alternative Coagulants”, *Chem Eng Transactions*, Vol (57), 2017.
[21] T.C.Shan, M.Al Matar, E.A. Makky, E.N. Ali. “The use of Moringa oleifera seed as a natural coagulant for wastewater treatment and heavy metals removal”, *Applied Water Science,* Vol 7, pp. 1369-1376, 2016. https://link.springer.com/article/10.1007/s13201-016-0499-8
[22] A.T.A. Baptista, P.F. Coldebella, P.H.F. Cardines, R.G. Gomes, M.F. Vieira, R. Bergamasco, A.M.S. Vieira. *Chemical Engineering Journal*, Vol 276, pp. 166-173, 2015.
[23] Hemapriya, G.; Abhinaya, R.; Dhinesh, K.S. “Textile Effluent Treatment Using Moringa Oleifera”. *Int. J. Innov. Res. Dev.,* vol 4(4) pp. 385–390, 2015.
[24] Parmar, K.; Dabhi, Y.; Patel, R.; Prajapati, S. “Effectiveness of Moringa oleifera as natural coagulant aid for waste water treatment of dairy industry”. *Asian J. Environ. Sci.,* Vol 7(2): 167-171, 2012.
[25] M. Sulaiman, D.A. Zhigila, K. Mohammed, DM. Umar, B. Aliyu, F.A. Manan. “Moringa Oleifera Seed as Alternative Natural Coagulant for Potential Application in Water Treatment: A Review”, *J. Adv. Res in Material Science*, Vol 56(1), pp. 11-21, 2019.
[26] G.S. Simate. “The Treatment Of Brewery Wastewater Using Carbon Nanotubes Synthesized From Carbon Dioxide Carbon Source”, PhD Thesis, *University of the Witwatersrand*, Johannesburg, 2012.
[27] L.Liang, C.Wang, S.Li, X.Chu, K.Sun. “Nutritional compositions of Indian *Moringa oleifera* seed and antioxidant activity of its polypeptides”, *Food Sci. and Nutrition,* Vol 7(5), pp. 1754-1760, 2019. https://doi.org/10.1002/fsn3.1015
[28] “Industrial Effluent standards entering Public Sewers in Eritrea”, available with Analytical lab, Ministry of Water, Land and Environment, Eritrea. Accessed with permission in the month of May 2021.
[29] WHO, Guidelines for Drinking Water Quality, Fourth edition, ISBN 978-92-4-154995-0 *Standard Methods for the Examination of Water and Wastewater,* CHEMICAL OXYGEN DEMAND (COD) 5220, 2017. DOI:10.2105/SMWW.2882.103.
[30] EPA Effluent Standards, Revised by EPA Order Huan-Shu-Shui-Tzu No. 1030005842 on January 22, 2014.
[31] Renewable water resources per capita of Eritrea. Available online: https://knoema.com/atlas/Eritrea/topics/Water/Total-Renewable-Water-Resources/Renewable-water-resources-per-capita (Accessed: 1st March 2022)
[32] Brewers Association (BA), USA. “Wastewater Management Guidance Manual”, 2021. Available online: www.brewersassociation.org., (Accessed: 20th April, 2021)
[33] Water and Environment Department Committee (WAEDC) Report (2014) Evaluation and Upgrading of process water for system manufacturing operations in Asmara Breweries Corporation Share Company (ABCSC). Accessed with permission during our project tenure, 2021.
[34]. M.M. Ozcan. “Moringa spp: Composition and bioactive properties”, *South African Journal of Botany*, Vol 124, pp.25-31. 2020. https://doi.org/10.1016/j.sajb.2018.11.017