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Article

Assessment of Brewery Wastewater and Potential Inline Practices to Curb Wastewater from Breweries

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Abstract: Beer brewing appertains to the extraordinary quality of water accompanying greater volumes of consumption, consequently rendering preeminent amounts of waste. Apart from technological demand, mental barriers predicate significant causes for the huge quantities of wastewater generated from breweries. However, by adopting best management practices, modern plants have succeeded to restrict water consumption up to 3.7 - 4.7 L/L of beer sold. Currently, Asmara Breweries (ABCSC) of Eritrea alone produces approximately 150,000 bbls of beer/year, and a weekly survey is organized to perceive the brewing process intensely to assess the critical performance indicators such as water use ratio and wastewater discharge ratio. Approximately, 14% of excess annual water consumption acquainted against BA benchmarks and wastewater to freshwater is estimated as 0.872 while BA benchmark at 0.55. Chase water and bottle cleaning water collectively contribute to 84% of total effluents. Direct reuse of chase water for rinsing or chasing reduces immensely freshwater consumption. Bottle cleaning water accredits plant CIP program after simple physicochemical treatment. Well-organized practices through employee involvement will lead to achieving internationally competitive performance indicators.

Keywords: industrial wastewater; characterization; Asmara breweries; environmental pollution; brewery effluents.

1. Introduction

Globally, water is a precious component of human life, most importantly for the people of arid and semi-arid areas in sub-Saharan countries of Africa. Eritrea is a northeast country in Africa, bordering the Red Sea coast with about 70% of its land classified as hot and arid and receiving average rainfall of 3-20 in the plateaus [4]. Collecting water is often a colossal waste of time for women and girls even though one roundtrip to collect water is 33 minutes on average in a rural areas and 25 minutes in urban areas of sub-Saharan Africa [13]. In other words, renewable water resources per capita in Eritrea fell gradually from 2948 m^3/year in 2002 to 2119 m^3/year in 2018 [9]. However, prudent utilization of freshwater resources for socio-economic development activities accompanied by promising protection of natural ecosystems is one of the most prominent issues of today's world. Plenty of research has been done or is in progress emphasizing optimization of freshwater consumption in domestic, agricultural, and industrial applications. Furthermore, there has 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 environment through industrial activities poses risk to human health and the environment.

The brewing industry is water intensive and consequently produces huge volumes of wastewater even though the beer is fifth most consumed alcoholic beverage in the world and brewing is a multi-billion-dollar industry that creates jobs, generates taxes, supports agriculture, and attracts tourism [11]. It was mentioned in several reports that for every 1 L of beer production, approximately 4 to 8 L of water is used depending on the production size, even higher in the case of small breweries, generally owing to inefficient water management processes and systems [10]. In other words, Beer brewing is characterized by the use of high-quality freshwater due to public perception about the deterioration in the quality of beer [11,12]. The freshwater consumption of modern breweries generally ranges from 3.7 L/L to 4.7 L/L of beer sold. The volume ratio of water to final beer is depending on the technical standard of individual production units forming the overall brewery process [12]. During production, beer passes through three main sections (brewing house, fermentation, clarification, bottle washing, and packing). Consequently, water consumption, wastewater, and solid-liquid separation constitute real economic opportunities for improvements in brewing.

Waste minimization initiatives in the process industries certainly drive the system towards the adoption of green technologies. Cleaner production eventually results in boosting both economic and environmental benefits. However, despite this growing evidence of the link between improved environmental performance and improved economic performance, the rate of adoption of Cleaner Production and waste minimization initiatives in industries is generally slow, especially in developing countries [6]. Luc et al. [8], presented technical and biological alternatives to reduce water consumption and waste minimization in brewery operations. Membrane processes may provide an alternative to conventional dead-end filtration with filter aids as well as a way to reduce water consumption [8]. In contrast, Yilin [16] compared Heineken Brewery with Zhujiang Brewery in the implementation of their water management regulations coupled with waste minimization policies. Explored that Heineken achieved to reduce specific water consumption to 3.6 hl/hl in its breweries by making and implementing detailed action plans whereas Zhujiang breweries in China reduced their water use to 4.06 hl/hl and need to improve their targets considering local water scarcity issues [16].

Wang and Smith explored a graphical method based on Water Pinch Analysis, where they combined the time constraint with concentration driving force constraint to locate the minimum fresh water and wastewater flow rates before detailed network design [14]. Tokos and Glavic [12] applied the principles of water pinch analysis and their solution offers water saving on the packaging line for returnable glass bottles and cans, both with acceptable payback periods. The effect of water reuse on water consumption ratio compared with typical brewery according to the BREF (2006) and to the publication of European Brewery Convention, EBC (1990). In specific, they confirmed that the water consumption in the packaging area can be reduced by 45,410 m^3/a [12].

Mental barriers such as 'Justification', ' done that before', and 'it is not my job' found to be the most damaging barriers, and are present in any operation, in varying degrees, regardless of product or service. Davis explained that getting employees to understand and realize that without change, the operations of the plant will gradually become less competitive and there are no substantial barriers to change other than their mental barriers [6,5]. Emanuel et al. [6] describe that personal water use measurements and minimization practices would bring in substantial savings of water to enable the brewery to meet a significant part of its water needs in the future [6].

Asmara Brewery Corporation Share Company (ABCSC) originally known as "MELOTTI BREWERY" was established in 1939 and currently, it is the only brewery in Eritrea, located in the southern region of Asmara city. The total average daily available process water is about 870 m^3/day, which is slightly less than the average planned water demand of 882.38 m^3/day, regardless of the status of water quality and water use and management [15]. 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 mandated to develop wastewater reuse and recycle technologies as early as possible.

This work mainly focused on the identification and measurement of freshwater use and discharge of wastewater from Asmara Brewery (ABCSC) through a questionnaire that enables quantifying plant performance parameters such as water use ratio and effluent discharge rates in the factory. Assessment of industry reports emphasizing mainly local and international practices and their benchmarks on water use and minimization in the breweries made to understand the significance of the problem. Application of potential in-line practices that include reducing, reuse, and reuse with simple physicochemical treatment and recycling principles are discussed for possible water savings. Appropriate water use policies and waste management regulations are recommended to adopt optimal practices to compete with the world's best breweries.

2. Materials and Methods

Material streams in concern with water utilization in brewery units and operations of ABCSC were observed and documented on weekly basis for eight consecutive weeks of July, Aug, and September months in 2021. All possible data in conjunction with identification and estimation of water consumption, wastewater management, and regulations associated with environmental issues obtained through a questionnaire structured into the following sections.

- Development of the existing plant PFD to understand material balances in operations
- Identification of freshwater accessibility and estimation of consumption rates at various operations
- Evaluation of wastewater discharges and their current disposal practices
- Process analysis connected with Reduce, Reuse, Reuse with simple treatment and Recycle principles to save potential amounts of fresh water.

2.1 ABCSC Brewing Process

Imported and local malt stored in the silos, conveyed to a hammer mill to prepare dry grist to increase surface area for the value of higher yields of extract. During the mashing process, hot water is blended with finely powdered malt (grist) in a Mash-Tun to convert starches into fermentable sugars. Separation of wort and grains takes place in a mash filter by several washes to remove the maximum amount of sugars from the spent grain. The wort was boiled for multiple benefits (such as to extract and isomerise hop components, coagulate proteins, sterilize and inactivate enzymes, form reducing and aromatic compounds, form coloring substances, remove undesired substances, acidify the wort, and evaporate water) from 78 to 98 °C in a kettle by adding hops and sugar. The hot wort is then, passed to whirlpool sedimentation where the trub is separated and consequently flushed to cooler using chase water. The hot water from the plate-type heat exchanger (cooler) is reused directly in mashing. Cold wort of 10 to 12 °C along with a little oxygen allowed fermenting by yeast.

The Green beer from the fermenters is allowed to be stored while surplus yeast is removed from the fermenters and maturation tanks. Rough beer passes through diatomaceous earth filters to separate clarified beer from Kieselguhr sludge and then allowed for further aging. A huge volume of fresh water was applied as chase water for pushing beer into maturation tanks. Maturation of beer is to achieve good carbonation of beer coupled with enhanced stability and brightness. Asmara Brewery uses returnable bottles and cans for packing beer to sell locally and to export respectively.

Returnable bottles are applied for washing with 2% caustic solution and checked for damages before it moves to filler. Filling and sealing happen with a filler that operates automatically with an extended program to check the level of beer in the bottle before it goes pasteurization. A tunnel pasteurizer handles 30000 bottles per hour to sterilize the packed bottles or cans before they dispatch at different temperature levels. All the waste discharges including spent grain, trub, surplus yeast, and Kieselguhr sludge from different sections: brewing house, fermentation, and bottling lines of the plant connected to the Asmara public sewer line as shown in Figure 1. Asmara Breweries remains one of the greater breweries in the world with a production capacity of approximately 150000 bbls/year.

3. Results

3.1 Water management in Asmara Brewery

The study of water balance helps to find efficient usage by understanding and managing water and effluent efficiently despite identifying any leaks in the supply line. Fresh water and wastewater from different brewing operations of ABCSC were recorded for eight subsequent weeks and reported in Table 1. Average values of fresh water and wastewater were determined as 7779.4 and 7250.42 hl/day respectively.

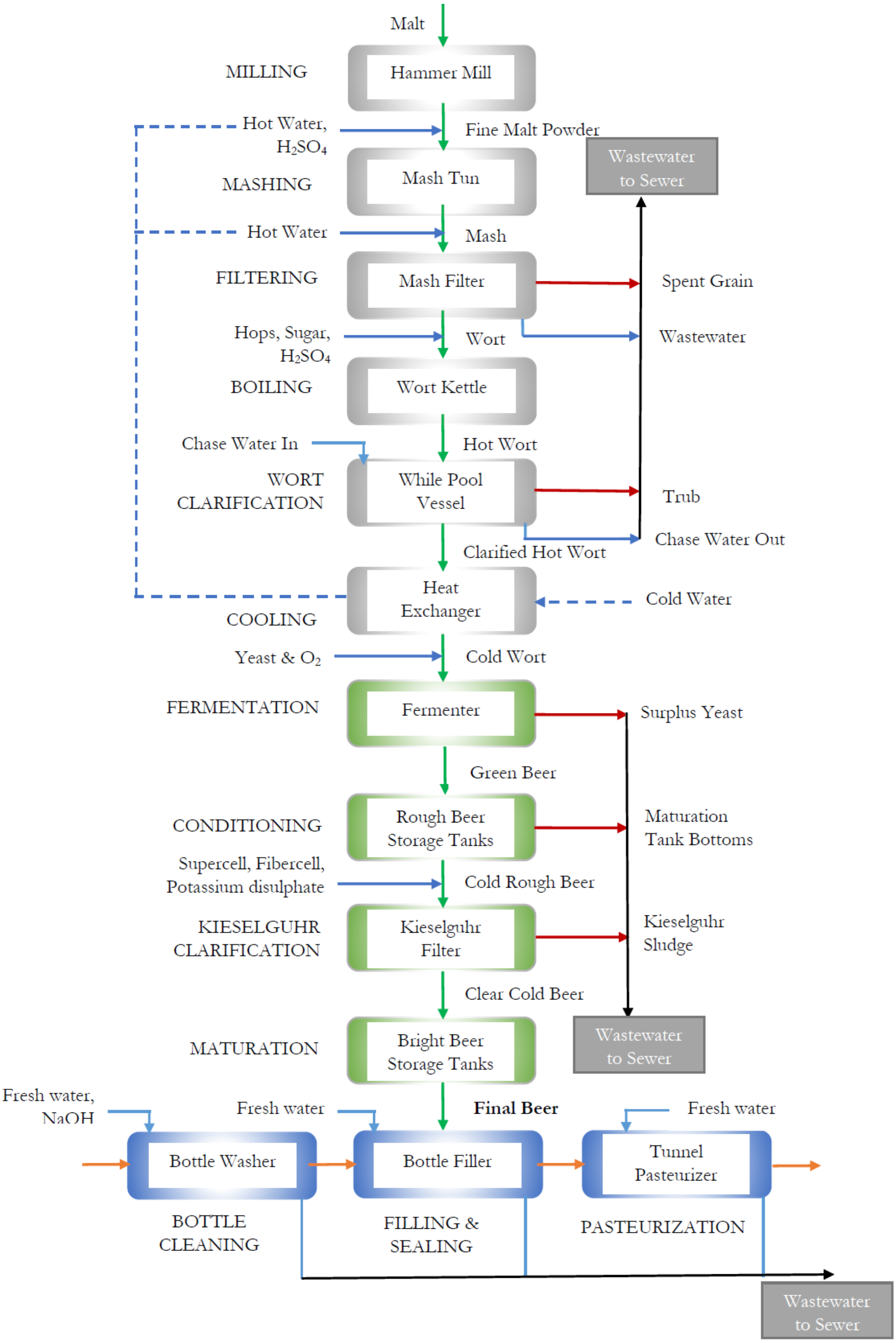

Figure 1. Production of Beer and Waste discharges from Asmara Brewery (ABCSC).

Plant production days approximated to 250 per year with 300,000 bottles of 300 ml per day for the study, thus Asmara breweries produce approximately 150000 bbls/year and belong to a larger production category. Breweries with production volumes greater than 100000 bbls/yr reported lower unit costs and appear to be more cost-efficient than breweries producing less than 100000 bbls/yr. In contrast, expensive water use was recorded for the case study due to a lack of targets, training, and awareness of employees on water management.

Table 1. Weekly report on water used and wastes generated from Asmara Brewery.

Water (hl)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week8
Water Used	7768.05	7191.80	7976.95	7833.91	7915.26	7769.56	7774.95	8004.76
Wastewater	7330.38	6753.33	7314.18	7172.67	7367.15	7331.48	7336.49	7397.65

3.2 Fresh Water Consumption

Asmara Brewery has the accessibility of fresh water from the municipal water supply and their wells within the premises of the factory. 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. The distribution of freshwater consumption with chase water inclusion and without is shown in a pie diagram in Figure 2. Daily average process water estimated is about 778 m^3/day, less than the planned as it was considered water used for CIP of operations due to lack of information. Water use in Mash-Tun, Filler, Bottle Cleaner, and Chase water is significant in ascending order. Figure 2 also describes that bottle cleaner stands at 62%, a significant operation when chase water is not included in the assessment.

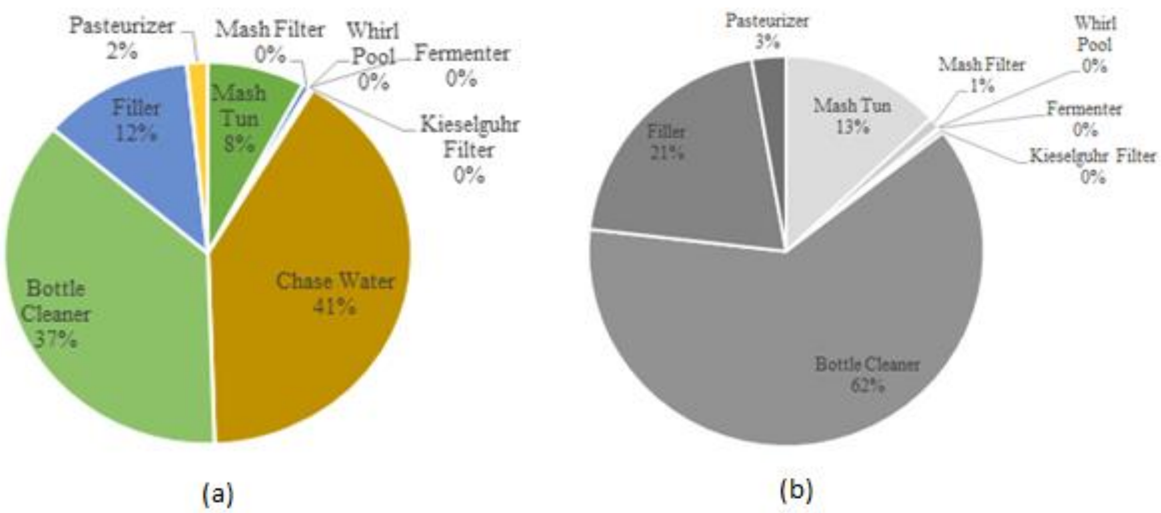

Figure 2. Water use distribution in Asmara brewery operations with (a) and without (b) chase water.

3.3 Effluents from the brewery operations

Discharges of waste from ABCSC brewery including chase water spent grain, trub, surplus yeast, and Kieselguhr sludge are allowed into public sewer lines without any primary concerns of reuse, which makes a huge burden economically and poses severe environmental issues along with the expense of sewage waste treatment. Entire chase water allowed to sewer besides bottle cleaner wastes, filler wastes, and other solid wastes. Wastewater discharges from bottle washers are about 70%, still higher when chase water is not concerned in calculations. Approximately, 87.2% of the water used ends up as effluents and eventually causes to raise in BOD and COD levels in municipal sewages.

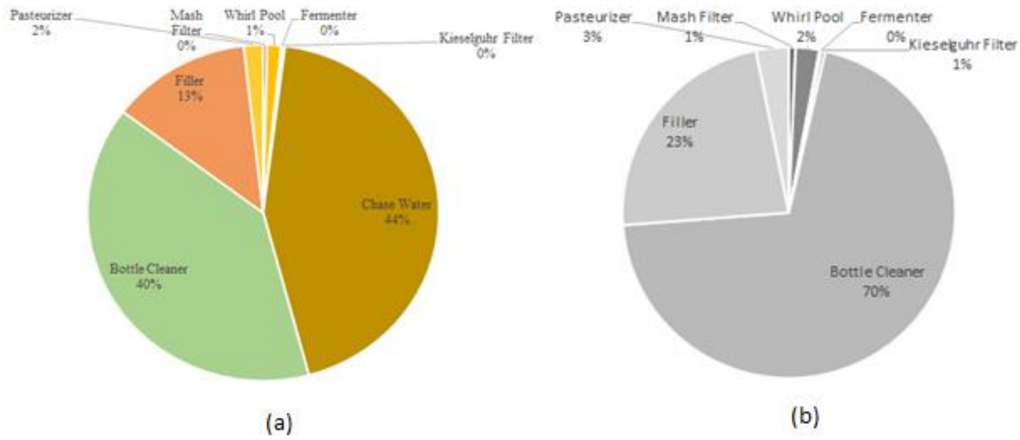

Figure 3. Wastewater distribution in Asmara brewery operations with (a) and without (b) chase.

4. Discussion

4.1 Specific water balance in Brewery operations

Specific water is defined as 1 L of fresh water consumed or wastewater discharged in brewery operations per 1 L of beer sold. Specific water volumes are estimated based on weekly reports and tabulated in Table 2 for further comparison. Average water use parameters evaluated for the brewery case studied compared with Breweries association benchmarks (BREF, 2006) and to the publication of the European Brewery Convention, EBC (1990) [12]. The volume ratios of water consumed in Brew house, Fermentation, Bottle washer, and Pasteurization sections are within benchmarks of BREF with slight deviations due to a lack of information on water use for CIP (Clean in Place) of operations. As the specific volumes depicted in Table 2, the chase water consumed to push beer from the filtering process to storage tanks was 3.51, highly significant and not considered by international standards because it might be reused in the process.

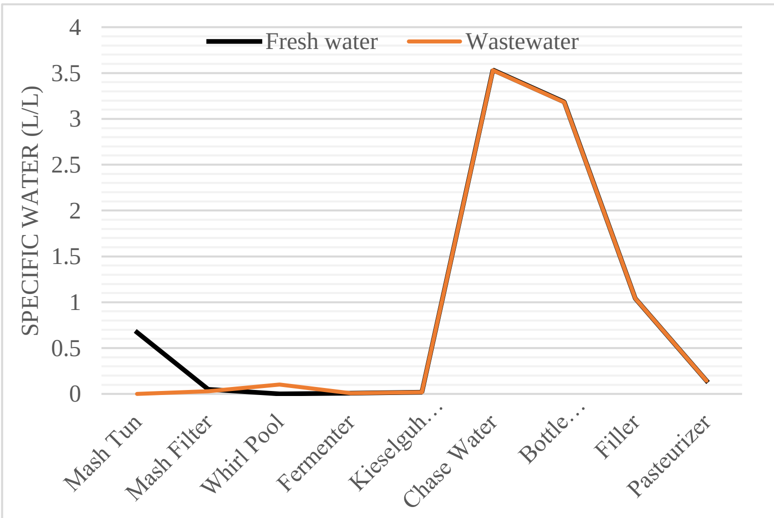

Figure 4. Specific volumes of fresh water and wastewater from brewery operations.

A comparative chart (Figure 4) was made to analyze intake water with effluents. In most of the operations, both parameters merged except mash tun, where fresh water from the wort cooler was directly reused. Voluminous wastewater is generated from general services such as rinsing of operation, flushing water, bottle washer, and filler despite a little water about 12% consumed in actual beer production. Xhagolli et al. [17] have reported that 65% of total wastewater discharged accounts for bottle cleaning and packaging sections from Albanian breweries [17] whereas Asmara breweries identified 55% of total effluents generated from bottle washing and packing.

Table 2. Fresh water use in Asmara Brewery Operations.

Department	Process Unit	Asmara Brewery (L of water/L of beer produced)	BREF (L of water/L beer produced) [12]	EBC (L of water/L of Beer sold) (Good Practice) [12]
Brewhouse to Wort cooling & CIP	Mash Tun Mash Filter Wort kettle Whirlpool Chase water to push hot wort	1.09 (without CIP& included Chase water)	1.3-2.36	1.75
Fermentation and yeast handling & CIP	Fermenter and Storage Tanks	0.0094 (without CIP & included Chase water)	0.32-0.53	0.09
Filtration & CIP	Kieselguhr Filter Chase water to push beer	3.5275	0.31-1.09	0.28
Bottle washer (25% production)	Bottle washer (25% of production)	0.796	0.13-0.61 (25%Production)	0.23 (25%Production)
Filling and Pasteurization	Filler	1.044	-	-
	Tunnel Pasteurizer	0.135	-	0.16
	Total	**8.98715**	3.7-4.7	4.53

Table 3. Comparison with local and International Benchmarks.

Parameter	Asmara Brewery (with Chase water)	Asmara Brewery (without Chase water)	Breweries Association Benchmarks [1]
Annual Average Water Usage (gal)	53454247	32415799	46776160
Water Use Ratio	8.98715	5.45	4.58
Annual Average Wastewater Discharge (gal)	46724035	26221502	27547209
Wastewater Discharge Ratio	7.84035	4.4	2.52
Wastewater/Freshwater (gal/gal)	0.872	0.807	0.55

4.2 Sustainability of Large-scale breweries

The sustainability of breweries primarily depends on achieving plausible economical optimization through wise utilization of power and water coupled with mitigations of effluents. Brewers realize an economy of scale when producing more than 100000 bbls/yr of beer. Breweries with a higher production volume may also have more automated processes, which can provide for tighter control of the amount of water used for cleaning and sanitization [1]. Unfortunately, Asmara brewery's water use and effluent parameters were noticed with higher volumes when chase water was accounted for. Flushing water significantly contributes to deciding its sustainability in terms of water, particularly in Eritrea where the rainfall decreases gradually over the past decade. Water use ratio and wastewater discharge greatly deviated from the benchmarks set by the Breweries Association as shown in Table 3.

Table 4. Characteristics of effluents from ABCSC and their aptness to reutilize.

Source	Operation	Specific effluent (L of waste/L of beer)	Characteristics of effluent and its appropriateness for reuse
Mash Filter	Running losses in spent grain and washing	0.0282	Cellulose, sugars, and traces of spent grain. It can be reused for mashing as it contains sugars.
Whirlpool	Spent hops and hot trub	0.1	Proteins, sludge, and wort, light green in color, high in SS
Chase water to push hot wort	Flushing water to push hot wort and to maintain pipelines	0.026	Relatively clean, very low SS and it can be reused directly for cleaning purposes
Fermenter and Storage Tanks	Rinsing	0.00915	Spent yeast, protein, high SS
Kieselguhr Filter	Cleaning, flushing, and leaks during filtration	0.017	Excess SS, beer, yeast, proteins
Chase water to push beer	Flushing water to transfer the clean beer to storage tanks	3.415	Relatively clear, it can be reused directly for rinsing of operations
Bottle washer	Discharges from the returnable bottle washings	3.098	High pH due to caustic used for cleaning, also high in SS due to thru load. It can be reused after a simple pH neutralization and sedimentation.
Filler	Beer spills from filling machine	1.016	It's a kind of foamy beer effluent along with washing water, and possible to reuse with a simple treatment
Tunnel Pasteurizer	Wastewater from the pasteurization unit	0.131	washing water produced once a week, and possible to reuse with simple treatment
	Total	**7.84035**	

4.3 Potential Inline Practices to Reduce Wastewater

Best practices to mitigate excess water usage in breweries were reported by several studies [10,8,1,2,3], and the effect of personal participation was documented by Puplampu and Siebel [6]. Technical alternatives such as replacing Kieselguhr with generable filter-aids in beer filtration, or replacing commercial filters with membrane filters to prevent high suspended solids (SS) in effluents. Conversion of spent grain, trub, and surplus yeast and Kieselguhr sludge into value-added biological products boosts the economy of the brewery.

Table 5. Best practices advocated by the breweries association for the reduction and reuse of water [3].

Source	Best practice advocated by BA
Mash Tun, Boiling Kettle, and Whirlpool	Train staff to add the correct amount of liquor by installing a meter to measure the volume of liquor, provide storage for surplus wort in case of frequent brewing, Storage of residual wort with trub for possible selling as an animal feed supplement. Do not mix wort/trub with surplus yeast to prevent fermentation and to preserve the quality of the by-product as animal feed. Use mechanical means such as a brush or rake to remove spent grains from the mash filter to save water.
Heat Exchanger	Make sure heat exchangers are well maintained regularly to control required water flow rates.
Fermentation vessels, Yeast disposal, and Filtration	Closed systems require cooling of fermenters and use vast amounts of water and it can be discharged into special locations instead of sewer lines for further circulation using adequate pumps. Open fermenters typically require manual cleaning, an optimized rinsing of the vessels minimizes potential usage of water, as well as lower the effluent BOD levels. Detergent sprays are available for more effective removal of deposits; foam is used to soften the deposits (after an initial rinse) with a minimum of water. The use of scrapers and brushes will reduce the time needed to clean the vessel with a hose. Avoid disposing of yeast slurry in the drain, as it has a high BOD value and high SS. Find an option to recover residual alcohol such as a centrifuge or filter. Since the yeast contains 40% of protein, the remains may be sold as animal feed. Replacement of traditional diatomaceous earth filters with cross-flow or membrane filtration may reduce water consumption.
Plant Cleaning (CIP System)	Using a CIP system is generally more efficient than manual Cleaning with increased vessel cleanliness and reduced water and chemical consumption.
Chase water	When beer is transferred in pipes, the pipes have to be cleaned often and it is usually practiced in breweries using huge volumes of chase water. Purging with CO_2 is an option but not done because of high-pressure systems. The pigging method can be applied for rinsing straight pipes but is difficult with bends. When to clean, and where to clean highly depends on the judgment of the operator.
Bottle Washer, Filler, and Pasteurizer	Deploy plastic belts instead of standard steel belts. Fitting a solenoid valve to isolate the flow when the conveyor is switched off is a low-cost measure that can produce large savings in water use. Optimize conveyor rinse jet pressures. Replace nozzles to increase the pressure and nozzle diameter. Ensure overflow points are visible to operators by extending the pipe to a position where operators can see it. Consider the re-use of the final rinse water of the washers for the pre-rinse stage (or any other stage or application). Optimize the caustic dosing to the minimum quality standards to allow minimum water use during rinsing.

Potential practices using an employee awareness program may include appointing an ambassador for water-related issues, a monthly incentive program to appreciate initiations on water-saving activities, and employee education sessions to share ideas and relative information on water usage. Setting annual targets such as water use ratio, and wastewater to fresh water ratio at each department of the plant. In addition to employees' active involvement, best practices in brewery operations are generalized and advocated by the brewer's association as shown in Table 5.

4.4 In-situ Wastewater Recycling Technologies

Most of the effluents generated from brewery operations are recovered and reused with simple pre-treatment technologies such as segregation of effluents from the disposal points, providing temporary storage tanks, which provide sedimentation of settleable solids, removal of suspended solids, pH neutralization, and biological or chemical treatments. Screening is typically the first step to removing the glass, labels, bottle caps, floating plastic items, and spent grains. Then it may be allowed into a grit chamber where sand, grit, and small stones settle down. Minute particles of matter are removed in sedimentation or chemical flocculation. Flocculation usually enhances sedimentation performance by increasing particle size, resulting in increased settling rates. If not, centrifugation is applied to remove most of the suspended solids at the cost of energy.

Adjusting pH in the waste streams is one of the most difficult processes. Good pH neutralization and adjustment include proper mixing, tank configuration, and instrument control. It usually consists flow equalization tank followed by a chemical adjustment process using continuous agitators. After the brewery wastewater has undergone physical and chemical treatment, biological treatment could be applied. Biological treatment of wastewater can be either aerobic (with air/oxygen supply) or anaerobic (without oxygen). Recently, biogas production using anaerobic digestion systems has become a more attractive option as it generates potential renewable energy from bio-waste resources.

5. Conclusions

Understanding water balance and management in breweries is an essential step to making a decision on water use policy and saving huge volumes of freshwater resources. Weekly assessment for eight consecutive weeks in Asmara Breweries (ABCSC) was documented and it would serve as the base for further development of the process of reducing, reusing, or recycling water. Annual average water consumption found excess than the breweries association benchmarking system for the production category greater than 100000 bbls/year of beer. As the plant adopted a returnable bottle package system, the consumption of water in packaging that includes bottle cleaning, filling, and pasteurization contributes to the first major water consumption with 51% of total water consumption in the plant. This study revealed that the chase water uses to push beer remained the second major element contributing significantly to excess water usage in the plant with 41% of total water consumption. All other processes contribute to the remaining 8% of the total water. As a result, plant-generating wastes include huge volumes of water from flushing and bottle washing sections, 44 and 40% of total effluents respectively. Plant performance variables such as water use, and wastewater generation per liter of beer produced are 8.98 (L/L) and 7.84 (L/L), higher than the benchmarks when chase water is included in the estimation. As the plant does not segregate the waste streams, effluents of the plant consequently cause higher BOD and COD levels and eventually result in severe environmental issues.

If the plant can replace chase water with alternatives, it could save, good amounts of freshwater. Employee awareness programs and implementation of potential practices would result in saving water. Hence, the plant should pay immediate attention to the prudent utilization of water resources by adopting the best practices advocated by the brewers association or any other international policies or from proven industries such as Heineken N.V. a German beer company.

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