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Characterization of Brewery Wastewater for Reuse in Kigali, Rwanda

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Abstract: Like many developing countries, Rwanda is grappling with water shortages in the face of both increased urbanization and industrialization. Other options that will provide water for industrial activities without necessarily tapping into new water sources must be explored. This study investigates the prospects of wastewater re-use using a case study of Bralirwa soft drink factory (BSDF) in Kigali City, Rwanda. From August 2009 to January 2010, laboratory experiments were conducted at both Bralirwa wastewater treatment plant laboratory and National University of Rwanda water laboratory. The main objective was to characterize wastewater from BSDF so as to determine its reuse options. The parameters analyzed included Temperature (T), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Ammonium Nitrogen (NH₄-N), Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD₅), Electro-Conductivity (EC), Salinity, equivalent OH⁻ and Residual Chloride. The Bralirwa soft drink factory wastewater removal efficiencies for TSS, BOD₅, EC, TDS, NH₄N, TP, Residual Chloride, and equivalent OH⁻, was 72%; 93%; 30%; 25%; 78%; 30%; 84% and 92%, respectively. Based on recommended Rwandan wastewater quality re-use standards, this study concluded that Bralirwa wastewater re-use options are lawn irrigation, agricultural irrigation, factory reuse etc.

Keywords: Brewery wastewater, removal efficiencies, Rwanda, wastewater treatment, wastewater reuse, water quality.

1. INTRODUCTION

The world's supply of freshwater is limited and threatened by pollution from various human activities. Rising demands of water to supply agriculture, industry and cities are leading to competition over the allocation of the limited freshwater resources [1]. As estimated by WHO (2006), "within the next 50 years, more than 40% of the world's population will live in countries facing water stress or water scarcity". Wastewater reuse has been used in various parts of the World as an alternative to address water shortages. On another front, the idea that water is an infinite resource is a reason for water shortages because its use in different sectors is with no limitations. In order to reduce water shortages, some authors, e.g. [2-6], suggest re-using treated wastewater as a reliable alternative water source. Water deficiency is the result of burgeoning population, unequal access to water resources by various social classes, growth in different sectors of the economy, practices that degrade rather than conserve water quality and the lack of institutions capable of managing water deficit and degradation [7]. In Rwanda, the direct re-use of treated wastewater is rather a new phenomenon.

In 2005, it was estimated that only 54% of Rwandan population and only 44% in the rural area had access to safe water supply [8]. Considering the population increase estimated to be 40% in Kigali the capital City of Rwanda, the potential re-use of treated wastewater is worth investigation. However, it is necessary to characterize such water and determine the possible reuse applications. According to [8], performance and reliability of wastewater treatment technologies are significantly affected by variability of raw waste loadings and the nature of the treatment processes and compliance to permit limits and/or quality constraints necessary for reuse are affected by control of this variability. The re-use of treated wastewater is rather a new phenomenon in Rwanda and like in many developing countries; there are no wastewater re-use regulations. Rwanda has developed regulations for wastewater disposal [9]. The maximum allowable wastewater effluent standards for pH limits are 6.0 - 9.0, 50 mg L⁻¹ for total suspended solids (TSS) and Biological Oxygen Demand (BOD₅) and 250 mg L⁻¹ for Chemical Oxygen Demand (COD).

Until now, water supply coverage is not sufficient in Rwanda [8] and wastewater re-use is yet to be explored. Experiences from elsewhere indicate that wastewater from soft drinks facilities could be re-used [10-14]. In 2009, the BSDF received 7,912 m³ of water and 38% (3,042 m³) of the water was used to produce soft drinks whilst 48% (3,829 m³) was discharged to the Bralirwa wastewater treatment plant. The prospects of re-using wastewater at Bralirwa soft drink

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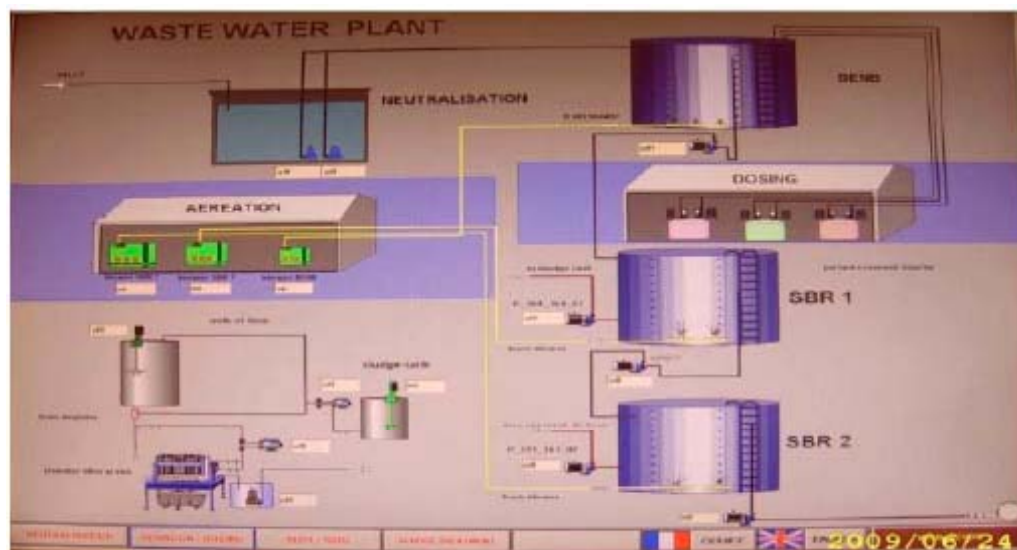


Fig. (1). A scheme of the BSDF wastewater treatment plant, Kigali, Rwanda.

factory (BSDF) therefore remain an attractive option. The main objective of this research is to characterize wastewater from BSDF and to propose possible re-use options.

2. MATERIALS AND METHODS

2.1. Description of Bralirwa Soft Drink Wastewater Treatment Plant

BSDF wastewater treatment plant in the Kicukiro District, in Kigali City (Rwanda), was officially opened in 2009. It is composed of five components as shown in Fig. (1). The Inlet tank and outlet tank have capacities of 50 m³ each. The treatment plant receives wastewater the BSDF production units only. Wastewater from the factory flows through a channel and passes through coarse screens which are intended to remove relatively large sized suspended material.

2.2. Sample Collection and Analysis

During this study, sampling was conducted between August 2009 and January 2010 where seasonal changes were recorded. A total of 28 samples were collected from the inlet and outlet tanks. The parameters measured at the water laboratory of the National University of Rwanda (NUR) were Total Suspended Solids (TSS), Ammonia Nitrogen (NH₃-N), Total Nitrogen (TN), Total Phosphorus (TP), Electro-Conductivity (EC) and equivalent OH⁻. Before the analysis samples were kept in the freezer in laboratory at a temperature of 0°C. Nutrients in the wastewater were analyzed as per Standard Methods for the Examination of Water and Wastewater [15].

Other parameters namely, Physico-chemical parameters, namely Temperature (T), Total Dissolved Solids (TDS), Turbidity, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD₅), Salinity, and Residual Chloride were measured at Bralirwa Wastewater Treatment laboratory. Portable meters (HACH) were used to measure EC, TDS and T and DO instantaneously at point of sample collection. Turbidity was measured with a turbidity meter. The TSS was measured using the gravimetric method. The meas-

urement of Most Probable Number of *E.coli* was performed by incubating multiple tubes in a water bath at 35°C ± 0.5°C for 3 hours, and then transferred to a water bath at 44.5°C ± 0.2°C. After 21 ± 2 hours, tubes were examined for growth and gas production. Gas production in 24 hours or less was a positive reaction indicating the presence of fecal coliforms. The faecal coliforms were analysed because of their health impacts in wastewater re-use. The Removal Efficiency (RE) was computed based on Equation (1):

$$RE = \frac{C_i - C_f}{C_i} \times 100 \quad \text{Eq. (1)}$$

with C_i is value of parameter before treatment; C_f is the value of the parameter after treatment.

2.3. Data Analysis

The data obtained were analyzed using descriptive statistics in Microsoft Excel. The results were expressed in terms of mean and standard deviation. The results were compared with standard water quality guidelines. A one-way analysis of variance test was used to compare the difference between means.

3. RESULTS AND DISCUSSIONS

3.1. Characterization of BSDF Wastewater

Table 1 summarizes the Removal Efficiency (RE) results of physico-chemical and microbiological parameters at the inlet and outlet at BSDF wastewater treatment plant.

With the exception of residual chlorides, Table 1 shows good removal efficiency and/or absence of faecal coliforms when pollutant concentrations in the influent and effluent were compared. According to Table 1 the wastewater treatment process best removed COD with an efficiency of 97% and least removed TN with an efficiency of 24%. The increase in residual chloride concentration was attributed to the use of chlorides in cleaning activities in the Bralirwa Soft Drink plant. The inlet and outlet temperature of the wastewater remained more or less the same due to the hot oxygen

Table 1. Variation of Physico-Chemical and Microbiological Parameters Considering the Inlet and Outlet Tanks at BSDF Wastewater Treatment Plant, August 2009 and January 2010

Parameters	Influent	Effluent
Temperature (°C)	29.7±2.0	28.1±0.9
TSS (mg L ⁻¹)	66.3±23.2	24.5±17
Salinity (mg L ⁻¹)	2.6±0.4	1.7±0.5
Ec (µS cm ⁻¹)	4,565±1,278	3,393±552
Nitrate (mg L ⁻¹)	4.6±5	1.0±0.8
Nitrite (mg L ⁻¹)	0.04±0.02	0.01±0
NH ₄ -N (mg L ⁻¹)	1.30±1.1	0.3±0.2
TN (mg L ⁻¹)	3.0±5.5	1.5±2.3
TP (mg L ⁻¹)	7.0±4.0	4.1±13.1
Chloride (mg L ⁻¹)	0.4±0.1	0.5±0.1
BOD ₅ (mg L ⁻¹)	197±25.4	22.5±9
COD (mg L ⁻¹)	1,757.8±951.0	35.3±11.3
FC (CFU/100 mL)	No faecal coliforms	No faecal coliforms.

from the compressors which is supplied during the aeration step. Encouraged by these findings, the BSDF wastewater treatment plant was divided into 10 segments in order to investigate changes in pollutant concentrations. A total of 14 samples were taken and analyzed for each segment. Table 2 shows measured concentrations of different parameters at selected sampling sites.

3.2. Temperature, pH and EC Profiles at BSDF Wastewater Treatment Plant

Fig. (2) shows temperature and EC profiles across the 10 sampling sites at BSDF wastewater treatment plant.

In Fig. (2a), the highest temperature measured was 30.5 ±1.6 °C for plant influent and the lowest was 26.6 ±1.3 °C at site SBR2b. In general, between influent and sampling site, outlet tank, the P (T<=t) =0.00024, which means that the decrease in temperature was highly significant. Between Inlet1 and Inlet2 sites, the P (T<=t) was equal to 0.05, indi-

cating that the change in temperature was significant. For the other 8 sites, the P (T<=t) values were greater than 0.05, hence any change in temperature at these sites was not significant. The mean temperature recorded for the wastewater explored for re-use purposes during this study was 27.4±0.5°C. This temperature allows the psychrophilic micro organisms to thrive because they thrive in temperature range of -2° to 30°C, with optimality requiring 12°C to 18°C. Mesophilic micro organisms also thrive in temperature of 20°C to 45°C, with optimality ranging from 25°C to 40°C [16].

In Fig. (2b), the wastewater pH ranged between 7.5±0.3 and 11.8±0.8. A Statistical analysis suggested that the variation in pH was significant with P(T<=t) of 0.02, 0.00, 0.04, for influent and inlet1; inlet2 and EQ1, respectively. For the influent and outlet tank sites, the P (T<=t) value of 0.000002 indicates that during treatment process, there was a significant decrease in pH. The allowable pH range for wastewater discharged into the environment should vary between 6.5 and 8.5 [17, 18]. This means that the effluent pH met the required standards in Rwanda.

In Fig. (2c), the highest and lowest EC values were 4,464.8±2,239.0 µS cm⁻¹ and 3,123.8±758.7 µS cm⁻¹ for influent and outlet sampling sites, respectively. Authors such as [1] proposed that the effluent should be in the range of 700 to 3,000 µS cm⁻¹.

3.3. TDS, TSS and Turbidity Profiles at BSDF Wastewater Treatment Plant

Fig. (3) shows TDS, TSS and Turbidity profiles across the 10 sampling sites at BSDF wastewater treatment plant.

In Fig (3a) the highest TDS values measured was 2,236.4±1,139.6 mg L⁻¹ for influent. The removal efficiency of TDS was 21.5% with the final value of 1,671.0±413.0 mgL⁻¹, which can be tolerated for artificial discharge since the tolerance limit is 1,500 mg L⁻¹ [18]. In Rwanda, the tolerance limit of discharged industrial wastewater is 2,000 mg L⁻¹ for total dissolved solids [9]. The difference in TDS was only significant between sites, inlet2 and EQ1, where statistically the P (T<=t) value was equal to 0.034. Differences in total dissolved salts with respect to the other sites were not statistically significant (P (T<=t) > 0.05).

Table 2. Variation of Physico-Chemical Parameters Considering the Exit of the Bralirwa Soft Drink plant (Influent) and Sequential Batch Reactor 1 (EQ 2), August 2009 and January 2010

Parameter Measured	Influent	Inlet1	Inlet2	EQ1	EQ2
TSS (mg L ⁻¹)	77.3±70.2	105.0±67.4	121.9±56.4	117.5±89.5	122.0±107.2
Turbidity (NTU)	76.9±97.2	132.6±236.8	83.5±99.3	72.9±22.6	65.9±26.2
Salinity (mg L ⁻¹)	2±0.9	2.5±0.8	2.7±1.2	1.7±0.5	1.6±0.5
NH ₄ -N (mg L ⁻¹)	1.4±0.4	0.6±0.1	0.5±0.1	0.5±0.1	0.4±0.1
TN(mg L ⁻¹)	2.8±2.3	2.2±1.9	4.4±4.1	3.1±2.9	2.5±2.4
TP (mg L ⁻¹)	16.3±7.4	15.7±7	13.3±6.6	15.1±8	14.1±7.7
Chloride (mg L ⁻¹)	2.3±1.8	1.7±1.3	1.1±0.5	2.3±1.2	1.7±0.9
BOD ₅ (mg L ⁻¹)	385.0±287.4	358.3±285.1	356.8±286.2	301.0±246.1	267.3±216.8

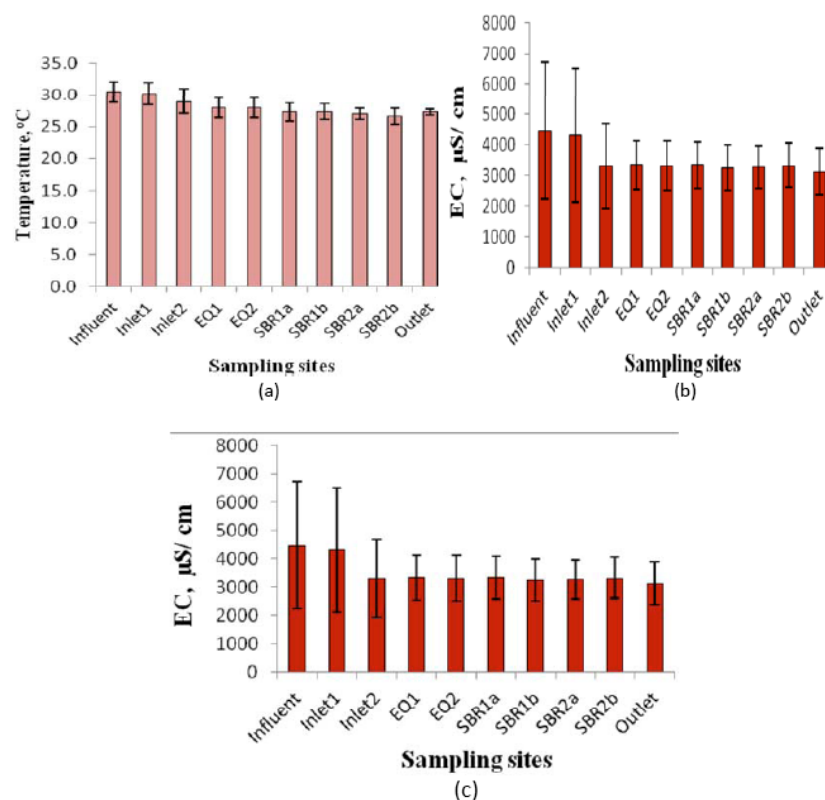


Fig. (2). Profiling wastewater temperature and EC for 10 sampling sites at BSDF wastewater treatment plant, August 2009 and January 2010.

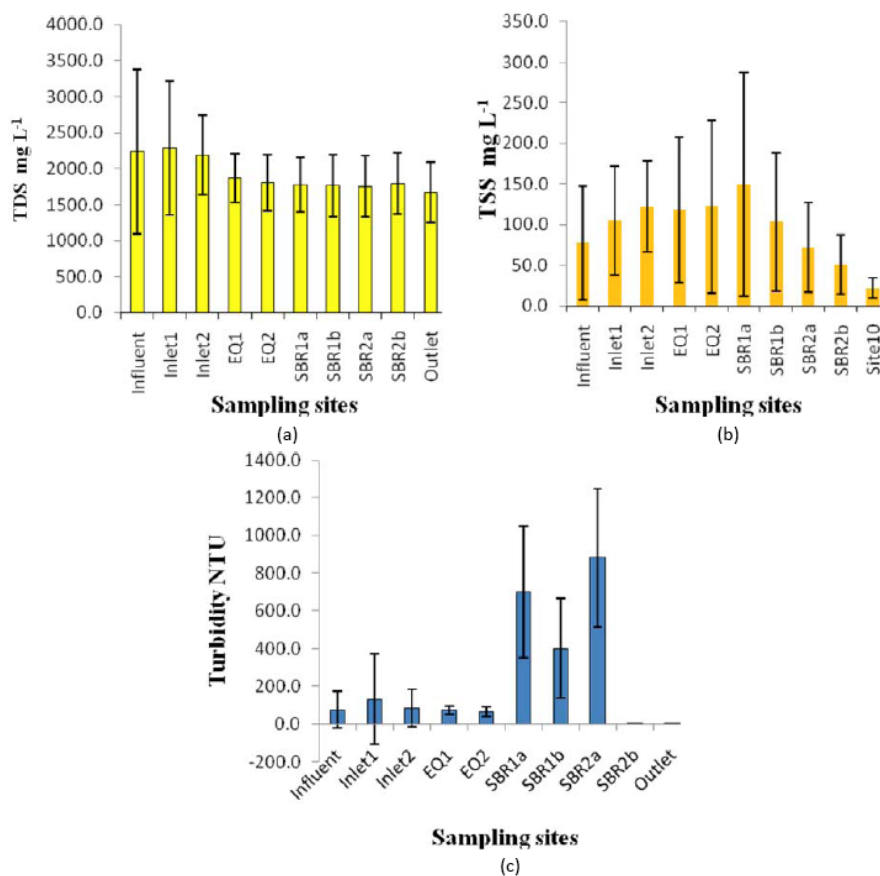


Fig. (3). Profiling wastewater TDS, TSS and Turbidity for 10 sampling sites at BSDF wastewater treatment plant, August 2009 and January 2010.

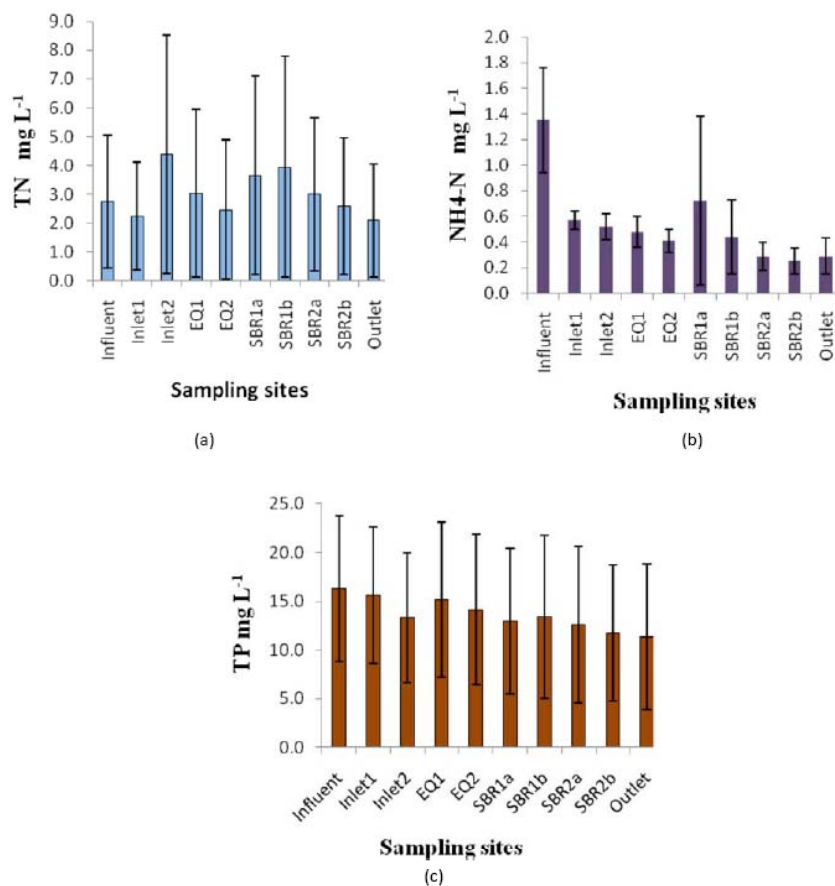


Fig. (4). Profiling wastewater TN, NH₄-N and TP for 10 sampling sites at BSDF wastewater treatment plant, August 2009 and January 2010.

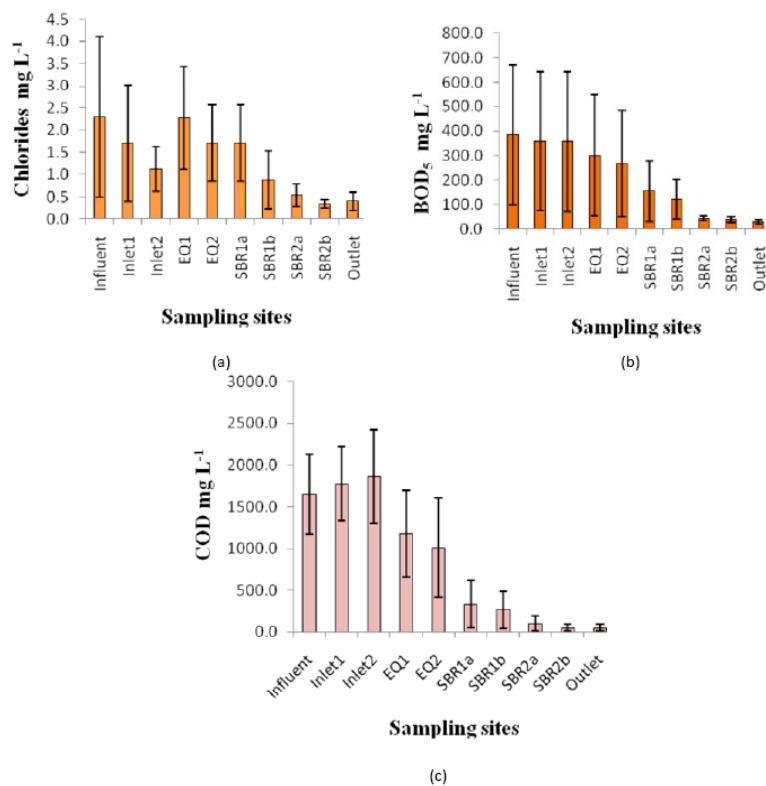


Fig. (5). Profiling wastewater Chlorides, BOD₅, COD for 10 sampling sites at BSDF wastewater treatment plant, August 2009 and January 2010.

In Fig. (3b) the highest TSS of $149.9 \pm 137.7 \text{ mg L}^{-1}$ was measured at site, SBR1a. The difference in TSS was only significant for sampling sites SBR2a and SBR2b, where statistical value shows $P(T \leq t)$ of 0.04. All other values of $P(T \leq t)$ were greater than 0.05 and the differences in TSS concentration were not significant. The overall removal efficiency of TSS was 72% with the final value of $21.7 \pm 12.6 \text{ mg L}^{-1}$. The TSS concentration suggests that the wastewater can be used in fisheries, since fisheries require reclaimed water quality of $\leq 30 \text{ mg L}^{-1}$ [2, 19]. According to [20], the allowable TSS value for water reuse for irrigation is 20 mg L^{-1} hence TSS value of the wastewater from BSDF suggested the water is not suitable to be reused for irrigation. In Rwanda, the discharge limit is 50 mg L^{-1} for total suspended solids (TSS), thus BSDF treated wastewater meets Rwanda discharge standards.

In Fig. (3c) the highest and lowest turbidity values were 879.1 ± 366.2 and 5.4 ± 0.6 NTU at sampling sites, SBR2 and SBR2b, respectively. The turbidity tolerance limit in Rwanda for discharged wastewater is 30 NTU [9], indicating that the effluent from BSDF wastewater treatment plant meets the Rwandese standards hence can be re-used for agricultural irrigation. However, [2] reported that the allowable turbidity for this reuse is ≤ 2 NTU.

3.4. TN, $\text{NH}_4\text{-N}$ and TP Profiles at BSDF Wastewater Treatment Plant

Fig. (4) shows TN, $\text{NH}_4\text{-N}$ and TP profiles across the 10 sampling sites at BSDF wastewater treatment plant.

From Fig. (4a) and (b), the highest concentration of TN and $\text{NH}_4\text{-N}$ were measured to be $4.4 \pm 4.1 \text{ mg L}^{-1}$ and $1.5 \pm 0.4 \text{ mg L}^{-1}$ respectively. These values were measured at inlet 2 for TN and in influent for $\text{NH}_4\text{-N}$. The $P(T \leq t)$ values of TN suggest that there is statistically significant difference between the influent and inlet1. The difference in concentration for $\text{NH}_4\text{-N}$ was very considerable between influent and inlet1. The TN concentration usually increases in anoxic conditions and decreases in aerobic conditions, however, during this study, the removal efficiency in anoxic conditions showed negative values. This was due to the fact that in the presence of oxygen, organic nitrogen and ammonia is converted into nitrate and in the absence of oxygen, there is denitrification caused by denitrifying bacteria which strip oxygen from NO_2^- , and convert NO_2^- into N_2 gas [16]. In Fig. (4c), the highest TP value is 16.3 ± 7.4 for the influent. The difference in TP concentration tended to increase between EQ1 and EQ2; EQ2 and SBR1a; SBR2a and SBR2b; where $P(T \leq t)$ values were 0.057; 0.053; 0.056, respectively. The mean value of TP recorded (11.4 ± 7.5) mg L^{-1} was obtained after an overall RE of 30% which means that the value was below that expected (15 mg L^{-1}) for discharge into catchments areas or artificial recharge as suggested by [19-21].

3.5. Chloride, BOD_5 and COD Profiles at BSDF Wastewater Treatment Plant

Fig. (5) shows Chloride, BOD_5 and COD profiles across the 10 sampling sites at BSDF wastewater treatment plant.

In Fig. (5a), the highest chloride residual value recorded was 2.3 ± 1.8 for influent. The difference in chloride residual tended to be significant especially between influent and inlet1 at $P(T \leq t) = 0.05$. The measured chloride residual was $0.4 \pm 0.2 \text{ mg L}^{-1}$. According to [20], the allowable effluent residual chloride should be below 1 mg L^{-1} for urban water re-use. According to [9], the minimum requirements for liquid wastes disposal and treatment for effluent residual chloride discharge is 1 mg L^{-1} . Therefore the BSDF effluent meets the required standards. Fig. (5b) shows that the highest BOD_5 value measured was $385.0 \pm 287.5 \text{ mg L}^{-1}$ in the influent. There was statistical significance in the variation in BOD_5 values for the influent and inlet2 sites; SBR1b and SBR2a, SBR2b and outlet, with $P(T \leq t)$ of 0.029; 0.024 and 0.028, respectively. Interestingly, the $P(T \leq t)$ value of 0.01 obtained between influent and outlet sites indicates that the difference in BOD_5 was significant. It can be concluded that the treatment plant removes the BOD_5 (Effluent $\text{BOD}_5 = 27.7 \pm 8.4 \text{ mg/l}$). The overall RE for BOD_5 of 92.8% was good for aerobic wastewater treatment. Agricultural reuse for non-food crops requires $\text{BOD}_5 \leq 30 \text{ mg L}^{-1}$, although urban reuse for parking areas, playgrounds and roadsides requires $\text{BOD}_5 \leq 10 \text{ mg L}^{-1}$ [2, 22]. The maximum allowable BOD_5 discharge in Rwanda is 50 mg L^{-1} . As can be seen in Fig. (5c), the highest COD values measured was $1,774.0 \pm 443.4 \text{ mg L}^{-1}$ at inlet1. Also the lowest COD measured was $50.6 \pm 38.2 \text{ mg L}^{-1}$ at SBR2b. The $P(T \leq t)$ values of 0.01, 0.01, 0.02 and 0.04 suggest that there is a significant variation between influent and inlet1; EQ2 and SBR1a; SBR1b and SBR2a; SBR2a and SBR2b, respectively. RE of 70% as far as the biological treatment of soft drink wastewater was concerned [22]. The measured effluent COD of $35.3 \pm 11.26 \text{ mg L}^{-1}$ was below allowable COD concentration for the discharge to catchments areas and surface irrigation of orchards. The allowable COD for discharge is 200 mg L^{-1} according to [18] while [1] recommended 80 mg L^{-1} for surface irrigation. Researchers such as [20, 23] proposed COD concentration value of $\leq 103 \text{ mg L}^{-1}$ for irrigation purposes or for discharging into streams.

4. CONCLUSIONS

Based on the findings of this study, it was concluded that:

1. With the exception of pH values, all the other parameters investigated in this work are below the WHO standards for wastewater reuse. The BSDF wastewater plant effluent meet the standards for irrigation of cooked vegetables, parking areas, playgrounds and roadsides inside Kigali City, plenteous trees and green areas, roadsides outside Kigali City, etc.
2. When Rwandan standards for treated wastewater for reuse are considered, the values measured for pH, TSS, $\text{NH}_4\text{-N}$ and COD are below the maximum allowable. Therefore treated effluent could be safely re-used.
3. Based on regulations for wastewater reuse and discharge, TDS, TSS, pH, $\text{NH}_4\text{-N}$ and COD meet the standards for wastewater reuse and discharge. Also, TN, TSS, Turbidity, pH, EC, BOD, COD were below

the maximum allowable for irrigation. Furthermore, pH and residual chloride recorded meet the standards for wastewater reuse for urban re-use.

4. The Bralirwa soft drink factory wastewater treatment process exhibited highest and lowest removal efficiencies for COD and TN of 97% and 24%, respectively. The removal efficiencies for TSS, BOD₅, EC, TDS, NH₃-N, TP, Residual Chloride, and equivalent OH⁻, were 72%; 93%; 30%; 25%; 78%; 30%; 84% and 92%, respectively. Based recommended Rwandan wastewater quality re-uses standards, this study concluded that Bralirwa wastewater re-use options are lawn irrigation, agricultural irrigation, factory re-use etc.
5. Since water availability in Rwanda is such an important problem, known effluent purification methods should be investigated e.g., constructed wetlands, sand beds for more widespread re-use.

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NOMENCLATURE

%	=	Percentage
Mg/l	=	Milligram per litre

Acronyms

RE Removal Efficiency

pH	=	potential of Hydrogen
T	=	Temperature
TDS	=	Total Dissolved Solids
TSS	=	Total Suspended Solids
TN	=	Total Nitrogen
NH ₄ -N	=	Ammonium Nitrogen
TP	=	Total Phosphorus
COD	=	Chemical Oxygen Demand
BOD ₅	=	Biological Oxygen Demand
EC	=	Electro-Conductivity
BSDF	=	Bralirwa soft drink factory
Inlet 1	=	Inlet tank
Inlet 2	=	Entrance to the Equalization tank
EQ 1	=	Equalization tank
SBR 1a	=	Sequential Batch Reactor 1, SBR ₁
SBR 1b	=	Sequential Batch Reactor 2, SBR ₂

SIDA/SAREC = Swedish International Development Cooperation Agency/ Swedish International Development Cooperation Agency

VICRES = Lake Victoria Research Initiative

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