NIPES Journal of Science and Technology Research 5(1) 2023 pp. 253-259 ISSN-2682-5821

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Effluent Quality Assessment and Treatment Efficiency of the Wastewater Treatment Plant of a Carbonated Drink Industrial Facility Located in Benin City, Nigeria

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Article Info

***Keywords*:**
Carbonated drinks, Industrial effluent, Wastewater treatment plant, Treatment efficiency, Benin City

Received 10 February 2023
Revised 14 March 2023
Accepted 15 March 2023
Available online 17 March 2023

https://doi.org/10.5281/10.5281/zenodo.7745495

Abstract

Effluent discharges from industries may pose a serious threat to the environment when not adequately treated and to this end, many industries have installed wastewater treatment plants (WWTPs) as a regulatory requirement to mitigate pollutants concentrations in their effluents before discharge. This study assessed the effluent quality and treatment efficiency of the WWTP of a carbonated drink industrial facility located in Benin City, Nigeria. Standard procedures were used to assess the physicochemical properties and heavy metals levels in the untreated and treated wastewater. The results showed that the levels of the physicochemical parameters (chloride, TDS, TSS, BOD, COD, phosphate, and oil and grease) and the heavy metals (Cr, Cu, Fe, and Zn) were significantly reduced ($p<0.05$) in the treated effluent in comparison to the untreated. However, some of the representative samples for COD (33.33%), TDS (50%), phosphate (16.67%), oil and grease (16.67%), Cu (66.66), and Zn (100%) had concentrations higher than the maximum permissible limits set by the National Environmental Standards and Regulations Enforcement Agency (NESREA) in the treated effluent. The capacity of the WWTP to ameliorate the pollutants concentrations in the wastewater evaluated as removal efficiency (%) showed that TSS > oil and grease > phosphate > chlorine > COD > BOD > TDS for the physicochemical parameters, while the trend for the heavy metals was Cu > Fe > Zn > Cr. Overall, there was much improvement in the effluent quality after the treatment processes, but more effort is needed to ensure that the installed WWTP operates optimally.

1. Introduction

The increasing industrial growth in Nigeria is associated with the attendant generation of more waste. The generated wastes pose an environmental burden and exert adverse effects on flora and fauna in the receiving ecosystems [1]. Carbonated drinks manufacturing is one such industry that generates a high volume of liquid waste [2]. It is a major industry in Nigeria with several brands of locally produced carbonated drinks currently being sold in various outlets. The ingredients in carbonated drinks which vary widely include water, carbon dioxide, caffeine, sweeteners, acids, colouring and flavouring agents, and many other substances present in much smaller amounts [3]. However, water forms the bulk of the products and constitutes up to 90% of their total constituent

[4]. The different operations and processes in carbonated drinks production generate huge volumes of wastewater. The wastewater is generated from several operations such as bottle washing, carbon and sand filter backwashing, and washing of pieces of equipment and bottling machines, process lines (pipe-work), floors, and the general facility sanitation processes [5]. Essentially, the operations consume between 2.5 to 3.5 litres per litre of carbonated drinks produced [6]; thereby releasing over 70% of the process water as wastewater. The generated wastewater typically has elevated levels of chlorides, phosphates, nitrates, sulphates, organic substances, suspended particles, as well as heavy metals [2, 7]. Hence, adequate treatment of the wastewater from carbonated drinks facilities is important to curb discharges that can adversely affect the environment. The National Environmental Standards and Regulations Enforcement Agency (NESREA) has stipulated minimum standards for industrial effluent quality before discharge [8]. This has necessitated industrial facilities to install wastewater treatment plants (WWTP) to meet the set quality guidelines. Installed WWTPs require proper maintenance and qualified personnel for maximum operational utilisation and quality effluent treatment. The influent and effluent quality monitoring and determination of the contaminants removal efficiency is a strategic way to measure the WWTP's operational efficiencies. Consequently, this study was undertaken to assess the quality of wastewaters (untreated and treated) from a carbonated drink facility located in Benin City, Nigeria. The removal efficiency (%) of the selected physicochemical parameters and heavy metals in the effluent samples compared to the influent samples were also determined and used to evaluate the treatment efficiency of the WWTP. This was done to monitor the quality of the effluent discharges from the carbonated drink facility and ensure that the WWTP is operating at an acceptable capacity. This is important to preserve the ecological integrity of the receiving water body where the effluent is discharged.

2. Methodology

2.1 Study area and samples collection

The study was carried out on the wastewaters (influent and effluent) collected from the WWTP of a carbonated drink industrial facility (latitude: 6.44507; longitude: 5.59804) located in Ovia North East Local Government Area in Benin City, Edo State (Figure 1). The sampling was done forth-nightly over three months (April to June 2016). The samples were collected in well-labelled pre-cleaned one-litre plastic containers which were rinsed with the wastewater samples thrice before collection. The samples for biological oxygen demand (BOD) were collected in 100 mL dissolved oxygen bottles, while the samples for the heavy metal analysis were collected in 120 mL amber-coloured glass bottles. All samples were refrigerated at 4 °C prior to the analyses [9].

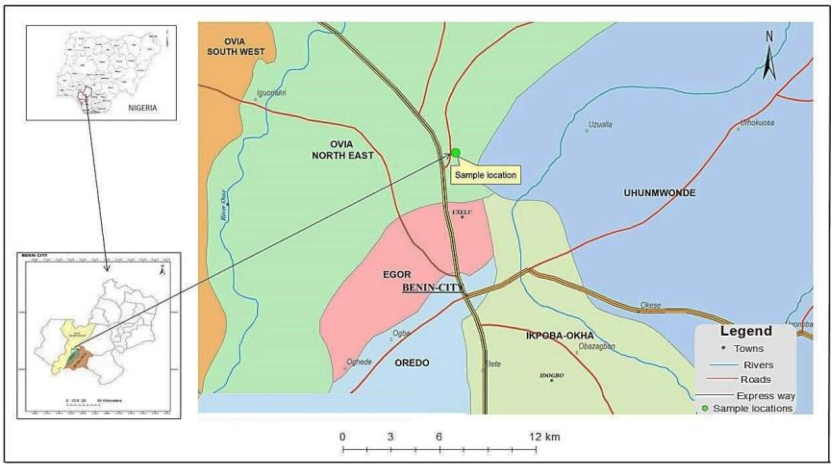

Fig. 1: Map showing the location of the carbonated drink industrial facility

2.2 Physicochemical parameters analyses

The physicochemical analyses of the samples were done following the procedure recommended by [9]. The analysed physicochemical parameters include pH, BOD, chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), chloride, phosphate, and oil and grease, while the analysed heavy metals are Cr, Cu, Fe, and Zn. The pH values were determined using a HANNAH field pH meter (HANNA Instruments, USA) which was calibrated using buffer solutions of known value (buffer 4 and 7) before the analyses. The TDS and TSS levels were determined using a portable HACH CO 150 TDS/conductivity/salinity meter and a HACH DR 2000 spectrophotometer, respectively (HACH, USA). Oil and grease measurements were determined by solvent extraction, employing the partition gravimetric method outlined in [9]. The BOD, COD, phosphate, and residual chlorine were determined using standard methods [9]. Samples for metal analysis were digested using 2 mL analytical grade nitric acid (HNO_3) and analysed with an atomic absorption spectrophotometer (Spectra AA Varian 400).

The pollutant removal efficiency of the WWTP was determined as a reduction percentage. The analysed physicochemical parameters and heavy metals concentrations of the untreated and treated wastewater were used to determine the removal efficiency (%) following the procedure described by Eribo and Kadiri [10] with some modifications. The formula employed was:

$$RE = \left(\frac{WC - C}{WC}\right) * 100 \qquad (1)$$

Where RE = removal efficiency (%)

WC = initial value of water quality parameter

C = value of water quality parameter after treatment

2.3 Statistical analyses

The descriptive and interactive graphing was done using OriginPro 9.exe software. Results were also subjected to statistical analysis (paired T-test) using PAST software to ascertain the level of significance between the untreated and treated effluents. P values < 0.05 were deemed to be statistically significant.

3. Results and Discussion

3.1. Physicochemical assessment of wastewaters quality

The trends of the physicochemical parameters assessed in this study are shown in Figure 2 (a - h). Physico-chemical parameters assessed in this study were found to be mostly higher in the untreated wastewater samples. The pH values obtained for the treated wastewater were in the neutral to slightly basic range (7.01-7.99), whereas the values for the untreated wastewater fluctuated more from the weakly acidic to the slightly basic range (6.47 – 8.24). The uniformity in the values obtained for the treated wastewater can be attributed to the pH adjustment usually carried out during the wastewater treatment processes. However, the pH levels of both wastewaters were within the range of 6.50 – 8.50 stipulated by NESREA [8]. The residual chlorine content of the untreated and treated wastewater were in the ranges of 0.32 – 2.32 mg/L and 0.12 – 1.16 mg/L, respectively. In bottling industries, chlorine is majorly used for sanitation processes of the bottling equipment and process lines, as well as, floors and walls. It is also utilised in water and wastewater treatment operations to eliminate microbes. These activities account for the concentrations of chlorine found in the wastewater samples, and the levels were well below the regulation limits. Solids are indicative of materials carried in solid form and lower water quality of the receiving water body if the concentrations are high. The TDS ranges for untreated and treated wastewater was 1240 - 2960 mg/L and 720 – 2280 mg/L, respectively. Although the maximum permissible limit for TDS is not stated by NESREA in its guidelines, a compendium of standards for wastewater reuse in the Eastern

Mediterranean Region showed that the value of 2000 mg/L was the highest value stipulated as the maximum permissible limit for wastewater discharge [11]. Most of the values (83.33%) for the untreated wastewater exceeded the 2000 mg/L, while half of the samples (one in May and two in June) still had higher levels after the treatment process. TSS levels for untreated (0.35 - 3.96 mg/L) and treated (0.07 - 0.68 mg/L) wastewater were measured, with all values for treated wastewater falling below the 0.75 mg/L limit set by NESREA [8].

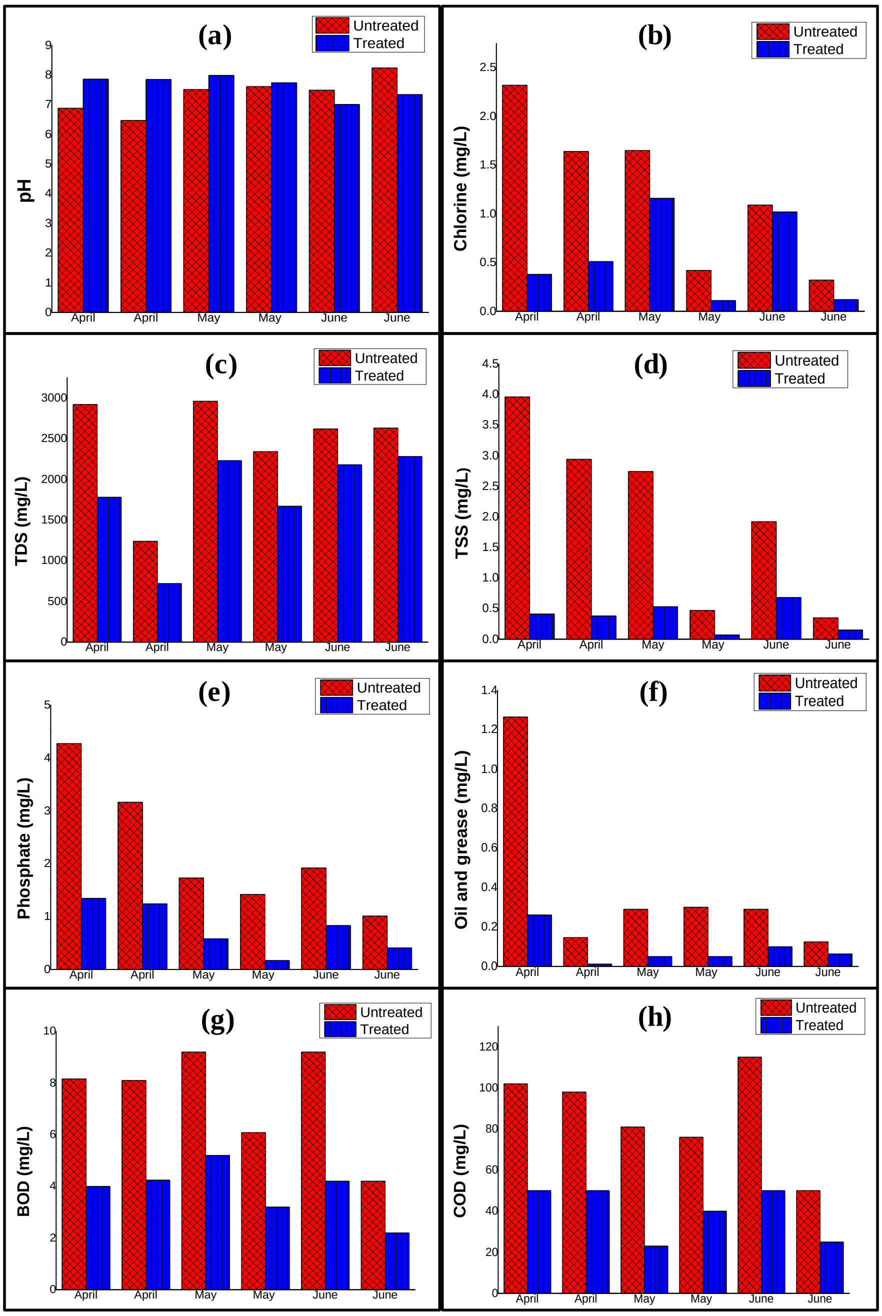

Fig. 2: Fortnightly variation in the physicochemical parameters of the treated and untreated wastewaters from the carbonated drink facility

Carbonated drinks facilities have varied sources contributing phosphate to the effluent stream which include the use of phosphate-based detergents such as trisodium phosphate (TSP), and phosphoric acid as raw material and sanitiser for bottling equipment [7]. High levels of phosphates in wastewater pose threat to the ecosystem of the receiving water body [12]. The recorded phosphate levels for the untreated wastewater (1.01 – 4.27 mg/L) were higher than the set limit of 3.5 mg/L [8]; however, after the treatment process, the measured levels were all below the maximum permissible limit. According to the NESREA guidelines [8], the maximum permissible limit for oil and grease for effluent discharge, irrigation, and reuse is 0.1 mg/L. The values for this parameter obtained for untreated and treated wastewater ranged from 0.13 – 1.24 mg/L and 0.01 – 0.26 mg/L, respectively. All the samples for the untreated wastewater had values higher than the set limit, while only one sample taken in April had a higher value than the set point for the treated wastewater. BOD is critical in wastewater quality assessment as it determines the level of oxygen needed by the anaerobic biological organisms to effectively break down the organic constituents present in the wastewater. Elevated BOD levels can adversely affect the aquatic fauna present in the receiving water body due to depleted oxygen levels. For effluent disposal purposes, NESREA has established the BOD standard at 6.0 mg/L, while 3.0 mg/L was mandated for fishery and recreational uses. The BOD levels in the untreated wastewater (4.20–9.20 mg/L) were higher than both of the established limits, whereas the treated wastewater exhibited values (2.20–5.20 mg/L) that were lower than the established limit for effluent discharges. However, if the treated effluent is not adequately diluted by the receiving water body, it may pose a threat to the aquatic organisms present. In the treated and untreated wastewater, the COD concentrations were 50.0 - 115.0 mg/L and 23 - 50 mg/L, respectively. All of the readings found for the untreated wastewater were, over the 30.0 mg/L maximum allowable level specified by NESREA [8]. Although the COD levels in the treated wastewater were significantly lower, only 33.33% of the analysed samples fell below the established limit.

3.2. Heavy metals assessment of wastewaters quality

Heavy metals pollution is a critical concern in wastewater quality assessment as they possess toxic, bio-accumulative, and persistent tendencies which can cause harm to plants and animals in the environment [13, 14]. The mean concentrations of heavy metal in the untreated wastewater were 0.41±0.19 mg/L, 1.58±0.91 mg/ L, 0.96±0.44 mg/ L, and 0.98±0.46 mg/ L for Cr, Cu, Fe, and Zn respectively, while the corresponding levels in the treated wastewater were 0.16±0.09 mg/ L, 0.31±0.26 mg/ L, 0.27±0.10 mg/ L and 0.28±0.11 mg/ L, respectively. The concentrations of Cr (0.041 – 0.267 mg/L) and Fe (0.11 – 0.38 mg/L) in the treated wastewater were below the 0.5 mg/L specified allowable limit for both metals. However, the concentrations of Cu (0.09 – 0.71 mg/L) and Zn (0.12 – 0.38 mg/L) were above the set limit of 0.01 mg/L and 0.2 mg/L, respectively [9]. Generally, the WWTP was able to significantly reduce ($p<0.05$) the heavy metals levels in the untreated water during the treatment processes (Figure 3 a-d).

3.3. Treatment efficiency of the wastewater treatment plant

Effluents contain a variety of contaminants that can be harmful if discharged without some form of treatment. Thus, treatment of effluents before discharge is very crucial for the protection of the environment. In this study, there was a marked reduction between treated and untreated effluents in most of the parameters except pH where the reverse was generally the case (Figure 4). The measurement of pH is used to determine the acid balance of a solution and can affect the solubility of many toxic chemicals including heavy metals. The increase in the pH of the treated effluent can be attributed to the addition of the lime during treatment and subsequent adjustment to the observed range; hence, removal efficiency for pH was not evaluated. The capacity of the WWTP to ameliorate the pollutants concentrations in the wastewater evaluated as removal efficiency (%) showed that TSS > oil and grease > phosphate > chlorine > COD > BOD > TDS for the physicochemical parameters, while the trend for the heavy metals was Cu > Fe > Zn > Cr. The reduction of the pollutant ranged from 27.40% (TDS) to 77.37% (TSS) for the physicochemical parameters and 62.83 (Cr) to 79.63 (Cu) for the heavy metals in the treated wastewater as compared to the untreated wastewater. Despite the significant reduction (p<0.05) of the pollutants, some of the representative samples for COD (33.33%), TDS (50%), phosphate (16.67%), oil and grease (16.67%), Cu (66.66), and Zn (100%) had concentrations higher than the limit stipulated by NESREA. The non-conformity of some of the assessed parameters may be due to the WWTP's design, operational challenges, inadequate/improper maintenance of the plant, and inadequate knowledge and experience of the operators of the facility [15, 16, 17].

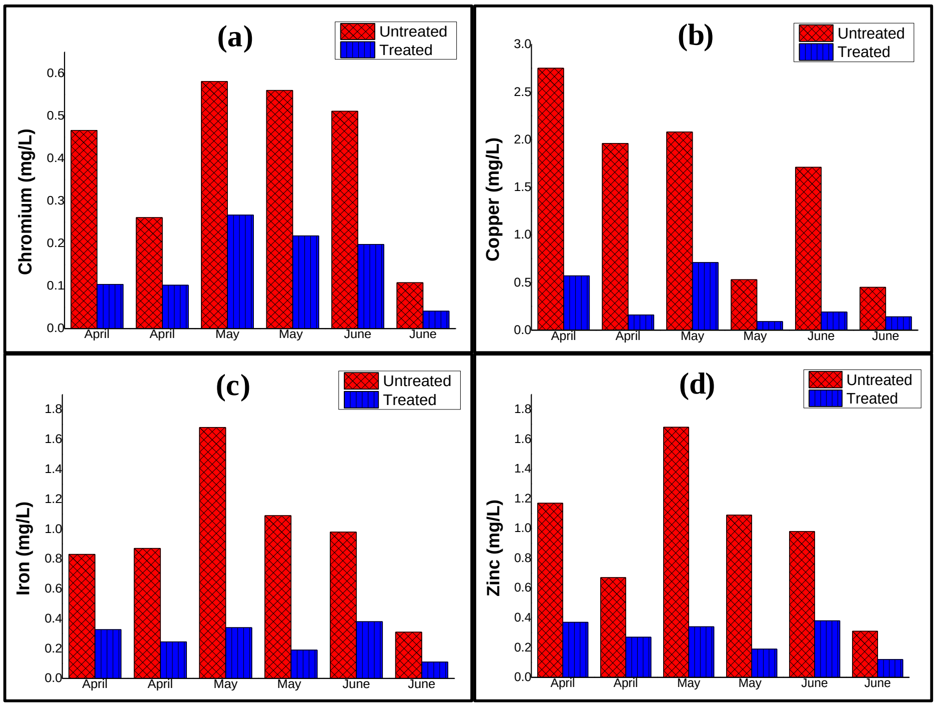

Fig 3: Fortnightly variation in the heavy metal levels of treated and untreated wastewaters from the carbonated drink facility

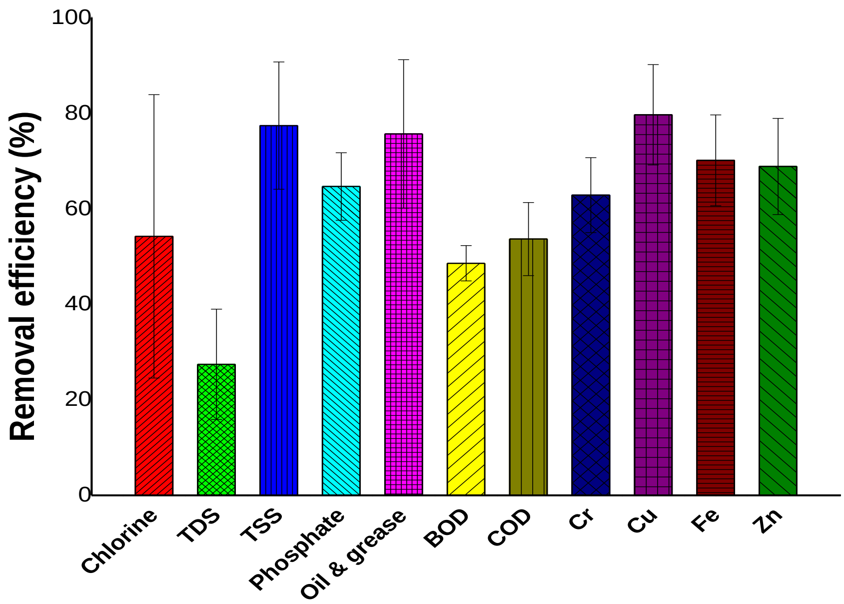

Fig. 4: Removal efficiency (%) of the pollutants by the wastewater treatment plant of the carbonated drink facility

4. Conclusion

This study assessed the effluent quality and treatment efficiency of the wastewater treatment plant of a carbonated drink industrial facility located in Benin City, Nigeria. The results for the measured physicochemical parameters (chloride, TDS, TSS, BOD, COD, phosphate, and oil and grease) and heavy metals (Cr, Cu, Fe, and Zn) indicate a significant ($p<0.05$) reduction in the pollutants levels in the treated wastewater as compared to the untreated except for the pH values where the reverse was mostly the case. Some of the representative samples for COD (33.33%), TDS (50%), phosphate (16.67%), oil and grease (16.67%), Cu (66.66), and Zn (100%) had concentrations higher than the limit stipulated by NESREA. The capacity of the WWTP to ameliorate the pollutants concentrations in the wastewater evaluated as removal efficiency (%) showed that TSS > oil and grease > phosphate > chlorine > COD > BOD > TDS for the physicochemical parameters, while the trend for the heavy metals was Cu > Fe > Zn > Cr. The WWTP sufficiently improved the effluent quality after the treatment processes. The observed shortfall in some of the assessed parameters may be corrected by ensuring proper maintenance routine and engaging qualified personnel to operate the WWTP facility.

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