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Research Article

Assessment of the effect of glass industry wastewater on the physico-chemical properties of Edor River, Ughelli, Delta State, Nigeria

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Abstract

Wastewater from industries in developing nations is usually discharged into water bodies without adequate treatment. This study assessed the effect of glass industry wastewater discharge on the physico-chemical properties of the Edor river in Ughelli, Delta State, Nigeria. Water samples were collected from different sampling stations including surface water and wastewater discharge outlets. Samples were analysed following standard methods and procedures. Methods including Winkler's, open reflux, gravimetric, argentometric, and Ethylenediaminetetraacetic acid (EDTA) procedures, were employed for specific measurements like biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), chloride and hardness respectively. Portable meters were used for assessing the pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), and turbidity. Additionally, sodium and potassium were measured using a flame photometer, while calcium and magnesium were determined using the EDTA titrimetric method. Colorimetric methods with a UV spectrophotometer were utilized to determine the nitrate, phosphate and sulphate concentrations. Heavy metals were analyzed using an Atomic Absorption Spectrophotometer (AAS). The results of the study showed that some parameters of the recipient water, such as COD (4.33–26.94 mg/L), BOD (1.93–11.96 mg/L), dissolved oxygen (3.73–5.65 mg/L), TDS (27.93–58.44 mg/L), EC (48.68–101.5 μS/cm), total hardness (25.37–46.65 mg/L), lead (0.003–3.125 mg/L), manganese (0.586–2.864 mg/L), cadmium (0.021–4.062 mg/L), and chromium (0.311–3.004 mg/L), were impacted by the wastewater discharge when compared to the control station. The Water Quality Index (WQI) of the recipient water ranged from 107.64 to 177.20, while the wastewater sample and control station had 67.07 and 79.00, respectively, indicating poor water quality that is unsuitable for drinking. Most of the parameters investigated were within the permissible limits for effluents (FEPA) and surface waters. However, turbidity, total suspended solids, copper, chromium, and lead exceeded the permissible limits at a few stations. The findings of the study showed that the river water quality was negatively impacted by industrial activities in the study area, which could likely affect inhabitants who depend on these water resources for survival. Therefore, factories and government agencies-should ensure continuous monitoring and proper treatment of industrial wastewater before disposal.

1. Introduction

Several industries in developing nations of the world release wastewater during operations into water bodies such as rivers, streams and oceans without adequate treatment [1]. Contaminants in wastewater may affect the physical and chemical properties of receiving water bodies, causing a wide range of biological effects on aquatic organisms [2]. Humans who consume water and fish obtained from such rivers are also at risk of heavy metal poisoning [3].

The glass industry produces bottles and glass objects from raw materials such as silica sand, soda ash (Na_2CO_3), limestone, dolomite, feldspar and glass cullet. Other chemicals, such as oxides of manganese, iron, selenium, nickel, cobalt, potassium carbonate, lead monoxide and salt cake are also included in the production process. In the course of production, large volumes of wastewater are usually discharged into nearby rivers and such discharges are often affected by lubricant oils and treatment chemicals, which may pose health risks to humans and negatively impact the water quality and biological community of the river.

A few studies on the characterization of glass industry wastewater include the works of Onwordi and Dan-Sulaiman [4], Singh [5], Akharame [6], Rathi [7] and Kumar [8]. This study fills this gap by providing localized data pertinent to the glass industry sector in the region. There is a paucity of data on in-situ investigations of the physicochemical properties of glass industry wastewater and water bodies that receive glass industry effluent under real field conditions, especially in developing nations. In recent years, many researchers have focused on the impact of wastewater from industries such as petroleum, textiles, paper and breweries with little attention given to the glass manufacturing industry. Also, there is limited research specifically addressing Edor River in Ughelli, Delta State. Hence, this study was conducted to assess the effect of wastewater discharge from a glass factory on the physicochemical characteristics of the Edor river in Ughelli, Delta State.

2. Materials and methods

2.1. Description of study area

This study was carried out in a stretch of Edor river, located beside a glass factory in the Ekreravwe community in Ughelli, Delta State (Fig. 1). The glass factory produces bottles for soft drinks, beer, malt, wine, spirits and generates large volumes of wastewater daily, which is discharged into the nearby river. The river lies between Latitude 5° 31' 57.06'' N and 5° 33' 8.89'' N, and Longitude 5° 55' 6.43'' E and 5° 58' 46.28'' E. It originates from Isiokolo in the Ethiope East Local Government Area, flows through Ekapamre, Ughevwughe and Iwhrekeka down to Okpare river.

The area is characterized by tropical equatorial climate with two distinct seasons: wet and dry. The area has mangrove vegetation with forest trees, oil palm (*Elaeis guinensis*), Indian bamboo (*Bambusa* sp.) and rubber trees (*Hevea brasiliensis*) with abundant shrubs and grasses. Farmlands within the study area are cultivated with crops such as cassava (*Manihot esculenta*), maize (Zea *mays*), water yam (*Dioscorea alata*), cocoysam (*Colocasia and Xanthosoma* sp.), plantain (*Musa paradisiaca*), pawpaw (*Cariaca papaya*) and a variety of leafy vegetables.

A major express road and bridge are located close to the downstream section of the river. Human activities within the area include fishing, swimming, laundry and washing of lorries along the riverbanks. Industrial activities in the study area include sand dredging, which supplies raw materials for glass production and building construction. Additionally, a mechanical workshop and trailer park are situated beside the factory for loading finished goods.

2.2. Sampling stations

Six sampling stations, including a control station were selected for this study. The control station was located in the upstream section of the river, away from the discharge point, and was presumed to be unaffected by the industrial effluent.

Station 1 was located in the downstream section of the river. It lies between latitude 5° 32' 13.64'' N and longitude 5° 55' 20.19'' E. It has minimal human activities with surrounding trees and vegetation primarily consisting of Indian bamboo (*Bambusa* sp.), Oil palm trees (*Elaeis guinensis*), rubber (*Hevea brasiliensis*), plantain (*Musa paradisiaca*), shrubs and grasses. Dredging operations were observed near this area. The water surface at this station was turbid.

Station 2 was situated in the midstream section of the river beside the glass factory. It is located between

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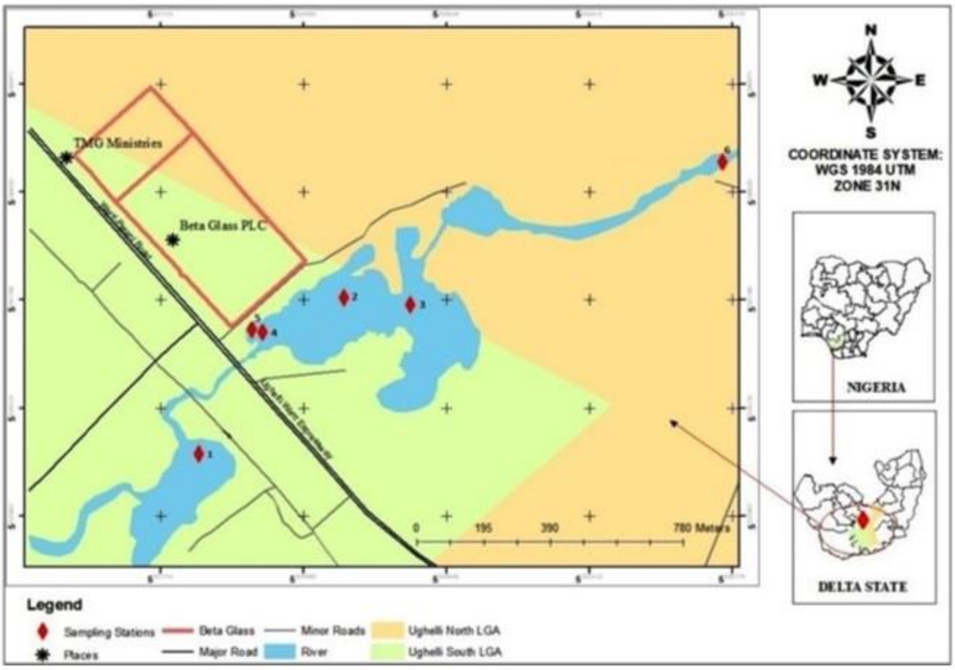

Figure 1. Map of the study area showing sampling stations (self, 2023).

latitude 5° 32' 28.41'' N and longitude 5° 55' 33.45'' E. Dredging activities were also observed near this station. A trailer park is located within this area, where loading and offloading operations are. conducted. The water surface at this station also was also turbid.

Station 3 was located in the upstream section of the river with respect to the discharge station. This station is located between latitude 5° 32' 27.75'' N and longitude 5° 55' 39.85'' E. There are human settlements along the riverbank, with activities like swimming, wood cutting, laundry, bathing and fishing. The water surface appeared turbid and brownish, likely due to nearby dredging operations.

Station 4 represented the wastewater discharge section of the river. It lies between latitude 5° 32' 24.80'' N and longitude 5° 55' 23.72'' E. This area is surrounded by vegetation, primarily Indian Bamboo (*Bambusa* sp.), along with grasses and shrubs.

Station 5 marks the actual discharge outlet. This is the point where wastewater from the factory enters the river. It is located at latitude 5° 32' 24.96'' N and longitude 5° 55' 23.54'' E. Water samples were collected from this point before it is discharged into the river.

Station 6 (control station). It is located in the upstream section of the river, away from the glass factory discharge outlets. It lies between latitude 5° 32' 41.31'' N and longitude 5° 56' 9.37'' E. The area is characterized by forest vegetation, with background trees, shrubs and grasses. The water surface here appeared relatively clearer than the other stations.

2.2. Sample collection

Water samples were collected from the different sampling stations every month for two years, covering both the wet and dry seasons. Samples were collected during the early hours of the day, between 8:00 a.m. and 12:00 noon, on each sampling day.

2.3. Sampling technique

Representative surface water samples were collected from the various stations using 1-litre plastic bottles for physico-chemical analysis. Each bottle was immersed just below the water surface, filled completely, and corked before being removed. The bottles were then labeled and stored in an ice-packed cooler box before being transported to the laboratory for analysis.

Water samples for dissolved oxygen (DO) and biochemical oxygen demand (BOD) were collected with 150 mL glass bottles and 250 mL glass amber bottles, respectively, with stoppers to avoid air bubbles. The glass bottles were immersed into the

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water and the stopper was removed below the water surface to allow the bottle fill with water. The stopper was replaced under water to keep out any air bubbles from entering the water sample before bringing out the bottle. For dissolved oxygen (DO), the oxygen content of the water was immediately fixed by adding 1.5 mL each of Winkler's solutions A (manganous sulphate) and B (potassium hydroxide in potassium iodide). The water samples for BOD were wrapped in black polyethylene bags and promptly transported to the laboratory. Water samples for heavy metal analysis were collected in 1litre plastic containers, and thoroughly rinsed with de-ionized water prior to use. The samples were preserved with 1 mL concentrated nitric acid (HNO_3). Wastewater samples were collected directly from the discharge outlet using appropriately labeled bottles before entering the river. All samples were collected and preserved following standard procedures before being transported to the laboratory for analysis [5, 9].

2.4. Methods of analysis

All analyses were conducted following the standard methods and procedures outlined in the Standard Methods for the Examination of Water and Wastewater by the American Public Health Association (APHA) [10] and the American Society for Testing and Materials (ASTM) [11]. In-situ parameters, such as pH, temperature, electrical conductivity, total dissolved solids and turbidity, were determined on-site using pre-calibrated digital meters. pH and temperature were determined using portable digital meter (Hannah Model HI9913101). The total dissolved solids and electrical conductivity were measured using portable TDS/Conductivity meter (Sper scientific 850039). Turbidity was determined using turbidity meter (MicroTPI Model 20008).

Dissolved oxygen (DO) and biochemical oxygen demand (BOD) were determined using the titrimetric procedure (Winkler's method). Biochemical oxygen demand was analysed after incubating for five days at 25^{0}C. The total suspended solids were determined gravimetrically by using the filtration technique. The total solids were determined by gravimetric method using evaporation techniques. The chemical oxygen demand (COD) was determined using Open Reflux titrimetric method. Chloride was determined by argentometric titration. Total hardness was determined by EDTA titrimetric method using Eriochrome Black T as indicator. Nitrate, phosphate and sulphate were determined by colorimetric methods using a UV Spectrophotometer (Uniscope SM-7504). Sodium and Potassium were determined using pre-calibrated Technicon auto analyzer flame photometer, while calcium and magnesium were determined using ethylene diamine tetraacetic acid (EDTA) titrimetric method [11, 12].

Heavy metals were determined using Atomic Absorption Spectrophotometer (Varian 220 Fast Sequential AAS) after digesting samples with 2 mL concentrated nitric acid (HNO_3) and filtered with Whatman filter paper into a standard flask before adding deionised water to mark. Heavy metals were determined by aspirating the samples into the Atomic Absorption Spectrophotometer using the appropriate lamps [5, 12].

2.5. Data analysis

Statistical analyses were carried out using SPSS version 25.0 and Microsoft Excel. Analysis of variance (ANOVA) at $p < 0.05$ was used to determine significant differences in the parameters across the various stations. Results were expressed as mean ± standard deviation (SD).

2.6. Water quality index (WQI)

Water quality index was determined using the Weighted Arithmetic Index method described and categorized by Uwaifo [13], Oboh and Agbala, [14] where 0-25 (Excellent Water), 25-50 (Good water), 51-75 (Poor water), 76-100 (Very poor), and >100 (unsuitable for drinking).

Water Quality Indices (WQI)

$$\mathrm{WQI} = \frac{\sum \mathrm{QiWi}}{\sum \mathrm{Wi}}$$

Qi = Quality rating of each parameter

$$= \frac{\mathrm{Vactual} - \mathrm{Videal}}{\mathrm{Vstandard} - \mathrm{Videal}} \times 100$$

V actual = Actual value of the water quality parameter obtained from laboratory analysis

V ideal for pH = 7 and for other parameters it is said to be zero

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Table 1. Summary of water physico-chemical characteristics.

Parameters (Units)	Station 1 X ± SD	Station 2 X ± SD	Station 3 X ± SD	Station 4 X ± SD	Station 5 X ± SD	Station 6 X ± SD	FEPA Effluent Limit [15]	FMEnv Limit [16]
PH	6.80±0.41	6.69±0.38	6.73±0.42	7.52±0.36	6.43±0.21	6.64±0.39	6-9	6.5-8.5
Water Temp (^{0}C)	29.58±2.042	29.48±0.32	29.46±0.54	28.39±0.26	27.75±0.52	29.50±0.29	35	25-35
EC (μs/cm)	68.61±12.18	71.94±13.73	48.68±6.19	101.5±20.00	55.25±14.86	49.08±10.47	1000	N/A
TDS (mg/l)	39.36±6.98	41.27±7.88	27.93±3.55	58.44±11.47	31.7±8.52	28.15±6.00	2000	500
Turbidity (N.T.U)	37.56±26.77	35.57±25.27	24.78±12.83	16.98±5.01	3.31±1.67	13.72±3.93	5	5.0
TSS (mg/L)	70.04±35.67	65.17±35.05	50.83±27.16	49.08±18.22	19.67±5.63	37.54±18.46	50	30
TS (mg/L)	109.40±33.34	106.4±35.64	78.76±26.96	107.5±13.32	51.37±11.34	65.70±16.19	2000	1500
DO (mg/L)	4.980±1.010	5.108±0.996	5.651±1.025	3.734±0.655	2.898±0.560	6.250±0.90	N/A	5.0
BOD_5 (mg/L)	3.50±1.31	3.71±1.14	1.93±1.0.34	11.96±5.29	36.64±10.01	1.11±0.23	50	30
COD (mg/L)	7.85±2.93	8.31±2.55	4.33±1.0.76	26.94±11.92	81.80±22.36	2.47±0.51	150	30
Sulphate (mg/L)	1.81±0.32	1.91±0.37	1.28±0.16	2.89±0.59	3.65±1.03	0.99±0.23	500	100
Phosphate (mg/L)	0.167±0.098	0.206±0.142	0.071±0.067	1.69±0.61	4.31±0.62	0.035±0.03	5	3.5
Nitrate (mg/L)	0.35±0.06	0.30±0.06	0.167±0.023	0.78±0.15	0.59±0.17	0.15±0.03	20	50
Chloride (mg/L)	6.07±0.98	5.93±1.13	4.03±0.51	8.28±1.63	2.75±0.74	3.88±0.83	250	250
Total Hardness (mg/L)	35.75±14.05	3.32±12.4	25.37±8.39	46.65±13.80	89.03±3.56	21.86±5.10	300	200
Calcium (mg/L)	3.86±1.52	3.59 ±1.34	2.74±0.91	5.04±1.49	9.62±0.39	2.36±0.55	200	75
Magnesium (mg/L)	6.37±2.50	5.94±2.21	4.53±1.49	8.32±2.46	15.87±0.63	3.89±0.90	150	50
Sodium (mg/L)	2.39±0.39	2.34±0.45	1.59±0.20	3.03±0.60	5.07±1.40	1.42±0.30	200	200
Potassium (mg/L)	1.01±0.16	0.97±0.18	0.64±0.08	1.29±0.25	2.41±0.60	0.60±0.13	75-200	50
Zinc (mg/L)	0.153±0.253	0.188±0.052	0.061±0.106	0.119±0.219	0.192±0.256	0.028±0.054	3	5
Iron (mg/L)	2.583±0.627	1.823±0.570	1.573±0.464	3.352±0.905	5.056±0.996	1.272±0.638	20	10
Copper (mg/L)	0.522±0.175	0.534±0.163	0.430±0.215	3.225±0.777	1.839±0.551	0.066±0.104	<1	2
Manganese (mg/L)	0.978±0.596	0.851±0.566	0.586±0.459	2.864±1.043	4.024±1.069	0.228±0.116	5	5
Chromium (mg/L)	0.449±0.125	0.430±0.557	0.311±0.359	3.004±0.526	2.39±0.775	0.007±0.013	0.05	<1
Cadmium (mg/L)	0.10±0.406	0.119 ±0.41	0.021±0.039	4.062±0.738	0.973±0.644	0.001±0.001	0.03	<1
Lead (mg/L)	0.003±0.004	0.026±0.06	0.006±0.012	3.125±0.953	4.56±1.474	0.004±0.005	0.05	<1

All results across rows were significantly different (P<0.05). FEPA = Federal Environmental Protection Agency limits for effluents, FMEnv= Federal Ministry of Environment for surface water). N/A: Not applicable

V standard = Recommended standard of the water quality parameter.
Wi = Unit weight = 1/ Si
Si= Standard permissible value for nth parameter
Qi = Quality rating of ith parameter for a total of n water quality parameters

3. Results and discussion

3.1. Physical and chemical characteristics of water samples

The physico-chemical characteristics of the water samples obtained from the different stations are shown in Table 1. Assessment of the physical and chemical parameters of the Edor river provides details of the characteristics of the water body, the background impact and the usability. The mean pH of the studied stations generally showed slightly acidic condition (< 7.0). The pH recorded in this study is consistent with the work of Onwordi and Dan-Sulaiman [4] who reported pH value of 6.48 in glass processing plant effluent in Ogun State, with the recipient water having a range of 6.92 to 7.17. Kumar [7] reported pH of 8.07 in glass effluent obtained from Haridwar India, while Singh [5] recorded a range of 4.2-7.4 in glass industry wastewater in the Firozabad district, India. The acidic nature of rivers in Nigeria have been previously reported by researchers such as Emeka [17] and Imoobe [18]. A pH range of 6.55-7.0, indicating a slightly acidic to neutral condition in Siluko river has also been reported by Oboh and Agbala [14] in Southern Nigeria.

The temperature values were relatively consistent across the different stations. However, the temperatures recorded at station 4 and station 5 were relatively lower than the other stations. This could be attributed to the vegetation surrounding station 4 and the enclosed channel through which the water for

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station 5 was conveyed, thereby reducing exposure to direct sunlight. The findings of this study corroborate the works of Dirisu [9], Uwaifo [13], Olomukoro [19], Ogbeibu [20] and Rim-Rukeh [21] in Southern Nigeria.

The turbidity is determined by the amount of suspended and dissolved substances in water. It can affect the light penetration and photosynthetic activity of primary producers in natural waters. In this study, the mean turbidity values obtained at the surface water stations generally exceeded the permissible limits, likely due to dredging activities. However, the wastewater sample had the lowest turbidity (3.31 NTU), as it was not directly influenced by dredging operations. Rathi [8] reported turbidity of 25.3 NTU in glass effluents obtained from Hindustan glass Ltd located in India, while Akharame [6] obtained 10.9 NTU in Benin city.

The total dissolved solids (TDS) obtained in this study were below the permissible limits. Similar findings were reported by Onwordi [4], who observed a TDS value of 78.6 mg/L at the glass wastewater discharge point. This may be attributed to the nature of the wastewater as well as the chemical composition. However, a higher TDS range of 423-961 mg/L were reported by Singh [7].

The electrical conductivity (EC) of water is roughly proportional to the amount of dissolved solids in the water, mostly in the form of inorganic salts. It can be considered as an important indicator of ecological and environmental management [20]. In this study, the mean conductivity value ranged within the medium category (between 50-600 μScm^{-1}) as classified by Abida and Harikrishna [22]. In most Nigerian inland waters, the EC values are typically below the FMENv. limits of $500 \mu Scm^{-1}$, suggesting the freshwater nature of the rivers [23].

Biochemical Oxygen Demand (BOD) is used to assess the organic pollution load of wastewater [23]. It is expected that unpolluted water will have a BOD of 5 mg/L or less. In this study, the BOD values were generally within the FMEnv permissible limit of 30 mg/L except in the wastewater sample. Singh reported a BOD_5 range of 6.4-8.8 mg/L in glass effluent obtained from different glass companies, while Onwordi [4] recorded 24.0 mg/L in glass effluent discharge point in Agbara Industrial Estate, Ogun State. Emeka [17] reported mean BOD range of 12.67 to 20.55 mg/L in the Ukwaka stream caused by the discharge of industrial effluents. The BOD_5 obtained at the discharge station can be attributed to the wastewater and decaying organic matter found around the station.

The low dissolved oxygen (DO) obtained in this study is likely due to the organic matter and chemical content of the water, which depleted oxygen. DO level that is below 1 mg/L will not support fish while a range of 5 to 6 mg/L is usually required for fish populations. Rathi [7] obtained DO value of 1.18 mg/L while Onwordi [4] reported a DO of 2.5 mg/L. Both results were below the minimum value of 5.0mg/l required for fish survival. The dissolved oxygen level obtained in this study is close to the value obtained in Ikpoba River (3.71 mg/L) reported by Ogbeibu and Ezeunara [24] and that of Zabbey and Hart [25] who obtained a DO range of 1.6-10.1 mg/L in Woji creek.

The COD of the surface waste ranged from 4.33 to 26.94 mg/L across stations 1 to station 4. However, the wastewater sample recorded a COD value of 81.80 mg/L, while the control station had 2.47 mg/L. The COD of the wastewater is likely due to the chemical composition of the raw materials used for glass production. However, these values were lower than the recommended limits of FMEnv and FEPA (effluent) as indicated in Table 1.

Total suspended solids (TSS) consist of components such as silt, clay, zooplankton and algae that are usually carried by the water. It contributes to the cloudiness and turbidity of water bodies. High TSS reduces the light penetration into the river, leading to reduced photosynthesis [26, 27]. The range of value (49.08-70.04 mg/L) obtained in this study for surface water especially at station 1 is similar to the findings of Onwordi [4] who reported a TSS range of 73.2 -74.0 mg/L However, Kumar [8] reported a higher TSS value of 364.25 mg/L in glass effluent obtained in India. High TSS can cause clogging of fish gills, as well as poor growth and survival of aquatic organisms.

The need to control and monitor anthropogenic inputs into water bodies has been emphasized by

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Iyama [28]. The Total Solids (TS) of the surface water stations ranged from 78.76-107.5 mg/L. Station 4 recorded the highest TS, which can be attributed to the accumulated debris and organic materials deposited on the surface of the water. The wastewater sample from the factory recorded the lowest value of TS (51.37 mg/L) compared to the other stations. The control station had 65.70 mg/L. However, the TS values across all sampled stations were lower than the recommended limits.

Sulphate occurs in natural aquatic ecosystems and other wastewater environments. The sulphate values obtained in this study were generally low and found to be within the limits. Beauchamp [29] reported that African waters are generally deficient in sulphate due to their low concentration in the non-sedimentary rocks of drainage areas. This conforms to the work of Oboh and Agbala [14] who reported similar sulphate values of 1.44 mg/L, 1.22 mg/L and 1.15 mg/L at different sampling points of the Siluko river in Southern Nigeria. On the contrary, Akharame [6] reported a high sulphate concentration of 680.30 mg/L in the effluent obtained from a bottling company in Benin City. Phosphate and nitrate make up the nutrient content of an aquatic habitat. They are indicators of eutrophication in rivers, ponds and lakes [30]. The range of values obtained in this study agrees with the moderate levels of phosphates in the Ontamiri River in Owerri, reported by Okeke and Adinna [31]. Kumar [8] recorded a phosphate concentration of 7.79 mg/L while Onwordi [4] reported 3.3 mg/L in glass effluents. Phosphate content in water cause digestive problems and can become toxic to humans and animals when present in very high concentrations [32]. Excessive nitrate in surface waters can deplete the level of dissolved oxygen in the receiving water body, thus endangering the aquatic biota and causing eutrophication [33]. The nitrate content in the Edor river could be attributed to the fertilizers applied in farms located upstream of the study area. Similar findings have also been reported by Dirisu and Olomukoro [9] in Agbede, Southern Nigeria.

Chloride concentrations were generally low and similar ranges have been reported by Ogbeibu and Anagboso [34], Imoobe and Koye [35] and Anyanwu [36] in Edo State. The total hardness at the investigated stations may be influenced by limestone and raw materials used in glass making. This is reflected in the hardness of the wastewater sample and that of the discharge station. Hardness of the water may also result from the inflow of weathered mineral salts.

The values of alkaline earth metals such as calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) assessed in this study were within the permissible limits stipulated by FMEnv. Calcium can be attributed to calcium carbonate, which is a component of the raw materials used in the glass production process while magnesium is a component of dolomite. This is reflected in the concentration of magnesium. Onwordi [4] reported similar values of 23.6 mg/L and 10.2 mg/L for calcium and magnesium ions, respectively in glass effluent discharge at Ogun station.

3.2. Heavy metal analysis

Heavy metal pollution in aquatic ecosystem is a global concern due to it toxicity, persistence and non-degradability [37]. While, some of them may have biological significance, they can also pose a serious threat to humans and the environment at elevated levels [38]. Industrial activities, such as effluent discharge, mining, and power generation are major sources of heavy metal contamination in water bodies [39]. The zinc content at the discharge section of the river and that of the outlet were 0.119 mg/L and 0.192 mg/L, respectively, while the surface water had a range of 0.061-0.188 mg/L. These values fell within the range of values reported by Onwordi and Dan-Sulaiman [4] who recorded a zinc concentration of 0.15 mg/L in glass industry effluent. They also reported concentrations of 0.15 mg/L and 0.17 mg/L at two other surface water stations that were 100 m and 200 m away from the discharge point, respectively. High zinc content can cause undesirable taste in water. Iron is a component of industrial effluents that are usually discharged into water bodies. It can be released from glass industry wastewater considering the fact that iron (II) oxide constitutes one of the raw materials used in glass production. Rust in pipes

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conveying wastewater may also contribute to the high iron content of the water. Kumar [40] reported a higher iron concentration of 12.89 mg/L in the composite glass effluent sample obtained from the Asahi glass company compared to the value obtained in this study (5.056 mg/L). Excessive iron in water renders it unsuitable for drinking.

Copper is not always present in natural water in significant quantity. The presence of copper in the water may be attributed to the wastewater discharged into the river. Kumar [40] reported a copper content of 6.88 mg/L in glass effluent which, was quite significantly higher than that obtained in the effluent obtained from the study site (1.84 mg/L).

Manganese can be released into water bodies through mining and industrial discharges. Akharame [6] reported a manganese concentration of 0.03 mg/L in glass effluent obtained from a factory in Benin City. Kumar [40] recorded a manganese concentration of 1.54 mg/L in glass industry effluent. His result was lower than the manganese content obtained in the wastewater sample (4.024 mg/L) and that of the discharge stations (2.864 mg/L) in this study Chromium can reach potentially harmful levels if effluents are not well treated [41]. The concentration of chromium was within the limits at the different surface water stations, except at stations 4 and 5, which recorded values of 3.004 and 2.39 mg/L, respectively. These values were higher than those obtained by Onwordi and Dan-Sulaima [4] who reported a chromium concentration of 0.06 mg/L in the effluent, with 0.05 mg/L and 0.03 mg/L obtained at other sampling points in the river away from the point of discharge. Kumar [8] on the other hand, reported a higher chromium concentration (7.64 mg/L) in the glass effluent from Haridwar in India.

Cadmium is a non-essential and highly toxic metal that occurs naturally in the environment. Natural sources include release from the earth's crust by volcanic eruptions and also by weathering of rocks. Onwordi and Dan-Sulaiman [4] reported cadmium concentration of 0.04 mg/L in the point of discharge (effluent), while Kumar [8] recorded 0.23 mg/L in a wastewater sample from a glass factory. These values were lower than those obtained in this study (0.973) mg/L.

Lead is naturally occurring, persistent and hazardous in nature. Its concentration can be increased by industrial and anthropogenic sources. The lead concentration in the surface water was 0.003 to 0.026 mg/L, whereas the effluent had 4.56 mg/L. Kumar [40] reported a lead concentration of 2.36 mg/L in glass effluent. However, Onwordi and Dan sulaiman [4] reported a lower concentration of 0.12 mg/L at the point of discharge and 0.02 mg/L at another point in the river. Exposure to a lead concentration of 10g/day can cause lead poisoning, low intelligent quotient in children and high blood pressure in adults [41]. It can also damage tissues and organs [42].

3.3. *Water quality index (WQI) of the different stations*

Table 2 summarises the water quality Index (WQI) of the different stations. The WQI ranged from 107.644 to 177.208 for the recipient water, while the wastewater sample and the control station had 67.07 and 79.00, respectively.

Table 2. Summary of WQI values at the sampling station.

Stations	WQI	Water Quality
Station 1	177.208	Unsuitable for drinking
Station 2	169.405	Unsuitable for drinking
Station 3	123.918	Unsuitable for drinking
Station 4	107.644	Unsuitable for drinking
Station 5	67.078	Poor water
Station 6	79.004	Very poor water

The water quality index of the different stations indicated poor water quality, showing that the water was unfit for human consumption. Some parameters, such as TDS, TSS, turbidity, DO, COD, BOD, significantly influenced the WQI result. High turbidity and TSS were particularly observed to contribute significantly to the poor surface water quality of the stations. These were largely attributed to the dredging operations in the vicinity. Iyama [28] identified high BOD and COD as factors that affected the quality of the Woji river in the Southern part of Nigeria. To improve water quality, glass companies must adopt enhanced safety and treatment protocols aimed at reducing impurities in the wastewater before discharge. Effective treatment of wastewater from the glass manufacturing industry involves targeting specific contaminants, such as suspended solids,

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heavy metals (lead, cadmium and arsenic), high pH, fluorides, nitrates, and occasionally oils and greases. A combination of physical, chemical, and biological treatment processes is required, depending on the composition of the wastewater and the desired water quality.

4. Conclusions

This study revealed that wastewater discharged from the glass industry can alter the physicochemical characteristics of the Edor River. However, dredging operations in the study area have also contributed to the degradation of water quality. Therefore, efforts should be made to minimize these impacts to safeguard the health of aquatic organisms and human consumers. To this effect, the following recommendations are made. There should be continuous monitoring of the water quality of the river by the factory and the relevant regulatory authority is necessary to ensure compliance with environmental standards. The glass factory should improve on their wastewater treatment system by incorporating advanced and targeted methods before discharging it into the river. Specifically, methods such as screening and sedimentation should be adopted to remove large solids, sand, or debris. The use of equalization tanks should be used to balance the pH, and pollutant load. The application of coagulation and flocculation using alum, ferric chloride and polyaluminum chloride should be encouraged. Other methods include the precipitation of heavy metals like lead, arsenic by adding lime or sulphides which can greatly improve the water. Activated carbon or specific ion-exchange resins can also be used to remove organic pollutants or trace metals. Dredging operations in the vicinity should be regulated and minimized, particularly during sensitive periods, such as the rainy season, to reduce turbidity and sediment re-suspension. Lastly, government agencies responsible for pollution control should implement stricter regulations and enforce penalties for violations to deter non-compliance.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Data collection, statistical analysis and drafted the manuscript, B.O.; Technical inputs, study design and reviewed the manuscript, P.T.F.

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Availability of data and materials

The data used for this study can be obtained from the corresponding author upon request.

Conflicts of interest

The authors declare no conflict of interest

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