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RESEARCH ARTICLE

Evaluation of selected physicochemical properties of River Otamiri, Imo State

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Abstract: Surface water monitoring is essential, especially when the water is normally used for industrial, agricultural, and domestic purposes. The study determined the physicochemical properties of the River Otamiri using the American Public Health Association standard methods for water analysis. In this study, river water samples were collected five times during the dry season from four sampling points (WSP-1, WSP-2, WSP-3 and WSP-4) along the watercourse of the river in Owerri West Local Government Area of Imo State. The levels of the selected physicochemical parameters were compared with the National Standard for Drinking Water Quality (NSDWQ) guidelines. The findings showed that the pH (4.99±0.11 – 6.30±0.08), dissolved oxygen (4.16±0.01 – 6.45±0.03), total hardness (17.10±1.78 – 27.80±2.54), chloride (68.30±0.58 – 91.90±0.64), and sulphate (39.55±3.32 – 51.21±2.11) were below the acceptable limit of the National Standard for Drinking Water Quality (NSDWQ). However, electrical conductivity (1116±29.75 – 1419±28.54), turbidity (18.90±2.81 – 31.70±8.13) and nitrate (45.50±3.06 – 69.90±2.11, except in water sample point-4) were above the recommended limit according to the NSDWQ guideline, while temperature levels (26.90±0.04 – 28.40±0.02) were within the acceptable limit. The study concludes that the River Otamiri is contaminated. It is therefore advisable to purify water from the river before use for domestic and industrial purposes.

Keywords: physicochemical, water quality, pollution, Otamiri River, Imo State

1 Introduction

Pollution of water bodies has become a global issue of concern due to the failure of surface water protection measures [1–5]. Water is a highly essential resource for the existence of all life forms, including food production, economic development, and general well being, and nearly most drinking water requirement of the populace is obtained from surface water such as streams, rivers, dams, reservoirs, lakes etc [6, 7]. Good-quality water is essential for living organisms, but the rapid increase in population growth, urbanization, and industrialization has led to the decreased availability of good-quality water [4, 5, 8]. Surface water serves as sink for the disposal of waste, especially effluents, from industries that are near them and agricultural discharges. Most of these water bodies receive untreated industrial effluent discharge from nearby industries and other solid wastes, which may lead to degradation of aquatic ecosystems, aesthetic view, heightened temperature of the water body, eutrophication, and pose a significant health risk to the water bodies and the environment [9–11]. The quality of water can be assessed by studying its physical and chemical properties [1, 3, 6, 12, 13].

The quality of water is influenced by anthropogenic activities such as agricultural activities, industrial activities, improper disposal of waste, climate change, population growth, and urban development, which have contributed greatly to the pollution of the surface water [14–16]. These activities introduce toxic substances into the water bodies, which may change the physical, chemical, and biological nature of the receiving water bodies and may influence consumer acceptance. Turbidity, color, taste, and odor in water influence consumer perceptions and behavior [11, 17]. High levels of pollutants in water bodies cause an increase in the physicochemical properties of water, such as biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), calcium ion, magnesium ion, total hardness, sulphate, OH, HCO^{3-}, acidity, alkalinity, and toxic metals such as Cd, Cr, Ni and Pb, thus making such water unfit for drinking, irrigation and aquatic life [18–20].

Industrial wastewaters range from high biochemical oxygen demand (BOD) from biodegradable wastes such as those from human sewage, pulp and paper industries, chemical industry, and slaughter houses. Others include those from plating shops and textiles, which may be toxic and require on-site physiochemical pre-treatment before discharge into the municipal sewage system [21, 22]. Different studies have shown that the release of untreated effluents has the potential to negatively impact aquatic organisms by decreasing pH to acid level, increasing conductivity, temperature turbidity, and total solids in such an environment, leading to a decrease in dissolved oxygen with microbial bloom from rich nutrients (nitro-groups, sulfur-groups, and phosphors) [13, 23–25]. Human exposure to contaminated water is associated with a significant number of serious health issues, such as skin infections, chronic illnesses, reproductive issues, and premature mortality in children who live in the vicinity of these rivers [26–28].

The Otamiri River is a major river within Owerri metropolis, Imo State, Nigeria. It is joined by the Nworie River at Nekede in Owerri and is constantly being fed by different streams within the community [3, 7]. Otamiri River serves as a source of water for Owerri urban, for fishing, industrial and domestic uses, sand dredging, and other uses. Industrial effluents and most of the commercial wastes, as well as all drainages in Owerri urban, are released into the Avu landfall in Owerri west, which later gets washed into the Otamiri River. Additionally, solid waste is also dumped without being lined and incinerated along the riverside. These wastes heaped at the riverside contain diverse chemical components that percolate into the soil and the river, posing health threats to man, flora, and fauna [29, 30]. Therefore, protecting river water quality and aquatic ecosystems is very important to avert water pollution and the global scarcity of water resources. The reliance of the community on the Otamiri River for fishing, domestic, and other uses, especially when the public water supply fails, necessitated this study. Hence, the current study aims to assess the surface water physicochemical properties of the River Otamiri in Imo state, Nigeria.

2 Materials and methods

2.1 Description of study area

Otamiri River is one of the major rivers in Imo State, Nigeria. The river is named after "Ota Miri," a god who controls all water by that name and is frequently the most powerful deity in the Mbari house [1, 3, 30, 31]. It is on Latitude 4^o 54' 14.00" N and Longitude 7^o 08' 30.00" E. The river flows into the Atlantic Ocean at Ozuzu in the Etche Local Government Area of River State after travelling south from Egbu via Owerri, Nekede, Ihiagwa, Eziobodo, Olokwu Umuisi, Mgbirichi, and Umuagwo [3, 30, 32]. The river is 30 kilometers long from its source to where it joins the Uramiriukwa River at Emeabian [33, 34]. The Otamiri watershed covers about 10,000 km^2 with an annual rainfall of 2250-2500 mm [33]. The watershed is mainly surrounded by depleted rainforest vegetation, with a mean temperature of 27 ^{0}C throughout the year [35]. The Nworie River joins the Otamiri at Nekede in Owerri, a river about 9.2 km long [34]. The Otamiri River is frequently used for industrial and human purposes. Some of the nearby communities use it as a source of drinking water when the public water system fails [30]. This study assessed the Otamiri River because of its relative closeness to the auto-mechanic village. The map of the study area and coordinates of the surface water sample were located with a global positioning system (GPS), as shown in Table 1 and Figure 1, respectively.

Table 1 Coordinates of the surface water samples from Otamiri River

P_ID	Latitude (N)	Longitude (E)	Point Name	Remarks
1	5.443	7.021	WSP-1	Water sample point-1
2	5.447	7.023	WSP-2	Water sample point-2
3	5.45	7.026	WSP-3	Water sample point-3
4	5.452	7.028	WSP-4	Water sample point-4

2.2 Samples Collection and Pretreatment

Surface water samples were collected five times during the dry season (November and December, 2022) from four sampling points (WSP-1, WSP-2, WSP-3 and WSP-4) along the Otamiri River in the Owerri West Local Government Area of Imo State. The sampling points were chosen along the watercourse of the river at: waste dumpsite (WSP-1), auto-mechanic village (WSP-2), sand dredging site (WSP-3), and normal site (WSP-4). The surface water samples were collected between 09:00 and 11:00 a.m. at a depth of 20 cm below the water

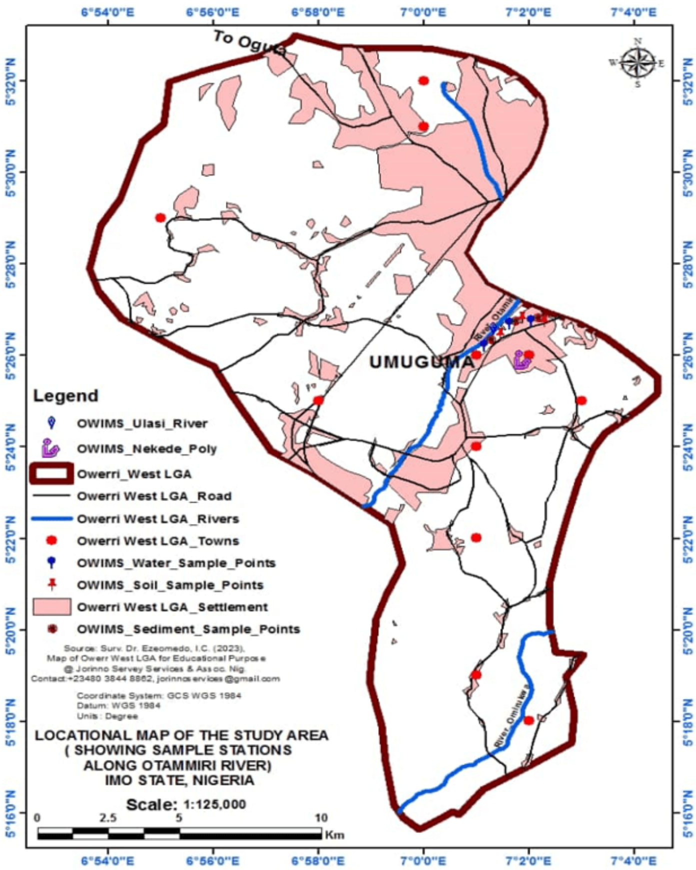

Figure 1 Map of the study area

surface. A total of twenty water samples were collected for the study. Sampling bottles were washed with detergent, rinsed with distilled water and pure acetone (99.9%), and dried in an oven overnight at 105°C.

2.3 Determination of physicochemical properties of Otamiri River

The physicochemical analysis was carried out using the American Public Health Association (APHA) Standard methods for the examination of water.

2.3.1 pH

pH was measured by the electrometric method using the laboratory pH meter Hanna model HI991300 [36]. An electronic method using a combination of glass electrodes with a reference potential provided by a standard calomel electrode is the standard method for measuring pH. The electrodes were rinsed with distilled water and blotted dry. The pH electrodes were then rinsed in a small beaker with a portion of the sample. A sufficient amount of the sample was poured into a small beaker to allow the tips of the electrodes to be immersed to a depth of about 2 cm. The electrode was at least 1 cm away from the sides and bottom of the beaker. The temperature adjustment dial was adjusted accordingly, and the pH of the sample was recorded.

2.3.2 Temperature

The temperature of the water was measured according to the methods described by APHA [36]. The mercury-in-glass thermometer was immersed in the water and allowed to assume the water temperature before reading. The value of the temperature was taken by switching the mode and was allowed to stabilize for three minutes before the value was recorded.

2.3.3 Electrical conductivity (EC)

Analysis was carried out according to APHA [36] guidelines. The conductivity cell was rinsed with at least three portions of the sample; the temperature of the sample was then adjusted to 20 ± 0.1 ^{o}C. The conductivity cell containing the electrodes was immersed in a sufficient volume of the sample, and the conductivity meter was turned on and the conductivity of the sample recorded.

2.3.4 Dissolved oxygen

The dissolved oxygen level in the surface water was determined according to the APHA [36] guideline using the modified Winkler method.

2.3.5 Turbidity

The turbidity of the surface water was measured using a turbidity meter according to the methods described by the American Public Health Association [36].

2.3.6 Total hardness

Hardness is measured using the standard analytical method of APHA [36]. Exactly 50cm^3 of the water sample was introduced into a beaker, and a 1cm^3 buffer solution of NH_3 added. Three (3) drops of Solocrome Black T indicator were also added, and the solution swirled properly. The mixture was titrated with 0.01 EDTA solution until the colour changed from wine red to pure blue, with no bluish tinge remaining. The total hardness of the water sample was calculated using Equation 1.

$$Total\ \ hardness\ (mg/CaCO_3) = \frac{Volume\ \ of\ \ Titrate \times 1000}{Volume\ \ of\ \ samples\ \ (cm^3)} \tag{1}$$

2.3.7 Chloride

Chloride content was determined according to the APHA standard method [36]. About 100 ml of the clear sample was pipetted into an Erlenmeyer flask, and the pH was adjusted to 7-10 with either H_2SO_4 or NaOH solutions. Then 1 ml of K_2CrO_4 indicator solution was added and titrated with a 0.01 M standard solution of $AgNO_3$ in a permanent reddish brown colouration. This was calculated using Equation 2.

$$Chloride\ \ concentration = titre\ \ value\ (t) \times 10 = 10 \times mg/l \tag{2}$$

2.3.8 Nitrate

Nitrate was determined using a PD303 UV spectrophotometer [36]. Nitrates react with phenoldisulphonic acid and produce a nitrate derivative, which in alkaline solution develops a yellow colour due to rearrangement of its structure. The intensity of the colour produced is directly proportional to the concentration of nitrates present in the sample. A known volume (50 ml) of the sample was pipetted into a porcelain dish and evaporated to dryness in a hot water bath. 2 ml of phenol disulphonic acid was added to dissolve the residue by constant stirring with a glass rod. A concentrated solution of sodium hydroxide and distilled water was added while stirring to make it alkaline. This was filtered into a Nessler's tube and made up to 50 ml with distilled water. The absorbance was read at 410 nm using a spectrophotometer after the development of colour. The standard graph was plotted by taking concentration along the x-axis and the spectrophotometric readings (absorbance) along the y-axis. The value of nitrate was found by comparing the absorbance of the sample with the standard curve and expressed in mg/l.

2.3.9 Sulphate

Sulphate was analyzed according to the APHA standard method [36]. About 250 cm^3 of the water sample was evaporated to dryness on a dish. The residue was moistened with a few drops of concentrated HCl and 30 cm^3 distilled water was added. This was boiled and then filtered. The dish was rinsed and the filter paper washed with several portions of distilled water, and both filtrate and washings were added together. This was heated to boiling, and then 10cm^3 of a 10% $BaCl_2$ solution was added, drop by drop, with constant stirring. The mixture was digested for about 30 minutes, filtered, and the filter paper washed with warm distilled water. It was then ignited, cooled, and weighed in an already-weighed crucible. This was calculated using Equation 3.

$$Mg/dm^3 SO_4^{2-} = mg\ BaSO_4 \times 411.5\ cm^3\ of\ \ water\ \ sample \tag{3}$$

2.4 Data analysis

The data generated from this study was analyzed using Microsoft Office Excel 2007. Descriptive statistics (mean ± standard deviation) were reported for the four sampling points. The data obtained were compared with the recommended limits set by the Nigerian Standard for Drinking Water Quality (NSDWQ).

3 Results and Discussion

3.1 Physicochemical properties of the water samples

The physicochemical analysis of surface water samples collected from the River Otamiri was carried out to ascertain the degree of pollution. Descriptive statistics (mean and standard deviation) of the parameters assessed in the surface water samples are depicted in Table 2.

Table 2 Physicochemical properties of surface water from the Otamiri River

Parameter	WSP-1	WSP-2	WSP-3	WSP-4	NSDWQ standards
pH	5.40±0.36	5.87±0.21	4.99±0.11	6.30±0.08	6.5–8.5
Temp. (oC)	27.20±0.05	28.40±0.02	26.90±0.04	27.70±0.02	25–35^{o}C
E.C (µs cm-1)	1278±23.55	1331±14.28	1419±28.54	1116±29.75	1000
Dissolved oxygen	5.94±0.02	5.32±0.03	4.16±0.01	6.45±0.03	10
Turbidity (NTU)	31.70±8.13	26.40±5.24	23.60±4.13	18.90±2.81	5
Total hardness (mg L-1)	19.30±2.15	17.10±1.78	21.20±3.41	27.80±2.54	150
Chloride (mg L-1)	68.30±0.58	87.45±0.77	91.90±0.64	73.27±0.42	250
Nitrate (mg L-1)	50.80±5.32	57.50±4.47	69.90±2.11	45.50±3.06	50
Sulphate (mg L-1)	46.70±1.54	51.21±2.11	45.64±1.13	39.55±3.32	250

Note: NSDWQ- Nigerian standard for drinking water quality

The mean pH values of the surface water samples ranged from 4.99±0.11 (WSP-3) – 6.30±0.08 (WSP-4). Generally, it can be seen that these values are significantly lower than the stipulated acceptable limit of the National Standard for Drinking Water Quality (NSDWQ) [28]. Furthermore, the pH of the studied surface water was acidic (low). pH is commonly used to express the concentration of the acidity or alkalinity of a solution. Studies conducted in some rivers in Nigeria have reported a similar pH value [2, 37–39]. Generally, the low pH of water bodies could be attributed to the presence of humic acids generated by the demise of aquatic life due to human activities [6, 40, 41].

The mean temperature (^{0}C) values of the surface water samples ranged from 26.90±0.04 ^{0}C (WSP-3) – 28.40±0.02 ^{0}C (WSP-2). These values were within the ambient temperature range stipulated by the National Standard for Drinking Water Quality (NSDWQ), higher than the values obtained by Sharma *et al.* [6], but were in agreement with the findings noted by Cosmas *et al.* [20]. Additionally, the finding conforms to earlier works by Okeke and Adinna [30] in the Otamiri River. The temperature values reported in the present study were due to the climatic condition of the study area [3, 7].

The mean electrical conductivity values of the surface water samples ranged from 1116±29.75 μs cm^{-1} (WSP-4) – 1419±28.54 μs cm^{-1} (WSP-3). It can be seen that these values are higher than the acceptable National Standard for Drinking Water Quality limit. The high E.C values were attributed to the impact of dissolved ions in the surface water. The electrical conductivity of river water is a very important parameter, as it is used to measure the soluble salt content of the water [39, 42].

The mean dissolved oxygen (DO) values of the surface water samples ranged from 4.16±0.01 mg/l (WSP-3) – 6.45±0.03 mg/l (WSP-4). It can be seen that the dissolved oxygen values are below the recommended limit stipulated by the National Standard for Drinking Water Quality. According to Garg *et al.* [43], a dissolved oxygen concentration greater than 10.00 mg/l supports aquatic life, while a low dissolved oxygen concentration (<6.5 mg/l) tends to become lethal. In addition, dissolved oxygen (DO) is a good indicator of decent water quality. The DO values in the present study were higher than the values obtained in a study conducted by Joseph *et al*. [37] and Ibe *et al.* [27], which had a maximum value of 4 mg/l.

The mean turbidity (NTU) values of the surface water samples ranged from 18.90±2.81 NTU (WSP-4) – 31.70±8.13 NTU (WSP-1). It can be seen that the turbidity values reported in this study are significantly higher than the stipulated limit recommended by the National Standard for Drinking Water Quality. According to Eze *et al*. [18], high turbidity values in surface waters such as rivers tend to reduce their aesthetic quality and also increase the cost of water treatment for domestic and industrial purposes.

The mean total hardness (mg/l) values of the surface water samples ranged from 17.10±1.78 mg/l (WSP-2) – 27.80±2.54 mg/l (WSP-4). It can be seen that the total hardness values are below the recommended limit stipulated by the National Standard for Drinking Water Quality. Worthy of note is that hardness in water is due to the presence of cations such as Ca^{2+} and

Mg^{2+}; and anions such as $HCO_3{}^-$, Cl^- and $SO_4{}^{2-}$ in surface water. Studies conducted by Akubugwo *et al.* [2] and Eze *et al.* [18] in River Njaba, Imo State, reported a similar finding to the present study.

The mean chloride (mg/l) values of the surface water samples ranged from 68.30±0.58 mg/l (WSP-1) – 91.90±0.64 mg/l (WSP-3). It can be seen that the chloride values are lower than the stipulated limit by the National Standard for Drinking Water Quality. It is important to note that although the chloride levels in the River Otamiri were generally low, the presence of the pollutant signifies the impact of human activities on the surface water. Studies conducted by Ahiarakwem and Onyekuru [40] and Joseph *et al.* [37] in Rivers Njaba and Nwangele, respectively, in Imo State, reported chloride levels similar to those obtained in the present study.

The mean nitrate (mg/l) values of the surface water samples ranged from 45.50±3.06 mg/l (WSP-4) – 69.90±2.11 mg/l (WSP-3). It can be seen that the nitrate values are generally higher than the stipulated limit by the National Standard for Drinking Water Quality, except in sample WSP-4. This is an indication of the leaching of unlined wastes from nearby waste dumpsites and auto-mechanic workshops within the auto-mechanic village into the studied river [44–46]. The high nitrate concentration recorded in the Otamiri River implies that consumption of the water could lead to the development of methaemoglobinaemia (blue baby syndrome) in infants [1, 37, 40].

The mean sulphate (mg/l) values of the river water samples ranged from 39.55±3.32 mg/l (WSP-4) –51.21±2.11 mg/l (WSP-2). It can be seen that the sulphate values are lower than the stipulated limit by the National Standard for Drinking Water Quality. Sulphate is generally considered non-toxic; however, drinking water containing high amounts of magnesium sulphate or sodium sulphate may lead to intestinal discomfort, diarrhea, and consequent dehydration, especially in drinking water containing > 500 mg/l of sulphate [2, 41, 47].

4 Conclusion

This study has revealed that Otamiri River is acidic (low pH), with electrical conductivity, turbidity, and nitrate values above the recommended limit according to the National Standard for Drinking Water Quality (NSDWQ). The high values reported pose a negative impact on the water quality and are a clear indication of the influence of anthropogenic activities within and around the river. It is important to note that consumption of water with high electrical conductivity, turbidity, and nitrate is detrimental to human health. The study recommends proper water treatment before usage by the local populace.

Author contributions

VCE: conceptualization, methodology and writing- original draft preparation; VIO: reviewing, supervision and editing, data curation; JOO: investigation, software and validation; CCA: editing, methodology and software; CNA: visualization, methodology; NJO: data curation and software.

Conflicts of interest

No potential conflicts of interest was reported by the author(s).

References

[1] Amadi AN, Olasehinde PI, Okosun EA, et al. Assessment of the Water Quality Index of Otamiri and Oramiriukwa Rivers. Physics International. 2010, 1(2): 102-109.
https://doi.org/10.3844/pisp.2010.116.123

[2] Akubugwo EI, Nwachukwu MI, Odika PC, et al. Water quality assessment of Njaba River, Nigeria. Journal of Environmental Science, Toxicology and Food Technology. 2013, 4(6): 33-37..
https://doi.org/10.9790/2402-0463337

[3] Ubaka KG, Ekwonu AM, Ogah JO, et al. Effect of pollution on the physicochemical characteristics of Otammiri River, Imo State. American Academic & Scholarly Research Journal. 2019, 11(4)

[4] Aralu CC, Okoye PAC, Abugu HO, et al. Pollution and water quality index of boreholes within unlined waste dumpsite in Nnewi, Nigeria. Discover Water. 2022, 2(1).
https://doi.org/10.1007/s43832-022-00023-9

[5] Aralu CC, Okoye PAC, Abugu HO, et al. Characterization, sources, and risk assessment of PAHs in borehole water from the vicinity of an unlined dumpsite in Awka, Nigeria. Scientific Reports. 2023,

13(1).
https://doi.org/10.1038/s41598-023-36691-3

[6] Sharma S, Tali I, Pir Z, et al. Evaluation of physicochemical parameters of Narmada River, MP, India. Researcher. 2012, 4: 13-19.

[7] Reuben Nwoye O, Edna Ifeyinwa C. Physicochemical and Bacteriological Qualities of Otamiri River Water and Sediment in South Eastern Nigeria. Frontiers in Environmental Microbiology. 2020, 6(2): 18.
https://doi.org/10.11648/j.fem.20200602.12

[8] Aralu CC, Okoye PAC, Abugu HO, et al. Potentially toxic element contamination and risk assessment of borehole water within a landfill in the Nnewi metropolis. Health and Environment. 2023, 4(1): 186-197.
https://doi.org/10.25082/he.2023.01.001

[9] Fakayode SO. Impact Assessment of Industrial Effluent on Water Quality of the receiving Alaro River in Ibadan, Nigeria. African Journal of Environmental Assessment. 2005, 10.

[10] Catherine EC, Emeka A, Emeka NK, et al. Impact of municipal solid waste on the water quality of Otamiri River in Owerri, South-Eastern Nigeria. World Journal of Biology Pharmacy and Health Sciences. 2021, 7(3): 65-72.
https://doi.org/10.30574/wjbphs.2021.7.3.0103

[11] USEPA. National Recommended Water Quality Criteria-Correction, United State Environmental Protection Agency EPA, 1999, 25.
https://www.epa.gov./ostwater/pci/revcom

[12] Amadi BA, Chikezie PC, Okeoma HC. Physiochemical characteristics of Nworie river and its effect on liver function on rats. Journal of Nigeria Environmental Science. 2006, 3(3): 183-187.

[13] Teshome JY, Gelanew A, Abayneh B. Impact of Dashen brewery effluent on irrigation water quality of Shinta River in Gondar, Ethiopia. Journal of Academia and Industrial Research. 2019, 8(1): 11-15.

[14] Bhalme SP, Nagarnaik PB. Analysis of drinking water of different places – A review. International Journal of Engineering Research. 2012, 2(1): 3150-3155.

[15] Anhwange BA, Agbaji EB, Gimba EC. Impact Assessment of Human Activities and Seasonal Variation on River Benue within Markurdi Metropolis. Internal Journal of Science and Technology. 2012, 2(5): 2224-3577.

[16] Eze VC, Onwukeme V, Enyoh CE. Pollution status, ecological and human health risks of heavy metals in soil from some selected active dumpsites in Southeastern, Nigeria using energy dispersive X-ray spectrometer. International Journal of Environmental Analytical Chemistry. 2020, 102(16): 3722-3743.
https://doi.org/10.1080/03067319.2020.1772778

[17] WHO.Guidelines for Drinking-water Quality. Fourth Edition. World Health Organization, Geneva, 2011.

[18] Eze VC, Ndife CT, Muogbo MO. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in Njaba River, Imo State, Nigeria. Brazilian Journal of Analytical Chemistry. 2021, 8(33): 57-70.
https://doi.org/10.30744/brjac.2179-3425

[19] Aralu CC, Okoye PAC, Abugu HO, et al. Toxicity and distribution of polycyclic aromatic hydrocarbons in leachates from an unlined dumpsite in Nnewi, Nigeria. International Journal of Environmental Analytical Chemistry. 2022: 1-12.
https://doi.org/10.1080/03067319.2022.2140415

[20] Cosmas A, Ahamefula S, Ahiarakwem C, et al. Seasonal Variations in physiochemical and Bacteriological Parameters of Rivers. Journal of Environmental Protection. 2015, 5: 1094-1110.

[21] Otokunefor TV, Obiukwu C. Impact of refinery effluent on the physicochemical properties of a water body in the Niger delta. Applied ecology and environmental research. 2005, 3(1): 61-72.
https://doi.org/10.15666/aeer/0301_061072

[22] Kanu I, Achi OK. Industrial Effluents and Their Impact on Water Quality of Receiving Rivers in Nigeria. Journal of Applied Technology in Environmental Sanitation. 2011, 1(1): 75-86.

[23] Abrha BH, Chen Y. Analysis of Physico-Chemical Characteristics of Effluents from Beverage Industry in Ethiopia. Journal of Geoscience and Environment Protection. 2017, 5(6): 172-182.
https://doi.org/10.4236/gep.2017.56016

[24] Naibaho J, Korzeniowska M. The variability of physico-chemical properties of brewery spent grain from 8 different breweries. Heliyon. 2021, 7(3): e06583.
https://doi.org/10.1016/j.heliyon.2021.e06583

[25] Nweke EN, Okechukwu VU, Omokpariola DO, et al. Pollution Evaluation of Industrial Effluents from Consolidated Breweries: A Case Study from Benue State, Nigeria. River Basin Management-Under a Changing Climate. IntechOpen, 2022.
https://doi.org/10.5772/intechopen.105955

[26] Eze VC, Nwabudike AR, Duru CE, et al. Human health risk assessment of the levels of dioxin-like polychlorinated biphenyls (PCBs) in soils from mechanic workshops within Nekede mechanic village, Imo State, Nigeria. International Journal of Environmental Analytical Chemistry. 2021, 103(19): 7686-7696.
https://doi.org/10.1080/03067319.2021.1974424

[27] Ibe FC, Opara AI, Ibe BO. Application of pollution risk evaluation models in groundwater systems in the vicinity of automobile scrap markets in Owerri municipal and environs, southeastern Nigeria. Scientific African. 2020, 8: e00450.
https://doi.org/10.1016/j.sciaf.2020.e00450

[28] Mohammadi AA, Zarei A, Majidi S, et al. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. MethodsX. 2019, 6: 1642-1651. https://doi.org/10.1016/j.mex.2019.07.017

[29] Onwukeme VI, Okechukwu VU. Leaching matrix of selected heavy metals from soil to ground water sources in active dumpsites: A case study of Southern Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology. 2021, 14(4): 1-18.

[30] Okeke PN, Adinna EN. Water Quality Study of Otamiri Otamiri-oche River in Owerri, Nigeria. Universal Journal of Environmental Research and Technology. 2013, 3(6): 641-649.

[31] Tahri M, Benyaich F, Bounakhla M, et al. Multivariate analysis of heavy metal contents in soils, sediments and water in the region of Meknes (central Morocco). Environmental monitoring and assessment. 2005, 102: 405-417. https://doi.org/10.1007/s10661-005-6572-7

[32] Enyoh CE, Isiuku BO. Determination and Human Health Risk Assessment of Heavy Metals in Floodbasin Soils in Owerri, Southeastern Nigeria. Chemistry Africa. 2020, 3(4): 1059-1071. https://doi.org/10.1007/s42250-020-00171-2

[33] Eze VC, Onwukeme VI, Ogbuagu JO, et al. Source apportionment of polychlorinated biphenyls in surface water and sediments from River Otamiri, Imo State. Scientific African. 2023, 22: e01957. https://doi.org/10.1016/j.sciaf.2023.e01957

[34] Eze VC, Onwukeme VI, Ogbuagu JO, et al. Toxicity and risk evaluation of polychlorinated biphenyls in River Otamiri, Imo State. Scientific African. 2023, 22: e01983. https://doi.org/10.1016/j.sciaf.2023.e01983

[35] Ibeh LM, Mbah CN. Surface water characteristics of urban rivers in Enugu south eastern, Nigeria. World Journal of Biotechnology. 2007, 8(2): 1412-1417.

[36] APHA. Standard Methods for the Examination of Water and Wastewater, 20th Ed., American Public Health Association, Washington, DC, 1998.

[37] Joseph A, Majesty D, Friday U. Water quality assessment of Nwangele river in Imo State, Nigeria. Journal of Ecobiotechnology. 2019, 11: 1-5.

[38] Eze VC, Enyoh CE, Ndife CT. Soil Cationic Relationships, Structural and Fertility Assessment Within Selected Active Dumpsites in Nigeria. Chemistry Africa. 2020, 4(1): 127-136. https://doi.org/10.1007/s42250-020-00194-9

[39] Ossai CJ, Iwegbue CMA, Tesi GO, et al. Spatial characteristics, sources and exposure risk of polychlorinated biphenyls in dusts and soils from an urban environment in the Niger Delta of Nigeria. Science of The Total Environment. 2023, 883: 163513. https://doi.org/10.1016/j.scitotenv.2023.163513

[40] Ahiarakwem CA, Onyekuru SO. A Comparative Assessment of the Physico-Chemical and Microbial Trends in Njaba River, Niger Delta Basin, Southeastern Nigeria. Journal of Water Resource and Protection. 2011, 3(9): 686-693. https://doi.org/10.4236/jwarp.2011.39079

[41] Okeke DO, Ifemeje JC, Eze VC. Determination of the levels of heavy metals and physicochemical properties of borehole water within selected mining sites in Ebonyi state, Nigeria. International Journal of Chemical and Biological Sciences. 2021, 3(2): 5-10. https://doi.org/10.33545/26646765.2021.v3.i2a.28

[42] Mahmood A, Malik RN, Li J, et al. Levels, distribution profile, and risk assessment of polychlorinated biphenyls (PCBs) in water and sediment from two tributaries of the River Chenab, Pakistan. Environmental Science and Pollution Research. 2014, 21(13): 7847-7855. https://doi.org/10.1007/s11356-014-2730-1

[43] Garg RK, Rao RJ, Uchchariya D, et al. Seasonal variations in water quality and major threats to Ramsagar reservoir, India. African journal of environmental science and technology, 2010, 4(2).

[44] Nwachukwu MA, Feng H, Achilike K. Integrated study for automobile wastes management and environmentally friendly mechanic villages in the Imo River Basin, Nigeria. African Journal of Environmental Science and Technology, 2010, 4(4).

[45] Nkwoada AU, Alisa CO, Amakom CM. Pollution in Nigerian auto-mechanic villages: A Review. Environmental Science, Toxicology and Food Technology. 2018, 12(7): 43-54. https://doi.org/10.9790/2402-1207014354

[46] Onwukeme VI, Eze VC. Identification of heavy metals source within selected active dumpsites in southeastern Nigeria. Environmental Analysis Health and Toxicology. 2021, 36(2): e2021008. https://doi.org/10.5620/eaht.2021008

[47] Al-Wabel MI, Usman ARA, El-Saeid MH, et al. Levels, Sources, and Risk Assessment of Polychlorinated Biphenyls (PCBs) in Soils from Industrial Areas: A Case Study from Saudi Arabia. Polycyclic Aromatic Compounds. 2016, 38(5): 420-433. https://doi.org/10.1080/10406638.2016.1224261