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Suitability Assessment of Heavy Metal Concentration in Eniong Creek, Niger Delta, Nigeria for Multiple Uses

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ABSTRACT

The heavy metal concentration in Eniong Creek, Akwa Ibom State, Nigeria was assessed in three locations, between March and August 2024. Standard analytical method and water quality assessment indices were applied to evaluate the waters' suitability to support aquatic biota and for drinking water and irrigation purposes. Water quality standards for drinking, aquatic life and irrigation were used as benchmark values for the assessment. Six (6) heavy metals were appraised and their range of values were: nickel (0.01- 0.09 mg/L), copper (0.01 - 0.08 mg/L), zinc (0.63 - 3.16 mg/L), lead (0.004 - 0.06 mg/L), cadmium (0.01 - 0.04 mg/L) and iron (0.27 – 1.25 mg/L).The mean concentrations of nickel, cadmium, iron, lead (stations 1 and 2) were higher than the threshold values for drinking water and support for aquatic biota. Zinc values also exceeded the limit required for the sustenance of aquatic biota. However, all the metals conformed to irrigation standard except cadmium. The drinking water pollution index (DWWPI), aquatic life water pollution index (ALWPI) and irrigation water pollution index (IRWPI) values were 2.37 - 2.79, 30.93 - 42.50 and 0.56 - 0.68 respectively. The DWWPI and ALWPI values were > 1, indicating poor water quality for drinking and aquatic life support. The level of pollution exacerbated by anthropogenic activities in the watershed could be responsible to observed variations. Hence, this study concluded that water was not potable or suitable to support diverse aquatic biota but can be used for irrigation purposes.

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INTRODUCTION

Aquatic ecosystems serve as valuable resource for diverse human needs; including drinking, irrigation, industrial and for recreational purpose as well as fisheries (Anyanwu et al., 2022a). Polluted water becomes less suitable for intended uses and continuous use of water from unwholesome sources for drinking could expose human population to a number of health issues (Odo et al., 2022). However, the sustainability, abundance and diversity of organisms in aquatic ecosystems are generally governed by its quality (Jonah et al., 2020; Jacob et al., 2023).

Presently, the levels of unregulated human socioeconomic activities and inappropriate societal behaviours have seriously resulted in pollution of rivers and other aquatic ecosystems (Odero et al., 2023).The siting of industries near rivers, disposal of effluents into rivers and agricultural activities do have direct and indirect implications on aquatic ecosystems by introducing toxic metals and other pollutants that could impair it quality (Anyanwu et al., 2023).

Metals pollution in aquatic ecosystems are so devastating and threaten lives because they are toxic in nature, non-biodegradable, persistent and tend to bio-accumulate (Ali et al., 2019). Heavy metals are a group of metals with high density and toxicity, even at low concentrations. They rank among the major polluting chemical agents in the aquatic ecosystem. Naturally, they occur at trace levels but anthropogenic activities have contributed to levels far higher than these natural levels, resulting in serious concerns about the environment and public health. Heavy metals like cadmium, mercury, and lead can be potentially harmful to living organisms even at lower concentrations and they have the tendency of being biomagnified through the food chain with severe consequences (George et al., 2015).Use of contaminated water for their basic needs such as drinking and other domestic activities as well as irrigation, predisposes humans to toxic elements (Albert et al., 2017; Jonah and Mendie, 2022; 2024). Eniong Creek is a very important rural freshwater body commonly used by inhabitants of the nearby communities for a number of socioeconomic needs such as drinking and other domestic uses, fishing and irrigation. This water is often used untreated; thereby predisposing unsuspecting consumers to potential health issues. Apart from human uses, the water can also adversely affect other ecosystem services such support for aquatic biota and irrigation, if it is contaminated by heavy metals. Hence, this study is aimed at evaluating the heavy metal concentrationof the waters of Eniong Creek, Akwa Ibom State, Nigeria vis-à-vis portability, sustainability of aquatic life and irrigation.

MATERIAL AND METHOD

Description of the Study Area

The study was conducted at Eniong Creek, Niger Delta, Nigeria within 5° 20′54.25″ N - 5° 21′59.09″ N and 7° 50′39.03″ E - 7° 52′10.6″E (Fig. 1).The region is known for its fishing and agricultural activities; characterized by tropical humid climate conditions. A short dry season usually occur between November and February while long wet season between March and October (Ekpo et al., 2025).

Characterization of Sampling Stations

Three stations were designated along a section of the river where the samples were collected. The criterion for the selection was based on the land use, accessibility, nearness to community and the levels of anthropogenic activities. The station 1 (N 5°21′59.09472″; E 7° 50′39.0282″) was upstream, situated in Okpoto, Iwere Clan, Ini L.G. Area, about two 2 km downstream of a human settlement; the anthropogenic activities (fishing and farming) were minimal. Station 2 (N 5°21′10.51812″; E 7° 51′41.29812″) was situated in Ikot Adaha of Ikpanya Clan, Ibiono Ibom L.G. Area, about 3.09 km away from station 1 towards the south. There are farmlands around the station and the community (Ikot Adaha) uses the river for their basic domestic water needs and irrigation especially in the dry season.

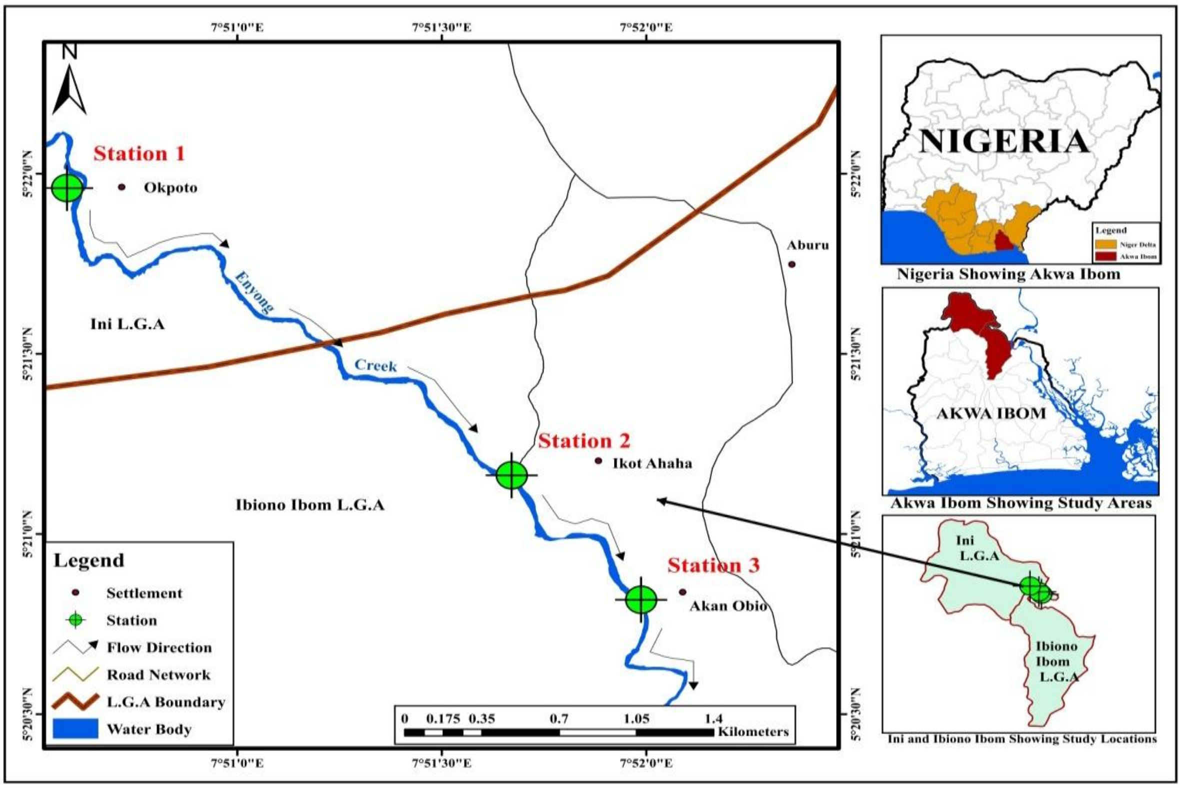

Figure 1. Showing the sampling stations of Eniong Creek, Niger delta, Nigeria

The station also receives runoff residential area and farmlands around it. Minimal sand mining activities were observed while intense farming, fishing, bathing, and lumbering were also observed at the station. Station 3 (N 5°20′54.28212″; E 7°52′10.614″) is located within Akan Obio community in Ikpanya Clan, Ibiono Ibom L.G. Area, about 0.98 km after station 2 in the southern direction. There is a horticultural garden on the right shore of the station while runoff from the Akan Obio community and surrounding farms are discharged into the river around the station. The major anthropogenic activities observed around the upper section of the station include sand mining, bathing, lumbering and washing of motorcycles. The water is majorly used for drinking, other domestic purposes and irrigation by the community.

Samples Collection and Analyses

Water samples were collected from the River once in a month between March and August, 2024. The samples were collected from below the surface of the water with a clean plastic bottles and the pH was immediately reduced with drops of nitric acid (HNO^3).The digestion process was carried with concentrated Analar grade Nitric acid according to Method 200.2 (USEPA, 1999).The determination of the heavy metals was carried out with UNICAM Solaar 969 atomic absorption spectrometer (AAS) operated with acetylene-air flame as stipulated by APHA (2017) and recorded in milligram per litre (mg/L). The six heavy metals evaluated were Iron (Fe), Zinc (Zn), Copper (Cu), Nickel (Ni), Lead (Pb) and Cadmium (Cd). Microsoft Excel was used to determine mean, standard error of the mean, minimum and maximum values from the data. On the other hand, significant spatial variations were determined with one-way Analysis of Variance (ANOVA) while tukey pairwise post-hoc was used to determine the source of the variation.

Water Quality Assessment

Water pollution index (WPI)

Water pollution index was used to evaluate the quality of the river based on the heavy metal content for different purposes. It was developed by Hossain and Patra (2020). The first process requires determining the pollution load of the metals using equation 1.

$$\mathrm{PLi} = 1 + \left(\frac{C_i - S_i}{S_i}\right) \quad (1)$$

Where, C_i is the analyzed concentration of each parameter while Si is the maximum acceptable value for the parameter. Three standards were used: FAO (1992) for irrigation, NESREA (2011) for aquatic life support and SON (2015) for drinking water. Then, the WPI was determined by adding all the individual pollution loads and dividing it by the number of parameters evaluated (n) as shown in equation 2. It should be noted that any parameter with the value of 0 was not used in the total 'n'.

$$\mathrm{WPI} = \frac{1}{n}\sum_{i=1}^{n} \mathrm{PL}_i \qquad (2)$$

RESULTS AND DISCUSSION

Heavy Metal Concentration

The heavy metals values were summarized in Table1 and it showed spatial variations with some that were significant. Nickel is considered as a major threat to human and ecosystem health (Sule et al., 2020).The values recorded for Nickel (Ni) was from 0.01 to 0.09 mg/L. The lowest concentrations were recorded in station 1 (July) and station 3 (April, May and August 2024). On the other hand, the highest concentration was reported in March 2024. The limit (0.01 mg/L) for aquatic biota set by NESREA (2011) was exceeded by most of the values except for station 1 (July) and station 3 (April, May and August 2024). The drinking water limit (0.02 mg/L) set by SON (2015) was also exceeded except in station 1(March and July 2024) and station 3 (April, May and August 2024). The lowest concentrations recorded in stations1 and 3 could be attributed low allochthonous due to late dry season and dilution after the onset of wet season. However, March 2024 had the highest concentration in station 2, which could be due to anthropogenic activities. Station 2 generally recorded significantly ($p<0.05$; $F = 11.79$) higher values than stations 1 and 3 (Table 1).Residential and agricultural waste waters and sand mining have been documented to contribute heavy metals in surface waters (Anyanwu and Umeham, 2020; Zahoor and Mushtaq, 2023; Al-Khuzaie et al., 2024).The Ni levels conformed to the irrigation water standard (0.20 mg/L) set by FAO (1992).The Ni values were within the ranges reported in related studies in Nigeria. For example, a range of 0.001 - 0.042 mg/L was reported in Eniong Creek, Niger Delta, Nigeria (Jonah et al., 2024) while 0.01 - 0.03mg/L was reported in Ikwu River, Umuahia, Nigeria (Anyanwu et al., 2022b).At trace amount, Ni is an essential nutrient for effective metabolic processes in some organisms (Song et al., 2017). It also facilitates other vital morphological and physiological functions in plants (Chukwu and Gulser, 2025). High intake of food or water contaminated with Ni could result in cancer (Chen et al., 2017).Toxicity of Ni can result in adverse effect on the mitochondria; leading to reduction in mitochondrial membrane potential, Deoxyribonucleic acid (DNA) and Adenosine triphosphate (ATP) (Genchi et al., 2020a). Studies affirmed that the toxicity of Ni in aquatic ecosystems adversely affect the biota, resulting in reduced growth and reproduction and death in some (Binet et al., 2018; Jonah, 2025).At elevated concentrations, plant metabolism will be altered, which will affect the actions of the enzymes, photosynthetic electron transport and synthesis of chlorophyll (Sreekanth et al., 2013).

Table 1.The mean concentrations of heavy metals at three different sampling stations, recorded in Eniong Creek, Niger Delta, Nigeria, water quality indices along with the regulatory standards

Heavy Metals (mg/L)	**Station 1 Mean±SEM**	**Station 2 Mean±SEM**	**Station 3 Mean±SEM**	**SON 2015**	**NESREA 2011**	FAO 1992
Nickel (Ni)	0.03±0.001^{a} (0.01 – 0.05)	0.06±0.01^{b} (0.03 – 0.09)	0.03±0.00^{a} (0.01 – 0.04)	0.02	0.01	0.20
Copper (Cu)	0.05±0.01^{b} (0.03 – 0.08)	0.05±0.01^{b} (0.03 – 0.08)	0.02±0.00^{a} (0.02 – 0.03)	1.0	0.001	0.20
Zinc (Zn)	1.12±0.13^{a} (0.63 – 1.68)	1.45±0.05^{ab} (1.28 – 1.63)	2.00±0.25^{b} (1.32 – 3.16)	3.0	0.01	2.0
Lead (Pb)	0.03±0.01^{b} (0.02 – 0.06)	0.02±0.00^{ab} (0.006 – 0.04)	0.01±0.00^{a} (0.004-0.009)	0.01	0.01	5.00
Cadmium (Cd)	0.03±0.00^{b} (0.01 – 0.04)	0.02±0.00^{a} (0.01 – 0.02)	0.02±0.00^{a} (0.01 – 0.03)	0.003	0.005	0.01
Iron (Fe)	0.58±0.10^{a} (0.27 – 0.85)	0.91±0.09^{b} (0.61 – 1.25)	1.05±0.06^{b} (0.78 – 1.24)	0.3	0.05	5.00
DWWPI	2.48	2.37	2.79	**WPI Classification**		
ALWPI	30.93	37.53	42.50	<0.5=Excellent Quality; >0.5-<0.75=Good Quality; >0.75-<1=Moderate Pollution; >1=High Pollution		
IRWPI	0.68	0.56	0.58			

SEM = Standard Error of the Mean; SON (2015) is Nigerian standard for drinking water quality; NESREA (2011) isGuidelines and Standards for Environmental Pollution Control in Nigeria; FAO (1992) is Wastewater treatment and use in agriculture. DWWPI isDrinking Water Water Pollution Index; ALWPI isAquatic Life Water Pollution Index and IRWPI = Irrigation Water Water Pollution Index.

Copper (Cu) is another critical micronutrient required in trace amounts for the proper development of aquatic organisms and plants. However, toxicity can occur at higher concentrations resulting negative effects on the health of organisms; often altering normal physiology, causing cell destruction, and eventual death of aquatic organisms (Mebane, 2023). Plant growth can also be hindered as a result of physiological and biochemical disorders triggered by Cu toxicity (Mir et al., 2021).The concentrations of Cu varied from 0.02 to 0.08 mg/L. Station 3 had the least values in April to July 2024; attributed to dilution after the onset of rains. On the other hand, the highest values recorded in stations 1 and 2 June 2024 could be due to anthropogenic activities exacerbated by rainfall event on the sampling day. The values were significantly ($P<0.05$; $F = 5.965$) higher than station 3. The concentrations of Cu conformed to the drinking water standard (1.0 mg/L) and irrigation water standard (0.20 mg/L) set by SON (2015) and FAO (1992) respectively. However, the limit for aquatic life (0.001 mg/L) set by NESREA (2011) was exceeded. The values were higher compared to the 0.0001 – 0.03 mg/L reported in Otamiri River, Imo State, Nigeria by Onyekuru et al.

(2017) but lower than 0.13 – 2.63 mg/L reported in some water bodies in Akwa Ibom State, Nigeria by Jonah et al. (2023).

Higher concentrations of Zinc (Zn) in aquatic environments pose significant and harmful effects on aquatic life including fish and invertebrates. Gill function can be impaired; leading to poor oxygen exchange as a result of acute toxicity of Zn in fish (Li et al., 2019).The study further reported that sub-lethal exposures to Zn could result in growth reduction, impair the efficacy of reproduction, and induce behavioral changes in aquatic organisms. Zn is essential nutrient for plant growth but higher concentrations could result to toxic effects in many plants; causing significant yield loss (Ul-Hassan et al., 2017).The concentrations of Zn varied from 0.63 to 3.16 mg/L. The lowest and highest values were recorded in stations 1 and 3 respectively in June 2024. This could be due to dilution and allochthonous input respectively due to rainfall event on the sampling day. The difference between stations3and 1 was significant ($P < 0.05$; F =7.897).The concentrations were higher than the aquatic life limit (0.01 mg/L) based on NESREA (2011).However, the values conformed to irrigation quality standard (2.0 mg/L) stipulated by FAO (1992) and drinking water standard (3.0 mg/L) stipulated by SON (2015) except in station 3 (June 2024). Jonah et al. (2024) had previously reported a lower range (0.001 – 0.06 mg/L) in the water body.

The concentrations of lead (Pb) were between 0.004 and 0.06 mg/L. Station 3 had the least value in May 2024. On the other hand, station 1 had the highest concentration in August 2024, which significantly ($P<0.05$; F = 10.61) exceeded station 3. This high concentration in station 1 (August 2024) could be due to combined effect of human activities and effect of August break. Between April and August 2024 in stations 1 and 2, the levels of Pb exceeded drinking water standard (0.01 mg/L) stipulated by SON (2015) and aquatic life by NESREA (2011). However, concentrations conformed to the irrigation water limit (5.00 mg/L) by FAO (1992). Related studies had higher values. For example, 0.01 – 0.15 mg/L was reported in Aba River, Aba, Abia State by Nwankwoala and Ekpewerechi (2017) and 0.05 – 0.33 mg/L reported in Ahi River, Umuahia, Abia State by Anyanwu et al. (2024). Lead is a known toxicant and a threat to humans and aquatic biota. At elevated levels in drinking water, structural damage to cells and its components like proteins, nucleic acid, membranes and lipids could occur; leading to stress at that level (Matthew et al., 2011). Dysfunction of a number of physiological systems in humans such as central nervous system, hematopoietic, cardiovascular, etc, are among the other health challenges associated with Pb toxicity (ATSDR, 2015). Also, neurotoxicity, oxidative stress and disruption of immune system have been reported in aquatic biota as a result of Pb toxicity (Lee et al., 2019).Though the values were relatively low, irrigation water with higher Pb content could adversely affect germination of seeds, root elongation, seedling development, growth of plants as well as transpiration in plants (Pourrut et al., 2011; Jonah et al., 2025).

Cadmium (Cd) is a toxicant that exposes humans and animals to health and environmental risks (Genchi et al., 2020b). The concentrations were from 0.01 to 0.04 mg/L. The lowest values were recorded in different stations and months. For example, station 1 (May 2024), 2 (April to July 2024) and 3 (April and August 2024). These could be attributed to dilution from increased runoff during the wet season (Hashim et al., 2025).On the other hand, anthropogenic activities exacerbated by runoff were responsible for the highest value observed in July 2024 (station 1). Though agricultural activities around station 1 was minimal, the variation between the station and the others (stations 2 and 3) was significant ($P<0.05$; $F = 4.293$). Agricultural runoffs laden with residues fertilizers and pesticides are major contributors of cadmium in the aquatic ecosystem (Hashim et al., 2025).The mean concentrations of Cd were higher than all the standard limits used in this study - 0.003 mg/L, 0.005 mg/L and 0.01 mg/L respectively for drinking water (SON, 2015), aquatic life (NESREA, 2011) and irrigation water (FAO, 1992). Health challenges like hypertension, damage of kidneys and bones, problem of reproduction as well as higher risk of cancer can occur in humans as a result of long-term exposure to high levels of Cd (Durmishi et al., 2016; Farias et al., 2024).Pains in the abdomen, dizziness, muscular cramps, sensational and nauseating feelings as well as vomiting, salivation and loss of consciousness are some other effects of elevated Cd exposure in humans (Nejabat et al., 2017).On the other hand, high Cd concentration results in decrease in the uptake and movement of nutrients and water in plants while increasing oxidative stress, impairing plant metabolism as well as altering plant morphology and physiology (Haider et al., 2021). Related studies in the region had higher values. For example, 1.17 – 2.01 mg/L was reported in Qua Iboe River at Ikot Ekpene, Akwa Ibom State, Nigeria by Akpan et al. (2024) and 0.00 – 0.08 mg/L was reported in upper coastal region of Qua Iboe River, Akwa Ibom State, Nigeria by Jonah and Mendie (2024).

In trace amounts, iron (Fe) is very important in human health and metabolism (Rushdi et al., 2023). However, neurotoxicity can occur in adults and children as a result of prolonged exposures to high concentrations (Urrutia et al., 2022). The concentrations were from 0.27 to 1.25 mg/L. Station 1 had the least concentration in May 2024; attributed to dilution. On the other hand, the highest concentration observed in station 2 (July 2024) could be due to anthropogenic activities exacerbated by runoff. Stations 2 and 3 were significantly varied ($P<0.05$; $F=7.626$) from station 1. The values conformed to the irrigation limit (5.00 mg/L) stipulated by (FAO, 1992) but exceeded the aquatic life limit (0.05 mg/L) and drinking water limit (0.3 mg/L) stipulated by (NESREA, 2011) and (SON, 2015) respectively except in May 2024 (station 1) for drinking water. The highest concentration observed in station 2 (July 2024) could have been influenced by human activities and allochthonous input from runoff. A number of health challenges in humans have been associated with elevated Fe content in drinking water such as hemochromatosis, stomach pain, diabetes, diarrhoea, vomiting and tiredness (Barton and Acton, 2017; Noor et al., 2024). The values of Fe were within the threshold of irrigation water; however, elevated levels in irrigation water can reduce the quality of crops and plant yields. On the other hand, toxicity of Fe does not occur in plants in well aerated soils; however, it can increase the acidity of the soil and loss of phosphorus and molybdenum that are essential for plant growth and development (Grabić et al., 2019).Related studies in the region had comparable values. For example, 0.14 – 1.13 mg/L was reported in streams at Essene, Ikot Abasi Local Government Area, Akwa Ibom State, Nigeria by Ndodo et al. (2024) and 0.19 – 3.92 mg/L was reported in upper coastal region of Qua Iboe River, Akwa Ibom State, Nigeria by Jonah and Mendie (2024).

Water Pollution Index (WPI)

The water pollution index (WPI) for drinking water ranged between 2.37 and 2.79, WPI for aquatic life ranged between 30.93 and 42.50 and irrigation water WPI was from 0.56 to 0.68 (Table 1). Based on WPI classification, good quality water should be less than 0.75 while values greater than 1 are indications of serious pollution. All the WPI values for drinking water and support for aquatic life were >1; indicating serious heavy metal pollution while that of irrigation water were within the good quality class. Combined effects of anthropogenic activities and rainfall influenced the values recorded for drinking water and aquatic life sustenance.

CONCLUSION and RECOMMENDATION

The concentrations of heavy metals as recorded in this study were varied. The concentrations of some heavy metals like iron, nickel, lead, zinc and cadmium were higher than their limits for drinking water and aquatic life support. On the other hand, all the metals conformed to irrigation limits except for cadmium. The water pollution index further confirmed the quality of the water for irrigation, aquatic life and drinking. Therefore, the water is considered good for irrigation but unfit for drinking and for support of aquatic biota. The levels of metals recorded attributed to the levels of pollutants exacerbated by anthropogenic activities in the studied locations. The concentrations of heavy metals in the water body require regular monitoring in order to minimize the associated risks of toxic metals pollution to humans and the aquatic biota.

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Conflict of Interests

The authors declare that there is no competing interest regarding to this manuscript.

Authors Contribution

ACH conceived the study and contributed to manuscript preparation. UEJ was involved in data collection and analysis. EDA contributed to data interpretation and manuscript revision. AEO contributed to methodology and final editing of the manuscript.

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