Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), vol 12(2), 2024
http://dx.doi.org/10.7770/safer-V12N2-art752

Evaluation of Heavy Metal Pollution status of Anambra River Basin using Different Indices

Evaluación del estado de contaminación por metales pesados de la cuenca del río Anambra utilizando diferentes índices

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ABSTRACT

Eighty-one (81) water samples were collected to investigate the concentrations of heavy metal and pollution status using synthetic pollution index (SPI), Comprehensive pollution index (CPI), Heavy metal evaluation index (HMEI) and Heavy metal pollution index (HPI). Eight (8) heavy metals, iron (Fe), manganese (Mn) zinc (Zn), copper (Cu), chromium (Cr) cadmium (Cd), nickel (Ni) and lead (Pb) were analysed following standard procedure and protocols. The results of analysis showed that Fe fluctuated between 1.32 and 4.10 mg/l, Mn between 0.51 and 2.04 mg/l, Zn between 0.81 and 3.20 mg/l, Cu between 0.43 and 1.92 mg/l, Cr fluctuated between 0.26 and 1.02 mg/l, Cd between 0.15 and 1.13 mg/l, Ni between 0.12 and 0.70 mg/l, and Pb fluctuated between 0.22 and 1.24 mg/l. Through results, it was also found that the mean concentrations of Fe, Mn, Cr, Cd, Ni and Pb exceeded their permissible values for drinking water (SON, 2015) whereas Mn, Cr, Cd, Ni and Zn levels exceeded their permissible values for health aquatic environment (FMEnv., 2011). The order of heavy metal concentration in the river basin were: Fe > Zn >Mn > Cu >Cr > Pb > Cd > Ni. The results of computed pollution indices revealed that most of pollution indices values were exceeded their highest classification values; SPI values were greater than 3, CPI > 2.0, HMEI >20 and HPI >1000, thus indicating that water from the river basin is unfit for drinking. In conclusion, water from Anambra River Basin pose a threat of heavy metals-related diseases to users/communities, thus, needs urgent attention for treatments by appropriated authorities.

Keywords / Palabras clave: Pollution indices current -status, Heavy metals, Anambra River Basin, fish landing

RESUMEN

Se recolectaron ochenta y una (81) muestras de agua para investigar las concentraciones de metales pesados y el estado de contaminación utilizando el índice de contaminación sintética (SPI), el índice de contaminación integral (CPI), el índice de evaluación de metales pesados (HMEI) y el índice de contaminación por metales pesados (HPI). . Se analizaron ocho (8) metales pesados, hierro (Fe), manganeso (Mn), zinc (Zn), cobre (Cu), cromo (Cr), cadmio (Cd), níquel (Ni) y plomo (Pb) siguiendo el procedimiento estándar y protocolos. Los resultados del análisis mostraron que el Fe fluctuó entre 1,32 y 4,10 mg/l, el Mn entre 0,51 y 2,04 mg/l, el Zn entre 0,81 y 3,20 mg/l, el Cu entre 0,43 y 1,92 mg/l y el Cr entre 0,26 y 1,02 mg. /l, el Cd entre 0,15 y 1,13 mg/l, el Ni entre 0,12 y 0,70 mg/l y el Pb osciló entre 0,22 y 1,24 mg/l. A través de los resultados también se encontró que las concentraciones medias de Fe, Mn, Cr, Cd, Ni y Pb excedieron sus valores permisibles para agua potable (SON, 2015) mientras que los niveles de Mn, Cr, Cd, Ni y Zn excedieron sus valores permisibles. para la salud del medio acuático (FMEnv., 2011). El orden de concentración de metales pesados en la cuenca del río fue: Fe > Zn > Mn > Cu > Cr > Pb > Cd > Ni. Los resultados de los índices de contaminación calculados revelaron que la mayoría de los valores de los índices de contaminación excedieron sus valores de clasificación más altos; Los valores de SPI fueron superiores a 3, CPI > 2,0, HMEI >20 y HPI >1000, lo que indica que el agua de la cuenca del río no es apta para beber. En conclusión, el agua de la cuenca del río Anambra representa una amenaza de enfermedades relacionadas con metales pesados para los usuarios/comunidades, por lo que necesita atención urgente para su tratamiento por parte de las autoridades correspondientes.

Palabras clave / Palabras clave: Índices de contaminación estado actual, Metales pesados, Cuenca del río Anambra, Desembarco de pescado

INTRODUCTION

One of important environmental components is water, which is an essential ingredient for survival of every life form on earth (Nwinyi *et al.,* 2020). Water is used for various activities major among these being for drinking, food preparation and for sanitation purposes (Abdulsalam and Sule, 2020). Surface water bodies such as streams and Rivers which have become important sources of water for cooking and drinking in remote villages These surface water sources are often vulnerable to contamination by human, animal activities and weather. The contamination of existing source of drinking water to rural communities is a growing threat to the environment and human health.

One of the principal contaminations of surface water is heavy metals and released into aquatic environment through natural processes and anthropogenic activities (Ato *et al*., 2010; Naveedullah *et al*., 2014). Metals constitute an important component of environmentally hazardous substances. These metals are discharged into the environment via several anthropogenic activities such as agriculture, dredging, transportation, industrial effluent discharge and indiscriminate waste dumping (Aladesanmi *et al*., 2014). Nowadays, many rivers in Nigeria have received elevated inputs of heavy metals as a result of an increase in atmospheric deposition, rapid development of industrialization and other anthropogenic activities around these water bodies. The presence of heavy metals in surface water (river) can make water from the river unfit for human consumption. Pollution of surface water bodies by heavy metal

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deteriorates drinking water and irrigation water quality and as such posing a risk to human health (Adesiyan *et al.*,2018). Globally, excessive pollution of surface water by various heavy metals has come a public health concern. Heavy metals lead to numerous hazards (cardiovascular, kidney, nervous, bone diseases, carcinogenesis, mutagenesis and teratogenesis, nutrient deficiency, enzyme malfunctioning and renal tubular dysfunction.

Sequel to consequences of heavy metal, monitoring of heavy metal characteristics is a vital for sustainable management of water resources (Olatunji and Osibanjo, 2012). Instead of traditional methods of water quality assessment, indices that can be effectively manage and evaluate the overall quality of water are employed. Comprehensive pollution index (CPI), synthetic pollution index (SPI), heavy metal evaluation pollution index (HMEI) and heavy metal pollution index (HPI) are mathematical and effective tool conversion of a complex number of environmental parameters into a single term representing the overall status of the water quality (Wu et al., 2018). They are considered beneficial, powerful and rapid tools for assessing the quality of water resources in a single term (Solangi et al.,2019). Many studies have employed different types of heavy metal pollution index models for evaluation of water quality (Ezugwu et al., 2019; Egbueri 2020) in southeast region. The review of the literature revealed that, heavy metal pollution index studies were only carried on groundwater, only a few is on surface water especially Anambra River. Basin using these powerful and rapid tools. Therefore, this study investigated heavy metal status of Anambra River using different pollution indices to baseline data for policy makers to be properly guided on the route to charter for management and control of heavy metal pollution.

MATERIALS AND METHODS

Study Area

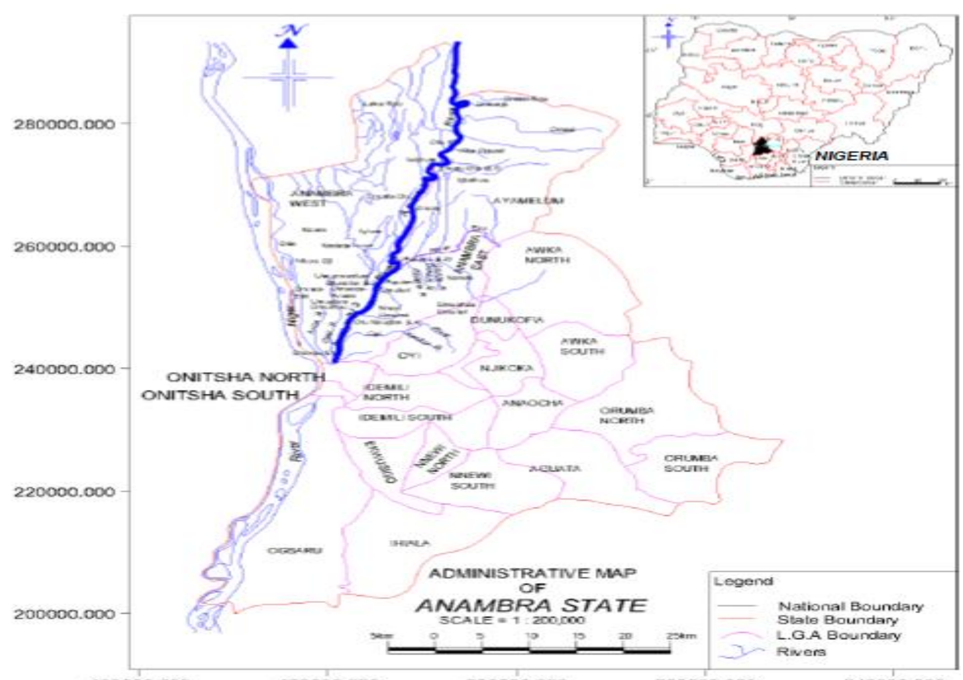

Table 1: Summary mean of spatial and temporal variation of heavy metals concentration in Anambra River Basin

Sampled Location	Description and Activitie	Coordinates
Ogurugu Fish Landing	An upstream, located in Ogurugu town in Enugu State. The substratum is a mixture of sand, clay, leaves of trees and detritus. Aquatic macrophytes include Pistia stratiotes, Nymphaea lotus and *Eichhornia crassipes*. Other vegetation around the Oguruguncludes oil Palm trees (*Elaeis guineensis*), Bamboo (*Bambusa vulgaris*) and crops like plantain, banana (Musa spp), and cassava (*Manihot esculenta*) and maize (Zea mays). Greater portion of the water surface is shaded by trees. Human activities observed include transportation of eople with canoe, bathing, washing of clothes, bicycles, manual dredging, fishing, farming	N 06^{O} 47” 28.5 E 006^{O} 56” 48.5
Otuocha Fish Landing	Middle stream with big market along it banks and open surface water. Human activities observed include transportation of people with canoe, intensive business activities including smoking and selling of fish, construction and selling of canoe, etc., washing of different items, fishing, farming of rice, cassava and yam along its flood plain and extraction of water for irrigation during the dry season cropping.	N 06^{O} 20” 30.7 E 006^{O} 50”. 336
Out-Nsugbe Fish landing	Downstream with partial shielding of surface water. Anthropogenic activities observed within and along the river are fishing, fermentation of cassava, farming activities, mechanical dredging, fishing and transportation via canoe	N 06^{O} 16”72.0 E 006^{O} 48”73.8

Heavy Metals sampling and Analysis: Water samples for heavy metal analysis were collected once a month for a period of 9 months (February –October, 2022) following standard protocol. Water samples were collected using sterile one litre plastic bottles. The bottles were rinsed with sample water before the water samples were collected. The pH of the water samples was reduced to pH 2 with Nitric acid (HNO_3) as described by Sharma and Tyagi (2013). The water samples were digested with concentrated analytical grade Nitric acid as described by Zhang (2007), while the determination of heavy metals was carried out with UNICAM Solaar 969 atomic absorption spectrometer (AAS) which used acetylene-air flame.

Pollution evaluation indices

Synthetic Pollution Index (SPI)

SPI is global powerful and time effective tool to assess the general quality of the water concerning heavy metals. The SPI model can be grouped into three steps (the constant of proportionality (Ki), the weight coefficient (Wi) and SPI according to Singh et al. (2015) as described in (Solangi et al. 2018)

Step a: The SPI

$$SPI = \sum_{i=1}^{n} \frac{C_i}{S_i} \, x \, W_i \quad \ldots\ldots \text{a}$$

Step b: The weight coefficient (Wi)

$$W_i = \frac{K_i}{S_i} \quad \ldots\ldots \text{b}$$

Step c: The proportionality (Ki)

$$K_i = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \quad \ldots\ldots \text{c}$$

Comprehensive pollution index (CPI)

The heavy metal comprehensive pollution index provides valuable information for management and control of heavy metals pollution. The equation for computing heavy metal pollution comprehensive pollution index is:

$$CPI = \frac{1}{n} \sum_{i=0}^{n} PI_i \quad \ldots\ldots \text{d}$$

Where, CPI = Comprehensive Polluted Index; *n* = number of monitoring parameters; PI_i = the pollution index number *i*.

PI_i is calculated according to the following equation:

$$PI_i = \frac{C_i}{S_i} \quad \ldots\ldots \text{e}$$

Where, *Ci* = measured concentration of ith heavy metal in water sample; *Si* = permitted standard of parameter according to Standard Organisation of Nigeria SON, (2015). CPI was computed using 8 heavy metals (Fe, Mn, Zn, Cu, Cr, Cd, Ni and Pb).

Heavy metal evaluation index (HMEI)

HMEI is another global time effective and reliable tool to assess the overall quality of the water concerning heavy metals. The HMEI produces the general quality and presence of heavy metal in water (Edet and Offiong, 2002). HMEI was estimated according to Mthembu et al. (2021) as:

$$\text{HEI} = \sum_{i=1}^{n} \frac{\text{H}_c}{\text{H}_{mac}} \quad \ldots\ldots \text{f}$$

Where, H_c is the value of the ith parameter from water samples, and H_{mac} is the maximum permissible concentration (MAC) of the ith parameter. The MAC for Zn, Fe, Cu, Mn, Cr, Cd, Pb, and Ni are 3, 2, 2, 0.4, 0.05, 0.003, 0.01, and 0.07 mg/L, respectively (WHO 2017) as cited by (Rima et al., 2021). Therefore, the level of the heavy metal evaluation index was classified into three divisions based on the calculated values, like low HMEI ≤ 10, medium HMEI (10–20), and high HMEI > 20 (Proshad et al. 2020).

Heavy metal pollution index (HPI)

The heavy metal pollution index is a useful and time effective mean weight arithmetic tool for determining pollution status of water bodies. The HPI is a mean weighted arithmetic tool to assess water quality index (Edet and Offiong (2002)

$$\text{HPI} = \sum_{i=1}^{n} Qiwi \Big/ \sum_{i=1}^{n} wi \quad \text{g}$$

Where Qi is the sub-index of the ith heavy metal, Wi is the unit weight of the ith heavy metal, and n is the number of heavy metals considered. Therefore, the sub-index (Qi) of the parameter was determined by

$$Q_i = \sum_{i=1}^{n} {(M_i} \Big/ {(S_i)} \; x \; {100} / {1} \quad \text{h}$$

$$W_i = {1}/{S_i} \quad \text{i}$$

Where Si was taken as SON (2015) recommended standard for ith heavy metal

RESULTS AND DISCUSSION

The spatial and temporal fluctuations of (Fe) were between 1.31 and 4.10 mg/l (Figure 1). The lowest value was recorded in station 1 (April, 2022) respectively, while the highest was recorded in station 1 (July, 2022). All the values were lower than acceptable limit (200 mg/l) set by FMEnv (2011) for healthy environments but quite higher than permissible limit of 0.30 mg/l set by SON (2015) for drinking water (Table 1).

There was significant difference (p<0.05) in Fe values across all the stations and months. The results recorded in this present study were within or little higher than result obtained by Anyanwu (2012) who recorded a range between 1.00 and 3.95 mg/l in Ogba River, Benin City. Higher level of Fe during rainy season may be ascribed to influx of iron-contained materials through run-off or flood. Extraction of water from Anambra River Basin for drinking may cause iron-related oxidative damage to the mitochondrial genome to the users.

Manganese (Mn): The spatial and temporal fluctuations of (Mn) were between 0.50 and 2.04 mg/l (Table 1). The highest value was recorded in Otuocha (July,2022) whereas the lowest was recorded in Ogurugu (April,2022). The concentrations of Mn recorded during this study period were above permissible limit of 0.20 mg/l set by SON (2015) for drinking water and 0.05 - 0.5 mg/l set by FMEnv. (2011) for healthy environments. There was no significant difference (P > 0.05) in the Mn values across all stations but across all the months revealed high significant (P < 0.05). The seasonal fluctuations registered in this study may be ascribed to run-off that emptied the fertilizer and other agro-chemicals into the rivers during the raining season and the results contradicted Adesiyan *et al*. (2018) who reported lower Mn concentration in rainy season in Rivers in Southwest.

The spatial and temporal fluctuations of zinc were between 0.81 and 3. 20 mg/l (Table 1). The lowest value was recorded in Ogurugu in March, 2022 while the highest value was recorded in Otu-Nsugbe in July, 2022. The concentrations (98.2%) of zinc registered were within permissible values of 3.0mg/l set by SON, (2015). The concentrations were higher values between May and August than between March and April (Fig.3) which could be ascribed to influx zinc contained materials/remnants of zinc due to anthropogenic activities.

The registered spatial and temporal fluctuations of copper were between 0.43 and 1.92 mg/l (Table 1). The lowest value was registered in Ogurugu (March, 2022) whereas the highest value was recorded in Out-Nsugbe (June, 2022). Most (89.72%) of copper values were within permissible limits (1mg/l) for healthy environment (FMEnv., 2011) and for drinking water (SON, 2015) table 1. The concentrations were higher values between May and August, 2019 than between March and April, 2019, which could be ascribed to of copper contained materials through anthropogenic activities such as farming. Influx. The present study recorded higher Cu concentrations than the recent studies conducted in some rivers in Nigeria. Aloke *et al*. (2019) and Nnabo (2015) who reported a range between 0.967mg/l and 0.075 mg/l and 0.02 mg/l and 0.08 mg/l in Enyigba stream but are lower than results of Ekpete *et al.* (2019) with range between 2.17 mg/l and 3.69 mg/l in surficial water of Silver River, southern ijaw, Bayelsa State, Niger Delta, Nigeria.

Chromium (Cr): The spatial and temporal variation of Cr ranged between 0.26 and 1.02 mg/l (figure5). The lowest value was recorded in Ogurugu in March 2022 while the highest value was recorded in Outocha in June, 2022. Most of Cr values recorded were far above acceptable limits permissible limit set (0.07mg/l) set by World Health Organization (WHO, 2017) and (0.05 mg/l) set by SON, 2015) for portable water and FMEnv., (2011) for healthy environment (table 1). Similarly, the results recorded in this study are higher than some of recent study on inland waters in Nigeria. Enitan et al. (2018) obtained values between 0.078 mg/L and 0.140mg/l in Ndawuse River, Abuja; Adesiyan *et al*. (2018) reported values between 0.005mg/l and 0. 22mg/l in four Rivers in Southwest, Amadi (2012) also recorded lower range between 0.001mg/l and 0.078mg/l in Aba. High concentrations of Cr in Anambra River could pose a public health concern due to its ability to cause liver and kidney disease. The higher concentration during rainy season (fig.5) may be ascribed to unsuitable farming activities and other anthropogenic and run-off influence.

The spatial and temporal variation of cadmium (Cd) ranged between 0.15 and 1.13 mg/l in fig.6. The lowest values were recorded in March 2022 in Ogurugu while the highest value was recorded in Otuocha in August, 2022. The recorded values of Cd exceeded acceptable limit (0.003 mg/l) set by SON (2015) respectively for drinking water as well as 0.03 mg/l set by FMEnv., (2011) for healthy environment. Higher concentrations were recorded in rainy season months and this may be as result of the geological formation of the soil and run-off from agriculture activities where agro-chemical and fertilizers containing Cd as impurity have been used to control diseases and improve crop production. Field observations have revealed that superphosphate and urea fertilizers and among agro-chemicals used by local farmers around the Rivers contain some levels of Cd. The high level of Cd observed in this study may poses a public health risk and raises cause for concern as the use of water from Anambra River Basin with this level of cadmium could adversely effects on human health such as renal diseases, cancer and bone pain (Itaiitai disease) (Adesiyan *et al*.2018).

Nickel: The spatial and temporal variations of nickel ranged between 0.12 and 0.70 mg/l. The lowest value was recorded in Ogurugu in March, 2022and the highest value was also recorded in Otuocha in June, 2017. All the values recorded were quite above acceptable limits (0.02 mg/l) set by SON, (2015) and WHO, (2017) for drinking water, permissible limit (0.05 mg/l) set for healthy environment (FMEnv., 2015) and Amadi (2012) who obtained Ni concentration between 0.004 – 0.211 in Aba River. However, the values were within or slight lower than the concentration range observed (Olatunji and Osibanjo, 2012; Nnabo, 2015; Anyanwu and Onyele, 2018). The up-shoot of values in Otuocha may be ascribed to effluent of Otuocha market that emptied into the River without treatment. The higher values obtained in all the sites during the rainy season months could be attributed to seasonal and anthropogenic influences such flood, dredging, and farming activities and market activities.

Lead (Pb): The spatial and temporal variation of lead (Pb) ranged between 0.22 and 1.24 mg/l. The lowest values were recorded in March, 20122 in Ogurugu while the highest value was recorded in Otuocha in August, 2022. The shoot-up in Otuocha could be attributed to orographic rainfall that fell in Otuocha without reaching the other sites during August break and exacerbated by anthropogenic influences (Marketing activities). All the values recorded were quite above acceptable limits (0.01 mg/l) set by SON, (2015) and WHO, (2017) for drinking water but were within the. standard range between 0.01 and 1.00 mg/l set by FMEnv., (2011) for healthy environment. The results of this present study were higher than the results recorded in Nigerian rivers, (Anyanwu (2012; Olatunji and Osibanjo,2012; Nnabo, 2015; Enitan *et al*., 2018; Adesiyan *et al*.,2018; Aloke *et al*., 2019;) Higher concentration and seasonality variation in this study could be attributed to anthropogenic activities and climatic variables. Higher concentrations of Pb recorded during rainy season are not in line with some of observation by most researchers, who obtained higher concentration during dry season (Olatunji and Osibanjo, 2012; Uzairu *et al*. 2014; Adesiyan *et al*. 2018). Extraction of water from Anambra River Basin for drinking may cause heavy metal- related diseases to the community and the level of Pb obtained may cause environments issues.

Heavy metal pollution Indices

Synthetic pollution index (SPI)

From the computed values on Table 2, the spatio-temporal variation of synthetic pollution index (SPI) ranged from 37.62 in Ogurugu (March, 2022) to 271.6 in otuocha (August, 2022). The mean concentration of were found to be 90.64±28.53 (Ogurugu), 161.70±86.87 (Otuocha) and 113.09±38.82 (Otu-Nsugbe) which were far above (≥3.0) value for unsuitable drinking. Based on the classification by (Solangi et al. 2019), 100% of sampled water were highly polluted with values computed far above >3.0 Consequently, the result of this SPI value indicates that water from Anambra River Basin were critically polluted with heavy metals and unsuitable for human consumption. A similar report (91.67%) of groundwater samples unsuitable for human consumption) was obtained by Egbueri (2020 using the SPI model in Onitsha, Nigeria. The spatial and temporal concentrations registered in this study were quite higher than the values reported by Hu et al. (2020) from deep and shallow hand dug well in Hailun, China. Similarly, Grema et al. (2021) reported a range far below the range registered in this study. The high SPI registered in this study may be attributed to high concentrations of Fe, Cr, Cd, Ni and Pb.

Table 2: Summary of mean of heavy metal pollution Indices with range in parentheses and classification /Criteria

Indices	Ogurugu	Otuocha	Otu-Nsugbe	Classification
SPI	90.64±28.53 (37.62 -106.53)	161.70±86.87 (44.91 -271.60)	113.09±38.82 (52.00 -155.95)	< 0.2 Suitable for drinking 0.2 - 0.5 Slightly polluted water 0.5 - 1.0 Moderately polluted 1.0 –3.0 Highly Polluted >3.0 Unfit for drinking (Solangi et al. 2019)
CPI	25.49±7.79 (11.55 -28.71)	42.34±19.26 (13.60 -68.94)	31.95±9.66 (15.83 -42.28)	0 - 0.20 (clean), 0.21 - 0.40 (sub clean), 0.41 - 1.00 (slightly polluted), 1.01–2.00 (medium polluted), >2.01 (heavily polluted) (Imneisi and Aydin, 2018)
HMEI	203.89±62.34 (92.27 – 295.69)	349.51±168.00 (108.79 – 551.49)	235.46±74.49 (111.53 -315.59)	< 10 low, 10 – 20 medium and >20 high (Proshad et al. 2020; Grema et al.2021)
HPI	7566.75±4275.85 (3763.04 – 10654.63)	14131.07±10654.63 (4491.76 -27159.78)	11318±3865.76 (5252.58 -5597.44	< 100 low ,100 - 1000 medium and > 1000 high (Grema et al.2021)

Comprehensive pollution index (CPI)

The spatial and temporal fluctuations of CPI vary from 11.55 (Ogurugu) in March, 2022 – 68.94 (Otuocha) in August, 2022. The recorded CPI values were quite above the heavily polluted class (>2.01) (Table 2). Higher CPI values registered in this study may be ascribed to high concentration of Zn, Ni, Cd, Cu, and Pb in the water body resulted from anthropogenic origin.

Heavy metal evaluation index (HMEI)

The spatial and temporal variation of HMEI values were between from 92.27 to 551.78 with mean values, 203.89±62.34(Ogurugu), 349.51±168.00 (Otuocha) and 235.46±74.49 (Otu-Nsugbe; Table 2). Based on proposed classification by Grema et al. (2022) and Proshad et al. (2021), Anambra River Basin is highly polluted with HMEI values greater than 20 (high polluted water class). However, based classification by Edet and Offiong (2002), HMEI as low (< 400), medium (400-800) and high pollution (> 800), 99.6% of the samples were with the class of low polluted (HMEI< 400) and rest high polluted (400-800) (Table 2). This suggests that water from Anambra River Basins has low pollution with respect to heavy metals and is safe for human consumption. The finding of this study was not in line with Ezugwu et al. (2019) who that all groundwater sampled in southeast Nigeria were excellent for drinking purposes. Similarly, the range of HMEI values registered in this study were lower than a range values (2.175 to 96.598) recorded by Rima et al. (2021) in surface water of Island Nijhum Dweep, Northern Bay of Bengal. High HMEI values were mainly due to Cd, and Pb concentrations in the analysed samples.

Heavy metal pollution indices (HPI)

The spatial and temporal fluctuations of HPI vary from 3762.04 (Ogurugu) in March, 2022 – 27159.78 (Otuocha) in August, 2022. All the values registered in this study were quite above the critical pollution index value is 100. All (100%) the water samples were within the high-class rank (HPI >30) following Ac Edet and Offiong (2002) classification. In addition, comparing the critical value of 100 proposed by Prasad and Bose (2001) and classification by Grema et al. (2022), water with HPI value < 100 is low polluted, HPI value from 100 – 1000 is medium polluted and > 1000 is high. In this study, 100% of the water sampled were above the critical value (100) and classified as high polluted water. This result condradicts the findings of Ezugwu et al. (2019) who reported that all groundwater was excellent for drinking purposes. The presence of these Zn, Ni, Cd, Cu, and Pb found within this location were attributed from anthropogenic origin which includes industrial activities, traffic sources municipal sewage, domestic wastes, and atmospheric depositions.

Conclusion: All the communities along Anambra River Basin are at risk of heavy metal-related diseases and as such the communities need water treatment plants if to continue extract their drinking water from the river.

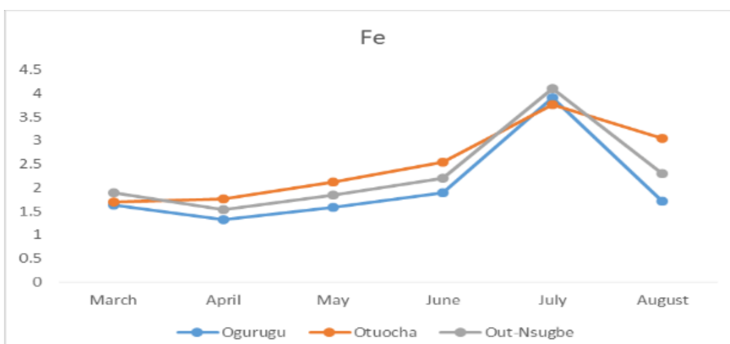

Fig.1: Spatial and temporal variations of Fe at the study stations of Anambra River Basin.

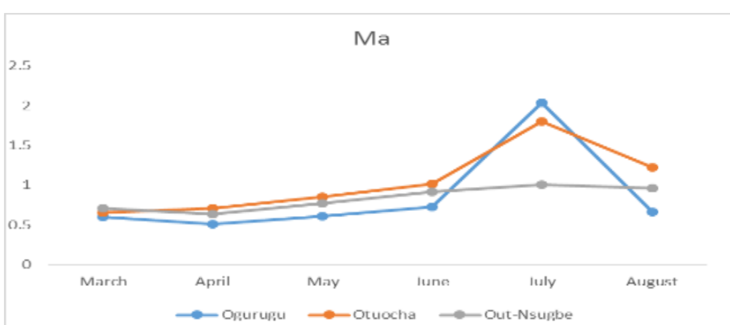

Fig.2: Spatial and temporal variations of Mn at the study stations of Anambra River Basin.

Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), vol 12(2), 2024
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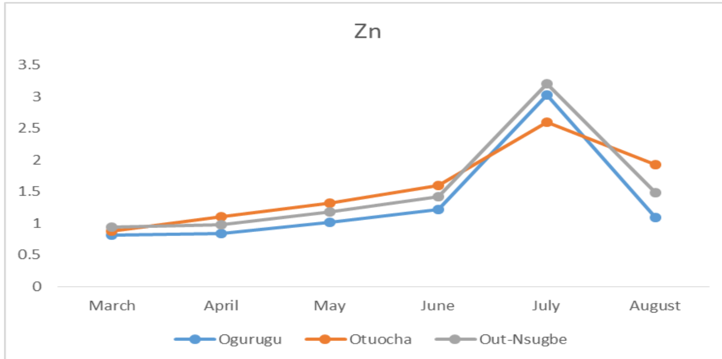

Fig.3: Spatial and temporal variations of Zn at the study stations of Anambra River Basin.

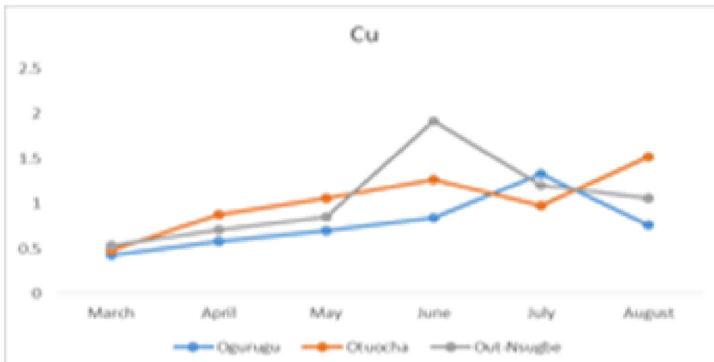

Fig.4: Spatial and temporal variations of Cu at the study stations of Anambra River Basin.

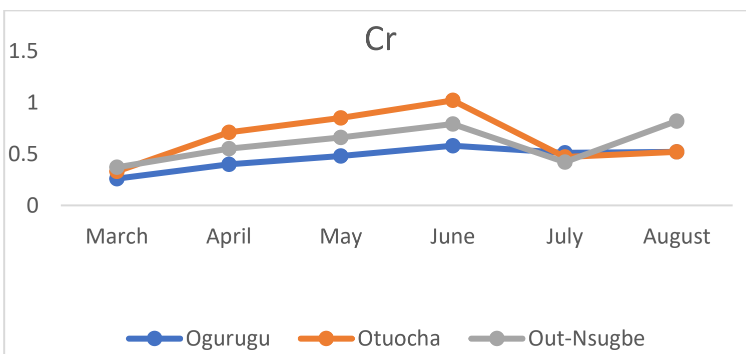

Fig 5: Spatial and temporal variations of Cr at the study stations of Anambra River Basin.

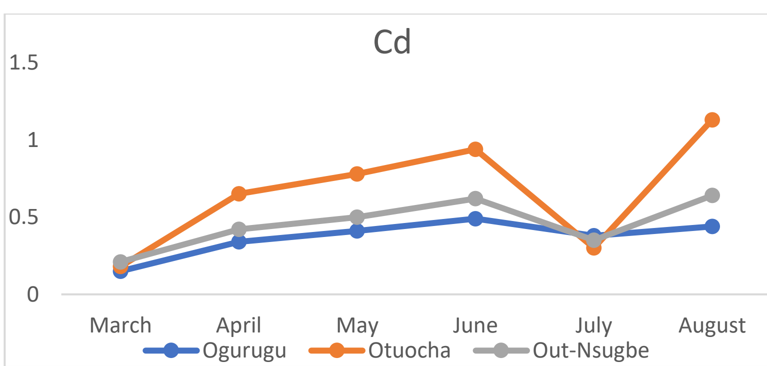

Fig.6: Spatial and temporal variations of Cd at the study stations of Anambra

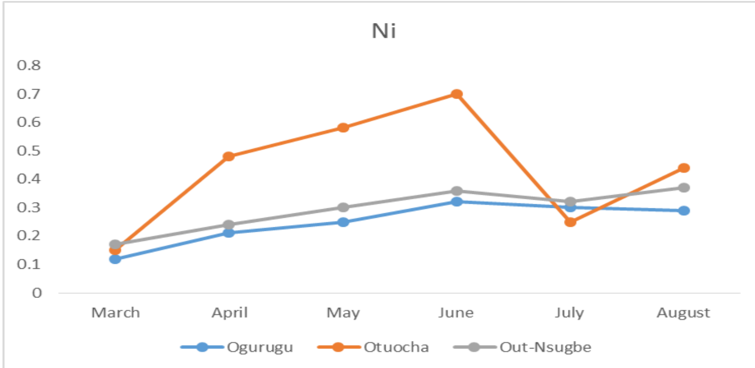

Fig.7: Spatial and temporal variations of Cr at the study stations of Anambra River Basin.

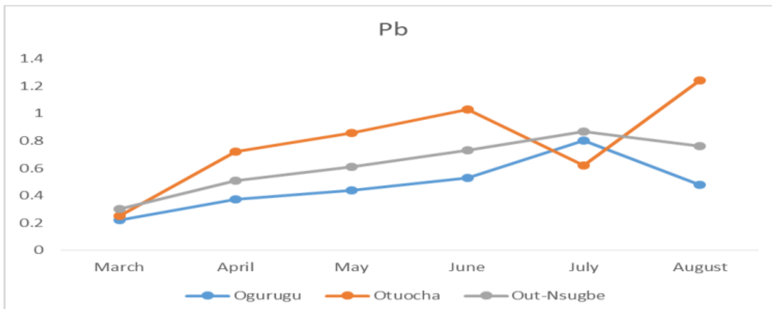

Fig.8: Spatial and temporal variations of Cr at the study stations of Anambra River Basin.

ACKNOWLEDGEMENTS

This project was funded by TETFund Nigeria through the office of Directorate of Research and Development, Michael Okpara University of Agriculture Umudike, Abia State, Nigeria. Authors acknowledged Tertiary Education Trust Fund (TETFund), Nigeria and Michael Okpara University of Agriculture Umudike, Abia State, Nigeria

Conflicting interest

Authors of this article declare no conflict interest

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Received: 02th October 2023; Accepted: 06th January 2024; Distribution: 10th February 2024