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Assessment of Heavy Metals Contamination of Water and Cupscale Grass (*Sacciolepis africana*) along the Epie Creek in Bayelsa State, Nigeria

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Abstract

This study was conducted to investigate the concentration of three heavy metals; iron, chromium and lead in surface water and plant (*Sacciolepis africana*) tissues along the Epie creek. This was aimed at determining the heavy metal loading of surface waters and the extent of bioaccumulation in the most prevalent grass species found growing within the river course. Metals were determined using atomic absorption spectrophotometer. Result of water analysis recorded the least and most significant iron concentrations of 3.42 ± 0.06 mg/L and 12.06 ± 0.06 mg/L for Agudama and Edepie axis respectively. Contrastingly, water samples showed chromium and lead levels which were below their instrument measurable limits. Consequently, lead (Pb) and chromium (Cr) levels were within WHO permissible limits, while iron (Fe) exceeded regulatory standard for water samples collected from all field locations. Similarly, iron recorded elevated iron concentrations in plant (cupscale grass) with the least amount being revealed for Igbogene stem (196.63 ± 5.21 mg/kg), and the most concentration been reflected for Edepie root sample (9,423.17 ± 48.55 mg/kg). Even though iron levels prevalently exceeded recommended threshold in plants, the stem were mostly within limit for iron. The only grass sample depicting significant lead amount (0.34 mg/kg) was the stem section collected at Akenfa location. Evidently, metals were least stored in plant stems and most bioaccumulated in plant roots. Furthermore, Cr and Fe are the only significantly correlating metals in plants ($r = 0.700$, $p < 0.01$). Overall, the increasing level of Fe in the water environment is further indication of the impact of unregulated dumping of scraps and domestic waste along the creeks embankment.

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Introduction

Studies on heavy metal pollution of rivers, lakes, fish and sediments have become a major environmental focus in recent decades because they are one of the most serious pollutants in our natural environment due to their toxicity and persistence [1]. In the aquatic environment, trace elements are distributed amongst the various environmental components such as water, suspended solids, sediments and biota [2]. Aquatic organisms, including fish accumulate pollutants directly from contaminated water and indirectly via the food chain (bioaccumulation) [3–6]. Some economic plants have been reported to reflect higher metal concentrations than roadside soils of major roads [7]. Areas of alarming metal thresholds are mostly locations of potential environmental impact [8].

Water pollution occurs when unwanted materials (with potentials to threaten human and other natural systems) find their way into rivers, lakes, wells, streams, boreholes or even reserved fresh water in homes and industries [9]. Heavy metals in water may be natural (weathering of rocks and soils) and anthropogenic (mining, industries, wastewater irrigation and agricultural activities [10-11]. Large quantities of heavy metals have been released into rivers worldwide due to global rapid population growth and anthropogenic activities [12-15].

Sacciolepis africana is a genus of plant in the grass family with the common name cupscale grass (*Sacciolepis africana).* They are widespread in tropical and warmer temperate regions and persist for periods exceeding 24 months. Also, it is normal that they flower yearly with grass growing as tall as 2 meters in height. Even though they occur as weeds of deep water rice, they are commonly found in superficial, slow-going water where their roots may be of wiry and condensed mass [16-17]. The plant is also widespread in the area of study (along the river course of the Epie creek), in the south-south part of Nigeria.

Rivers are by far the cheapest form of water supply compared to other sources like groundwater and seawater desalination. Meeting water quality expectations for streams and rivers is required to protect drinking water resources, encourage recreational activities and provide a good environment for fish and wildlife [18]. There has been report of the positive identification of bacterial isolates like *Pseudomonas*, *Enterobacter*, *Bacillus*, *Citrobacter*, *Erminia*, *Klesbsiella*, *Shigella*, *Salmonella*, *Proteus*, *Serratia*, *Micrococcus*, *Corynebacterium* species, *Staphylococcus aureus* and E-coli in water samples from Epie creek, traversing different locations at Akenfa, Agudama-Epie, Tombia, Opolo and Biogbolo. Bacteriological contamination was attributed to the presence of anthropogenic activities along the river course [19].

This study was conducted to measure the quality of surface waters of Epie Creek with respect to its total metal concentrations. The Epie creek is located within latitude 5°23'N, 5°30'N, and Longitude 6°58'E, 7°04'E. It traverses through the stretch of Yenagoa (Igbogene axis) to government house (Okutukutu axis), being one of the major essential surface waters in Bayelsa State. The creek is connected to Ikoli and Taylor creeks. Also, the creek serves as a recipient channel for domestic, commercial and poorly managed industrial wastes, while the water is often used for drinking, bathing, recreational and transportation activities. Heavy metal concentrations in the water were compared with those of *Sacciolepis africana plant.*

The aim of this study is to evaluate the level of heavy metal contamination of water from Epie creek, especially those emanating at points close to waste dumpsites. The study also aims to determine the level of bioaccumulated trace/heavy metals within different sections (leaves, stems and roots) of *Sacciolepis Africana* (cupscale grass).

Materials and Methods

Materials

Solutions and reagents used include: distilled water, 37% hydrochloric acid (Sigma-Aldrich Chemicals, USA), 65% nitric acid (Riedel-De Haen, Germany).

Equipment

Flame atomic absorption spectrophotometer (Model: GBC Avanta Ver. 2.02/AA6600), analytical weighing balance (Model: Mettler AE200), hot plate (Model: Corning PC-351), Soil sieve (Model: Endecotts Ltd - stainless steel with 2mm mesh and brass frame).

Methods

Study Area

Study was conducted along the stretch of Epie

Creek, from Igbogene to Okutukutu axis of Yenagoa City. Yenagoa metropolis with latitude 5°23'N and 5°30'N, and Longitude 6°58'E and 7°04'E is located in Bayelsa State, within the south-south region of the oil-rich Niger Delta zone of Nigeria.

Sample Collection and Preservation

Three replicate water samples were randomly collected from six locations along the Epie Creek. Surface waters were directly collected from the superficial layer into sampling containers. The sites were: up-Igbogene (control) (latitude 05.0386, longitude 06.4033); Igbogene (latitude 05.0255, longitude 06.3996); Akenfa (latitude 05.0019, longitude 06.3787); Agudama (latitude 04.9791, longitude 06.3675); Edepie (latitude 04.9616, longitude 06.3660); and Okutukutu axis (latitude 04.9543, longitude 06.3448). The sampling stations were selected based on their proximity to effluent discharge points in which waste dump sites were used as point sources of pollution along the river, while up-Igbogene axis was sampled as control. The grass species were found sprouting within the water environment but at close proximity to the river embankments. From each of the field locations, three replicate grass samples were collected.

Samples were collected in the dry season month of December 2017. The water samples were collected from the sampling stations in clean, sterilized 250 mL plastic bottles. They were then acidified with 5 mL concentrated nitric acid and transported to the laboratory for heavy metal analysis. In the field, the containers were severally rinsed with habitat water at each sampling point prior to collection.

Each sample was collected by submerging the receiving container into the river at about 100 mm to 300 mm below the surface with the open end aligned against the flow direction of water current. Similarly, the plant (*Sacciolepis africana*) samples were collected from around point source waste dump sites. Afterwards, vegetation samples were placed in aerated polyethylene bags in order to retain their fresh condition while been transported to the laboratory.

Sample Preparation/Analysis

Analysis of Heavy Metals in Water and Plant Tissues

All laboratory wares were washed with laboratory detergent, soaked in 10% hydrochloric acid solution overnight, thoroughly rinsed in distilled water, and then dried at 85°C. Exactly 100 mL of unfiltered water was strained through whatmann filter paper, transferred into a 150 mL glass beaker, before adding 5 mL of concentrated nitric acid solution. Afterwards, the acidified water was evaporated to near-dryness on a hot plate. A further 5 mL of concentrated nitric acid solution was added before the sample mixture was continuously heated for 15 minutes. Sample was concentrated to about 5 mL before leaving it to cool at room temperature. Thereafter, the acid digest was filtered into 100 mL volumetric flask and the volume made up to mark with distilled water. The filtration step aids in the removal of silicate and other insoluble materials prior to the aspiration of acid extracts for Pb, Cr, and Fe analysis on the atomic absorption spectrophotometer (AAS). Instrument detection limits were 0.02 mg/L, 0.006 mg/L and 0.09 mg/L for Pb, Cr and Fe respectively. The solution was stored in 125 mL polypropylene bottle and aspirated through the nebulizer unit of the instrument. Concentrations of the respective metals were reported in mg/l units [20-21].

The plant samples were isolated into their leaf, stem and root sections. All the plant parts were washed with distilled water to remove dirt, dust, and other contaminants. Furthermore, the vegetation samples were washed with distilled water and dried at room temperature (22°C to 25°C) before further subjecting them to oven-drying at 60°C. The dried plant parts were crushed, powdered and homogenized. The powdered samples were stored in polyethylene sampling bags for further processing. Subsequently, a muffle furnace was used to dry-ash the plant samples. Five grams of each dry-ash sample was weighed into a conical flask. Each of the weighed samples was mixed with 10 mL of 1 N hydrochloric acid (HCl) and 10 mL of 1 N nitric acid (HNO_3). A mixture of the ash solution was predigested at about 50°C on a hot plate. Heating continued until white fumes evolved, resulting in a clear brown-colored solution. The heat was further intensified to 120°C for few minutes until sample was adequately concentrated. Afterwards, the cooled ash solution was filtered and made up to mark in 50 mL volumetric flask using distilled water. Filtrates were made through whatmann No. 1 filter paper and collected into clean and sterilized polypropylene vials. Subsequently, the

filtered sample (ash) solutions were aspirated into the atomic absorption spectrophotometer (AAS) and the concentrations of test elements such as lead (Pb), iron (Fe), and chromium (Cr) were determined at wavelengths of 217.0, 248.3 and 357.90 nm respectively. Subsequently, concentrations were recorded in mg/kg units [22-25].

Chemical Analysis

The concentrations of Pb, Cr and Fe in the different sample matrices were determined using FAAS (GBC Avanta PM, A6600, Australia). The operational condition of equipment is provided in Table 1 below.

Statistical Analysis of Data

In order to determine the association and variation between test metals in surface waters and vegetation of Epie Creek, descriptive statistical analysis was carried out using statistical package for social science (SPSS) version 20. Data was expressed as mean ± standard deviation. The range (minimum and maximum) of the values obtained across the sampling points was also presented. One way analysis of variance (ANOVA) was used to show significant variation at P = 0.05. Where significant variation occurred, Waller-Duncan statistics was used to compare mean values of each test parameter under investigation. Heavy metal distribution in water and vegetation was correlated using Spearman's rho correlation matrix.

Results and Discussion

Heavy Metals in Water

The concentrations of chromium (Cr), lead (Pb) and iron (Fe) in the water and plant (cupscale grass) samples from Epie creek (up-Igbogene (control)) and the other five sample locations (Igbogene, Akenfa, Agudama, Edepie and Okutukutu) are presented in Tables 2 and 3.

The result shows a wide range of concentrations of the selected heavy metals. The concentrations of iron (Fe) in mg/L are: 4.05 ± 0.06, 5.06 ± 0.04, 3.42 ± 0.06, 4.05 ± 0.04, 12.06 ± 0.06 and 5.44 ± 0.05 respectively for up-Igbogene (control), Igbogene, Agudama, Akenfa, Edepie and Okutukutu sampling sites. Iron was the most significant mineral concentration across all sample locations while lead and chromium were below the instrument detection limits of 0.02 and 0.006 mg/L respectively. Iron levels exceeded the stipulated WHO permissible limit of 1.0 mg/L. The result obtained from this study showed an increasing level of iron in the surface water environment as compared to the concentration range of 0.32 to 2.52 mg/L that was previously reported [26]. The spike in iron may be from the turbid appearance of water samples emanating from soil runoffs or leachates from increasing anthropic occurrences of waste dumpsites. A greater mobility factor of 0.84% for iron in dumpsite environments as compared to 0.71% in uncontaminated control habitats has been reported in a previous study [27].

Results obtained for the metals (Cr, Fe and Pb) in water samples were compared with WHO maximum permissible limits. The permissible limits of Cr, Fe and Pb for water according to WHO are 0.1 mg/L, 1.0 mg/L and 0.05 mg/L respectively [28]. Consequently, the concentrations of Cr and Pb were recorded within WHO permissible limits while Fe values exceeded stipulated regulatory comparison (Table 4). The results of Cr and Pb obtained in this study partially corroborated [20] where Cr recorded mean values of 0.27 ± 0.05 mg/L and 0.23 ± 0.01 mg/L in the Middleton creek, Bayelsa

Table 1. Operational status of FAAS

Metals -	Slit width (nm)	Wavelength (nm)	Lamp current (mA)	Flame composition		Check standard concentration, (mg/L)	Detection limit (mg/L)
				Acetylene (L/min)	Air (L/min)		
Pb	1.00	217.0	5.0	2.0	10.0	0.5	0.02
Cr	0.2	357.9	6.0	2.0	10.0	0.5	0.006
Fe	0.2	372.0	7.0	2.0	10.0	5.0	0.09

Table 2. Concentration of heavy metals in surface waters of Epie Creek

Sample Location(s)	Iron, Fe (mg/L)	Lead, Pb (mg/L)	Chromium, Cr (mg/L)
up-Igbogene (Control)	4.05±0.06b	ND	ND
Igbogene	5.06±0.04c	ND	ND
Agudama	3.42±0.06a	ND	ND
Akenfa	4.05±0.04b	ND	ND
Edepie	12.06±0.06e	ND	ND
Okutukutu	5.44±0.05d	ND	ND

Data is expressed as mean ± standard error; different letters along the column indicate significant variation ($p < 0.05$) according to Duncan statistics. Also, ND represents non-detection.

Table 3a. Concentration of metals in plant tissues obtained from Epie creek

Sample Identity/Location(s)	Iron, Fe (mg/kg)	Lead, Pb (mg/kg)	Chromium, Cr (mg/kg)
up-Igbogene (control) leaf	638.07 ± 2.17f	ND	3.19 ± 0.14h
stem	295.13 ± 7.40ab	ND	0.95 ± 0.10de
root	5,010.43 ± 96.11j	ND	3.07 ± 0.10h
Agudama leaf	1,012.85 ± 23.83g	ND	1.59 ± 0.11f
Stem	492.57 ± 12.37cde	ND	0.45 ± 0.04bc
Root	9,233.13 ± 38.25l	ND	7.26 ± 0.19j
Akenfa leaf	601.37 ± 11.45ef	0.21 ± 0.02b	1.11 ± 0.08e
Stem	408.93 ± 8.58bc	0.34 ± 0.03c	0.21 ± 0.03ab
Root	2,399.30 ± 29.31h	ND	4.74 ± 0.25c
Edepie leaf	469.50 ± 22.53cd	ND	0.25 ± 0.02ab
Stem	298.13 ± 6.93ab	ND	ND
Root	9,423.17 ± 48.55m	ND	8.83 ± 0.36k
Igbogene leaf	365.53 ± 13.33bc	ND	1.20 ± 0.06e
Stem	196.63 ± 5.21a	ND	ND
Root	7,122.73 ± 76.74k	ND	ND
Okutukutu leaf	564.90 ± 17.54def	ND	0.70 ± 0.09cd
Stem	288.53 ± 16.58ab	ND	ND
root	3,993.87 ± 96.11i	ND	3.04 ± 0.13g

Data is expressed as mean ± standard error; different letters along the column indicate significant variation ($p < 0.05$) according to Duncan statistics. Also, ND represents non-detection.

Table 3b. FAO/WHO guidelines and test results for heavy metals in water and plant samples

Heavy metal	Concentration of metal in water (mg/L)	Drinking water permissible limit (mg/L)	Concentration of metal in plant (mg/kg)	Plant sample permissible limit (mg/kg)
Iron	3.42 – 12.06	1.0	196.63 – 9,423.17	425.0
Chromium	ND	0.1	<0.006 – 8.83	0.10
Lead	ND	0.05	<0.02 – 0.34	0.30

Note: ND represents non-detection. Chromium ND = 0.006 mg/l, Lead ND = 0.02 mg/l.

Table 4. Correlation coefficient of heavy metal concentrations in plant (cupscale grass) tissues Spearman's rho correlation of cupscale grass in the vicinity of water-side waste dumps

Parameters	IRON	LEAD	CHROMIUM
IRON	1.000		
LEAD	-0.113*	1.000	
CHROMIUM	0.700**	-0.137*	1.000

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.01 level (2-tailed). N=54 (n=3).

state, during the dry and wet seasons respectively. In addition they reported Pb amounts below measurable detection limit of the instrument (0.02 mg/L). On the other hand, [21] had reported Pb values ranging between <0.001 and 0.007 mg/L in the surface waters of Kolo creek. Contrastingly, the concentrations of Pb and Cr significantly exceeded WHO limits in oil contaminated surface waters of Azuabie creek [29]. The trace or non-detectable levels of Pb and Cr along Epie creek is an indication that activities releasing these micropollutants into the environment are rare.

Concentration of Heavy Metals in the Plant (Sacciolepis Africana)

The concentrations of Cr, Pb and Fe in the various plant sections; roots, stem and leaves, obtained from all the sample and control locations are presented in Table 3a.

Results indicate that the concentration of iron in vegetation sample was in the order; root > leaf > stem. The study further shows that the concentrations (mg/kg) of lead (Pb) in most of the sample locations and up-Igbogene (control) were below measurable detection limit of the instrument for various parts of the plant (Table 3).

Results show that the highest concentrations of iron (Fe) and chromium (Cr) were found in the plant roots, followed by the leaves, and lastly the stem across all sampling sites. There was significant difference in the concentration of iron and chromium in the roots, leaves and stem for all sample sites. The concentration of metals in the plant tissues revealed the trend; roots > leaves > stem. This may have resulted from the embedding of roots in soil and direct absorption of minerals from bottom soil which ultimately leads to elevated concentrations. The absorbed minerals are transported to the leaves where they are used for photosynthesis whilst being accumulated in leaves. The stem only allows transfer of minerals from the roots to leaves, leading to decreasing element concentrations in the stem.

The FAO/WHO maximum permissible limit for Fe, Cr and Pb in leafy vegetable is 425.0 mg/kg, 0.10 mg/kg and 0.3 mg/kg respectively [30]. For iron (Fe) concentrations, values ranged between 365.53 mg/kg and 1,012.85 mg/kg (leaves), 196.63 mg/kg and 492.57 mg/kg (stem) and 2,399.30 mg/kg and 9,423.17 mg/kg (roots). The most significant iron concentrations were recorded at the root section of the grass species. Apart

from stem sample collected at Agudama sample station, all other stem samples were found at concentrations within the FAO/WHO regulatory limit of 425.0 mg/kg for iron (Fe) (Table 3b). Trends across both sampling locations were observed to be similar for Fe mineral. Apart from the samples of Edepie stem, Igbogene stem and root, and Okutukutu stem which showed Cr values below the instrument detection limit of 0.006 mg/l, chromium (Cr) levels ranged from 0.25 to 3.19 mg/kg (leaves), <0.006 to 0.95 mg/kg (stem) and <0.006 to 8.83 mg/kg (roots) across all sampling locations, with the root section of *Sacciolepis africana* plant collected from Edepie axis reflecting the most significant concentration of 8.83 mg/kg. Most of the chromium concentrations obtained in this study exceeded FAO/ WHO recommendation of 0.10 mg/kg. Apart from the observed presence of lead (Pb) in Akenfa leaf (0.21 mg/ kg) and Akenfa stem (0.34 mg/kg), all other sample locations recorded lead (Pb) values below the instrument detection limit of 0.30 mg/kg. The levels of iron (Fe) and chromium (Cr) in common edible vegetable leaves and stems sold in Yenagoa metropolis has been assessed previously [22]. Iron (Fe) values reported in both studies are similar, with reported concentrations ranging between 307.6 mg/kg and 1,051.31 mg/kg. On the other hand, chromium (Cr) level in this study was lower when compared to the range of 8.12 mg/kg to 31.72 mg/kg reported for the commonly consumed vegetables. The dissimilarities in chromium (Cr) composition of plant tissues from the two different studies may have resulted from the variations in the trace/heavy metal bioaccumulation potential of the diverging plant species as well as the difference in geology of field area.

Statistical Analysis Result

The data was statistically analyzed using student's t-test at a 0.05 significance level. There was no basis of statistical correlation for samples where lead and chromium concentrations were reportedly below measurable detection limit of the instrument at 0.02 mg/ l and 0.006 mg/l respectively.

Iron concentrations ranged from 291.44 mg/kg to 4,967.55 mg/kg, showing significant variation ($p < 0.05$) among the various locations apart from stem samples collected from Akenfa axis and leaf samples from Igbogene axis ($p > 0.05$) (Table 3).

Lead concentrations ranged from <0.02 mg/kg to 0.34 mg/kg. Akenfa leaf and stem samples of *Sacciolepis africana* were significantly different ($p < 0.05$) across the various field locations of the river (Table 3).

Chromium concentrations ranged between <0.006 mg/kg to 8.83 mg/kg. Apart from samples of Akenfa stem and Edepie leaf which depicted no significant difference ($p > 0.05$), all other cupscale grass samples showed marked significant differences ($p < 0.05$) across the various field locations of Epie creek (Table 3).

The mean concentrations highlighted in Table 3 were used to establish correlation coefficients. These were presented in Table 4. Apart from chromium and iron that depicted significant positive correlation ($r = 0.700$, $p < 0.01$), all other heavy metals, lead and iron ($r = -0.113$, $p < 0.05$) and chromium and lead ($r = -0.137$, $p < 0.05$) depicted negative correlations (Table 4).

Conclusion

In comparison to trace/heavy metal values reported for surface water samples, results of this finding revealed comparatively greater heavy metal distribution in *Sacciolepis africana* (cupscale grass) samples. Also, the elevated threshold levels of iron in water is reminiscent of an environment receiving anthropic inputs from soil and dumpsite leachates, which has in turn reduced the clarity and increased the turbidity of the water environment. Consequently, mineral iron loading of the water makes it unsafe for human consumption, as it may only serve irrigational purposes for nearby farmlands. Apart from the lead in Akenfa stem section which slightly exceeded FAO/WHO limits, all other spatially diverging samples were within specified regulatory recommendations for lead. Even though, most of the iron and chromium concentrations exceeded FAO/WHO limits, the stem section of weed species been evaluated appears to be the least bioaccumulated with heavy metals. The comparative evaluation of Epie creek reveals that there is significant deterioration in water quality. This is with respect to the increasing iron concentration when compared to previous studies. Consequently, water derived from the Epie River may not be suitable for public use or even recreational activities.

References

1. Ghorade, I.B. (2013). Ecosustainability assessment of Godavari river water for sustainable utilization. Ph.D. Thesis, Dr. B.A.M. University, Aurangabad.
2. Shakweer, L.M., Abbas, M.M. (2005). Effect of ecological and biological factors on the uptake and concentration of trace elements by aquatic organisms at Edku lake, Egypt. *Journal of Aquatic Resource*. 31(1): 271–288.
3. Hammer, M.J. (2004). Water and Wastewater Technology, Practice-Hall Inc.: Upper Saddle River, NJ, USA, pp. 139-141.
4. Mohammed, F.A.S. (2009). Histopathological studies on Tilapia zilli and Soleavulgaris from lake Quran, Egypt. *World Journal of Fish Marine Science*, 1: 29–39.
5. Abah, J., Ubwa, S. T., Onyejefu, D. I., Nomor, S. A. (2013). Assessment of the levels of some heavy metals in mudfish (Clariasanguillaris) from River Okpokwu, Apa, Benue Sate, Nigeria. *International Journal of Biosciences*, 3(4): 142-150.
6. Aljerf, L., AlMasri, N. (2018). Persistence and Bioaccumulation of Persistent Organic Pollutants (POPs) in the Soil and Aquatic Ecosystems: Syrian Frontiers in Ecology and Environment. *Sustainability in Environment*, 3(4): 358-386.
7. Tanee, F.B.G., Albert, E. (2013). Heavy Metals Contamination of Roadside Soils and Plants along Three Major Roads in Eleme, Rivers State of Nigeria. *Journal of Biological Sciences*, 13(4): 264-270.
8. Moldoveanu, A.M. (2014). Assessment of Soil Pollution with Heavy Metals in Romania. *InTech Open Science*, Book Chapter 9: 285-305.
9. Aboyeji, O.O. (2013). Freshwater pollution in some Nigerian local communities, causes, consequences and probable solutions. *Academic Journal of Interdisciplinary Studies*, 2(13): 111–117.
10. Chanpiwat, P., Sthiannopkao, S., Kim, K. (2010). Metal content variation in wastewater and biosludge from Bangkok's central waste water treatment plants. *Microchemistry Journal*, 95, 326–332.
11. Muhammad, S., Shah, M., Khan, S. (2010) Arsenic health risk assessment in drinking water and source apportionment using multivariate statistical techniques in Kohistan region, Northern Pakistan. *Food Chemistry Toxicology.* 48, 2855–2864.
12. Srebotnjak, T., Carr, G., de Sherbinin, A., Rickwood, C. (2012). A global water quality index and hot-deck imputation of missing data. *Ecology Indica.*, 17: 108–119.
13. Su, S., Xiao, R., Mi, X., Xu, X., Zhang, Z., Wu, J. (2013). Spatial determinants of hazardous chemicals in surface water of Qian tang River, China. *Ecology Indica.*, 24: 375–381.
14. Islam, M., Han, S., Masunaga, S. (2014). Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. *Journal of Water Environmental Technology*, 12: 109–121.
15. Islam, M., Ahmed, M., Raknuzzamanb, M., Al- Mamunb, M., Islam, M. (2015). Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. *Ecological Indicators*, 48: 282–291.
16. Johnson, D.E. (1997). Weeds in rice in West Africa. WARDA/WARDA, Bouake, Ivory Coast. 198p.
17. Akobundu, I.O., Agyakwa, C.W. (1998). A Handbook of West African Weeds. International Institute of Tropical Agriculture, Ibadan, Nigeria. 100p.
18. Amadi, A.N., Olasehinde, P.I., Okosun, E.A., Yisa, J. (2010). Assessment of the Water Quality Index of Otamiri and Oramiriukwa Rivers. *Physics International*, 1(2): 116-123.
19. Ben-Eledo, V.N., Kigigha, L.T., Izah, S.C., Eledo, B.O. (2017a). Bacteriological Quality Assessment of Water from Epie Creek, Niger Delta Region of Nigeria. *International Journal of Ecotoxicology and Ecobiology*, 2(3): 102-108.
20. Aigberua, A., Tarawou, T., Abasi, C. (2017). Spatial and Seasonal Assessment of Heavy Metals in Surface Waters of the Middleton River in the Niger Delta, Nigeria. *International Journal of Natural Resource Ecology and Management*, 2(5): 94-98.
21. Uzoekwe, S.A., Aigberua, A.O. (2019). Heavy Metal Distribution and Assessment of Ecological Risk in Surface Waters and Sediment within the Flow stations in Kolo Creek, Nigeria. *Journal of Chemical*

Society of Nigeria, 44(5): 809-824.

22. Izah, S.C., Aigberua, A.O. (2017). Comparative Assessment of Selected Heavy Metals in Some Common Edible Vegetables Sold in Yenagoa Metropolis, Nigeria. *Journal of Biotechnology Research*, 3(8): 66-71.
23. Aigberua, A., Tarawou, T. (2017). Assessment of Heavy Metals in Muscle of Tilapia zilli from Some Nun River Estuaries in the Niger Delta Region of Nigeria. *Academic Journal of Chemistry*, 2(9): 96-101.
24. Aigberua, A.O., Izah, S.C., Isaac, I.U. (2018). Level and Health Risk Assessment of Heavy Metals in Selected Seasonings and Culinary Condiments Used in Nigeria. *Biological Evidence*, 8(2): 6-20.
25. Aigberua, A.O. (2019). Composition of Potential Heavy Metal Contaminants in Selected Liquid and Powdered Herbal Medicines Commonly sold in Port Harcourt Metropolis, Nigeria. *International Journal of Medicinal Plants and Natural Products*, 5(1): 30-39.
26. Ben-Eledo, V.N., Kigigha, L.T., Izah, S.C., Eledo, B.O. (2017b). Water Quality Assessment of Epie Creek in Yenagoa Metropolis, Bayelsa State, Nigeria. *Archives of Current Research International*, 8(2): 1-24.
27. Aigberua, A., Numbere, A.O. (2019). Assessment of Dumpsite Soils in Mangrove Forest at Eagle Island, Nigeria: It's Effect on Potential Bioavailability of Heavy Metals in the Environment. *Journal of Petroleum & Environmental Biotechnology*, 10: 1-9.
28. World Health Organization (WHO) (2008). Guidelines for drinking water quality recommendation. *Geneva,* Switzerland.
29. Moslen, M., Aigberua, A. (2018). Heavy Metals and Hydrocarbon Contamination of Surface water in Azuabie Creek within Bonny Estuary, Nigeria. *Journal of Applied Science and Environmental Management*, 22(7): 1083-1088.
30. Dio, D.W., Madusolumuo, M.A. (2017). Heavy Metal Content of Vegetables grown near Lake Geriyo, Yola, Adamawa State, Nigeria. *Innovat International Journal of Medical & Pharmaceutical Sciences*, 2(1): 15-17.