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Assessment of Arsenic and Copper Pollution of the Benya Lagoon, Ghana By Neutron Activation Analysis

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ABSTRACT

Heavy metal concentrations in some water bodies and the soil beneath these waters. These would have detrimental consequences on these water users and consumers of the fish in that water. Instrumental Neutron Activation Analysis technique using the Ghana Research Reactor-1 was employed to find out the concentrations of two heavy metals, Arsenic (As) and Copper (Cu) in the sediments, fishes, and water collected from the Benya Lagoon in the KEEA, Ghana. Cumulatively, Copper was found to be greater in concentration than Arsenic concerning the three parts of the ecology under study. On the other hand, Arsenic was more concentrated in the sediments than Copper, and Copper was more concentrated in the water and fish than Arsenic. Cumulatively, the level of contamination of Arsenic and Copper decreased in the order fish > sediment > water. Though Arsenic and Copper were found in elevated amounts in both water and fish which rendered the Lagoon water unsuitable for human use and the fish from the Lagoon unsafe for consumption, their concentrations in the sediment were found to have a low ecological risk index on the environment.

Keywords: Benya Lagoon; Heavy Metal Pollution; Health Risk; INAA; Good Drinking Water.

1 Introduction

Over the last two decades, the pollution of aquatic systems by heavy metals due to activities like urbanization [1] has been an issue of major concern. Heavy metals like Arsenic and Copper, are regarded as severe pollutants due to their toxicity resolution, bioaccumulation, and biomagnifications problems [2]. They are not degraded chemically or biologically and so stay for longer periods in the environment [3].

Heavy metals are natural constituents of water bodies like lagoons and lakes but over the period, the rapid expansion of human activities such as the direct industrial discharges into water bodies, input from weathering, and the effect of local activities nearby such as fishing, sewage disposal, has indeed accelerated the rate of environmental pollution [4]. Agricultural runoffs containing pesticides and fertilizers are normally deposited in the bed sediments and aqueous phases of lagoons and are normally the final destinations for both androgenic components produced or derived from the environment. Sediments function as bowls for a range of pollutants such as heavy metals and pesticides, and they perform a portion in the remobilization of pollution in aquatic schemes as well as the interaction of water and sediment [5].

Copper (Cu), and Arsenic (As), adversely affect all living things as they get in integrated into the food chain, get accumulate, and may build up to concentrations that may be harmful to living organisms. Within the aquatic environment, heavy metals are considered toxic at high levels, but in trace amounts, play essential biochemical roles in the life processes of all aquatic life. They are consequently considered micronutrients or trace elements [6].

Below 20 mg of organic Arsenic in humans affects expression of gene, helps reproductive health, and digestive issues. Its overdose, however, makes it carcinogenic, gastrointestinal problems, sources anemia, depression, and even death [7], [8]. Copper, on the other hand, aids in iron, protein and estrogen metabolism, hormone synthesis and is required by women for the correct functioning of their reproductive system as it boosts their fertility and maintains pregnancy. Nonetheless, high intakes above 10 mg/d can cause nervous system disorders, liver and kidney damages [9], [10].

Generally, fish has been widely studied to identify edible and commercial species and those unsafe for human consumption [11]. A study of samples from a freshwater system is considered as one of the most significant means of estimating the level of metal pollution in that system within that system.

The municipality of Komenda Edina Eguafo Abrem (KEEA) surrounds the Benya Lagoon in Ghana's Central Region and it serves as the hub for many commercial activities some of which include salt mining and fishing. Concerning fishing, the lagoon serves as the habitat for a variety of fish, notable among them being the Sarotherodon Melanrotheron (Blackchin Tilapia). Located along the Gulf of Guinea, Benya Lagoon spans a total length of about 10.19 kilometres (Fig. 1).

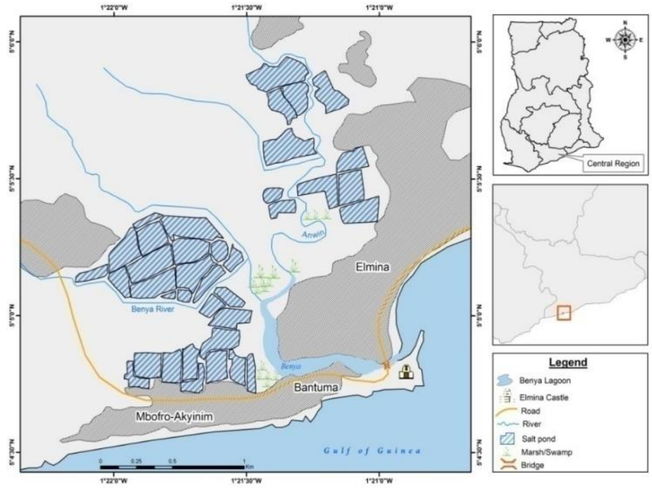

Fig. 1 A map of Benya lagoon [12]

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Due to heavy pollution, the lagoon is drying up so the survival of these commercial ventures is however threatened. The Benya lagoon is polluted due to some practices of residents living within the environs of the lagoon. Generally, sanitation within the KEEA municipality is poor, to the extent that liquid and solid wastes disposal facilities are not readily accessible. This has resulted in all manner of wastes being dumped straight into the lagoon without any prior treatment. Some of such wastes include liquid wastes and human excreta from homes being spilled directly into drains and open spaces which in time end up in the lagoon and surrounding farms. Others include rubbish generated from domestic activities and commercial ventures like markets, and toxic solid wastes like scrap metals from auto-mechanic shops in the area [12], [13]. Fig. 2 shows the various sources of pollution to the Benya Lagoon.

This study aims at assessing the pollution levels of Arsenic and Copper present in the sediments, water, and fish from the Benya Lagoon using the Ghana Research Reactor-1 located at the Ghana Atomic Energy Commission, which operates on the principles of Instrumental Neutron Activation Analysis (INAA).

(a) Dumping of waste around the lagoon

(b) Liquid and solid wastes dumped around boat settlement at the background

(c) Boats in the Benya Lagoon. Market and shops around the lagoon in the background

(d) Refuse and unserviceable/retired boats abandoned along the bank of the lagoon

Fig. 2 Sources of pollution of the Benya lagoon

2 Sample Containers and Equipment Preparation

All the sampling apparatus and receptacles used are cleaned before and after use with heavy-metal grade acetone and heavy-metal grade HCl was used as a rinse before putting samples in them. Blank containers are verified first for background contamination, and the results are subtracted from the main data.

2.1 Sample Collection

During the sample period, professional fishermen's services were used. Their abilities and boats aided in accessing some of the most difficult-to-reach locations required for the study. Using a sediment coring device, superficial (upper 10cm) random sediment samples were taken in the lagoon. The overlying water was siphoned and into a plastic bowl, the upper 5 cm of sediment from surface-grab was removed with plastic spoon. To make a composite sample, this technique was performed three times within each sampling station and all three sections were placed in the same bowl. They were then mixed using a plastic spoon until a uniform colour and consistency were achieved. To avoid cross-contamination, each composite sediment sample was also placed in a tagged Ziploc plastic bag. They were then put in the fridge at a temperature of –10 °C.

The water samples were obtained by submerging the water sampler beneath the surface of the lagoon. Each water sample was sieved with an inline filter unit, measured into a pre-cleaned 1.5 litre bottle, and coded with indelible ink. 5% suprapur HCl was added to the filtered water samples for preservation. To avoid cross-contamination, each water sample was also placed in a tagged Ziploc plastic bag. At room temperature, the water sample were stored in the dark before the laboratory analysis.

The fish samples were bought from the fisher mongers around the Benya Lagoon and taken to the laboratory of the Department of Fisheries, University of Cape Coast. The scales of the fish were well removed using a new kitchen stainless steel knife. It was then washed with deionized water, dry-cleaned with blotting paper, and had it separated into its various parts like tissues, bones, and gills. These were then kept in a refrigerator at a temperature of – 10°C. The samples were then transported to the Preparation Laboratory at the Ghana Atomic Energy Commission (GAEC) at Kwabenya, in Accra for analyses. The average concentration of Copper and Arsenic present in the water sample, fish and sediments, were then calculated.

2.2 Sample Preparation

The irradiation capsules were cleaned by rinsing them in deionized water after immersing them in an acidic reagent for 24 hours. For another 24 hrs they were soaked in HNO3 after which they were thoroughly rinsed with deionized water and air-dried. 1000 ppm single standard reference solution of the elements Arsenic and Copper and were packed the same way as the samples. They were then crammed between the wrapped samples and then all were wrap up together into one polyethylene ampoule for irradiation.

2.3 Sample Irradiation and Counting

INAA was used for the determination of the concentration of As and Cu in the water, sediment, and fish samples. Operating at 15 kW, Ghana Research Reactor-1 facility situated at GAEC was used to irradiate the prepared samples, when there is a thermal neutron flow of 5×10^{11} $ncm^{-2}s^{-1}$. With a pressure of 0.6 MPa, a pneumatic transfer system pushed the samples into the irradiation locations. The half-life of the components of interest was used to classify the irradiation. The induced radioactivity in the samples was counted using PC-based -ray spectrometry. A model Modules for electronic devices and a spectroscopic amplifier (model 2020, Canberra Industries Incorporated) were used to connect a computer-based Multichannel Analyzer to a GR2518 n-type high-purity Germanium brand (HPGe) detector. With 1.8 keV energy resolution and γ-ray energy of 1332 keV, the detector has a relative efficiency of 25%. The energy emitted was used to subjectively identify the γ-ray product radionuclides, and the quantitative analysis was completed using the comparator approach to translate the counts to the area beneath the photo peaks. The appropriate amount of chilling time can make all the difference.

3 Results

From the investigations carried out, the mean concentration values of Arsenic and Copper obtained for the various samples are shown in Table 1. GHAAR-1 has a detection limit of 0.00001µg/g for Arsenic and 0.01 µg/g for Copper.

Table 1 Mean concentrations of Arsenic and Copper in the Sediments, Water and Fish from the Benya Lagoon

Element	Sediment (mg/kg)	Water (mg/l)	Fish (mg/kg)
As	61.9 ± 29.60	0.12± 0.08	93.17 ± 15.44
Cu	56.2 ± 59.50	0.08± 0.04	123.35 ± 15.70

4 Analysis and Discussion

4.1 Sediment

4.1.1 Heavy Metals Concentration Assessment

The average concentration of As and Cu in the sediments were found to be 61.9 ± 29.60 mg/kg and 56.2 ± 59.50 mg/kg, respectively. The sediment was found to be more concentrated with Arsenic than Copper.

4.1.2 USEPA and CBSOG Assessment

The metals concentrations were matched with sediment conditions proposed by US Environmental Protection Agency (USEPA) [14] and Consensus-Based Sediment Quality Guidelines (CBSOG) [15]. Table 2 shows the limits of the various pollution levels and the mean values obtained from the study.

The USEPA scale has no available data on Arsenic for its levels of pollution. However, using the CBSOG scale, the Benya will be classified as being heavily polluted. For Cu, the lagoon may be considered slightly or heavily polluted concerning the CBSOG and USEPA scale.

Table 2 Comparison of measured concentration values with guidelines for sediments as proposed by USEPA and CBSOG SQG (2003)

Metal	USEPA Pollution Level			CBSOG SQG (2003) Pollution Level			Benya Lagoon Study
	Not	Slightly	Heavily	Not	Slightly	Heavily	Mean
As	----	----	----	< 9.8	9.8 – 21.4	> 21.4	61.9
Cu	<25	25-50	> 50	<25	25-75	>75	56.2

4.1.3 Geo-accumulation Index Assessment

The amount of heavy metal pollution in sediment can be analyzed by determining its geo-accumulation index (I_{geo}). This is expressed mathematically in Eq. (1) (reference) as:

$$I_{geo} = log_2 [Cn/1.5Bn] \qquad (1)$$

where C_n is the concentration of element '*n*' and B_n is the geochemical background value (world surface rock average) [16]. The factor 1.5 is unified to account for likely variants in background data owing to lithogenic influence.

For Cu, B_n= 32 and C_n=56.2 while for As Bn=13 and Cn=61.9. Substituting these values into equation 1 yields I_{geo} values of 0.2 and 1.7 for Cu and As respectively.

For its classification, the I_{geo} scale consists of seven grades (0 – 6) ranging from unpolluted to highly polluted. This is shown in Table 3.

Comparing the calculated I_{geo} values for Cu and As to the grading system shown in Table 3, it can be deduced that the sediment quality of the Benya lagoon falls within the 'Uncontaminated to moderately contaminated' classification region concerning Cu, while it can be considered 'Moderately contaminated' regarding As.

Table 3 I_{geo} class showing the pollution Grades of Geo-Accumulation Index of Metals class

I_{geo} Class	I_{geo} Value	Sediment Quality
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} \leq 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} \leq 2$	Moderately contaminated
3	$2 < I_{geo} \leq 3$	Moderately to heavily contaminated
4	$3 < I_{geo} \leq 4$	Heavily contaminated
5	$4 < I_{geo} \leq 5$	Heavily to extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

4.1.4 Assessment According to Contamination Factor, (C_F)

Another indicator that categorizes the extent of environmental contamination is the C_F. It is used to assess the likely anthropogenic contribution of metals in observed sediments [17]. Mathematically, is as expressed in Eq. (2):

$$C_F = \frac{\text{Measured Concentration}}{\text{Background Concentration}} \quad (2)$$

Value of Background Concentration in metal = world surface rock average [16].

Using equation 2:

For Cu, $C_f = \frac{56.2}{32} = 1.7$

For As, $C_f = \frac{61.9}{13} = 4.8$

The pollution grades with their corresponding intensities used in evaluating the degree of environmental contamination are provided in Table 4.

Table 4 CF Ranges [16]

C_F	Grade	Intensity
$C_F < 1$	I	Low contamination factor
$1 \leq C_F < 3$	II	Moderate contamination factor
$3 \leq C_F < 6$,	III	Considerable contamination factor
$C_F \geq 6$	IV	Very high contamination factor

Comparing the calculated CF values for Cu and As to the ranking system shown in Table 4, the following deductions can be made about the sediment quality of the Benya Lagoon. For Cu, the calculated value of 1.7 means a Grade II and an Intensity of a ‘Moderate contamination factor’. For As, the calculated value of 4.8 means a Grade III with an Intensity classification of ‘Considerable contamination factor’.

4.1.5 Potential Ecological Risk, PER Assessment

The PER factor is a diagnostic tool for lake and coastal contamination control. It is a system whose major goal is to suggest contaminating agents and where contamination research should be emphasized [9]. Three basic modules make up PER; degree of contamination (C_D), toxic response factor (T_R), and potential ecological risk factor (E_r). The PER assessment system, as given in Table 5, is dependent on the abundance of the element and numerous preconditions:

(1) Concentration – will increase with an aggravated metal pollution degree in sediments;

(2) Species number – the metals in sediment express the additive effect, as a result, the PER is larger with the presence of multiple metals in sediment. The metals As and Cu are the objects that have previously been considered;

(3) Toxic response – heavy metals with a high biological toxicity have more evidence for RI and magnitude for abundance correction;

(4) Sensitivity – built on the Biological Production Index (BPI), the sensitivity is different for different water quality systems [18], [19]. The PER is mathematically expressed in Eq. (3) as:

$$E_r^i = T_r^i \times C_F^i \quad (3)$$

where,

T_r^i : The metal toxic response factor for a given substance [20]. The values for Cu and As are 5 and 10, respectively. C_F^i : The ratio of the reference records, C_D^i and measured concentration values in sediments, C_R^i (contamination factor)

Table 6 is the PER of a given contaminant. Mathematically, the Risk Index RI, is expressed in Eq. (4) as:

$$RI = \Sigma\, E_r^i \quad (4)$$

The PER factor E_r for Cu and As are calculated as follows:

For Cu: $E_r = 5 \times 1.7 = 8.5$

For As: $E_r = 10 \times 4.8 = 48$.

The calculated RI value for the lagoon sediment will therefore be:

RI = 8.5 + 48 = 56.5

Table 5 Indices and Grades of PER Factor

Critical Range for *i*th Heavy Metal	Grade for Ecological Risk Factor
$E_r^i < 40$	Low
$40 \leq E_r^i < 80$	Moderate
$80 \leq E_r^i < 160$	Considerable
$160 \leq E_r^i < 320$	High
$E_r^i \geq 320$	Very high

Table 6 Indices and Grades of PER Index

RI Class	Critical Range for Heavy Metal	Grade for Ecological Risk Index
A	RI < 110	Low
B	$110 \leq$ RI < 220	Moderate
C	$220 \leq$ RI < 440	High
D	RI ≥ 440	Very high

Regarding Table 5, Cu can be said to be of ‘Low-Grade Ecological risk’ as the calculated PER factor yielded $E_r < 40$. As yielding a calculated potential ecological risk factor E_r of 48 makes it ’Moderate Grade Ecological factor’. The combined concentration of Copper and Arsenic in the lagoon sediment is calculated as 56.5. Comparing this value with the rankings provided in Table 6, the lagoon was found to have a ‘Low Ecological Risk index’ concerning the presence of Arsenic and Copper.

4.2 FISH (Sarotherodon melanotheron)

4.2.1 Analysis According to Dietary Recommendation

The dietary requirement for a micronutrient is an intake level that meets specified criteria for adequacy, thereby minimizing the risk of nutrient deficit or excess. The Reference Daily Intake or Recommended Daily Intake (RDI) of a nutrient is the daily intake level that is considered sufficient to meet the requirements of 97–98% of healthy individuals in every demography in the United States (where it was developed, but has since been used in other places). The RDI is based on the older Recommended Dietary Allowance (RDA) [21]. Newer RDAs have since been introduced into the Dietary Reference Intake system, but the RDI is still used for nutrition measurements.

Table 7 Cu and As Total Mean daily intake in the *S. melanotheron*

Element	Daily intake (µg/d)	Daily intake (mg/d)
As	5615.73	5.61573
Cu	7434.80	7.43480

Table 8 Recommended Dietary Allowance and Maximum Upper Limit (UL) for the various Life Stage Groups [21]

Life Stage Group	Cu		As	
	RDA (µg/d)	UL (µg/d)	RDA (mg/d)	UL (mg/d)
Infants				
0-6 months	200	ND	ND	ND
7-12 months	220	ND	ND	ND
Children				
1-3 y	340	1,000	ND	ND
4-8 y	440	3,000	ND	ND
Males				
9-13 y	700	5,000	ND	ND
14-18 y	890	8,000	ND	ND
19-30 y	900	10,000	ND	ND
31-50 y	900	10,000	ND	ND
50-70 y	900	10,000	ND	ND
>70 y	900	10,000	ND	ND
Females				
9-13 y	700	5,000	ND	ND
14-18 y	890	8,000	ND	ND
19-30 y	900	10,000	ND	ND
31-50 y	900	10,000	ND	ND
51-70 y	900	10,000	ND	ND
>70 y	900	10,000	ND	ND
Pregnant Women ≤ 18 y	1000	8,000	ND	ND
19-30 y	1000	10,000	ND	ND
31-50 y	1000	10,000	ND	ND
Lactation Women				
≤ 18 y	1300	8,000	ND	ND
19-30 y	1300	10,000	ND	ND
31-50 y	1300	10,000	ND	ND

ND = Due to a paucity of research on detrimental effects in this age group and concerns about the inability to handle excessive quantities, the answer is unknown. To avoid high amounts of intake, the only source of intake should be food. [21].

The Upper limits (ULs) of nutrient intakes have been established for several micronutrients and are defined as the maximum intake from food, water, and supplements that is unlikely to pose the risk of adverse health effects from excess in almost all (97.5%) apparently healthy individuals in an age- and sex-specific population group.

The average intake of fish is 22kg/caput/year, and therefore the average intake of fish per day is calculated as 60.274 g/d [22]. So if an average fish intake per day is represented by M (M = 60.274 g/d) and the concentration of elements in the fish be represented by N µg/g of sample. The concentration of the element in fish per day can then be given by the relation expressed in Eq. (5) as;

$$P = M \times N \qquad (5)$$

P is expressed in µg/d.

The daily intake in grams per capita of the investigated elements is therefore calculated as follows:

$P_{As} = 60.274\ g/d \times 93.17\ mg/kg = 5615.73\ \mu g/d$

$P_{Cu} = 60.274\ g/d \times 123.35\ mg/kg = 7434.80\ \mu g/d$

Table 7 are the calculated value.

The calculated daily mean intake for Arsenic was 5615.73µg/d. Although there is no available data on its upper limit there is no justification for taking its supplements or adding them to food. Arsenic is a dangerous element and should not be part of food nutrients. It is poisonous and a source of anemia, gastrointestinal difficulties, despair, and even death [7], [8]. Arsenic is poisonous but up to 20 mg may regulate gene expression, backing procreative health and treating digestive hitches in the body [9].

Table 9 UL of the RDA and the calculated means differences

Life Stage Groups	Cu	As
Infants 0-6 months 7-12 months	No UL	No UL
Children		No UL
1-3 y	+6434.8	
4-8 y	+4434.8	
Males		No UL
9-13 y	+2434.8	
14-18 y	-565.2	
19-30 y	-2565.2	
31-50 y	-2565.2	
50-70 y	-2565.2	
>70 y	-2565.2	
Females		No UL
9-13 y	+2434.8	
14-18 y	-565.2	
19-30 y	-2565.2	
31-50 y	-2565.2	
51-70 y	-2565.2	
>70 y	-2565.2	
Pregnant Women		No UL
≤ 18 y	-565.2	
19-30 y	-2565.2	
31-50 y	-2565.2	
Lactation Women		No UL
≤ 18 y	-565.2	
19-30 y	-2565.2	
31-50 y	-2565.2	

+ denotes values above the ULs; - denotes values below the ULs.

The total mean daily intake of copper was found to be 7434.80 µg/d. This exceeds the RDA(AI) for all the various life stages and the UL of infants from 0-13 years. This means that people who consume fish from the Benya lagoon are at risk of experiencing medical conditions such as nervous system disorders and liver and kidney damage, conditions associated with the excess consumption of Copper [9], [10].

4.2.2 Health Risk Estimation

Estimating the overall health effects, the Hazard Index, HI as expressed in Eq. (6), was calculated by comparing the Average

Daily Dose of each element (ED) with its Reference Dose (RfD). The reference dose is an evaluation of a daily intake amount that is unlikely to have adverse effects throughout a lifetime. The HI is determined using the calculation provided in the handbook of the United States Environmental Protection Agency [23]:

$$\text{Hazard index (HI)} = \frac{ED}{RfD} \qquad (6)$$

Presented in Table 10 is the health risk associated with eating *S. Melanotheron* from the Benya Lagoon. HI < 1 suggests unlikely adverse health effects whereas HI > 1 suggests the probability of adverse health effects [23]. High HI values for the trace element examined that registered values > 1 have been emphasized for the major life stage groupings. From Table 10, except for children between 1-13 years, who recorded a health risk index >1 the rest of the life stage groups recorded a health risk index < 1 suggesting an unlikely adverse health effect for Cu for all the life stage groups. Consequently, children between 1-13 years who consume *S. Melanotheron*from the Benya Lagoon are at risk of developing health problems associated with excessive Cu intake. The health risk index associated with As was not determined as there is no available data on its UL.

Table 10 Estimated Health risk linked with the eating of S. Melanotheron from the Benya Lagoon

Life Stage Groups	Hazard Index	
	Cu	As
Infants		
0-6 months	ND	ND
7-12 months	ND	ND
Children		
1-3y	7.4348	ND
4-8y	2.4783	ND
Males		
9-13y	1.4867	ND
14-18y	0.9294	ND
19-30y	0.7435	ND
31-50y	0.7435	ND
50-70y	0.7435	ND
>70y	0.7435	ND
Females		
9-13y	1.48670	ND
14-18y	0.9294	ND
19-30y	0.7435	ND
31-50y	0.7435	ND
51-70y	0.7435	ND
>70y	0.7435	ND
Pregnant Women		
≤ 18y	0.9294	ND
19-30y	0.7435	ND
31-50y	0.7435	ND
Lactation Women		
≤ 18y	0.9294	ND
19-30y	0.7435	ND
31-50y	0.7435	ND

4.3 Water

The Directives/Regulations listed in Table 11. are founded on the ’Environmental Quality Objective’ (EQO) methodology, in which ‘Environmental Quality Standards (EQSs) are laid down for various types of water in which contaminants may be found, with concentrations more or less firmly limited. Monitoring under these directives/regulations can be used to regulate the extent to which pollutants are present in a given water sample [24].

The ‘Drinking Water Directive’ and Quality of Surface Water for Drinking Water Abstraction, the European Communities Regulations were signed in November 1989 and took effect the same year in December. This standard is dependable and can therefore be used to evaluate the quality of water obtained for the Benya Lagoon. The "Surface Water Regulation" is a contradiction. This is because it provides the idea that it covers surface water quality in general, whereas in fact it only covers the quality of surface water utilized as a source of drinking water for humans, as well as the appropriate treatment after abstraction. The directive deals with the so-called "raw water" [24]. The ‘Drinking Water Directive’ was aimed at protecting public health, and therefore heavy metals were proposed to be in much lower quantities as compared to any other regulation such as the ’Surface Water Regulation’.

Table 11 Comparison with Surface Water Regulations and Drinking Water Directives of the European Union published by the Environmental Protection Agency of the Republic of Ireland.

Element	Cu (mg/l)	As (mg/l)
Mean Concentration of metals obtained after analysis	0.080	0.120
Surface Water Regulations [1989] - I/PV value [24]	0.050	0.005
Drinking Water Directive [98/83/EC] - I/PV value [24]	0.002	0.010

Comparing the concentrations of the two investigated metals in the Benya Lagoon (0.12 mg/l for As and 0.08 mg/l for Cu) with the Surface Water Regulations and Drinking Water Directives of the European Union (shown in Table 11) it will be realized that the measured concentrations of As and Cu exceeded both standards set by the European Union. The mean concentration of Cu exceeded the Surface Water Regulation by 0.03 mg/L and the Drinking Water Directive by 0.078 mg/L while for As, its mean concentration exceeded the Surface Water Regulation by 0.115 mg/L and the Drinking Water Directive by 0.11 mg/L. These findings clearly indicate that water from the Benya lagoon is not suitable for any use; be it domestic use for washing, drinking, or cooking, or commercial purposes like irrigation for farming. It is however disturbing to mention that inhabitants within the environs of the lagoon do use water from the lagoon for all these purposes. Such inhabitants are therefore at risk of developing various health problems due to bioaccumulation of these heavy metals in their body systems over some time.

Fig. 3 and Fig. 4 depict the concentrations of Arsenic and Copper measured in the samples of sediment, water, and fish from the lagoon. It can be deduced that Cu is present in a greater amount bearing in mind the three components of the ecosystem (sediment, water, and fish) in this study and exists in higher concentrations in the fish. Arsenic, on the other hand, Arsenic exists in higher amounts in the sediments. The water sample had almost equal concentrations of Arsenic and Copper.

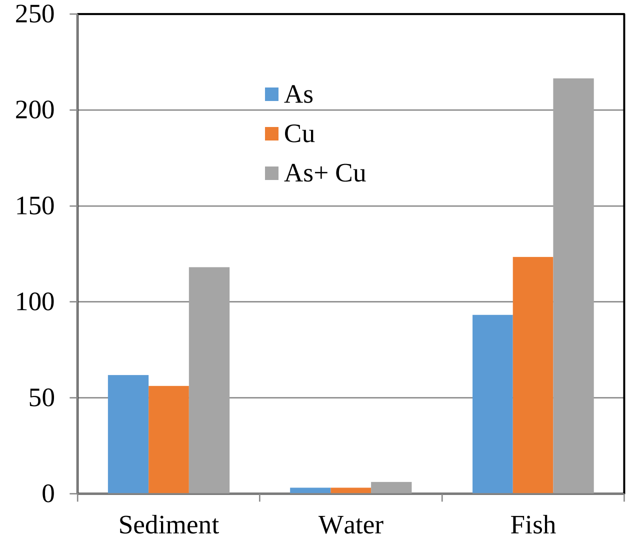

Fig. 3 Concentrations of As and Cu in sediment, water, and fish, respectively

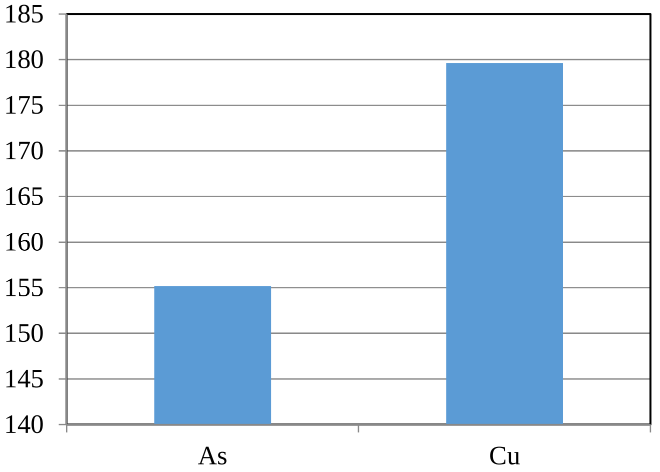

Fig. 4 As and Cu Cumulative concentrations in the three all samples

The sum of the concentrations of As and Cu present in the mediums studied decreased in the order fish > sediment > water. This is because the Benya lagoon takes its source from other water bodies and is located a few metres from the Gulf of Guinea. It is therefore not stagnant as other rivers flow into it. It is also worth mentioning that at high tides there is an influx of water from the Gulf of Guinea into the lagoon and at low tide the vice versa takes place. This process dilutes whatever concentrations there are in the lagoon. On days when there are no tides at all, the metal particles which are heavier than the other particles in the water tend to sink to the base of the lagoon to add up to the sediments, thereby increasing its metal concentration. This explains why the concentration of the heavy metals investigated was lowest in the water as compared to the measured concentrations in the sediments and fish.

In the fish, a phenomenon called bioaccumulation is responsible for the extremely high levels of metal concentrations recorded. By eating and undertaking its respiratory activities, the fish has these metals integrated into its system, with the rate at which these metals are absorbed is greater than the rate at which they are broken down. Most of the time these metals are not biodegradable, resulting in their bioaccumulation in the fish over time. The average daily intake of Arsenic and Copper in the fish was calculated to be 5615.73 µg/d and 7434.80 µg/d respectively. These are values that exceed the RDA (AI) of all the various life stage groups. This indicates that *Sarotherodon melanotheron*, (Blackchin Tilapia) from the Benya Lagoon is unsafe for human consumption.

5 Conclusion

The collective, concentrations of Copper and Arsenic were found to have a low ecological risk index and will therefore have minimal effect on the ecological system in and around the Benya Lagoon. However, the mean concentration of Cu exceeded the Surface Water Regulation and Drinking Water Directives of the European Union by 0.03 mg/L and 0.078 mg/L respectively, while Arsenic exceeded the same standards by 0.115 mg/L and 0.11 mg/L respectively. This makes water from the Benya lagoon unsuitable for any use, be it domestic or commercial.

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