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Uses, A., Chukwu, O. L. & Rahman, M. M. et al. (2017) Concentrations of arsenic in water and fish in a tropical open lagoon, Southwest-Nigeria: health risk assessment, Environmental Technology and Innovation, 8, pp164-171

Available from: <http://dx.doi.org/10.1016/j.eti.2017.06.005>

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Accessed from: <http://hdl.handle.net/1959.13/1353883>

Accepted Manuscript

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PII: S2352-1864(16)30176-6
DOI: <http://dx.doi.org/10.1016/j.eti.2017.06.005>
Reference: ETI 135

To appear in: *Environmental Technology & Innovation*

Received date : 14 December 2016
Revised date : 10 June 2017
Accepted date : 24 June 2017

Please cite this article as: Usese, A., Chukwu, O.L., Rahman, M.M., Naidu, R., Islam, S., Oyewo, E.O., Concentrations of arsenic in water and fish in a Tropical Open Lagoon, Southwest-Nigeria: Health risk assessment, Part 1. *Environmental Technology & Innovation* (2017), <http://dx.doi.org/10.1016/j.eti.2017.06.005>

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PART 1**Concentrations of arsenic in water and fish in a tropical open lagoon, Southwest-Nigeria: health risk assessment**

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ABSTRACT

This study assesses the concentrations of arsenic (As) in water, muscle tissue of four demersal fish species (*Chrysichthys nigrodigitatus*, *Mugil cephalus*, *Liza falcipinnis* and *Bathygobius soporator*) and whole tissues of periwinkle (*Tympanotonus fuscatus*) in Lagos Lagoon, Nigeria. The observed mean total As concentration in water ($1.29\mu\text{g l}^{-1}$) during the wet and dry seasons did not exceed the World Health Organization (WHO) guideline value of $10\mu\text{g l}^{-1}$. Among the examined biota, *Tympanotonus fuscatus* recorded higher As levels ($2.31 \pm 0.24\text{mg kg}^{-1}$) and *Chrysichthys nigrodigitatus* recorded the least As content ($0.67 \pm 0.08\text{mg kg}^{-1}$). A significant positive correlation ($p < 0.05$) was observed between As concentrations in fish muscles and water during both dry and wet seasons. The health risks associated with human consumption of fish estimated using Target Hazard Quotient (THQ) were lower than the USEPA guideline value of 1 for all fish species examined except in populations that consume larger amounts of fish. However, higher THQ values (>2) were obtained for *Tympanotonus fuscatus*, suggesting the potential for non-carcinogenic health outcomes in adults after a prolonged period of consumption. This calls for continuous monitoring and enforcement of regulations to ensure safety of fishery resources from Lagos Lagoon.

Keywords:

Arsenic

Water

Muscle tissue

Health risk

Lagos lagoon

1. Introduction

Increasing levels of heavy metals and metalloids reaching aquatic ecosystems from natural or anthropogenic sources have generated many concerns worldwide. This is largely due to their non-biodegradability and tendency to accumulate in environmental media, plants and animals tissues. These elements potentially bio-accumulated by edible biota are subsequently transferred through food chain ultimately creating public health problems for people (Agusa et al., 2005; Rahman et al., 2013). Fish and shellfish are major sources of animal protein and known to be the most significant sources of toxic metals/metalloids including arsenic (As) in the human diet. The ability of fish to bio-accumulate these heavy metals/metalloids in their muscle tissues and other organs is usually considered to indicate the concentrations in water and their accumulation in food chains (Pintaeva et al., 2011).

Arsenic is a metalloid and ubiquitous in open ocean and seawater with typical levels from $1\text{--}2\mu\text{g l}^{-1}$ or less than $2.0\mu\text{g l}^{-1}$ (Ng, 2005; WHO, 2001). The presence of As can be natural in many environments with natural As contamination of groundwater being reported in many regions worldwide. Highly toxic inorganic forms of As (arsenite and arsenate) are usually present in groundwater. Arsenic is released into the aquatic environment through natural processes and anthropogenic activities such as mining, wood preservatives, use of pesticides and herbicides (Mandal and Suzuki, 2002). Metal distribution in fish is determined mainly by its content in water and food (Farkas et al., 2000). Runoff of As-contaminated waste materials and their accumulation in aquatic plants such as sea grass, a food source for aquatic organisms might also lead to the contamination of edible biota (Bhattacharya et al., 2007). As reported in literature, the largest quantity of As in the US diet accounting for about 90% of total As exposure is derived from saltwater finfish and seafood (Adams et al., 1994; US Food and Drug Administration (US-FDA) 1993). Since fish and shellfish, the cheapest sources of animal protein for most coastal communities and villagers are known to be the most significant source of As in the human diet, elevated levels of As in edible fish tissues can

cause health risks (EFSA, 2009). Consequently, several researchers have attempted to document the status of As in some contaminated aquatic ecosystems in recent years; studies focusing on As in water, food and seafood with the associated human health risk have received considerable attention globally. Human exposure to As and other toxic metals via food chain transfer, surface, ground and drinking water has been reported to result in both acute and chronic effects (Fidan et al., 2008; Rahman et al., 2013)

In Nigeria, some studies have reported low levels of As in water and edible biota (Atobatele and Olutona, 2015) and others reported values greater than the provisional WHO limit ($10 \mu\text{g l}^{-1}$) in surface water and fish from reservoirs and freshwater ecosystems (Benzer, 2016; Egbinola and Amanambu, 2014; Garba et al., 2012a; Garba et al., 2012b; Kayode et al., 2011; Musa et al., 2008). Of particular concern are the symptoms of As poisoning observed in the inhabitants who live in parts of Biu Volcanic Province in North-Eastern Nigeria. Arsenic levels exceeding $10 \mu\text{g l}^{-1}$ in drinking water sourced from surface waters in the area have been reported (Usman and Lar, 2013). With the exception of a few, most studies on metal pollution in Lagos Lagoon did not incorporate As in their investigation. Aderinola et al. (2009) reported As levels in the Lagos lagoon as 0.10 mg l^{-1} , 0.36 mg kg^{-1} and 0.01 mg kg^{-1} for water, finfish and shellfish (periwinkles), respectively. Despite this, information is still scarce on the potential public health risk associated with levels of As in water and edible fisheries resources based on current and internationally acceptable maximum allowable limits. It is important to note that metals/metalloids recorded at low levels in water and sediment could at most times be higher in aquatic organisms through bio-concentration and bioaccumulation processes, resulting in progressively higher concentrations at higher trophic levels in the food chain. Furthermore, estimation of risk via food chain transfer of any toxic metal is usually based on the proportion of bio-accumulated heavy metals in edible biota. Several methods have been proposed to estimate the potential risks to human health of heavy metals in species of fish which may be divided into carcinogenic and non-carcinogenic effects (Yi et al., 2011). These methods for

estimating risk typically based on the Target Hazard Quotients (THQ) as used by many researchers (Chien et al., 2002; Wang et al., 2005) have been shown to be valid and useful. The THQ-based risk assessment method does not provide a quantitative estimate of the probability of an exposed population experiencing an adverse health effect; however, it does provide an indication of the risk level associated with pollutant exposure. This study estimates the levels of As in water and fish as well as periwinkle from Lagos Lagoon to determine the risk associated with As when humans consume it.

2. Materials and methods

2.1. Site description and sampling

Sampling was conducted in Lagos lagoon, a habitat that has a wide array of fishery resources and is well known for its multiple usages. The Lagoon which receives a number of important rivers (Yewa, Ogun, Ona and Osun) draining more than 103,626 km² of the country (Don-Pedro et al., 2004) also serves as a source of livelihood for many people.

Seventy-five bottom water samples (500 ml, approximately 15-30 cm below the surface) were collected from fifteen stations and approximately 50 ml was filtered using 0.45 µm syringe filters and transferred to acid-washed sample bottles, then acidified with nitric acid (7M) and stored at 4°C prior to analysis. Sixty-four samples of four demersal fish species (*Chrysichthys nigrodigitatus*, *Mugil cephalus*, *Liza falcipinnis* and *Bathygobius soporator*) were also caught with the help of a professional fisherman using gill nets of 1-3 cm diameter (Ayoola and Kuton, 2009) at designated locations (Fig. 1) from September 2013 to February 2015. Fish samples were thoroughly washed with water immediately after collection to remove mud or other fouling substances and labelled before being transported to Aquatic toxicology and Ecophysiology laboratory located at the University of Lagos. Twenty-four samples of *Tympanotonus fuscatus* 'periwinkles' (Mollusca, Gastropoda, Mega gastropoda, Melanidae) of 32-35 mm in length with an aperture diameter of 0.7-9.0 mm were also collected. This was done by handpicking at the edge of the lagoon in most zones rather than

the designated sampling stations because macrobenthic animals have a preference for shallow waters. The collection was done in three replicates during both dry and wet seasons.

2.2. Pre-treatment of samples, samples processing and analysis

In the laboratory, the samples were kept at 4°C until further processing was required. Fish samples were filleted, the muscle tissues were separated, washed with distilled water and excessive water removed by air drying. Subsequently, the air-dried samples were oven dried at 60°C until a constant weight (wt) was obtained. The dried samples were powdered in porcelain mortar, sieved through 1 mm mesh and stored in airtight zip lock bags. Also, soft tissue of whole periwinkles was properly cleaned (by copiously rinsing all exposed and partially enclosed parts) with double distilled water to eliminate debris and all external adherents prior to processing for analysis. The processed samples (water and fish) were thereafter transported under strict quarantine procedure for further processing at the laboratory located at the University of South Australia, Adelaide, Australia.

Powdered dry muscle tissues of biota (0.5g) were placed in Teflon digestion tubes. 3ml of ultra-pure HNO₃ and 1 ml of hydrogen peroxide (H₂O₂-Merck) were added. Then the vessels were covered and left in a fume-hood overnight. The closed vessel microwave digestion system (Mars 6, CEM) was employed to digest homogenized fish samples after heating according to the digestion program (program: power 1600W (100%), ramp time 15 mins, temperature 200°C, hold time 15mins and cooling time 15mins). After digestion, sample solutions were cooled to room temperature and then transferred into a 25 ml volumetric flask, to which Milli-Q water was added (ELGA Lab-pure system). Water samples were analyzed directly without any chemical treatment.

An Agilent 7500c (Agilent Technologies, Tokyo, Japan) inductively coupled plasma mass spectrometer (ICP-MS) was used to determine the amount of As in water, fish and shellfish. The detection limit of As in solution matrix of the ICP-MS was 0.1 µg l⁻¹.

2.3 Quality control and analysis of certified reference materials (CRMs)

Certified reference materials such as trace elements in natural water from the National Institute of Standard and Technology (NIST SRM 1640a) and DORM-3 (dog muscle fish) from the National Research Council, Canada were used to verify the results of As in water, fish and shellfish, respectively. DORM-3 was digested after utilizing the same procedure as biota samples. The analytical results for As in trace elements in natural waters and DORM-3 indicate that the differences between certified and measured results were less than 5% (Table 1).

2.4. Statistical analysis

In this study, averages of duplicate samples collected and examined for As in water and all species of fish were used to represent the data. SPSS (version 21.0) and Paleontological Statistics (PAST Version 3.14) helped to test the relationship between As concentrations in water and biota. Other calculations were also done utilizing Microsoft Excel 2010 and the results were expressed as mean $\pm$ SE. Data of As in water and fish tissues were tested for normality. Statistical comparisons of the As level in muscles of different fish species were also conducted using two-way ANOVA.

2.5. Estimating ecological and health risk

2.5.1. Evaluation of the risk associated with As in water

The risk associated with the levels of As in bottom water to ecological receptors was assessed by comparing with the guideline value ($10\mu\text{g l}^{-1}$) set by the WHO and Standard Organization of Nigeria (SON).

2.5.2 Human health risk from consumption of fish and shellfish

The risk associated with levels of As from human consumption of demersal fish and the shellfish, *Tympanotonus fuscatus* from Lagos Lagoon was estimated using Bio-concentration factors (BCFS), THQ and Target Cancer Risk (TR). THQ and TR were calculated as per USEPA Region III Risk-Based Concentration Table (USEPA, 2011) using risk estimation assumption values as reported by Bhupander and Mukherjee (2011). A

comparison was also made with THQ assumption values as reported by Osakwe et al. (2014) for Nigerian populations that consume larger quantities of fish. The THQ which expresses the risk of non-carcinogenic effects signifies non-obvious risk. Conversely, an exposed population of concern will experience health risk if the dose is equal to or greater than the RfD. The Target cancer risk (TR) was used to indicate carcinogenic risks. The equation used for estimating THQ was as follows:

$$THQ = (MC \times IR \times 10^{-3} \times EF \times ED) / (RfD \times BWa \times ATn)$$

Where,

THQ is the target hazard quotient,

MC is the mean As concentration in fish (mg kg^{-1} , dry wt.) = 0.79

IR is the fish ingestion rate (g day^{-1}) = 19.5, as described by (Little et al., 2002; Speedy, 2003) and adopted from Bhupander and Mukherjee (2011).

EF is the exposure frequency (day year^{-1}) or number of exposure events per year of exposure = 287 days per year, as described by (Little et al., 2002; Speedy, 2003) and adopted from Bhupander and Mukherjee (2011)

ED is the exposure duration for adult (year) = 30(USEPA, 2011).

RfD is the reference dose ($\mu\text{g g}^{-1} \text{day}^{-1}$) = 3×10^{-4} (USEPA, 2011)

BWa is the body wt of an adult (kg) = 56 as suggested by (Shukla et al., 2002) and adopted from Bhupander and Mukherjee (2011).

ATn is the averaging time, non-carcinogens (day year^{-1}) = 10950 (USEPA, 2011).

3. Results and discussion

3.1. Concentrations of As in water

Concentrations of As (mean and range) in bottom water, fish and periwinkle are provided in Table 2. Fig. 1 presents the mean spatio-temporal variation of As in bottom water from 15 sites on the Lagos lagoon. Arsenic levels in water varied from below detectable level to $4.0 \mu\text{g l}^{-1}$ (mean: 1.5 and 1.0; and $1.0 \mu\text{g l}^{-1}$ for wet and dry seasons, respectively) depicting

insignificant ($P < 0.05$) and irregular seasonal fluctuation. Generally, As contents in water samples were observed to be slightly higher during the wet season compared to the dry season although the differences were not significant. The result, however, shows a strong positive correlation ($R=0.768$; $P < 0.05$) between the examined wet and dry season samples. This may probably be due to loads of contaminants drained via rivers, streams, creek and residential areas that are in the vicinity of Lagos lagoon or related to the Lagoon water level. Consequently, samples from the western axis which receives municipal and domestic wastes had relatively higher levels while a significant decrease ($P < 0.05$) was observed in mean As levels towards the north-east sites (Fig. 1). The observed mean value for all sites examined ($1.3 \pm 0.16 \mu\text{g l}^{-1}$) was below the WHO limit of $10 \mu\text{g l}^{-1}$ as accepted by the SON's and the Federal Ministry of Environment. The value of As in Lagos lagoon surface water as investigated in this study was much higher than the value of $0.06 \mu\text{g l}^{-1}$ reported from Tuskegee Lake, in the United States (Ikem et al., 2003).

Similarly, other researchers reported levels of As lower than the WHO guideline value ($10 \mu\text{g l}^{-1}$) for uncontaminated underground waters in Nigeria and freshwater ecosystems in sub-Saharan Africa (Amori et al., 2013; Ouédraogo and Amyot, 2013; Oyem et al., 2015). However, Aderinola et al. (2009) reported a relatively higher mean content of As of up to $10 \mu\text{g l}^{-1}$ in the Lagos lagoon surface water while Atobatele and Olutona (2015) recorded concentrations of $1.5 \pm 0.22 \mu\text{g l}^{-1}$ in Aiba Reservoir, Iwo, Nigeria. Unlike this study, Egbinola and Amanambu (2014) and Kayode et al. (2011) reported very high concentrations of As ($> 275 \mu\text{g l}^{-1}$) in underground and surface waters from Ibadan, Oyo state and major towns in Ogun State, Nigeria. High As concentrations in water from wells and boreholes in the range of $20 \mu\text{g l}^{-1}$ to $810 \mu\text{g l}^{-1}$ in northern Nigeria were also documented (Garba et al., 2008; Garba et al., 2012b; Musa et al., 2008). These high concentrations of As were attributed to the disposal of As-containing materials, burning of solid wastes, natural processes, agricultural and other human activities (Garba et al., 2008; Garba et al., 2012b; Musa et al., 2008). Arsenic levels in

water samples from this study were much lower compared to reported concentrations of 23.8 $\mu\text{g l}^{-1}$ in surface waters close to abandoned mining area (Rapant et al., 2006) and 97.5 $\mu\text{g l}^{-1}$ for Manchar Lake (Arain et al., 2009).

3.2. Arsenic concentration and bioaccumulation in fish muscles and periwinkle

The mean concentration of As in fish muscles and periwinkle (0.79mg kg^{-1}), which ranged from below detection limit to 2.41mg kg^{-1} , was within the maximum limit (1.4mg kg^{-1}) of FAO/WHO (1983). The highest mean concentration for all examined biota (2.31mg kg^{-1}) was recorded in *Tympanotonus fuscatus*. The mean As contents for species of demersal fish ranged from $0.47\text{--}2.26\text{mg kg}^{-1}$ in *Liza falcipinnis* to $0\text{--}2.41\text{mg kg}^{-1}$, $0.25\text{--}2.27\text{mg kg}^{-1}$ and $0.21\text{--}1.41\text{mg kg}^{-1}$ in muscles of *Bathygobius soporator*, *Mugil cephalus* and *Chrysichthys nigrodigitatus*, respectively. Although spatial differences in mean As contents were observed in muscles of examined fish, there was no significant difference in the recorded values. The highest mean concentrations of 0.98mg kg^{-1} were observed in the muscle of *Liza falcipinnis* while the lowest mean content of As (0.67mg kg^{-1}) was recorded in *Chrysichthys nigrodigitatus*. None of the investigated fish samples exceeded the Food Standards Australia New Zealand (FSANZ) recommended value of 9.6mg kg^{-1} , dry wt As (assuming 79% moisture content). The concentrations of As detected in examined fish in this study varied widely in As content when compared to other studies (depending on the species and location).

The present result is similar to values for As in fish muscle from the Black Sea along Turkey's north coast recorded as ranging from 0.11 to 0.32mg kg^{-1} (Tuzen, 2009). Contrary to this report, a study from some sections of the Lagos lagoon showed that the finfish, *Oreochromis niloticus* ($0.36 \pm 0.42\text{mg kg}^{-1}$) and periwinkles (0.01mg kg^{-1}) accumulated relatively lower levels of As as compared to this study (Aderinola et al., 2009). Other published reports also reveal significant differences in As concentrations ranging from $2.0\text{--}14.8\text{mg kg}^{-1}$ in the muscles of fishes from Manchar Lake, Pakistan (Shah et al., 2009) to $3.01\text{--}3.90\text{mg kg}^{-1}$ and $4.70\text{--}14.90\text{mg kg}^{-1}$ total average As concentrations detected in culture and

wild sea breams from the coasts of Croatia, respectively (Rožič et al., 2014). In another study, it was indicated that average total As concentrations in striped marlin (*Tetrapturus audax*) and sailfish (*Istiophorus platypterus*) caught in the Gulf of California were 4.0 mg kg^{-1} and 5.1 mg kg^{-1} , respectively exceeding the international legal limit of 1 mg kg^{-1} , wet wt. (Soto-Jiménez et al., 2010).

The presence of As in fish has also been detected in several species such as sardine, chub mackerel, horse mackerel (Vieira et al., 2011), blue fish, carp, mullet tuna, and salmon (Castro-González and Méndez-Armenta, 2008). These results, including As concentration in muscle tissue of ten fish species from Bangshi River during pre-monsoon and post-monsoon seasons in the range of $1.97\text{--}6.24 \text{ mg kg}^{-1}$, dry wt basis (Rahman et al., 2012) were higher than the results obtained for demersal fish species in this study.

Arsenic level in muscles of different species of fish revealed significant differences between tissue concentrations ($p < 0.05$). A mostly negative ($r = -0.533$) but significant correlation was observed for As in *Mugil cephalus* and water during the wet season. Comparison of derived concentration factors confirmed that the bio-concentration factors based on As concentration in water samples was also the highest for *Tympanotonus fuscatus* and about five to seven times higher than bioaccumulation factors in demersal fish species (Table 2). The computed bio-concentration factors also show that the fish species and *Tympanotonus fuscatus* accumulated between 10 to 100 times more As when compared with the levels in water. It has been reported that the concentrations of toxic metals in water reflected a possible correlation between metal content of fish (Jalil Tariq et al., 1996). Atobatele and Olutona (2015) observed marked differences in As distribution in fish species from Aiba Reservoir, Iwo, Nigeria. They also noted that bagrid fishes of the genus *Chrysichthys* and *H. odoe*, a piscivore with a higher trophic status, have relatively lower levels of As in their systems (Atobatele and Olutona, 2015). From their report, the total As content in three cichlid species (*T. zillii*, *S. Galilaeus* and *O. niloticus*) was higher than two bagrid

species (*Chrysichthys nigrodigitatus* and *Chrysichthys auratus*) and piscivore *Hepsetus odoe* with a higher trophic status. These differences were largely attributed to their trophic level in the food chain. According to De Gieter et al. (2002), interspecies differences in As levels of fish are directly related to their food source and the fact that As is metabolized and does not seem to biomagnify along the food chain. The statistical tests such as normality and homogeneity for As in water and biota are presented in Table 3 which shows that chi-square goodness of fit test distribution is normal ($p > 0.05$) for As in water and biota. Bartlett's test (Table 3) also revealed that the distribution is non-homogeneous for As in water ($p < 0.05$) but homogeneous for As in biota ($p > 0.05$).

3.3. Risk estimation from human consumption of fish and periwinkle

The risk assessments in terms of human health revealed that none of the investigated species of fish exceeded the critical value of 1 which is the international guideline value except for the shellfish, *T. fuscatus*. Total As THQ derived from potential human consumption of fish caught in Lagos lagoon were within the 0.61 (*Chrysichthys nigrodigitatus*) to 2.11 (*T. fuscatus*) range in adults. The estimated THQ of As was found to be 0.61, 0.68, 0.89 and 0.78 through the consumption of *Chrysichthys nigrodigitatus*, *Mugil cephalus*, *Liza falcipinnis*, and *Bathygobius soporator*, respectively (Table 4). A THQ value of 0.61 for *Chrysichthys nigrodigitatus* was the lowest compared to other fish species. The obtained THQ does not underline any potential non-carcinogenic risk for human consumers. THQ values for risk assessment of As greater than 1 (1.22) were derived from the consumption of Tilapia (*Oreochromis mossambicus*) cultured in southwest Taiwan by Kar et al. (2011) while lower values for THQ which ranged between 0.1–0.5 for adults were obtained in a study by Copat et al. (2013) conducted in Italy. *Tympanotonus fuscatus* also recorded higher TR values (7.9×10^{-4}) when compared to values obtained for demersal fish species (Table 4).

Since the annual per capita fish consumption in African countries including Nigeria is usually above 20 kg per person, especially among people living in coastal communities, there is more chance of non-carcinogenic health outcomes being experienced due to increased fish consumption rate and frequency. As such, in contrast to the lower THQ values (0.61, 0.68, 0.89 and 0.78 for *Chrysichthys nigrodigitatus*, *Mugil cephalus*, *Liza falcipinnis*, and *Bathygobious soporator* respectively) obtained with a fish ingestion rate of 19.5g per day (Bhupander and Mukherjee (2011), significantly higher values of THQ for mean total As were derived as 2.54, 2.82, 3.75, 3.26 and 8.79 for *Chrysichthys nigrodigitatus*, *Mugil cephalus*, *Liza falcipinnis*, *Bathygobious soporator* and *Tympanotonus fuscatus*, respectively. In this computation as given by Osakwe et al. (2014), fish consumption was 68gday⁻¹ (i.e. fish consumption rate of an average Nigerian). Consumption at this rate and frequency suggests that people who regularly eat fish will experience increased adverse effects.

4. Conclusion

Lagos Lagoon was found to accumulate As in varying and sometimes very low but measurable concentrations throughout the study. While the concentrations of As in water, muscles of fish and shellfish were not uniformly distributed throughout the study period, they nonetheless revealed concentrations that were below action levels and guidelines for human consumption. Among all stations examined, those on the western axis contained the highest levels of As. Despite the relatively higher content of As recorded in *Tympanotonus fuscatus* as compared to other fish species examined, the observed levels in all fish samples were lower than the permissible levels in fish and shellfish as per FAO/WHO (1.4 mg kg⁻¹) and FSANZ set values (9.6 mg kg⁻¹, dry wt). In spite of these irregular concentrations between sites, fish and shellfish samples did not show elevated As concentrations relative to the observed spatio-temporal variations. However, exposure of people from the Lagos area to lower levels of As in these fish species may still pose a public health risk due to consumption of increased quantity of fish from the area.

In the present study, risk was not assessed for children who regularly consumed these species of fish. Therefore, further temporal studies that take into account risk to children, other commercially valuable fish resources and intake levels by human consumers are needed.

Acknowledgements

We extend our thanks for the laboratory support offered by the Centre for Environmental Risk Assessment and Remediation (CERAR), Mawson Lakes Campus of the University of South Australia, Adelaide. The first author is grateful to CRC CARE, Australia for the financial support which enabled her to conduct an analysis of samples in Australia as part of her PhD study.

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Table 1

Arsenic concentration in CRMs

CRM	Certified values	Observed values (n=4)	% Recovery
NIST 1640a($\mu\text{g l}^{-1}$)	26.67 ± 0.41	25.36 ± 1.42	95.1
DORM-3(mg kg^{-1} , dry weight)	6.88 ± 0.30	6.61 ± 0.43	96.1

Table 2
Concentrations (mean, median, and range) of As in water, sediment and bioaccumulation in fish species and shellfish

Parameter	Water ($\mu\text{g/l}$), n=75		Edible biota (mg/kg), dry weight				
	Wet season	Dry season	<i>Chrysichthys nigrodigitatus</i>	<i>Mugil cephalus</i>	<i>Liza falcipinnis</i>	<i>Bathygobius soporator</i>	<i>Tympanotonus fuscatus</i>
Number of samples			22	16	14	12	24
Mean $\pm$ SE	1.54 $\pm$ 0.22	1.04 $\pm$ 0.21	0.67 $\pm$ 0.08	0.74 $\pm$ 0.12	0.98 $\pm$ 0.15	0.86 $\pm$ 0.23	2.31 $\pm$ 0.25
Range	00.4- 2.90	0.2- 3.40	0.21- 1.41	0.25-2.27	0.47-2.26	0-2.41	0-5.2
BW/AF			514.3	569.7	757.2	658.3	1776.9

*BW/AF: Bio-water accumulation factor

Table 3

Statistical tests (normality and homogeneity) for water and biota

Parameters	Number of samples	Chi-square goodness of fit test (normality)			Bartlett's test (homogeneity)		
		chi2stat	df	P value	bartstat	Df	P value
Arsenic in water	75	3.0004	2	0.0832	16.5897	3	0.0009
Arsenic in biota	88	0.1127	3	0.0604	6.6926	4	0.1531

chi2stat – Chi-square statistics; df- degree of freedom; bartstat: Bartlett's statistics

Table 4Estimated target hazard quotients (THQ) and target cancer risk (TR) and estimated daily intake (EDI) of As in fish species and *Tympanotonus fuscatus*

Fish species	Mean concentration (mg/kg dry wt.)	EDI	THQ ^a	TR ^a	THQ ^b	TR ^b
<i>Chrysichthys nigrodigitatus</i>	0.67	0.65	0.61	1.2 x 10 ⁻⁴	2.54	7.63 x 10 ⁻⁴
<i>Mugil cephalus</i>	0.74	0.72	0.68	1.3 x 10 ⁻⁴	2.82	8.46 x 10 ⁻⁴
<i>Liza falcipinnis</i>	0.98	0.96	0.89	1.7 x 10 ⁻⁴	3.75	1.12 x 10 ⁻³
<i>Bathygobius soporator</i>	0.86	0.84	0.78	1.5 x 10 ⁻⁴	3.26	9.77 x 10 ⁻⁴
<i>Tympanotonus fuscatus</i>	2.31	2.26	2.1	3.9 x 10 ⁻⁴	8.79	2.64 x 10 ⁻³

^aRisk estimation assumption values as reported by Bhupander and Mukherjee (2011)^bRisk estimation assumption values as reported by (Osakwe et al., 2014)

Figure caption

Fig.1. Study area, sampling sites and spatio-temporal variations in As levels in bottom water of Lagos Lagoon during the wet and dry seasons.

Highlights

- Concentrations of arsenic in water, sediment, fish and periwinkle
- Distribution pattern influenced by adjoining land based activities
- Potential health risk estimated by comparing USEPA/WHO values
- Relatively higher arsenic levels in *Tympanotonus fuscatus* with THQ 1