EXAMINING THE CARCINOGENIC AND NON-CARCINOGENIC HEALTH RISKS ASSOCIATED WITH HEAVY METALS EXPOSURE FROM THE CONSUMPTION OF ANCHOVIES (*ENGRAULIS ENCRASICOLUS* - LINNAEUS, 1758)

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ABSTRACT
The primary objective of this study was to determine the concentrations of Lead (Pb), Mercury (Hg), Cadmium (Cd), and Arsenic (As) in fresh, sun-dried, and smoked European anchovy (*Engraulis encrasicolus*) from the Tema Fishing Harbour in Ghana. Additionally, the study assessed the associated human health risks among various age groups. This investigation was conducted in response to the widespread consumption of these fish due to their high affordability. Hg concentrations in the fish samples were measured using the Direct Mercury Analyzer (DMA 80), while Pb, As, and Cd concentrations were determined using Atomic Absorption Spectroscopy (AAS) Varian-AS245, following homogenization of the samples with a high-speed stainless-steel blender. Fresh fish samples recorded the highest concentrations of Pb (0.946 ± 0.122 mg/kg) and As (0.71 ± 0.08 mg/kg), while dried fish had the highest Hg concentration (0.034 ± 0.003 mg/kg). Cadmium levels were below the detection limit in all fish samples. The metal concentrations were within the safety limits established by the EU, FAO, and USEPA except for lead in fresh fish. For human health risk assessments, the Estimated Daily Intake (EDI) values were also within the Joint FAO/WHO Expert Committee limits, except for toddlers and children aged 4-6 years, where the values exceeded these limits. The Target Hazard Quotient (THQ), and Hazard Index (HI) values were below 1, likewise the Target Carcinogenic Risks (TR) values were also within recommended limits, suggesting that the population is not at risk of significant carcinogenic or non-carcinogenic health effects from consuming this fish. However, to better protect vulnerable age groups, it is highly recommended to limit the inclusion of this fish species in the diets of toddlers and children.

Keywords: Heavy metals, Anchovy, human health risks, *Engraulis encrasicolus*

Introduction

Heavy metals are naturally occurring components of the Earth's crust that enter the environment through processes such as volcanic activity, weathering of rocks, surface runoff, and atmospheric deposition, as well as through anthropogenic activities like untreated waste discharge, mining, and oil spills (Lanaka, 2006; Mendil *et al*., 2010). In Ghana, industrial and agricultural production, urban and coastal development, tourism, and mining contribute significantly to environmental pollution (Botwe, 2018).

Fish is a vital source of protein and essential fatty acids, contributing to key functions such as brain development in human (Irish Sea Fisheries Board, 2005; Duran *et al*., 2014). This nutritional value has led to increased fish consumption globally, including in Ghana, where fish, particularly European anchovy, is widely consumed due to its affordability. Anchovy is typically eaten fresh, sun-dried, or smoked.

However, the conditions under which fish is handled, processed, stored, and marketed in Ghana are often unsatisfactory, leading to contamination by pathogens, rodents, and heavy metals (Aboagye, 2016). Heavy metals can bioaccumulate and biomagnify in fish, posing health risks to humans who consume them in excessive amounts (Ahmed *et al*., 2015; Akoto *et al*., 2014; Bandowe *et al*., 2014).

Although heavy metals such as Hg, Pb, As, and Cd have no known biological role, excessive intake can lead to severe health effects. Hg can disrupt the nervous system and cause brain damage, while Pb can lead to anaemia, reduced fertility, and cognitive impairment. As exposure increases cancer risk and impairs blood cell production, and Cd exposure is linked to high blood pressure, liver disease, and neurological damage (Agusa *et al*., 2005; Hajeb *et al*., 2009; Lenntech, 2018). Human health risk assessment evaluates the extent, nature, and likelihood of adverse health effects in individuals exposed to pollutants in contaminated environments. Human health risk assessments are therefore crucial for evaluating the potential risks of consuming contaminated aquatic resources. The USEPA (2014) defines human health risk assessment as the process of characterizing potential health risks to humans due to environmental hazards. It is currently one of the most effective methods for analyzing the potential risks of human exposure to heavy metals and offering crucial insights for public health researchers and policymakers to reduce risks within affected populations. Typically, the health risk assessment of each pollutant in fish is conducted according to a specific risk assessment framework and is categorized as either carcinogenic or non-carcinogenic (Peng *et al*., 2016, cited in Yi *et al*., 2017). The USEPA has established a methodology for assessing both the carcinogenic and noncarcinogenic effects of heavy metals. Carcinogenic risks are assessed by comparing exposure levels with adverse effect thresholds, while non-carcinogenic risks are determined using the Target Hazard Quotient (THQ) model, which estimates the risk level associated with daily exposure over a lifetime (Solomon *et al*., 2013; Li & Zhang, 2010, cited in Yi *et al*., 2017; Sultana *et al*., 2017).

The study site, Tema fishing harbour is known for heavy industrial activities, and hence exposure to heavy metals through various means (air, water and fish) is a high possibility but this remains a serious knowledge gap as no published studies on the health risks associated with fish landed from this site has been conducted. This study was therefore aimed at evaluating the potential of both carcinogenic and non-carcinogenic risks posed to children and adult Ghanaians through the consumption of anchovies, a highly affordable and widely consumed fish, landed from the main fishing harbor in the capital town of Ghana.

Experimental

Study Area

The Tema Harbour is located in the southeastern part of Ghana, along the Gulf of Guinea. The harbor is divided into two sections, the fishing area and the main shipping port (Ghana Ports and Harbours Authority, 2016). The harbour is a major good transport point for the country as well as land-locked countries at the north of Ghana. Tema harbour is noted for heavy industrial activities due to the location of many companies around it. These companies discharge their industrial wastes into water ways which eventually enters the sea (Nyarko *et al*., 2011). Also, shipping activities at the Tema Harbour introduces pollutants into the coast through oil spillage and leakage during the discharge of oil for transportation to the Tema Oil Refinery at the oil berth (Nyarko *et al*., 2011).

Fish Sample Collection

Fish samples (fresh, dried and smoked) were obtained from the Tema Fishing Harbour area. The fresh samples were bought from fishermen immediately after capture and preserved with ice, however, smoked and dried samples were bought at the open fish market inside the Tema Fishing Harbour. The samples were immediately transported to the Department of Marine and Fisheries Sciences, University of Ghana for laboratory analysis.

Sample Preparation for Heavy Metal Analysis

Length and weight measurements of the fresh fish samples were taken to estimate the fish condition factor. For the heavy metal analysis, whole fish samples were used instead of the flesh or any other edible parts because anchovies are mostly consumed whole. Fresh, dried and smoked samples were each divided into four components (representing each analyte- As, Hg, Cd, and Pb). For each component of the fresh, dried and smoked samples, 200g was weighed and oven dried at 40°C for 48h. The oven dried samples were homogenized in a high-speed stainless-steel blender. Homogenized samples for fresh, smoked and dried fish were stored in sample tubes for heavy metal analysis.

Mercury concentration was analyzed in the fish samples using the Direct Mercury Analyzer DMA-80 at the Department of Marine and Fisheries Sciences. Four portions of each sample (fresh, smoked and dried) were scooped into sampling boats and exactly 0.2 g of each portion was measured. Arsenic, Cadmium and Lead samples were analyzed using the Atomic Absorption Spectroscopy AAS Varian- AS245 at the Ghana Atomic Energy Commission.

Human Health Risk Assessment

Estimated Daily Intake of Metal

The dietary exposures of heavy metals for different age groups were estimated using the average concentrations of the heavy metals in the fish samples. The age groups assessed include: toddlers 1-3 years (14 kg), children 4-6 years (21 kg), children 6-11 years (31 kg), adolescents 12-19 years (67 kg), adults >19 years (77 kg) (Kail, 2011). The estimated amount of heavy metals consumed in a day by the target population (various age groups) was compared with the current provisional tolerable daily intake suggested by the Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2009). According to Copat *et al*. (2012), the estimated daily intake of each metal for fish consumption for the various age groups is calculated using the equation:

$$EDI = FIR \times C \; BWa$$

Where: FIR is the fish ingestion rate which is 72g/person/day for Ghana (FAO, 2016), C is the metal concentration in fish (μg w.w) and Bw is the average body weight of the targeted age groups ranging from14 kg-77 kg.

Non-carcinogenic Risk

The non-carcinogenic risk of consuming heavy metals through fish was estimated using the Target Hazard Quotient THQ (USEPA, 1989). THQ is the ratio of a single substance exposure level over a specific period to a reference dose for that substance derived from a similar exposure period (USEPA, 1989). The THQ was estimated using the formula:

$$THQ = EF \times ED \times FIR \times C \; Rfd \times WAB \times TA \times 10^{-3}$$

Where: EF is exposure frequency (365 days/year); ED is exposure duration for the 9 different age categories. FIR is the fresh food ingestion rate (fish = 76.7 g/person/day) (FAO, 2016); C is the metal concentration in fish (μg/g ww); Rfd is the oral reference dose which represents an estimation of the daily exposure to which human population may be continually exposed to a contaminant over a lifetime without an appreciable risk of deleterious effects. The oral reference doses of 0.003, 0.0003, 0.001 and 0.0035 mg/kg/day for Hg, As, Cd and Pb, respectively (USEPA, 2000) were used in estimating the THQ.WAB is the average body weight and TA is the average exposure time for noncarcinogens (365 days/year × ED). In estimation of THQ, it is assumed that the ingestion dose is equal to the adsorbed contaminant dose and that cooking has no effect on the contaminants. In estimating THQ, the Rfd is used as a threshold to determine whether a population will be at risk of any adverse health effect. Therefore, if THQ value is less than 1, it means that your daily intake is less than the oral reference dose, which implies that the population will not face an adverse health effect. However, if THQ value is above 1, it means that the daily intake is above the oral reference dose, which implies that the population will face an adverse health effect.

Hazard Index

The Hazard Index HI is the summation of all the THQ for each metal under study (USEPA, 2011). HI gives a cumulative risk of heavy metal contamination in fish. If HI is greater than 1, it implies that there will be an adverse health effect due to consumption of that fish sample. However, if HI is less than 1, it implies that consumption of the fish will not cause an adverse health effect. HI is expressed as:

HI= THQ (Hg) +THQ (Cd) +THQ (As) +THQ (Pb).

Carcinogenic Risk (TR)

For estimating the possibility of developing cancer through fish consumption, the carcinogenic risk TR was used. Carcinogenic risks are estimated as the incremental probability of an individual to develop cancer, over a lifetime, as a result of exposure to that potential carcinogen (i.e., incremental or excess individual lifetime cancer risk; USEPA, 1989). A TR value between 10−6 and 10−4 is unacceptable while a TR value less than 10−4 has the potential to cause carcinogenic health effect. TR was calculated using the equation:

TR = $EF \times ED \times FIR \times C \times CSFo\ BW \times TA$

Where: TR = a unit less probability of an individual developing cancer over a lifetime and CSFo is the oral carcinogenic slope factor from the Integrated Risk Information System (USEPA, 2010) database, which is 1.5 (mg/kg/day) for Arsenic and 8.5× 10−3 (mg/kg/day) for Lead. CSFo is however not available for other metals. THQ and TR consumption limits calculations for arsenic were made on the assumption that the toxic inorganic arsenic was 3% of total arsenic (Storelli *et al*., 2003; Copat *et al*. 2013).

Statistical analysis

The data were statistically analyzed using the statistical package, Microsoft excel analysis tool pack. The means and standard deviations of the metal concentrations in fish species were calculated. Multivariate post hoc Tukey tests were employed to examine the statistical significance of the differences among mean concentrations of trace metals among the fresh, dried and smoked fish samples for each metal.

Results and discussion

Concentration of Heavy Metals in Fish

Concentration of heavy metals in smoked, dried and fresh *Engraulis encrasicolus* were determined and their mean and standard deviations are shown in Table 1. Cadmium was not detected in all samples because it was below detection limit (<0.002 µg/g). All other metals, arsenic, mercury and lead, were detected in all three analyzed samples. Fresh fish samples recorded the highest concentrations for all metals except mercury, where dried fish samples recorded the highest concentration. Smoked fish samples recorded the lowest concentrations across all metals.

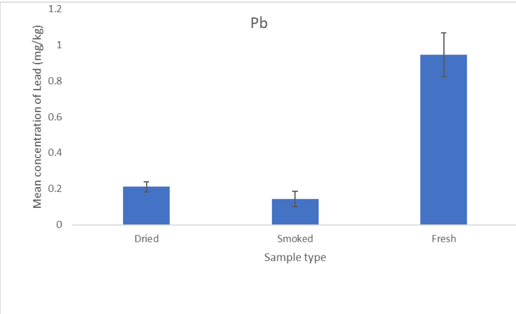

Fig. 1: Mean concentration of lead in dried, smoked and fresh *E. encrasicolus.* (Error bars are standard deviations).

Fig 1 shows the mean concentrations of lead estimated in the dried, smoked and fresh fish samples. The concentrations of lead ranged from 0.144 – 0.946 mg/kg, with smoked fish samples recording the lowest concentration, followed by dried fish then fresh fish, recording the highest lead concentration. Using one-way ANOVA, there was a significant difference ($p= 0.00$) among the three sample types. Post hoc analysis (using tukey test) showed significant differences between fresh fish and the other fish samples.

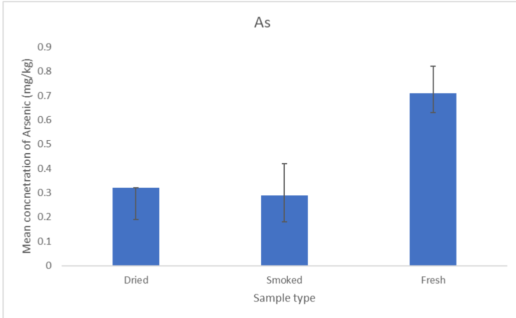

Fig. 2: Mean concentration of arsenic in dried, smoked and fresh *E. encrasicolus.* (Error bars indicate standard deviations).

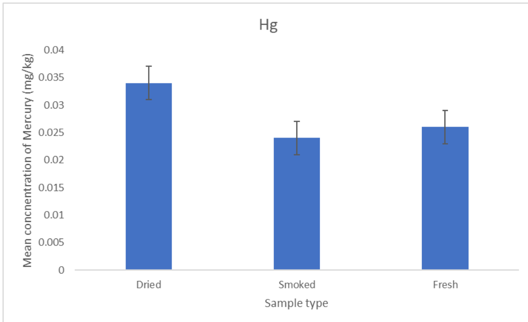

Fig. 3: Mean concentration of mercury in dried, smoked and fresh *E. encrasicolus.* (Error bars indicate standard deviations).

The mean concentration of arsenic in dried, smoked and fresh fish are shown in Fig. 2. Arsenic concentrations ranged from 0.29 – 0.71 mg/kg, with smoked fish samples recording the lowest concentration, followed by dried fish then fresh fish recording the highest concentration. There was significant difference ($p= 0.00$) among the three samples. Again, post hoc analysis using tukey test showed significant differences between fresh, dried and smoked fish.

Mean concentrations of mercury among smoked, dried and fresh fish samples ranged from 0.024 – 0.034 mg/kg. Smoked fish recorded the lowest concentration of mercury, followed by fresh fish then dried fish, recording the highest concentration with significant difference (p= 0.03) among the three treatments.

As an objective for this study, the concentrations of lead, arsenic, mercury and cadmium were determined in processed and unprocessed European anchovy, *Engraulis encrasicolus.* Lead concentrations ranged from 0.144 – 0.946 mg/kg, which was within the permissible limits of 0.3mg/kg and 0.5 mg/kg for lead concentrations in smoked and dried fish but above limits for fresh fish as given by FAO (1983) and EU (2006) respectively. The concentrations of arsenic (0.20 – 0.71 mg/kg) were below the permissible limit (1.75 mg/kg) for arsenic concentration in fish as recommended by USEPA (1998). The concentration of mercury was also less than the permissible limit of 0.5 mg/kg by the EU because the values recorded were between 0.024 mg/kg and 0.034 mg/kg. Cadmium, however, was below detection limit across all samples, <0.002 mg/kg. This implies that from this study, the public is not at any health risk from the consumption of *Engraulis encrasicolus* whether in the dried or smoked state as sold from the Tema fishing harbour. However, fresh fish could pose health risks to the public due to the high concentration of lead recorded in fresh fish.

In order of increasing concentrations, the heavy metals across fish samples recorded fresh fish> dried fish> smoked fish. Increased metal concentration in fresh fish can be attributed to anthropogenic activities along Ghana's coast such as oil exploration, use of chemicals in fishing, deposition of industrial wastes, and illegal mining activities. (Bandowe *et al*., 2014; Akoto *et al.,* 2014; Botwe, 2018) which pollutes the environment of fishes. Also, observed lower levels of heavy metals, As and Pb, in dried and smoked fish as compared to fresh fish was due to the processing techniques (drying and smoking) which require high temperatures and may lead to changes in the chemical forms of the metals or dissociate them from the fish proteins (Bala *et al.,* 2018). Ganjavi *et al.* (2010) also reported that the reduction in metal concentration during processing is related to the decrease in protein content and the release of heavy metals as free salts with the loss of water. Mercury concentration however was higher in dried fish than fresh and smoked fish. This could be attributed to the drying techniques such as open sun drying, mostly done on the ground (Gordon *et al.*, 2011), which introduces dust and other contaminants on the fish (Abboah-Offei, 2016; Sabo, 2018). Also, after drying, ambient exposure of dried fish to contaminants containing elemental heavy metals released in the air by factories close to the Tema harbour market and fumes from the nearby highway can contaminate the fish (Abboah-Offei, 2016).

From the concentration of heavy metals observed in this study, all heavy metals were within tolerable limits except lead in fresh fish. However, the toxicity of these metals depends on the amount that is consumed by the population over time.

TABLE 1

Mean concentrations of heavyrace metals in dried, smoked and fresh E. encrasicolus (The error values are standard deviations).

Sample	Pb (mg/kg)	As (mg/kg)	Hg (mg/kg)
Dried	0.211±0.028	0.32±0.13	0.034±0.003
Smoked	0.144±0.043	0.29±0.11	0.024±0.003
Fresh	0.946±0.122	0.71±0.08	0.026±0.003

Estimated Daily Intake of Heavy Metals

Table 2 shows the daily intake of trace metals through the consumption of dried, fresh and smoked *E. encrasicolus*. There was an observed decrease in EDI from toddlers to adults for all the metals under study. For lead, EDI ranged from 0.133 in smoked fish to 4.798 in fresh fish. Arsenic EDI values ranged from 0.267 in smoked fish to 3.601 in fresh fish. Mercury had EDI values ranging from 0.022 in smoked fish to 0.172 in dried fish.

The Estimated Daily Intake- EDI depends on the concentration of metals and the amount of fish ingested by the population (Copat *et al.*, 2012). Results from the EDI were compared with the Provisional Maximum Tolerable Daily Intake (PMTDI) suggested by the joint FAO/WHO Expert Committee on Food and Additive (JECFA, 2009). EDI for As was between 0.267 – 3.601 mg/kg/person/day across the entire population. EDI values were within permissible limits, except for toddlers and children (4-6 years) for fresh fish consumption which exceeded the PMTDI limit of 2.14 mg/person/day for arsenic. EDI values for Hg ranged between 0.022 – 0.132 mg/person/day for the entire study population which was below the PTMDI value for Hg (0.57mg/person/day). Therefore, none of the age groups was at risk of any potential health threat for Hg. In the case of Pb, EDI values were between 0.133 – 4.798 mg/person/day for the entire study population. All values were within PMTDI limits of 3.57mg/person/day, except for toddlers and children (4-6 years). The high PMTDI in children has been noted to be a common occurrence with regards to heavy metals exposure through ingestion from different studies especially in developing countries (Wahil et at. 2020; Zhang *et al*. 2019; Alidadi *et al*. 2019). This high vulnerability of children as compared to adults may be attributed to the fact that children generally have underdeveloped organ systems and hence, limited ability to metabolize dangerous chemicals at a young age.

TABLE 2

Estimated daily intake (EDI) of Pb, As and Hg through the consumption of dried, smoked and fresh E. encrasicolus from the coastal waters of Ghana.

Age group	**Estimated daily intake (mg/person/day)**		
Dried fish	**Pb**	**As**	**Hg**
Toddlers 1-3 years	1.156	1.753	0.186
Children 4-6 years	0.771	1.169	0.124
Children 6-11 years	0.522	0.792	0.084
Adolescent 12-19 years	0.242	0.366	0.039
Adult >19 years	0.210	0.319	0.034
Smoked fish	**Pb**	**As**	**Hg**
Toddlers 1-3 years	0.789	1.589	0.131
Children 4-6 years	0.526	1.059	0.088
Children 6-11 years	0.356	0.718	0.059
Adolescent 12-19 years	0.165	0.332	0.027
Adult >19 years	0.143	0.289	0.024
Fresh fish	**Pb**	**As**	**Hg**
Toddlers 1-3 years	5.183	3.890	0.142
Children 4-6 years	3.455	2.593	0.095
Children 6-11 years	2.341	1.757	0.064
Adolescent 12-19 years	1.083	0.813	0.030
Adult >19 years	0.942	0.707	0.026

Target Hazard Quotient of Heavy Metals

Table 3 shows the target hazard quotient and hazard index for heavy metals across all age groups. There was an observed decrease in THQ and HI values from toddlers to adults across all metals. THQ and HI values ranged from 0.001 in smoked fish to 0.024 in fresh fish for lead. Arsenic recorded THQ values ranging from 0.027 in smoked fish to 0.362 in fresh fish. Mercury THQ values ranged from 0.075 in smoked fish to 0.575 in dried fish. The lowest HI value was recorded in smoked fish as 0.102 and the highest value was recorded in fresh fish as 0.826.

Target Hazard Quotient (THQ) was used to estimate non-carcinogenic health effect due to consumption of fish by a population. A THQ greater than one (1) means that a population will face an adverse health effect from the consumption of fish and a THQ less than 1 means that there will be no adverse effects. All the THQ values estimated in this study were less than 1 for all metals across all age groups. Bandowe *al.* (2014) also obtained a similar result of THQ less than 1 for fish species from Tema. Therefore, the Ghanaian population does not face any adverse non-carcinogenic health effects, (health effects either than cancer), from the consumption of *Engraulis encrasicolus*. Hazard Index (HI) estimates the combined effect resulting from multiple trace metal consumption of a fish species. If it exceeds 1, it implies that exposure or consumption of that fish species may result in some non-carcinogenic health effects, such as reduced learning abilities in children, disruption of the nervous system, damage to brain functions, DNA and chromosomal damage, allergic and reproductive effects (Lenntech, 2018), and vice versa. The estimated HI from this study was less than 1 across all age groups, indicating that none of the age groups will face any adverse non carcinogenic health effect through the consumption of *Engraulis encrasicolus*.

Target Cancer Risk of Heavy Metals

Target risk (TR) estimates the cancer-causing risk of an analyte. TR values were estimated for Pb and As. In the case of As, inorganic arsenic was used in the estimation of its target risk. Although Hg has the potential of causing cancer, its TR was not estimated because the Oral Carcinogenic Slope Factor (CSFo) has not been established for Hg (USEPA, 2010). Table 4 shows the target cancer risk for Pb and As. For lead, the highest TR value was recorded in fresh fish as 2.01×10^{-6} and the lowest value was recorded in smoked fish as 8.87×10^{-8}. Similarly, the highest TR value for As was recorded in fresh fish as 8.04×10^{-6} and the lowest value was recorded in smoked fish as 6.28×10^{-7}.

To cause cancer, TR values should be above 10^{-4} (USEPA, 2010). All the TR values estimated in this study, for both inorganic As and Pb were below 10^{-4}, meaning that, the age groups are not at risk of any carcinogenic health risk through the consumption of the fish.

TABLE 3

Target hazard quotient (THQ) for Pb, As, Hg and their hazard index (HI) from the consumption of dried, smoked and fresh E. encrasicolus from the coastal waters of Ghana.

Age group	**Target Hazard Quotient**			**Hazard Index**
Dried fish	**Pb**	**As**	**Hg**	**HI**
Toddlers 1-3 years	0.006	0.177	0.624	0.807
Children 4-6 years	0.004	0.118	0.416	0.538
Children 6-11 years	0.003	0.080	0.028	0.111
Adolescent 12-19 years	0.001	0.037	0.130	0.169
Adult >19 years	0.001	0.032	0.113	0.147
Smoked fish	**Pb**	**As**	**Hg**	**HI**
Toddlers 1-3 years	0.004	0.159	0.445	0.608
Children 4-6 years	0.003	0.106	0.297	0.405
Children 6-11 years	0.002	0.072	0.020	0.094
Adolescent 12-19 years	0.001	0.033	0.093	0.127
Adult >19 years	0.001	0.029	0.081	0.111
Fresh fish	**Pb**	**As**	**Hg**	**HI**
Toddlers 1-3 years	0.026	0.393	0.477	0.896
Children 4-6 years	0.017	0.262	0.318	0.597
Children 6-11 years	0.012	0.177	0.022	0.211
Adolescent 12-19 years	0.005	0.082	0.100	0.187
Adult >19 years	0.005	0.071	0.087	0.163

TABLE 4

Target Cancer Risk (TR) of Pb and As from consumption of dried, smoked and fresh E encrasicolus collected from the coastal waters of Ghana.

Age group	Target carcinogenic risk	
Dried fish	**Pb**	**As**
Toddlers 1-3 years	1.41×10^{-7}	7.60×10^{-7}
Children 4-6 years	3.76×10^{-7}	3.04×10^{-6}
Children 6-11 years	3.82×10^{-7}	3.09×10^{-6}
Adolescent 12-19 years	3.54×10^{-7}	2.86×10^{-6}
Adult >19 years	4.87×10^{-7}	3.94×10^{-6}
Smoked fish	**Pb**	**As**
Toddlers 1-3 years	9.62×10^{-8}	6.81×10^{-7}
Children 4-6 years	2.56×10^{-7}	2.72×10^{-6}
Children 6-11 years	2.60×10^{-7}	2.77×10^{-6}
Adolescent 12-19 years	2.41×10^{-7}	2.56×10^{-6}
Adult >19 years	3.32×10^{-7}	3.53×10^{-6}
Fresh fish	**Pb**	**As**
Toddlers 1-3 years	6.33×10^{-7}	1.68×10^{-6}
Children 4-6 years	1.69×10^{-6}	6.73×10^{-6}
Children 6-11 years	1.71×10^{-6}	6.84×10^{-6}
Adolescent 12-19 years	1.58×10^{-6}	6.33×10^{-6}
Adult >19 years	2.18×10^{-6}	8.72×10^{-6}

Conclusions

Concentration of heavy metals in smoked, sun-dried and freshly caught *Engraulis encrasicolus* were all within acceptable limits. Therefore, *E. encrasicolus* (anchovies) from Tema harbour are safe for consumption, as the public particularly those within the age groups of (Children 6-11 years, Adolescent 12-19 years and Adult >19 years) per this study, will not be at risk of any carcinogenic or non-carcinogenic effects through its consumption. However, minimizing the input of this species of fish in the feed of toddlers and children (4-6 years) is highly recommended, as the estimated daily intake of Pb and As in the fresh fish was not safe for this age group.

References

ABBOAH-OFFEI, O. (2016). *Analysis of Heavy Metal Concentrations in Smoked Fish from the Major Food Markets in the Accra-Tema Metropolis* (Doctoral dissertation, University of Ghana).

AGUSA, T., KUNITO, T., YASUNAGA, G., IWATA, H., SUBRAMANIAN, A., ISMAIL, A., & TANABE, S. (2005). Concentrations of trace elements in marine fish and its risk assessment in Malaysia. *Marine pollution bulletin*, ***51*** (8-12), 896-911.

AHMED, M. K., BAKI, M. A., ISLAM, M. S., KUNDU, G. K., HABIBULLAH-AL-MAMUN, M., SARKAR, S. K., & HOSSAIN, M. M. (2015). Human health risk assessment of heavy metals in tropical fish and shellfish collected from the river Buriganga, Bangladesh. *Environmental* *science and pollution research*, ***22*** (20), 15880-15890.

AKOTO, O., DARKO, G., ADEI, E. & BISMARK ESHUN, F. (2014). Concentrations and Health risk assessments of heavy metals in fish from the Fosu lagoon, *International Journal of Environmental Research*, **8** (2):403-410.

ALIDADI H., TAVAKOLY SANY S.B., ZARIF GARAATI OFTADEH B., MOHAMAD T., SHAMSZADE H., FAKHARI M. (2019). Health risk assessments of arsenic and toxic heavy metal exposure in drinking water in northeast Iran. *Environ. Health Prev. Med.* **24**, 59. doi: 10.1186/s12199-019-0812-x Arsenic

BALA, F. E., IKUJENLOLA, A. V., & OMOBUWAJO, T. O. (2018). Effect of processing on the heavy metal contents of Sarotherodon galilaeus, Tilapia zillii, and Clarias gariepinus from two water bodies in Osun State, Nigeria. *Journal of Food Processing and Preservation*, ***42*** (2), e13493. https://doi.org/10.1111/jfpp.13493

BANDOWE, B. A. M., BIGALKE, M., BOAMAH, L., NYARKO, E., SAALIA, F. K., & WILCKE, W. (2014). Polycyclic aromatic compounds (PAHs and oxygenated PAHs) and trace metals in fish species from Ghana (West Africa): bioaccumulation and health risk assessment. *Environment international*, ***65***, 135-146.

BANK OF GHANA (BOG), (2008). The Fishing Sub-Sector and Ghana's Economy. Research Department BOG: Accra, 40 pp.

BOTWE, B. O. (2018). *Sediments in the Tema Harbour (Ghana): chemical pollution and sedimentation rates*. CRC Press.

COPAT, C., ARENA, G., FIORE, M., LEDDA, C., FALLICO, R., SCIACCA, S., & FERRANTE, M. (2013). Heavy metals concentrations in fish and shellfish from eastern Mediterranean Sea: consumption advisories. *Food and Chemical Toxicology*, ***53***, 33-37.

COPAT, C., BELLA, F., CASTAING, M., FALLICO, R., SCIACCA, S., & FERRANTE, M. (2012). Heavy metals concentrations in fish from Sicily (Mediterranean Sea) and evaluation of possible health risks to consumers. *Bulletin of Environmental Contamination and Toxicology*, ***88*** (1), 78-83.

DURAN, A., & TUZEN, M. (2014). Assessment of trace metal concentrations in muscle tissue of certain commercially available fish species from Kayseri, Turkey, ***186*** (7), 4619–4628. https://doi.org/10.1007/s10661-014-3724-7

EPA, U. (2000). *Guidelines for preparing economic analyses*. EPA 240-R-00-003.. Washington, DC, US Environmental Protection Agency.

EUROPEAN UNION, (2006). Setting maximum levels for certain contaminants in foodstuffs, Commission Regulation (EC) No 1881/2006; OJ L **364**, 20.12.2006, p. 5

FAO Fisheries & Aquaculture - Fishery and Aquaculture Country Profiles - The Republic of Ghana. (2016). Retrieved October 1, 2018, from http://www.fao.org/fishery/facp/GHA/en

FAO, (1983). Compilation of legal limits for hazardous substances in fish and fishery products. Food and Agriculture Organization, FAO Fish Circ., **464**, 5-100.

FOOD AND AGRICULTURE ORGANIZATION AND WORLD HEALTH ORGANIZATION, (FAO/WHO). (2011). Joint FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods, fifth session, 64-89 pp.

GHANA PORTS & HARBOURS AUTHORITY :: Fishing Harbour. (n.d.). Retrieved February 12, 2019, from https://ghanaports.gov.gh/page/17/Fishing-Harbour

GORDON, A., PULIS, A., & OWUSU-ADJEI, E. (2011). Smoked marine fish from Western Region, Ghana: a value chain assessment.

HAJEB, P., JINAP, S., ISMAIL, A., FATIMAH, A. B., JAMILAH, B., & RAHIM, M. A. (2009). Assessment of mercury level in commonly consumed marine fishes in Malaysia. *Food control*, ***20*** (1), 79-84.

IRISH SEA FISHERIES BOARD. (2005). Nutritional aspects of fish. Dublin: Bord Iascaigh Mhrara.

KAIL, R. V. (2011). Children and their development 6th ed (Mydevelopmentlab Series).

LI, S., & ZHANG, Q. (2010). Risk assessment and seasonal variations of dissolved trace elements and heavy metals in the Upper Han River, China. *Journal of Hazardous Materials*, ***181*** (1-3), 1051-1058.

MENDIL, D., ÜNAL, Ö. F., TÜZEN, M., & SOYLAK, M. (2010). Determination of trace metals in different fish species and sediments from the River Yeşilırmak in Tokat, Turkey. *Food and Chemical Toxicology*, (5), 1383-1392.

NYARKO, E., & KLUBI, B. E. (2011). Polycyclic Aromatic Hydrocarbons (PAHs) Levels in Two Commercially Important Fish Species from the Coastal Waters of Ghana and their Carcinogenic Health Risks. *West African Journal of Applied Ecology*, ***19*** (1). Retrieved from https://www.ajol.info/index.php/wajae/article/view/77566

PENG, Q., NUNES, L. M., GREENFIELD, B. K., DANG, F., & ZHONG, H. (2016). Are Chinese consumers at risk due to exposure to metals in crayfish? A bioaccessibility-adjusted probabilistic risk assessment. *Environment international*, ***88***, 261-268.

SOLOMON, K. R., GIESY, J. P., LAPOINT, T. W., GIDDINGS, J. M., & RICHARDS, R. P. (2013). Ecological risk assessment of atrazine in North American surface waters. *Environmental toxicology and chemistry*, ***32*** (1), 10-11.

STORELLI, M. M., GIACOMINELLI, S. R., STORELLI, A. & MARCOTRIGIANO, G. O. (2003). Total mercury and methylmercury content in edible fish from the Mediterranean Sea, *Journal of Food Protocol*, **66** (2), 3-300.

SULTANA, M. S., RANA, S., YAMAZAKI, S., AONO, T., & YOSHIDA, S. (2017). Health risk assessment for carcinogenic and non-carcinogenic heavy metal exposures from vegetables and fruits of Bangladesh. *Cogent Environmental Science*, ***3*** (1), 1291107.

TANAKA, T. (2006). Reproductive and neurobehavioural toxicity study of Ponceau 4R administered to mice in the diet. *Food and chemical toxicology*, ***44*** (10), 1651-1658.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, (U.S.E.P.A.). (2011). Regional Screening Level (RSL) Summary Table. www.epa.gov/regshwmd/risk/human/index html. [accessed 22nd May, 2015]

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, (U.S.E.P.A.). (2010). Integrated Risk Information Systems of Arsenic, Inorganic (CASRN7440-38-2). www.epa.gov./ncea/iris/subst/0278.html.

USEPA (United States Environmental Protection Agency). (1989). Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual. EPA/540/1–89/002. *Office of Soild Waste and Emergency Response, Washington, DC, USA*.

USEPA, O. (2014, July 21). Human Health Risk Assessment [Collections and Lists]. Retrieved May 29, 2019, from US EPA website: https://www.epa.gov/risk/human-health-risk-assessment

WAHIL, M.S.A., WAHAB A.A.A., MUN W.C. (2020). Health Risk Assessment on High Groundwater Arsenic Concentration among Adult and Children in Beranang Subdistrict, Malaysia

YI, Y., TANG, C., YI, T., YANG, Z., & ZHANG, S. (2017). Health risk assessment of heavy metals in fish and accumulation patterns in food web in the upper Yangtze River, China. *Ecotoxicology and Environmental Safety*, ***145*** (June), 295–302. https://doi.org/10.1016/j.ecoenv.2017.07.022

ZHANG Y., XU B., GUO Z., HAN J., LI H. & JIN L. (2019). Human health risk assessment of groundwater arsenic contamination in Jinghui irrigation district, China. *J. Environ. Manag.* 2019; **237**, 163–169. doi: 10.1016/j.jenvman.02.067.

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