

# Estimation of human health risk from exposure to methylmercury via fish consumption in Ghana

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## Introduction

Fish is an important source of nutrition in many parts of the world. A fish consumption advisory enables countries such as the United States to recommend the amount of specific species of fish that may be eaten based on estimates of possible health effects associated with contaminants. These advisories may include recommendations to limit or avoid eating certain species of fish caught from specific water bodies or from water-body types (e.g., lakes, rivers or coastal waters) due to chemical contamination.<sup>1</sup>

In Ghana, fish is a primary source of protein, due to its low cost compared to other animal proteins and because of its beneficial nutritional factors such as healthy fat content. It is estimated that fish consumption contributes about

**Background.** Fish advisories have been established by some nations to protect the public from the potentially harmful health effects linked to eating contaminated fish. Advisories are based on estimations of the health risks associated with concentrations of contaminating chemicals found in fish, and the average levels of consumption of fish in the population. Fish is an important source of nutrition in Ghana; however, little is known about the possible health effects associated with metal concentrations found in fish.

**Objective.** The overall aim of the present study was to estimate metal concentrations in fishery resources so as to inform guidelines on fish consumption.

**Methods.** We collated previously published data on levels of metals in fish in Ghana. We also estimated the potential for adverse health effects by calculating a hazard quotient (HQ) based on the reported levels of mercury in fish and either the United States Environmental Protection Agency (USEPA) Reference Dose (RfD) or the FAO/WHO Expert Committee on Food Additives Provisional Tolerable Weekly Intake (PTWI). Both are estimates of methylmercury exposure that is considered safe (0.0001 mg/kg body weight (bw) per day and 0.0016 mg/kg bw/week, respectively). We also compared HQ estimates across different fish species and water bodies in Ghana.

**Results.** Mercury was the only metal for which there was sufficient data to estimate the possible adverse health effects from eating fish caught in Ghana. The mean concentration of mercury was 0.10 mg/kg ( $\pm 0.15$ ) wet weight (N= 63 fish samples). This concentration was associated with a HQ of less than 1 when using the Joint FAO/WHO PTWI, but above 1 when using the USEPA RfD. Higher concentrations of mercury (Hg) were detected in fish collected from rivers in gold mining areas of Ghana (0.25 mg/kg ww  $\pm 0.23$ ) versus fish collected from lakes/reservoirs (0.04 mg/kg w.w  $\pm 0.04$ ) and marine areas (0.06 mg/kg w.w  $\pm 0.04$ ).

**Conclusions.** These results suggest regular monitoring of fish collected from water bodies in gold mining regions is warranted. Results also suggest that regulatory bodies may want to consider the development of guidelines for fish consumption advisories when warranted, and remediation of primary sources of mercury contamination to optimize the health benefits of fish consumption.

**Competing Interests.** The authors declare no competing financial interests.

**Keywords.** heavy metals, Ghana, risk assessment, methylmercury, fish, seafood safety, mercury database, hazard quotient

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60% of total animal protein intake in Ghana.<sup>2,3</sup> The nutritional benefits of fish, especially the supply of long chain fatty acids, have been noted by the World Health Organization (WHO).<sup>4</sup> This resource, however, may be affected by many domestic and industrial activities that introduce pollutants to the water. The issue of pollution has become a matter of concern, especially because some of these pollutants, notably

metals, bioaccumulate in fish such that concentrations found in fish tissue are higher than those found in the surrounding water. Studies conducted in the Faroe Islands and New Zealand suggest that high consumption of contaminated fish may lead to harmful levels of exposure to metals, although there is complexity in interpretation and generalization of these findings to other populations.<sup>5-7</sup>

Metal pollution has been a major international issue, especially for non-essential metals like methylmercury (MeHg), cadmium (Cd) and lead (Pb). MeHg is a neurodevelopmental toxin.<sup>8</sup> The epidemiologic evidence of the effects of metals are epitomized by the case of methylmercury (MeHg) poisoning in Minamata, Japan in the 1950s, when a chemical plant contaminated the water, resulting in widespread cases of nervous system disorders and deaths from the consumption of contaminated fish and seafood.<sup>9</sup> In addition, loss of cognitive and motor skills in children exposed to methylmercury *in utero* via fish and seafood (including whale and shark meat) consumption has been identified in the Faroe Islands and New Zealand.<sup>5-7</sup> Cadmium accumulates in the kidneys and causes renal dysfunction.<sup>10,11</sup> Lead exposures may cause nervous, reproductive, immunological and gastrointestinal system disorders.<sup>12,13</sup>

The occurrence and severity of the effects of exposure to methylmercury, cadmium and lead depend upon the amount to which a person is exposed and characteristics of the individual, including life stage.<sup>14</sup> Fortunately, detailed studies of these metals make it possible to estimate the levels that are unlikely to result in adverse health impacts. For example, the World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO), through the Joint FAO/WHO Expert Committee on Food Additives (JECFA), and also the United States Environmental Protection Agency (USEPA), through the Integrated Risk Information System (IRIS), have established levels that are likely not to constitute any adverse health effects. For example, the USEPA Reference Dose (RfD) is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without

Abbreviations				
ANOVA	Analysis of Variance	mg/kg		milligram per kilogram
<i>bw</i>	Body Weight	NIMD		National Institute for Minamata Disease
<i>Cd</i>	Cadmium			
<i>DI</i>	Dietary Intake	<i>ng</i>		nanogram
<i>FAO</i>	Food and Agriculture Organization of the United Nations	<i>Pb</i>		Lead
<i>g</i>	gram	<i>PTWI</i>		Provisional Tolerable Weekly Intake
<i>Hg</i>	Mercury	<i>RfD</i>		Reference Dose
<i>HQ</i>	Hazard Quotient	<i>SEM</i>		Standard Error of the Mean
<i>IRIS</i>	Integrated Risk Information System	<i>SF</i>		Slope Factor
<i>JECFA</i>	Joint FAO/WHO Expert Committee on Food Additives	<i>μg/g</i>		microgram per gram
<i>kg</i>	kilogram	<i>USEPA</i>		United States Environmental Protection Agency
<i>mg</i>	milligram	<i>WHO</i>		World Health Organization
		<i>ww</i>		Wet Weight

an appreciable risk of deleterious effects during a lifetime.<sup>15</sup> These safety values are commonly used to inform monitoring programs, such as after the Deepwater Horizon oil spill.<sup>16</sup> Using these limits, this study intends to: 1) compile published studies estimating concentrations of mercury (Hg), Cd, and Pb in fish and seafood from bodies of water in Ghana; 2) estimate the average dose of MeHg, Cd and Pb through fish consumption in Ghana; and 3) characterize non-cancer and cancer health risks associated with fish consumption in Ghana. This work will synthesize current datasets on estimating health risks associated with contamination of fish, which has been identified as an important data gap by

the FAO/WHO.<sup>4</sup> Also, monitoring of contamination in fisheries has become important because of Ghana's traditional production of gold and as the country begins its commercial production of crude oil.<sup>17</sup> Although evidence is limited, one study measured an increase in elemental Hg in air after the MT Hebei Spirit oil spill off the coast of Korea.<sup>16,18</sup>

## Methods

### Literature Search

Data were gathered from scientific publications identified using PubMed, a web-based database that comprises over 23 million citations for biomedical literature.<sup>19</sup> The following

searched terms were used: [mercury, methylmercury, cadmium, lead, Pb, Cd, Hg, MeHg, heavy metals], AND fish AND Ghana. The search generated seventeen different publications before July 30, 2013. Seven were eliminated due to their irrelevance in terms of country or chemical studied. The metal concentrations found in muscle tissue of fish published in these papers were then organized in a spreadsheet. Based on this literature review, there was insufficient data for analysis of Pb or Cd; therefore, we focused on determining the health risks associated with mercury exposure from fish consumption. The concentration of mercury in fish was first converted into mg per kg fish tissue weight for uniformity. Then, all dry weight measurements were multiplied by five to convert to wet weight (ww) measurements based on the Consortium for Risk Evaluation with Stakeholder Participation methods for dry weight to wet weight conversion in fish.<sup>20</sup> The trophic levels of the fish were also determined.<sup>21-23</sup> Fish species within trophic levels 2-3, 3-4, and 4-5 were considered low, middle and high trophic levels respectively. The locations of the water bodies where the fish were caught were mapped and identified as a river, lake/reservoir, or marine body of water. Using the map generated by Hilson, the samples were divided into auriferous (gold-bearing) vs. other regions.<sup>24</sup>

### Calculation of health risks

To calculate non-cancer health risks, the HQ was used. The HQ is a widely used estimate in risk characterization and is the ratio of the estimated exposure to a chemical over the level at which no adverse effect is expected. The HQ is derived by dividing dietary intake (DI) by the health benchmark, hence an HQ of less than 1 means no adverse health effects are expected and an HQ greater than 1 means adverse health effects are possible.<sup>14</sup> To derive the DI, we calculated the average fish consumption per person per day (0.068

kg), using the average (25 kg) of the FAO estimation of fish consumption in Ghana of 20 to 30 kg per year per capita.<sup>25,26</sup> We then multiplied this value by the mean concentration of mercury that was found in fish in published works identified in our literature search. We assumed that 100% of the mercury measured was methylated using previous research showing that between 90% to 100% of total mercury in fish and seafood is methylmercury.<sup>7,27,28</sup> The JECFA health guideline value, which is the provisional tolerable weekly intake (PTWI) of 0.0016 mg/kg bw, was divided by 7 days to attain a per day value of 0.0002 mg/kg bw/day.<sup>29</sup> Also, the RfD of 0.0001 mg/kg/day from the USEPA IRIS for methylmercury was applied to the HQ calculation for comparison.<sup>30</sup>

The cancer risk from eating contaminated fish is usually expressed using the life time average daily dose by the slope factor (SF), which is a 95% upper bound confidence interval. However, for methylmercury, the SF was not derived, because available data shows that systemic non-cancer effects would be seen at methylmercury exposures lower than those required for tumor formation.<sup>30</sup>

### Statistical Analysis

The mean concentration of mercury in each reported species resulted in 63 samples in our analyses. Mercury concentrations in unidentified species of fish were included in the initial analysis (n=4), but were not included in the trophic level analysis.<sup>31</sup> The distribution of concentrations was not normal, therefore non-parametric analyses were employed. One-way analysis of variance (ANOVA) was used to compare the means of the groupings (source of fish and trophic levels). We used the Kruskal-Wallis test to compare mercury concentrations among the different sources of fish (water type) as well as the trophic level of the fish. A Mann-Whitney test was

carried out to compare the differences between the auriferous vs. other regions. Significance levels for all tests were set at an alpha=0.05. All statistical analyses were performed using GraphPad Prism version 5.00 for Windows.

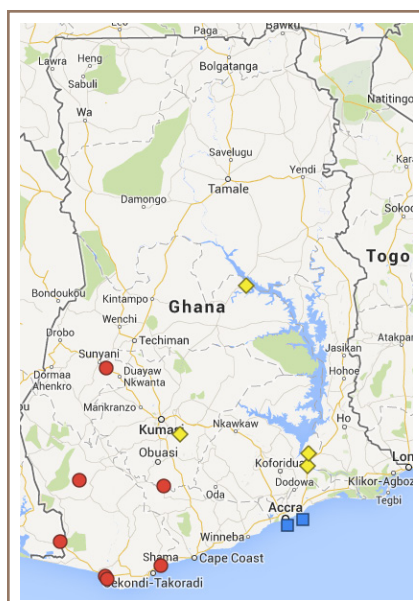
## Results

### Overview of Hg Database

Based on the literature search, mercury was the most common metal pollutant evaluated in fish in Ghana. The mercury contents in fish were analyzed by the use of cold vapor atomic fluorescence spectroscopy or an open flask procedure developed at the National Institute for Minamata Disease (NIMD) in Japan by Akagi and Nishimura (1991).<sup>32</sup> The recovery of referenced material or spiked samples was over 95%. The detection limit, when provided in articles, was 0.5 ng Hg g<sup>-1</sup>. Sixty-three samples comprising 53 different species were analyzed from 10 different water sources. Data were not sufficient to further evaluate other metals of interest, since only one study in the searched database had results for cadmium and lead. All of the identified fish species were species commonly consumed by Ghanaians. Marine sources provided 36.8% of the different fish species included in the analysis, followed by lakes/reservoirs at 33.3%, and rivers accounted for 29.8% of fish species included in the analyses. All of the studies were conducted in the southern half of Ghana, with the exception of one study in the Upper Volta Basin in the Yeji, Brong-Ahafo Region of Ghana (*Figure 1*). The highest value of total mercury detected was 0.89 mg/kg ww in the Kafue pike fish (*Appendix 1*). The least polluted sample with a value of 0.01 mg/kg ww was taken from Lake Bosumtwi in Tilapia fish.

### Non-cancer risk assessment

To estimate the potential non-cancer health risk associated with MeHg exposure via fish and seafood consumption by Ghanaians, the hazard



**Figure 1 — Sampling sites for mercury in fish in Ghana. Sampled sites with yellow diamonds indicate lakes/reservoirs, blue squares indicate marine areas and red circles indicate rivers.**

Type of Sample	Value	Source
Fish intake rate	0.068 kg	FAO 2012 <sup>25</sup>
Body weight (male)	65 kg <sup>a</sup>	
Body weight (female)	62 kg <sup>b</sup>	
Life expectancy (male)	62 years	WHO 2011 <sup>45</sup>
Life expectancy (female)	65 years	WHO 2011 ref. <sup>45</sup>
PTWI* (MeHg)	0.0016 mg/kg bw	JECFA 2003 <sup>29</sup>
Reference Dose (MeHg)	0.0001 mg/kg bw/day	USEPA_IRIS website <sup>30</sup>

**Table 1 — Parameters used in estimating health risk**  
<sup>a,b</sup> Body weight measurements were back calculated from BMI values from a study of 4377 participants in the Greater Accra Region.<sup>43</sup> BMI is given as weight in kilograms divided by the square of height in meters (kg/m<sup>2</sup>).<sup>44</sup>\* Provisional Tolerable Weekly Intake (PTWI)

Water Body	Composite Samples	No. of Species	Mean Hg mg/kg ww ± SD	HQ
Rivers	17	13	0.25 (±0.23)	>1
Lakes/Reservoirs	23	22	0.04 (±0.04)	<1
Marine	23	21	0.06 (±0.04)	<1

**Table 2 — Summary of mean concentrations of mercury/HQ per type of water body**

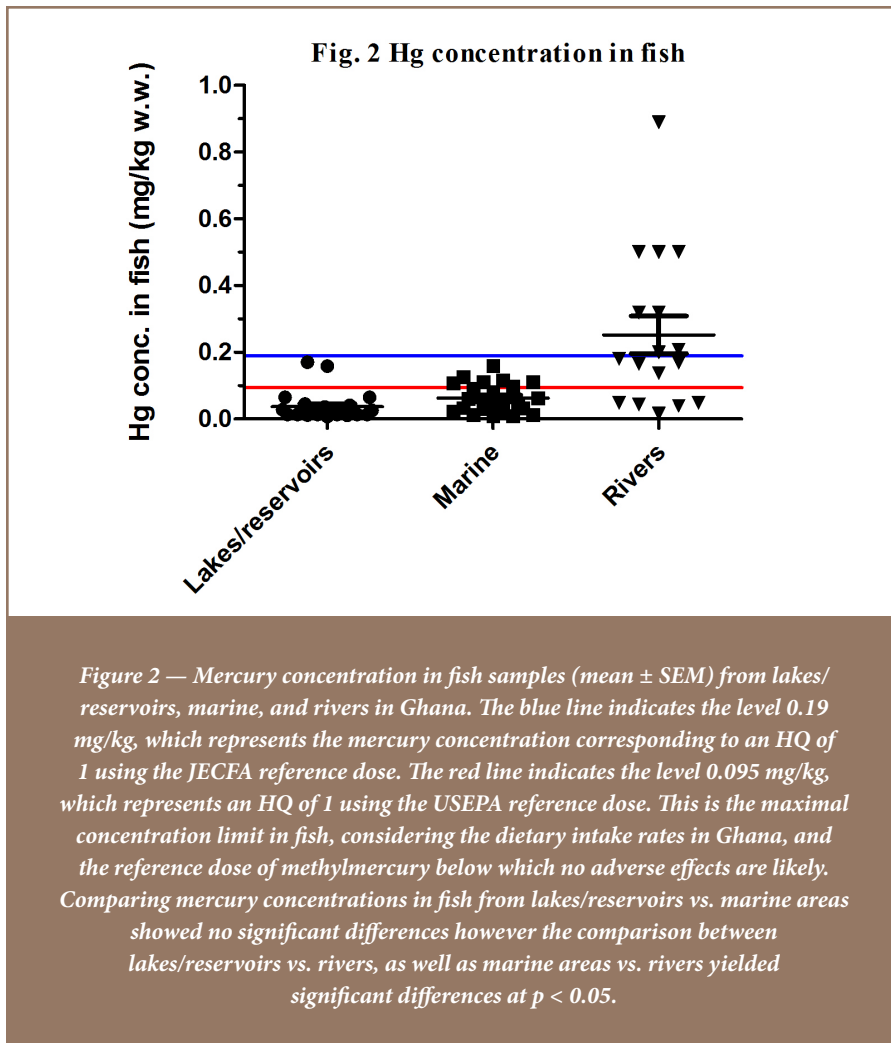
quotient (HQ) was used. Table 1 presents the values used to determine daily intake, exposure duration, and ultimately the hazard quotient. Based on values presented in Table 1, the estimated safe level of methylmercury exposure for an adult male Ghanaian was calculated as 0.013 mg/day (0.0002 mg/kg bw/day \* 65kg) using the JECFA PTWI and 0.0065 mg/day (0.0001 mg/kg bw/day \* 65kg) using the USEPA RfD.

Of the fish samples identified in the studies, 13% of the fish had mercury concentration levels that produced an HQ of more than 1 using the JECFA PTWI. All of the samples that produced an HQ of > 1 were from river sources. In comparison, using the more conservative USEPA standards, 33% of the fish had an HQ > 1. Out of these sites with an HQ > 1, 52% were from rivers, 38% were from coastal

marine waters and 10% were from lakes/reservoirs. The remaining sites (67%) had an HQ < 1, meaning that adverse health outcomes are unlikely for an adult male or female, based on the concentration and consumption rate of fish. It is important to note the HQ calculations are based on estimated average daily exposures over a lifetime.

Table 2 presents the mercury levels and HQ associated with the source of the fish sampled. Out of the sixty-three (63) samples, the mean concentration of mercury in fish from rivers, lakes/reservoirs, and marine areas were 0.25 (±0.23), 0.04 (±0.04), and 0.06 (±0.04) mg/kg ww, respectively. Significant differences were identified between the mercury concentration among the fish from the various water sources (p < 0.0001), with significant differences between mercury in fish from rivers

compared to marine areas and lakes/reservoirs. All other differences in sources of mercury in fish tested were not significant at p < 0.05 (Figure 2). Mean concentrations of mercury were highest in fish from riverine sources in the auriferous regions of Ghana (mean concentration of 0.25 mg/kg ww).<sup>20</sup> Unfortunately, there were no samples taken from rivers in non-auriferous regions to allow a direct comparison. Samples from Lake Bosomtwi and Lake Volta (Yeji), had the lowest mercury levels (mean of 0.04 mg/kg ww). When the mercury database was sorted into samples from auriferous regions vs. samples from non-auriferous regions, a Mann-Whitney U test showed that there were highly significant differences between the mean of the samples taken from the auriferous regions (0.22 mg/kg ww) vs. the non-auriferous regions (0.05 mg/kg



ww). Fish from the auriferous region produced an HQ > 1 irrespective of whether WHO or USEPA standards are used, and those of the non-auriferous region produced an HQ < 1.

A comparison of the trophic levels of fish showed significant differences between the mean mercury concentrations of high ( $0.14 \pm 0.20$ ) and low trophic levels ( $0.03 \pm 0.01$ ), as well as between the middle trophic level ( $0.09 \pm 0.11$ ) and the low trophic level. However the high and middle trophic levels were not significantly different, meaning that the mercury concentration was not dependent

on whether fish were in the high or middle trophic group (Figure 3). The World Health Organization and United States Department of Agriculture recommend approximately 2 servings of fish per week, whereas current intake estimates in Ghana suggest approximately 5 fish servings per week.<sup>25,26,29,33-35</sup> Assuming only 2 servings per week (weekly serving size of 0.17 kg) and a mean mercury concentration of 0.10 mg/kg, the associated HQ is < 1 even using the USEPA more stringent RfD of 0.0001 mg/kg/bw per day. However, in individual fish samples, one sample out of the 63 was associated with an HQ

> 1 even at the recommended twice weekly serving using the JECFA PTWI. This sample was of *Hepsetus odoe* (Kafue pike), taken from River Pra. Using the USEPA RfD, the recommended 2 servings per week generates an HQ > 1 in 10% of the samples. All of these samples were from river sources (Appendix 1).

A summary of all the datasets compiled indicates an average mercury concentration of 0.10 mg/kg ww ± 0.15 in fish from Ghana. The estimated overall HQ is less than 1 using the Joint FAO/WHO Expert Committee on Food Additives Provisional Tolerable Weekly Intake (JECFA PTWI), and slightly above 1 (1.1) using the USEPA RfD. The difference between HQ values for males ( $0.5 (\pm 0.8)$ ) vs. females ( $0.6 (\pm 0.8)$ ) using JECFA estimates and also males ( $1.1 (\pm 1.6)$ ) vs. females ( $1.2 (\pm 1.7)$ ) using the USEPA RfD was negligible (Appendix 1).

## Discussion

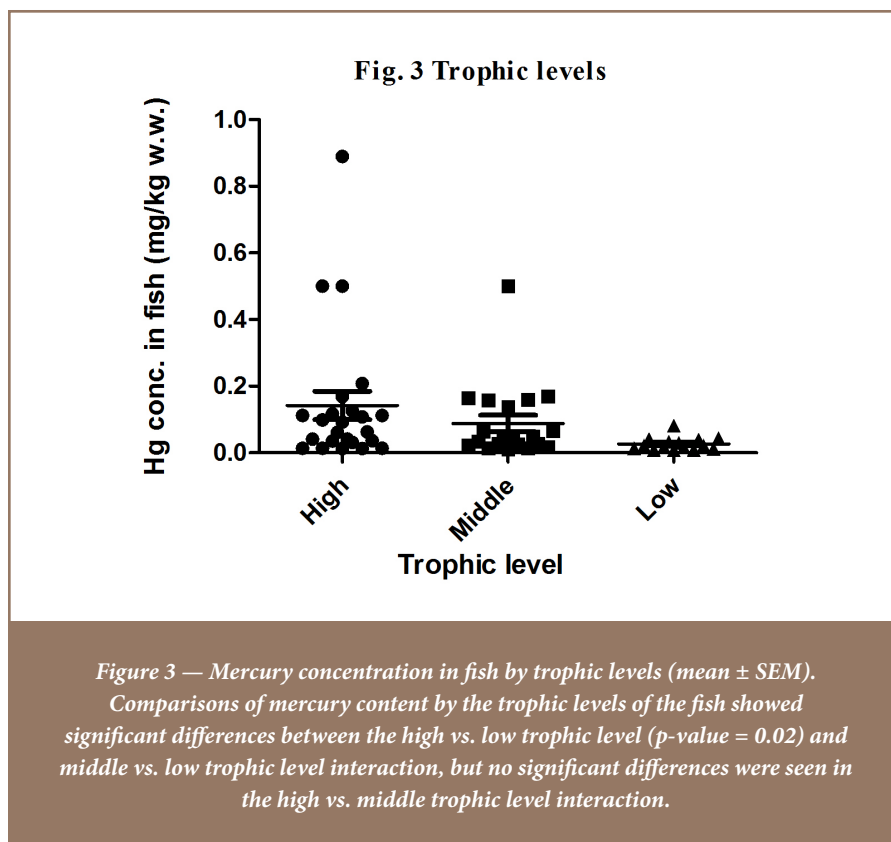
Fish is an important source of nutrition in Ghana.<sup>2,3</sup> In a country where 59% of women have some level of anaemia and 40% of all deaths that occur before the age of five are due directly and indirectly to undernutrition, consideration of malnutrition is critical in estimating risk from fish consumption.<sup>36,37</sup> However, it is also important to develop and evaluate risk management and communication strategies that both minimize risks and maximize benefits from fish consumption.<sup>4</sup> In order to enhance the benefits of fish consumption, generation and analysis of monitoring data on contamination levels is critical.

This study provides an overall summary of the mercury contamination status and possible health risks associated with methylmercury in fish in Ghana. When considering a mean mercury concentration of 0.10 mg/kg wet weight in fish, our results indicate

methylmercury is not likely to cause health effects at the estimated mean fish consumption levels of approximately 5 servings per week, using the JECFA PTWI. This initial attempt to estimate the potential risk associated with methylmercury in fish reveals River Pra to be the more polluted water body in terms of mercury contamination (Appendix 1). In total, the most polluted fish samples were from rivers in the gold mining region, with a mean Hg concentration of 0.25 mg/kg ww, corresponding to an HQ > 1 using both the JECFA and USEPA health values. The least polluted were the reservoirs with a mean of 0.03 mg/kg ww, corresponding to an HQ < 1. Concentrations of methylmercury were noted in the order: rivers > marine > reservoirs/lakes.

Our results suggest that 12.6% of the fish analyzed in Ghana are above the level at which adverse health effects are possible using the JECFA PTWI, and 33% using the more conservative USEPA RfD. These adverse health effects are possible from a lifetime consumption of contaminated fish at the estimated consumption rate of 68 g/day. The mean mercury concentrations found in the present study (0.10 mg/kg ww ( $\pm 0.15$ )) in fish in Ghana are lower than the mean levels found in a recent study by Karimi et al. That study compiled mercury concentrations in fish that may be consumed by the US population. The mean level of Hg in fish (calculated from their supplemental table) was found to be 0.29 mg/kg ww ( $\pm 0.55$ ).<sup>38</sup>

This study is the first paper to synthesize the available data on methylmercury exposure via fish consumption in Ghana. However, the study is limited by several factors. There was a limited data set (10 publications) and the geographical spread of the samples did not include northern regions of Ghana. It is also important to note that both the USEPA RfD and JECFA PTWI include



uncertainty factors, thus the use of the HQ is meant as a conservative estimate of the potential for human health effects and is not measuring risk directly. Limitations of the epidemiological studies used in the estimation of the dose-response relationships are also important to note and have been critiqued previously.<sup>39</sup>

We also note that fish is usually eaten cooked in Ghana. A study by Obodai et al. showed that Hg concentrations in cooked *S. melanotheron* (0.334 mg/kg  $\pm 0.14$ ) samples were significantly lower than the concentrations recorded in uncooked *S. melanotheron* (0.479 mg/kg  $\pm 0.13$ ).<sup>40</sup> However, some regulatory bodies like the United States Food and Drug Administration and the California Office of Environmental Health Hazard Assessment do not consider cooking fish to significantly reduce the amount of methylmercury in the fish.<sup>41,42</sup>

Further study into the cooking methods of Ghanaians and the methylmercury concentrations in cooked fish is needed to estimate a more accurate level of exposure.

## Conclusion

The fish collected and analyzed for Hg in Ghana thus far have a relatively low average level of MeHg ( $\sim 0.1$   $\mu\text{g/g}$ ), although higher levels are seen in rivers in the gold mining regions (0.25 ( $\pm 0.23$ )). These results suggest that regular monitoring of fish collected from water bodies in gold mining regions is warranted. Results also suggest that regulatory bodies may want to consider development of guidelines for fish consumption advisories when warranted, and remediation of primary sources of mercury contamination to optimize the health benefits of fish consumption.

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