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# Children's IQ Reduction Due to Prenatal Fish MeHg Exposure in Coastal Areas: A Comparative Analysis

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## ABSTRACT

Maternal dietary exposure to heavy metals like methylmercury (MeHg) through fish consumption has long been associated with neurological disabilities, including Intelligence Quotient (IQ) reduction. The most common exposure pathway to MeHg is dietary intake through fish consumption. However, there has been limited research comparing the IQ reduction caused by different fish species in different coastal areas. As Kuwait, Hong Kong, and Shanghai are three coastal areas with different cuisines and fish consumption rates, they are chosen as sites where the health risk of children's IQ reduction due to the consumption of fish is to be assessed in this analysis. The results of this study suggested that among the fifteen types of seafood examined in Kuwait, hamoor was determined to be the most dangerous species, causing the highest mean IQ reductions in Kuwait. Frozen cod fillet was estimated to cause the highest mean and median IQ reductions amongst the twenty-six seafood types in Hong Kong, China. River eel and sardine are considered to be capable of inflicting the highest mean and maximum IQ reductions in Shanghai. Overall, seafood in Kuwait is more prone to causing serious intellectual disabilities because of its highest mean IQ reduction on average amongst the three locations examined. On the other hand, most types of seafood in Hong Kong and Shanghai have much lower mean IQ reductions, and are thus considered generally safe for consumption.

## Introduction

Methylmercury (MeHg) is a powerful neurotoxin that can damage the human central nervous system with symptoms such as ataxia and paresthesia (Bakir et al., 1973). Being the most toxic form of mercury compound, MeHg can also adversely affect various organs and organ systems, including the immune, reproductive, and cardiovascular systems (Farina & Aschner, 2019). Both natural processes, such as volcanoes and forest fires, and anthropogenic activities, such as fossil fuel combustion and waste incineration, can cause mercury to deposit in water bodies. The mercury deposited will be methylated by micro-organisms to create MeHg (Bellinger et al., 2016). The methylated mercury then biomagnifies and bioaccumulates until ingested by humans through food intake. The MeHg concentration in long-lived predatory fish tends to be higher due to their longer life span and higher trophic position in the aquatic food chain.

MeHg can have severe health impacts on the exposed population. For adults, exposure to MeHg can induce loss of coordination, impairment of hearing and vision, tremors, et cetera (Diez, 2009). Apart from these issues related to the nervous system, MeHg can also affect other parts of the human body, and is suspected of triggering autoimmune diseases (Gardner et al., 2010) and cardiovascular diseases (Virtanen et al., 2012). Women of child-bearing age and young children are most susceptible to developmental problems that result from MeHg exposure (Laird et al., 2017). Maternal dietary exposure to MeHg through consumption of MeHg-contaminated seafood may cause impairments of the baby's neurological development, resulting in various forms of intellectual disabilities (Bellinger et al., 2016), including reduced IQ score, cerebral palsy, and delayed onset of walking and talking (Diez, 2009).

Among all pathways, nearly all MeHg exposures to humans are by ingestion (Bellinger et al., 2016). Although other categories of food also contain MeHg, its concentration in fish was measured to be about "three to four orders of magnitude greater than that in fruit and vegetable" (Cheng et al., 2013), making seafood consumption the primary pathway to MeHg dietary exposures.

Many studies have been done to assess MeHg levels in food and health risks due to dietary exposure to MeHg. The concentration of MeHg in fifteen different species of fish common in Kuwaiti marketplaces had been measured by previous research (Laird et al., 2017). In Cambodia, researchers determined the MeHg concentrations of different types of foodstuffs, including vegetables, rice, meat, and fish (Cheng et al., 2013). Studies have also been conducted concerning IQ loss due to maternal dietary exposure to different sources in various places. In Nepal, researchers established a relationship between MeHg in rice consumption and IQ loss and the subsequent economic costs (Wang et al., 2021). Similar studies were done in the Faroe Islands, Seychelle Islands, and New Zealand, where researchers determined the relationship between MeHg concentration in maternal hair and the IQ points reduced using biomarker samples and cognitive test scores (Axelrad et al., 2007; Cohen et al., 2005). In addition to studies that connected MeHg with intelligence, some researchers also assessed other adverse effects of MeHg. For example, one study suggested that MeHg exposure may trigger autoimmune diseases by increasing the concentration of pro-inflammatory cytokines (Gardner et al., 2010); another research suspected that MeHg could increase the mortality caused by cardiovascular diseases (Virtanen et al., 2012).

However, despite the abundant research done by previous studies, there have been few comparative analyses examining the varied patterns in IQ reduction due to different fish species in different coastal regions. Since Hong Kong, Shanghai, and Kuwait are all coastal areas with fish being an important part of the cuisines (FAO, 1988), they are fitting study locations for this analysis.

The main objective of this research is to estimate and compare the IQ points loss of children due to MeHg through maternal dietary exposure to different types of seafood in Kuwait, Hong Kong, and Shanghai. This study quantitively compares different types of seafood for their MeHg levels and how each affects children's IQ, providing citizens in these coastal areas with scientific evidence to understand the underlying risk of fish consumption on their children's IQ prenatally. The results obtained from this study are hoped to assist the Kuwaiti and Chinese government in more accurately assessing the risk of MeHg on local children's IQ, and to help women in coastal regions to make better-informed decisions in their dietary choices regarding fish consumption.

## Methods

### Study Site and Study Population

This study focused on women of child-bearing age (18-45 years of age) and young children in coastal areas in the assessment of IQ reduction due to maternal dietary exposure to MeHg by seafood consumption. The sample size was 2393 households (10646 individuals) in Kuwait (Laird et al., 2017), 7593 children aged 3–5 years in Hong Kong (Chan et al., 2018), and 771 pregnant women in Shanghai (Cai et al., 2023).

### Risk Assessment

In this study, four steps of risk assessment were conducted, namely hazard identification, exposure assessment, dose-response relationship, and risk characterization.

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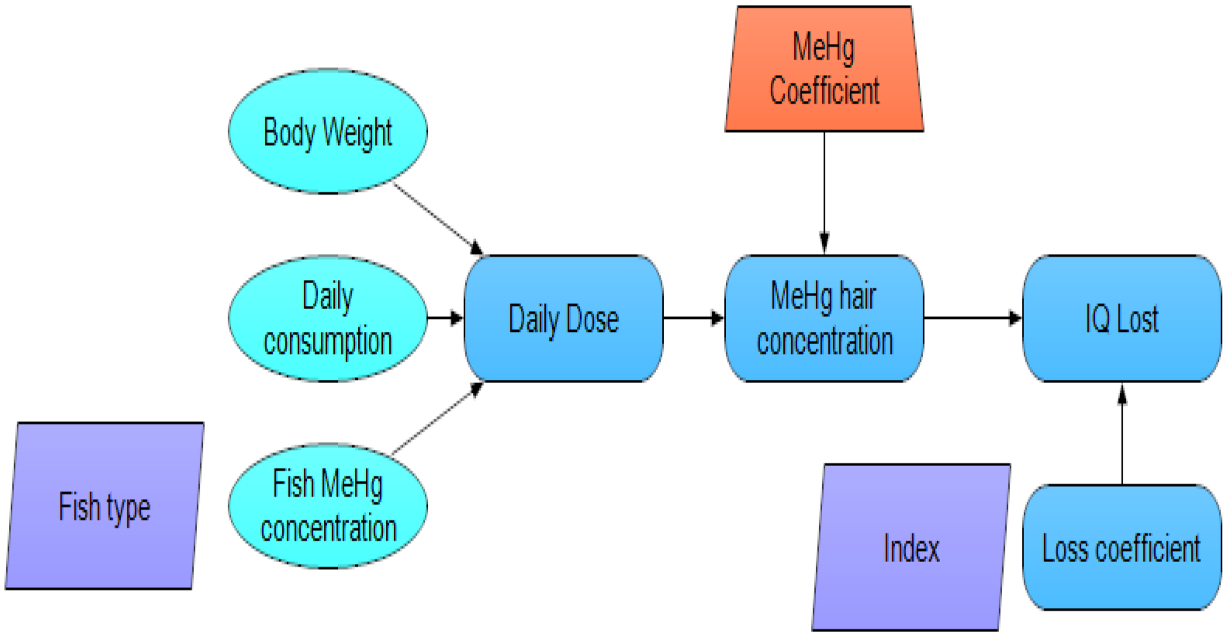


**Figure 1.** MeHg and IQ Loss Model. This is the Analytica model used in this study to calculate the IQ loss of children in coastal regions due to maternal dietary exposure to MeHg through fish consumption

First, MeHg exposure was identified as a cause of IQ reduction for children. Then, the average daily dose of MeHg intake (DD) was calculated using the formula DD = FMC × DCF ÷ BW, where FMC is the concentration of MeHg in various seafood species in the study locations. DCF is the average mass of seafood consumed daily by a typical citizen, estimated to be 103 $g{\cdot}day^{-1}$ (Laird et al., 2017) with a geometric standard deviation of 1.11554672 (Evans et al., 2012) in Kuwait, a mean of 31.7 $g{\cdot}day^{-1}$ and a median of 44.5357 $g{\cdot}day^{-1}$ in Hong Kong (Chan et al., 2018), a mean of 66.24 $g{\cdot}day^{-1}$ and a median of 50 $g{\cdot}day^{-1}$ in Shanghai (Cai et al., 2023). BW is the estimated body weight of a woman of child-bearing age in the study locations. Due to the 40 percent obesity rate among Kuwaiti women, BW's value for Kuwait was estimated to be 72 kg (Weiderpass et al., 2019), with a standard deviation of 10. For Hong Kong and Shanghai, the BWs are estimated to be 57.12 kg (Hong Kong Centre for Food Safety et al., 2021) and 55 kg (Cai et al., 2023) respectively, with a standard deviation of 9.77.

As for the dose-response relationship, previous studies have presented two possible coefficients to connect MeHg concentration in maternal hair with IQ reduction. The central estimate of IQ points gained per 1 µg/g increase in maternal hair MeHg concentration was determined to be -0.18 (Axelrad et al., 2007), while -0.7 was the upper-bound estimate (Cohen et al., 2005) of IQ points gained per 1 µg/g increase in maternal hair MeHg concentration. -0.7 was identified as the upper-bound estimate because it extrapolated the results from exposures in the Faroe Islands to much lower levels of exposure in the USA (FAO/WHO, 2010).

Last but not least, the IQ reduction due to maternal dietary exposure to MeHg (IQR) was determined using the formula IQR = DD × MC × LC, where MC is the correlation between the average daily dose and MeHg concentration in maternal hair, estimated to be 9.3 (FAO/WHO, 2010); LC is the relationship between MeHg concentration in maternal hair and the IQ points reduced, containing the two previously mentioned co-efficients: the central estimate of -0.18 and the upper-bound estimate of -0.7. The definitions and values of the parameters used in the model are summarized in Figure 2.

| Parameter | Definition | Value |
| --- | --- | --- |
| FMC | The methylmercury concentration in different types of seafoods | Kuwait: Table 1<br>Hong Kong: Table 5<br>Shanghai: Table 7 |
| DCF | The average daily consumption of fish for a typical citizen in coastal regions | Kuwait - μ: 103, σ: 1.11554672<br>Hong Kong - μ: 31.7, Med: 44.5357<br>Shanghai - μ: 66.24, Med: 50 |
| BW | The body weight of a typical woman of child-bearing age in coastal areas | Kuwait - μ: 72, σ: 10<br>Hong Kong - μ: 57.12, σ: 9.77<br>Shanghai - μ: 55, σ: 9.77 |
| MC | The correlation between MeHg intake and its concentration in maternal hair | 9.3 |
| LC | The relationship between maternal hair concentration of MeHg and IQ loss | Central Estimate: -0.18<br>Upper-bound Estimate: -0.70 |

**Figure 2.** Parameters used in the model. This table shows the definitions and values of the parameters used in the model.

### Statistical Analysis

Data were analyzed by Analytica. MeHg concentrations in fish and average daily fish consumption were described. The underlying risks were described through the probability density distribution and cumulative density of IQ points reduction due to maternal dietary exposure to MeHg in different types of seafood. The statistical significance was set at $p\text{-value} < 0.05$.

## Results

This analysis demonstrates how different species of fish can affect children's IQ in Kuwait, Hong Kong, and Shanghai through maternal dietary exposure to MeHg.

### Kuwait

As displayed in Figure 3, hamoor and sha'em contain the highest concentrations of MeHg among the 15 types of seafood measured in Kuwait, with 0.55 and 0.42 μg/g, respectively. Their high concentrations of MeHg also result in a high daily intake of the substance by Kuwaiti women: the average daily doses of MeHg for hamoor and sha'em were determined to be 0.7971 and 0.6115 $\mu g \cdot kg^{-1} \cdot day^{-1}$, which are substantially higher than the 0.2623 $\mu g \cdot kg^{-1} \cdot day^{-1}$ average of the fifteen species combined.

| Fish Type | MeHg (μg/g) | Std. Dev. (μg/g) |
|---|---|---|
| Chanaed | 0.23 | 0.1 |
| Crab | 0.09 | 0.03 |
| European Seabream | 0.09 | 0.001 |
| Hamoor | 0.55 | 0.38 |
| Khobat | 0.27 | 0.04 |
| Lessen Althour | 0.23 | 0.26 |
| Maid | 0.06 | 0.01 |
| Nagroor | 0.19 | 0.1 |
| Newaiby | 0.22 | 0.11 |
| Shaem | 0.42 | 0.21 |
| Shrimp | 0.09 | 0.06 |
| Suboor | 0.05 | 0.02 |
| Zobaidy | 0.07 | 0.06 |
| Tilapia | 0.02 | 0 |
| Canned Tuna | 0.12 | 0.1 |

**Figure 3.** MeHg Concentration in Seafood (Kuwait). This shows the mean MeHg concentration and standard deviations of 15 types of seafood purchased in Kuwaiti marketplaces (Laird et al., 2017).

Consequently, hamoor (orange spotted grouper) and sha'em (yellowfin seabream) had been identified as the two most hazardous species of fish for Kuwaiti children in terms of IQ reduction due to MeHg exposure. As displayed in Figure 4, the mean and median IQ reductions caused by MeHg in these two types of fish were estimated to be higher than all thirteen other species. The central estimates of mean and median IQ reduction caused by hamoor were 1.334 and 1.089, respectively, those for sha'em being 1.024 and 0.9060. This assertion is also supported by Figure 5, which shows that hamoor and sha'em have a higher probability of inflicting IQ reductions of more than one IQ point.

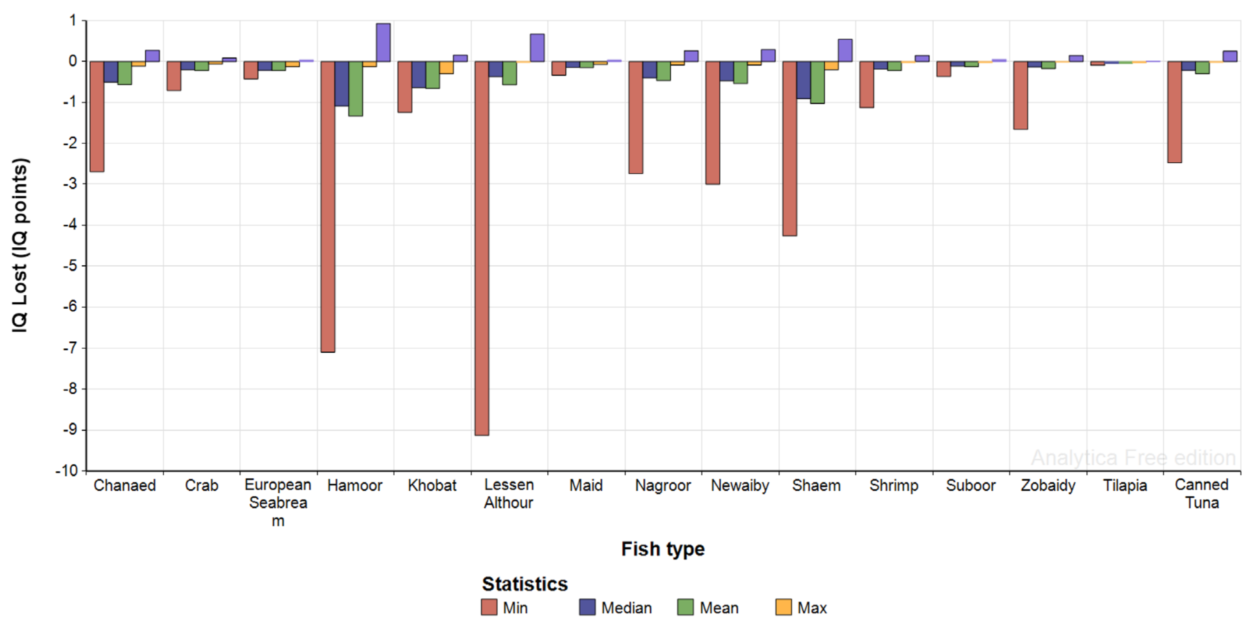

**Figure 4.** Statistics of IQ Loss (Central Estimate) (Kuwait). This figure demonstrates the central estimates of minimum, median, mean, and maximum IQ loss for 15 species of seafood in Kuwait due to dietary exposure to MeHg, along with their standard deviations.

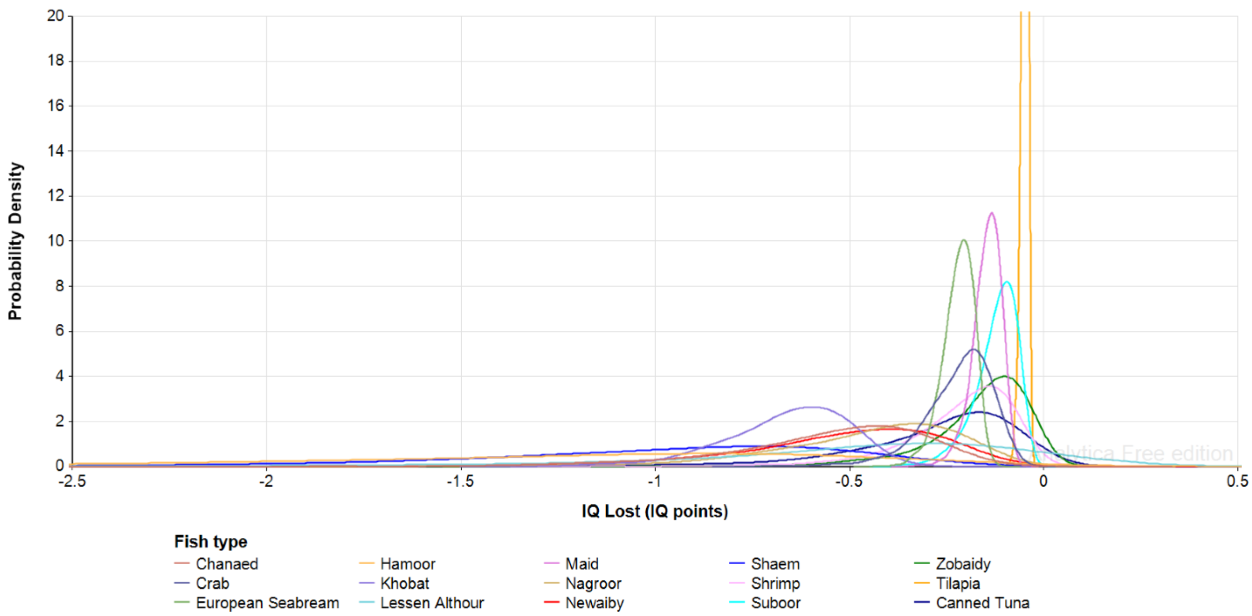


**Figure 5.** Probability Density of IQ Loss (Central Estimate) (Kuwait). This graph illustrates the probability density of central estimate IQ loss for 15 species of seafood in Kuwait due to maternal dietary exposure to MeHg.

Although lessen althour (largescale tonguesole) was estimated to have the highest maximum IQ reduction of about 9.13 (central estimate), it is less notable than hamoor and sha'em due to its relatively large variance. As shown in Figure 4, lessen althour has the second-highest standard deviation (central estimate: 0.6720), making the result very uncertain. Moreover, lessen althour's mean IQ reduction was only the seventh highest, which further reduces its potential risk.

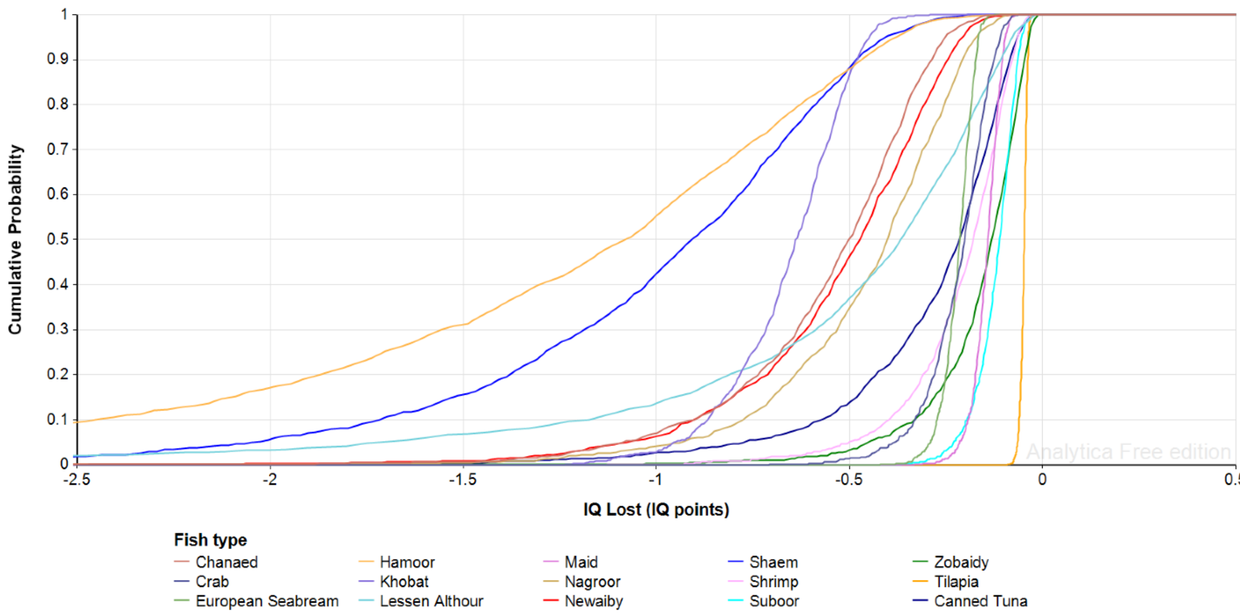


**Figure 6.** Cumulative Probability of IQ Loss (Central Estimate) (Kuwait). This is a graph showing the cumulative probability of central estimate IQ loss for 15 species of seafood in Kuwait due to maternal dietary exposure to MeHg.

The safest type of seafood among all fifteen was determined to be tilapia (mango fish). The cumulative probability graph, Figure 6, suggests that it is almost impossible for tilapia to cause an IQ reduction of more than 0.2 IQ points. Combining with the fact that it also has the lowest mean (central estimate: 0.04885) and median (central estimate: 0.04764) IQ reduction, as displayed in Figure 7, tilapia is most likely to be the least harmful kind of seafood among all species tested, with respect to possible IQ reduction due to maternal dietary exposure to MeHg through fish consumption.

**Statistics of IQ Loss (Central Estimate)**

| | Minimum | Median | Mean | Max | Std. Dev |
|---|---|---|---|---|---|
| Chanaed | -2.692604142 | -0.502584777 | -0.561839359 | -0.112049228 | 0.274141899 |
| Crab | -0.70661462 | -0.202573398 | -0.220725487 | -0.062121259 | 0.08803481 |
| European Seabream | -0.422977399 | -0.215141139 | -0.219837792 | -0.126471547 | 0.04019246 |
| Hamoor | -7.091989088 | -1.088901511 | -1.334289941 | -0.125015301 | 0.928641083 |
| Khobat | -1.240136362 | -0.639691297 | -0.65955709 | -0.29493001 | 0.156259835 |
| Lessen Althour | -9.128379867 | -0.369237978 | -0.566103804 | -0.019021608 | 0.672023664 |
| Maid | -0.332611777 | -0.141226955 | -0.14656349 | -0.072316353 | 0.036704977 |
| Nagroor | -2.74132887 | -0.402037794 | -0.464110093 | -0.08590389 | 0.262585999 |
| Newaiby | -2.998455793 | -0.47448574 | -0.53723585 | -0.083903656 | 0.292230196 |
| Shaem | -4.259851044 | -0.905975102 | -1.023698847 | -0.20023175 | 0.541859202 |
| Shrimp | -1.127525127 | -0.179751108 | -0.218670685 | -0.023113502 | 0.147374903 |
| Suboor | -0.364072488 | -0.112278793 | -0.122552029 | -0.023684521 | 0.054715065 |
| Zobaidy | -1.656972273 | -0.13319025 | -0.169890721 | -0.013074503 | 0.146981862 |
| Tilapia | -0.092607671 | -0.04763608 | -0.048850316 | -0.028374544 | 0.008895083 |
| Canned Tuna | -2.473780953 | -0.215814982 | -0.294078043 | -0.019909392 | 0.251248894 |

**Statistics of IQ Loss (Upper-bound Estimate)**

| | Minimum | Median | Mean | Maximum | Std. Dev |
|---|---|---|---|---|---|
| Chanaed | -10.47123833 | -1.954496354 | -2.184930842 | -0.435746997 | 1.066107386 |
| Crab | -2.747945743 | -0.787785439 | -0.858376893 | -0.241582675 | 0.342357596 |
| European Seabream | -1.644912109 | -0.836659985 | -0.854924748 | -0.491833795 | 0.156304011 |
| Hamoor | -27.57995756 | -4.234616988 | -5.188905326 | -0.486170616 | 3.61138199 |
| Khobat | -4.822752518 | -2.487688378 | -2.564944238 | -1.146950038 | 0.607677137 |
| Lessen Althour | -35.49925504 | -1.43592547 | -2.201514795 | -0.073972922 | 2.61342536 |
| Maid | -1.293490243 | -0.549215934 | -0.569969126 | -0.281230262 | 0.142741575 |
| Nagroor | -10.66072338 | -1.563480308 | -1.804872582 | -0.334070682 | 1.021167772 |
| Newaiby | -11.66066142 | -1.84522232 | -2.089250527 | -0.326291994 | 1.136450764 |
| Shaem | -16.56608739 | -3.523236507 | -3.981051073 | -0.778679027 | 2.107230229 |
| Shrimp | -4.384819939 | -0.699032087 | -0.850385996 | -0.089885843 | 0.573124622 |
| Suboor | -1.415837455 | -0.436639749 | -0.476591222 | -0.092106471 | 0.212780807 |
| Zobaidy | -6.44378106 | -0.517962084 | -0.660686136 | -0.05084529 | 0.571596128 |
| Tilapia | -0.360140942 | -0.185251423 | -0.18997345 | -0.110345447 | 0.034591989 |
| Canned Tuna | -9.620259263 | -0.839280484 | -1.143636832 | -0.077425412 | 0.977079031 |

**Figure 7.** Statistics of IQ loss (Kuwait). This is a table displaying the estimates of minimum, median, mean, and maximum IQ loss for 15 species of seafood in Kuwait due to dietary exposure to MeHg, together with their standard deviations.

## Hong Kong, China

The central estimate of the mean IQ reduction of children caused by the 26 species of fish in Hong Kong is -0.09 IQ points. As displayed in Figure 8, amongst all types calculated, frozen cod fillet is estimated to cause an

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IQ reduction of -0.89 on average and 10.9 on maximum, significantly more than all other 25 species. This is also supported by Figure 9, where the cumulative probability line of frozen cod fillet is always above that of other fish species, suggesting a higher chance of causing more IQ reduction to children in Hong Kong compared with other fish species. The high IQ reduction caused by frozen cod fillet can be explained by its high MeHg concentration, with a mean of 0.58 μg/g, shown in Figure 10.

**Statistics of IQ Loss (Central Estimate)**

| | Minimum | Median | Mean | Maximum | Std. Dev |
|---|---|---|---|---|---|
| Grass carp | -0.123309536 | -0.003321631 | -0.005475384 | -0.000215695 | 0.007573932 |
| Mud carp | -1.139887268 | -0.029916295 | -0.046783855 | -0.001276636 | 0.062639693 |
| Crucian carp | -0.235120685 | -0.011696306 | -0.018832556 | -0.000859274 | 0.02318547 |
| Grey mullet | -0.189143953 | -0.008360601 | -0.0125778 | -0.000496742 | 0.014283747 |
| Mandarin fish | -0.864985106 | -0.033317956 | -0.056358038 | -0.00115768 | 0.072982782 |
| Big head carp | -0.853052725 | -0.024270898 | -0.040093057 | -0.000634473 | 0.052524636 |
| Common sea bass | -0.964298652 | -0.026885323 | -0.042489896 | -0.001197786 | 0.056329136 |
| Macau sole | -0.861614391 | -0.04907982 | -0.081348724 | -0.002519117 | 0.098093756 |
| Golden-threadfin | -1.829666694 | -0.079867384 | -0.124070905 | -0.004740655 | 0.144239142 |
| Horse head | -1.353724748 | -0.064550712 | -0.098029271 | -0.002817122 | 0.110303561 |
| Rabbitfish | -0.183948887 | -0.010668369 | -0.015835382 | -0.000675727 | 0.016681687 |
| Grouper | -2.14565417 | -0.078607689 | -0.134897699 | -0.002057226 | 0.174721849 |
| Barramundi | -0.301650593 | -0.013974039 | -0.021278719 | -0.000440306 | 0.023469557 |
| Hairtail | -2.263666208 | -0.151496721 | -0.24238493 | -0.004772852 | 0.275949157 |
| Sweetlips | -0.762133469 | -0.048897539 | -0.075078587 | -0.00248208 | 0.085590669 |
| White pomfret | -0.293772833 | -0.015451625 | -0.023287205 | -0.000810476 | 0.026991994 |
| Pompano | -0.266167485 | -0.019068825 | -0.028261558 | -0.001034909 | 0.029120871 |
| Big-eye | -0.665825579 | -0.049814476 | -0.074491914 | -0.002583963 | 0.080182256 |
| Yellow croaker | -0.640454491 | -0.029009366 | -0.046014365 | -0.001566969 | 0.054510852 |
| Yellowfin seabream | -1.278781487 | -0.034136901 | -0.058909414 | -0.001342833 | 0.081589292 |
| Halibut | -2.4115517 | -0.093810932 | -0.158247874 | -0.003440675 | 0.202140086 |
| Frozen salmon fillet | -0.360148448 | -0.013121674 | -0.021908562 | -0.000398154 | 0.029351315 |
| Frozen Cod fillet | -10.89750814 | -0.529900672 | -0.886408173 | -0.015142468 | 1.041253723 |
| Capelin | -0.20479882 | -0.013164315 | -0.021012019 | -0.000565943 | 0.023754968 |
| Frozen catfish fillet | -0.078736135 | -0.004285965 | -0.006986884 | -0.000226482 | 0.007896557 |
| Minced dace | -0.312568548 | -0.012888233 | -0.019667301 | -0.000799975 | 0.022159539 |

**Statistics of IQ Loss (Upper-bound Estimate)**

| | Minimum | Median | Mean | Maximum | Std. Dev |
|---|---|---|---|---|---|
| Grass carp | -0.479537084 | -0.012917453 | -0.021293159 | -0.000838814 | 0.02945418 |
| Mud carp | -4.432894931 | -0.116341146 | -0.181937214 | -0.004964697 | 0.243598806 |
| Crucian carp | -0.914358218 | -0.045485636 | -0.073237717 | -0.003341621 | 0.090165716 |
| Grey mullet | -0.735559818 | -0.03251345 | -0.048913667 | -0.001931773 | 0.055547905 |
| Mandarin fish | -3.36383097 | -0.129569831 | -0.219170148 | -0.00450209 | 0.283821931 |
| Big head carp | -3.317427262 | -0.094386824 | -0.155917445 | -0.002467396 | 0.204262475 |
| Common sea bass | -3.750050314 | -0.104554035 | -0.165238486 | -0.004658056 | 0.219057753 |
| Macau sole | -3.350722632 | -0.190865965 | -0.31635615 | -0.009796565 | 0.381475716 |
| Golden-threadfin | -7.115370477 | -0.310595381 | -0.482497964 | -0.018435879 | 0.560929997 |
| Horse head | -5.264485131 | -0.251030547 | -0.381224941 | -0.010955475 | 0.428958295 |
| Rabbitfish | -0.715356783 | -0.041488102 | -0.061582041 | -0.002627829 | 0.064873227 |
| Grouper | -8.344210663 | -0.305696568 | -0.524602163 | -0.008000324 | 0.679473858 |
| Barramundi | -1.173085638 | -0.054343485 | -0.082750574 | -0.0017123 | 0.0912705 |
| Hairtail | -8.803146365 | -0.589153915 | -0.942608059 | -0.018561091 | 1.07313561 |
| Sweetlips | -2.96385238 | -0.190157094 | -0.291972284 | -0.009652532 | 0.332852601 |
| White pomfret | -1.142449904 | -0.060089655 | -0.090561355 | -0.003151852 | 0.104968866 |
| Pompano | -1.035095774 | -0.074156542 | -0.109906059 | -0.004024644 | 0.11324783 |
| Big-eye | -2.589321696 | -0.193722963 | -0.289690777 | -0.010048744 | 0.311819885 |
| Yellow croaker | -2.490656355 | -0.112814201 | -0.178944753 | -0.006093769 | 0.211986648 |
| Yellowfin seabream | -4.973039115 | -0.132754615 | -0.229092167 | -0.005222129 | 0.317291692 |
| Halibut | -9.378256611 | -0.364820292 | -0.6154084 | -0.013380402 | 0.786100333 |
| Frozen salmon fillet | -1.400577299 | -0.051028732 | -0.085199963 | -0.001548375 | 0.114144002 |
| Frozen Cod fillet | -42.37919831 | -2.060724837 | -3.447142893 | -0.058887375 | 4.049320034 |
| Capelin | -0.796439855 | -0.051194558 | -0.081713405 | -0.002200889 | 0.09238043 |
| Frozen catfish fillet | -0.306196079 | -0.01666764 | -0.027171216 | -0.000880764 | 0.030708832 |
| Minced dace | -1.215544354 | -0.050120907 | -0.076483947 | -0.003111015 | 0.086175986 |

**Figure 8.** Statistics of IQ loss (Hong Kong). This is a table displaying the estimates of minimum, median, mean, and maximum IQ loss for 26 species of seafood in Hong Kong due to dietary exposure to MeHg, together with their standard deviations.

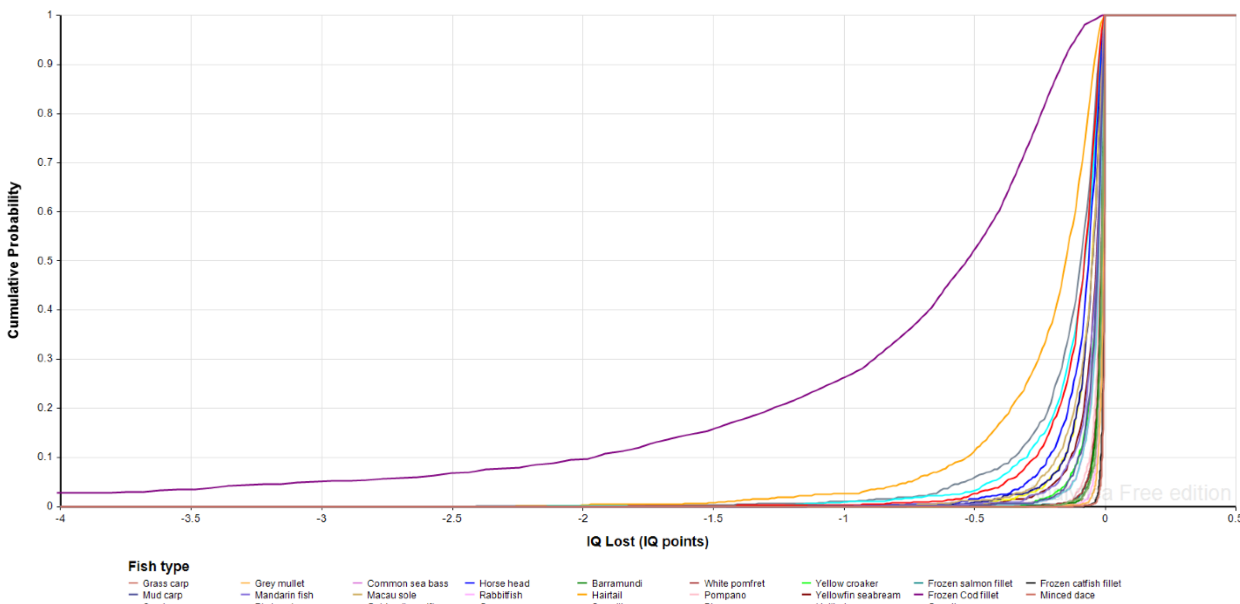


**Figure 9.** Cumulative Probability of IQ Loss (Central Estimate) (Hong Kong). This is a graph showing the cumulative probability of central estimate IQ loss for 26 species of seafood in Hong Kong due to maternal dietary exposure to MeHg.

| Fish Type | MeHg (μg/g) | Std. Dev. (μg/g) |
|---|---|---|
| Grass carp | 0.00356 | 0.00211 |
| Mud carp | 0.03087 | 0.01525 |
| Crucian carp | 0.0126 | 0.006 |
| Grey mullet | 0.00872 | 0.00431 |
| Mandarin fish | 0.03581 | 0.02302 |
| Big head carp | 0.02622 | 0.01372 |
| Common sea bass | 0.02833 | 0.01495 |
| Macau sole | 0.05165 | 0.04251 |
| Golden-threadfin | 0.08546 | 0.03447 |
| Horse head | 0.06693 | 0.03804 |
| Rabbitfish | 0.01135 | 0.00338 |
| Grouper | 0.08383 | 0.06332 |
| Barramundi | 0.01493 | 0.0057 |
| Hairtail | 0.15835 | 0.10677 |
| Sweetlips | 0.05086 | 0.02374 |
| White pomfret | 0.0155 | 0.01018 |
| Pompano | 0.02035 | 0.00552 |
| Big-eye | 0.05249 | 0.021 |
| Yellow croaker | 0.03064 | 0.01797 |
| Yellowfin seabream | 0.03648 | 0.0303 |
| Halibut | 0.09999 | 0.07575 |
| Frozen salmon fillet | 0.01369 | 0.01022 |
| Frozen Cod fillet | 0.58423 | 0.40006 |
| Capelin | 0.01426 | 0.00725 |
| Frozen catfish fillet | 0.00469 | 0.00249 |
| Minced dace | 0.01359 | 0.00558 |

**Figure 10.** MeHg Concentration in Seafood (Hong Kong). This shows the mean MeHg concentration and standard deviations of 26 types of seafood in Hong Kong (Chan et al., 2018).

Grouper, hairtail, golden-threadfin, and halibut can also be potentially dangerous relative to other fish species in Hong Kong. They all have a mean IQ reduction (central estimate) of more than 0.12 IQ points, and can all cause more than 1.8 IQ points losses. Although they are less dangerous compared with frozen cod fillet, these four fish species may still cause nonnegligible prenatal IQ reduction for children in Hong Kong.

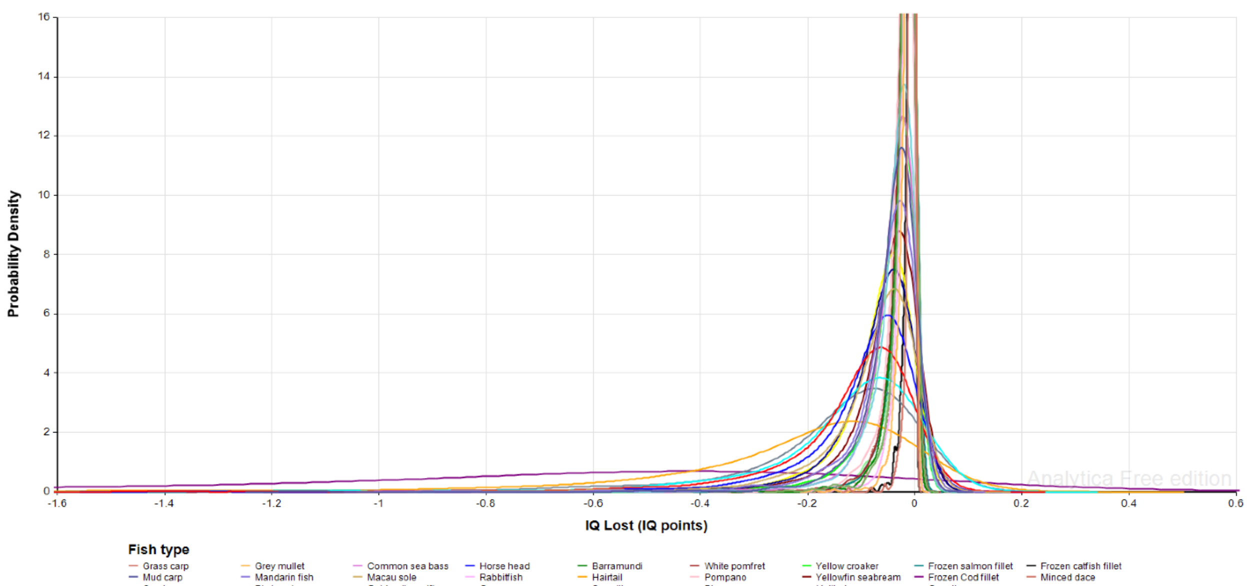


**Figure 11.** Probability Density of IQ Loss (Central Estimate) (Hong Kong). This graph illustrates the probability density of central estimate IQ loss for 26 species of seafood in Hong Kong due to maternal dietary exposure to MeHg.

The other 21 species of fish are much less notable. Given the fact that all of their mean IQ reductions in central estimate are below 0.1 and can almost never cause an IQ reduction of over 1.4, they are viewed as considerably less harmful and virtually harmless compared with the other five fish species, particularly frozen cod fillet. In Figure 11, it is evident that most of the fish species cause an IQ reduction very close to 0, which is also supported by Figure 12, where the maxima and mean IQ reduction of 21 fish species are evidently lower than that of the other five species.

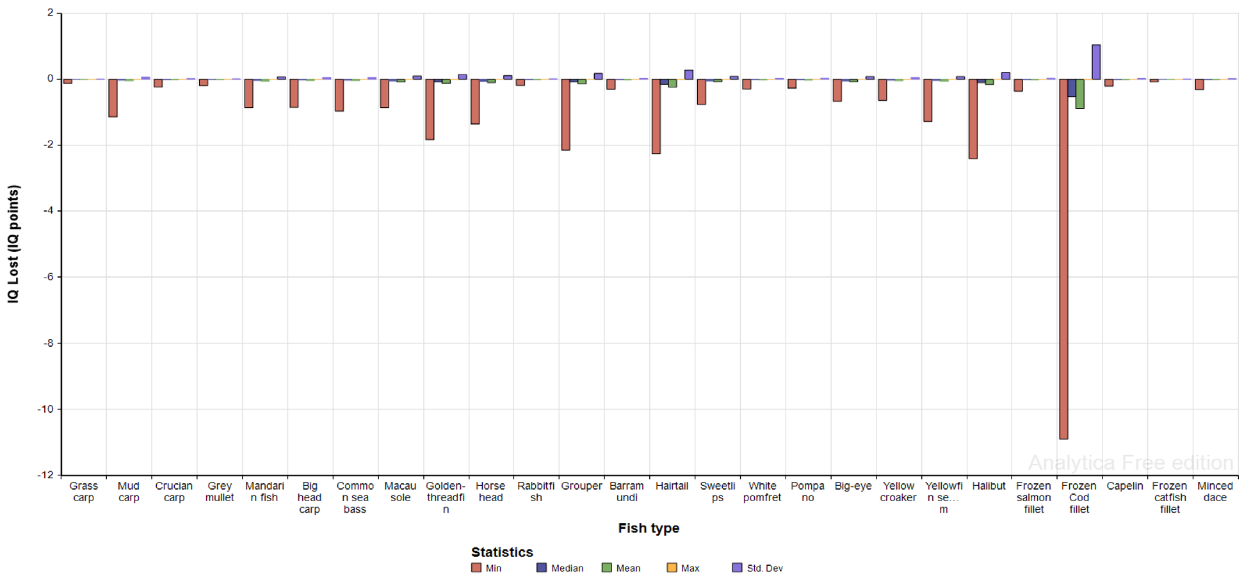


**Figure 12.** Statistics of IQ Loss (Central Estimate) (Hong Kong). This figure demonstrates the central estimates of minimum, median, mean, and maximum IQ loss for 26 species of seafood in Hong Kong due to dietary exposure to MeHg, along with their standard deviations.

## Shanghai, China

River eel and sardine are considered the most dangerous species in Shanghai in terms of prenatal IQ reduction caused by MeHg. As displayed in Figure 13, the maximum IQ reductions in central estimate are 4.26 and 4.75, respectively, which can be accounted for by their high MeHg concentration, 0.068 µg/g for river eel and 0.066 µg/g for sardine, shown in Figure 14.

**Statistics of IQ Loss (Central Estimate)**

| | Minimum | Median | Mean | Maximum | Std. Dev |
|---|---|---|---|---|---|
| River eel | -4.2588984 | -0.077096973 | -0.142254887 | -0.002717782 | 0.235259013 |
| Sturgeon | -0.806182365 | -0.016106964 | -0.030332405 | -0.000328171 | 0.0505313 |
| Longsnout catfish | -0.47208342 | -0.011324602 | -0.021458735 | -0.000293003 | 0.034490269 |
| Japanese mackerel | -0.378239173 | -0.017656081 | -0.02833963 | -0.001093542 | 0.033660623 |
| Saury | -0.942875368 | -0.043246928 | -0.065352332 | -0.002078894 | 0.077186012 |
| Large yellow croaker | -2.899834262 | -0.0243807 | -0.052642892 | -0.000159886 | 0.11884673 |
| Salmon | -1.004173654 | -0.011157259 | -0.020919178 | -0.000109872 | 0.041434648 |
| Small yellow croaker | -0.663360014 | -0.015919982 | -0.031873498 | -0.000391209 | 0.04971662 |
| Sardine | -4.747471294 | -0.071292217 | -0.138539677 | -0.001431843 | 0.246179769 |
| Conger eel | -1.391484852 | -0.066207841 | -0.110079968 | -0.001987355 | 0.142662879 |
| Belt fish | -0.708386976 | -0.025603409 | -0.043110626 | -0.001072118 | 0.055570835 |
| Spanish mackerel | -0.479397177 | -0.007844029 | -0.016751706 | -0.000111255 | 0.029721574 |
| Snapper | -2.577184304 | -0.066216256 | -0.139891727 | -0.000512953 | 0.242594371 |
| Flatfish | -1.949896643 | -0.028607285 | -0.073746349 | -0.000302958 | 0.139704588 |
| Butterfish | -0.343501468 | -0.008461445 | -0.018583581 | -0.00014222 | 0.029917204 |
| Sea bass | -0.700782392 | -0.008909987 | -0.026308331 | -9.43911E-05 | 0.055560605 |
| Swimming crab | -0.413073065 | -0.027695795 | -0.044875738 | -0.001174032 | 0.052755297 |
| Brown crab | -0.501784377 | -0.019089055 | -0.032157677 | -0.000312943 | 0.041442271 |
| Chinese mitten crab | -0.954045589 | -0.033868644 | -0.051415189 | -0.00248921 | 0.061159217 |
| Squid | -1.611129731 | -0.020711756 | -0.046582313 | -0.00030094 | 0.09400826 |
| Mussels | -0.46010473 | -0.014712919 | -0.033370201 | -0.00028084 | 0.052852736 |

**Statistics of IQ Loss (Upper-bound Estimate)**

| | Minimum | Median | Mean | Maximum | Std. Dev |
|---|---|---|---|---|---|
| River eel | -16.56238267 | -0.29982156 | -0.553213448 | -0.010569152 | 0.914896162 |
| Sturgeon | -3.135153642 | -0.062638191 | -0.117959352 | -0.001276219 | 0.19651061 |
| Longsnout catfish | -1.835879966 | -0.044040118 | -0.083450638 | -0.001139456 | 0.134128825 |
| Japanese mackerel | -1.470930118 | -0.068662536 | -0.110209674 | -0.004252664 | 0.130902422 |
| Saury | -3.666737544 | -0.168182497 | -0.254147959 | -0.008084588 | 0.300167825 |
| Large yellow croaker | -11.27713324 | -0.094813835 | -0.204722359 | -0.000621778 | 0.462181729 |
| Salmon | -3.905119767 | -0.043389342 | -0.081352359 | -0.000427282 | 0.161134744 |
| Small yellow croaker | -2.579733387 | -0.061911043 | -0.123952494 | -0.001521368 | 0.193342409 |
| Sardine | -18.46238836 | -0.277247511 | -0.538765411 | -0.00556828 | 0.95736577 |
| Conger eel | -5.411329981 | -0.257474938 | -0.428088765 | -0.007728603 | 0.554800086 |
| Belt fish | -2.75483824 | -0.099568811 | -0.167652435 | -0.004169347 | 0.216108802 |
| Spanish mackerel | -1.864322356 | -0.030504557 | -0.065145522 | -0.00043266 | 0.115583897 |
| Snapper | -10.0223834 | -0.257507663 | -0.544023383 | -0.001994818 | 0.943422555 |
| Flatfish | -7.582931391 | -0.111250553 | -0.286791357 | -0.001178172 | 0.543295618 |
| Butterfish | -1.335839042 | -0.032905618 | -0.072269481 | -0.000553078 | 0.116344682 |
| Sea bass | -2.725264858 | -0.03464995 | -0.102310175 | -0.000367076 | 0.216069019 |
| Swimming crab | -1.606395254 | -0.107705869 | -0.174516759 | -0.004565679 | 0.205159487 |
| Brown crab | -1.951383688 | -0.074235214 | -0.125057633 | -0.001217 | 0.161164386 |
| Chinese mitten crab | -3.710177291 | -0.131711395 | -0.199947956 | -0.009680262 | 0.237841401 |
| Squid | -6.265504508 | -0.080545719 | -0.181153438 | -0.00117032 | 0.365587677 |
| Mussels | -1.789296173 | -0.057216908 | -0.129773005 | -0.001092155 | 0.205538419 |

**Figure 13.** Statistics of IQ loss (Shanghai). This is a table displaying the estimates of minimum, median, mean, and maximum IQ loss for 21 species of seafood in Shanghai due to dietary exposure to MeHg, together with their standard deviations.

| Fish Type | MeHg (μg/g) | Std. Dev. (μg/g) |
|---|---|---|
| River eel | 0.069 | 0.067 |
| Sturgeon | 0.014 | 0.013 |
| Longsnout catfish | 0.01 | 0.009 |
| Japanese mackerel | 0.014 | 0.01 |
| Saury | 0.031 | 0.017 |
| Large yellow croaker | 0.024 | 0.026 |
| Salmon | 0.01 | 0.01 |
| Small yellow croaker | 0.016 | 0.02 |
| Sardine | 0.066 | 0.071 |
| Conger eel | 0.056 | 0.053 |
| Belt fish | 0.021 | 0.017 |
| Spanish mackerel | 0.008 | 0.01 |
| Snapper | 0.071 | 0.108 |
| Flatfish | 0.037 | 0.062 |
| Butterfish | 0.009 | 0.012 |
| Sea bass | 0.014 | 0.031 |
| Swimming crab | 0.022 | 0.016 |
| Brown crab | 0.016 | 0.014 |
| Chinese mitten crab | 0.025 | 0.014 |
| Squid | 0.025 | 0.033 |
| Mussels | 0.017 | 0.024 |

**Figure 14.** MeHg Concentration in Seafood (Shanghai). This shows the mean MeHg concentration and standard deviations of 21 types of seafood in Shanghai (Cai et al., 2023).

Snapper and conger eel are also worth mentioning. Having mean IQ reductions in central estimate of 0.14 and 0.11 respectively, they ranked second in fourth among the 21 species of fish in mean IQ reduction in Shanghai. Compared with conger eel, snapper is considered the more dangerous species of the two because it can cause an IQ reduction of up to 2.58 in central estimate. This is also demonstrated in Figure 15, where the probability of causing an IQ reduction of more than 0.2 is higher for snapper than for conger eel.

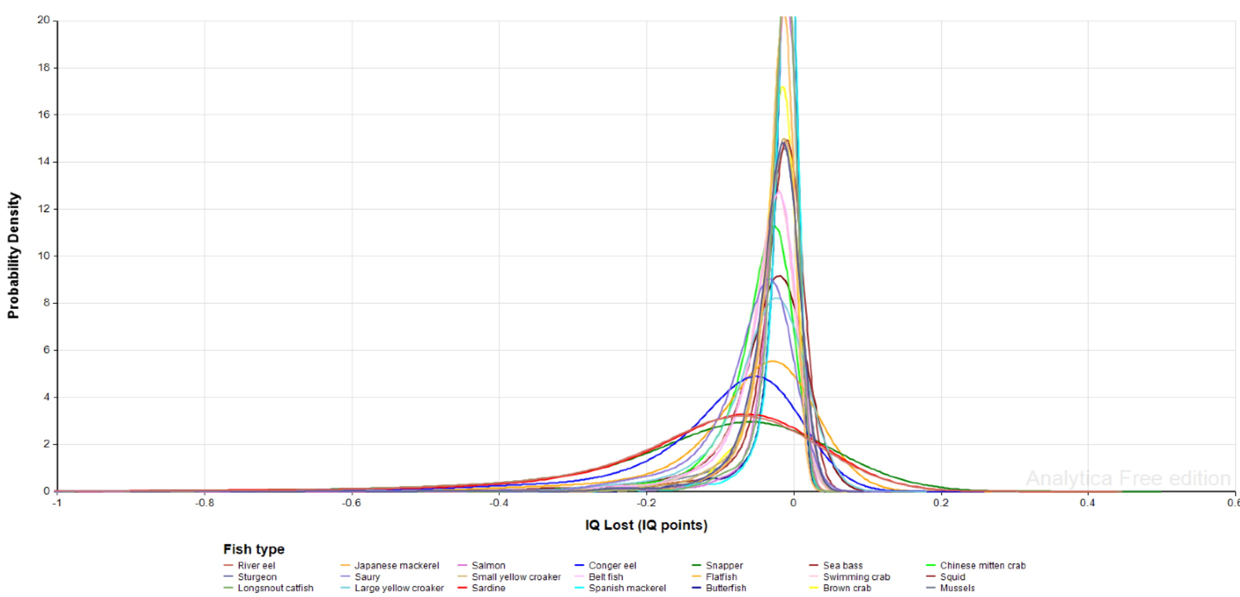

**Figure 15.** Probability Density of IQ Loss (Central Estimate) (Shanghai). This graph illustrates the probability density of central estimate IQ loss for 21 species of seafood in Shanghai due to maternal dietary exposure to MeHg.

Although large yellow croaker has a maximum IQ reduction of 2.9 in central estimates, it is considered not so dangerous due to the fact that its mean IQ reduction in central estimate is only 0.05, which is relatively low compared with species like river eel, sardine, and snapper. In Figure 16, the cumulative probability of large yellow croaker causing an IQ reduction of more than 0.4 is a lot lower than the fish species considered to be more dangerous. Similarly, squid is also considered less harmful to children's IQ despite the fact that it can cause an IQ reduction of 1.61 in central estimate; squid's mean IQ reduction in central estimate is also 0.05.

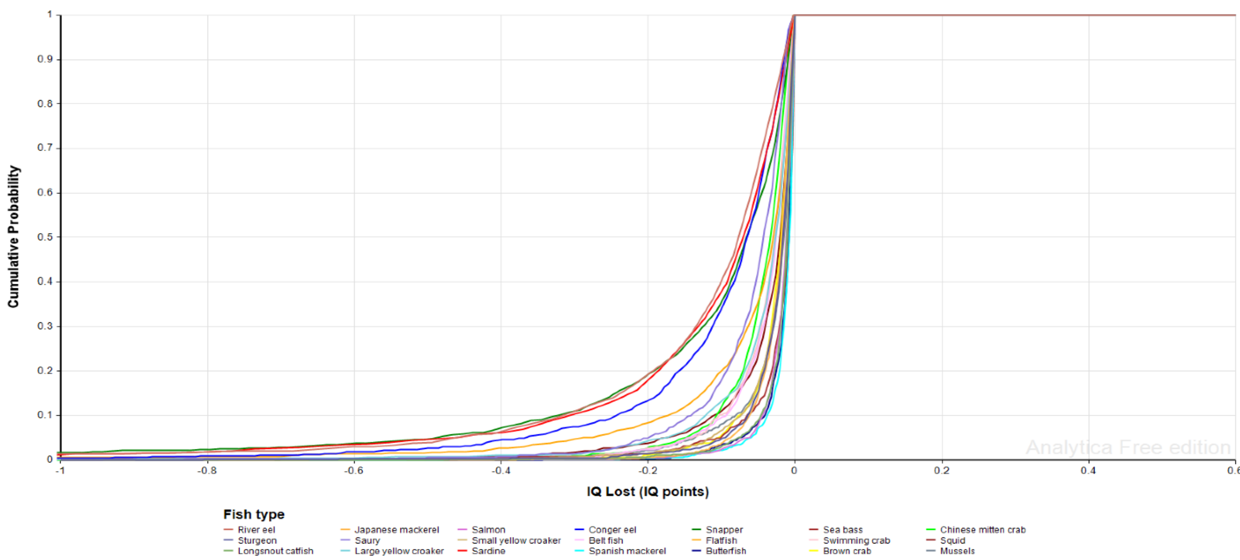


**Figure 16.** Cumulative Probability of IQ Loss (Central Estimate) (Shanghai). This is a graph showing the cumulative probability of central estimate IQ loss for 21 species of seafood in Shanghai due to maternal dietary exposure to MeHg.

All the other 15 species are considered not dangerous to Shanghai infants in terms of prenatal IQ reduction caused by MeHg through fish consumption. As shown in Figure 17, the maximum and mean IQ reduction caused by these fish species are visibly lower than the aforementioned species because they are nearly unable to cause an IQ reduction of over 1 in central estimate, and their mean IQ reductions are all below 0.08 in central estimate.

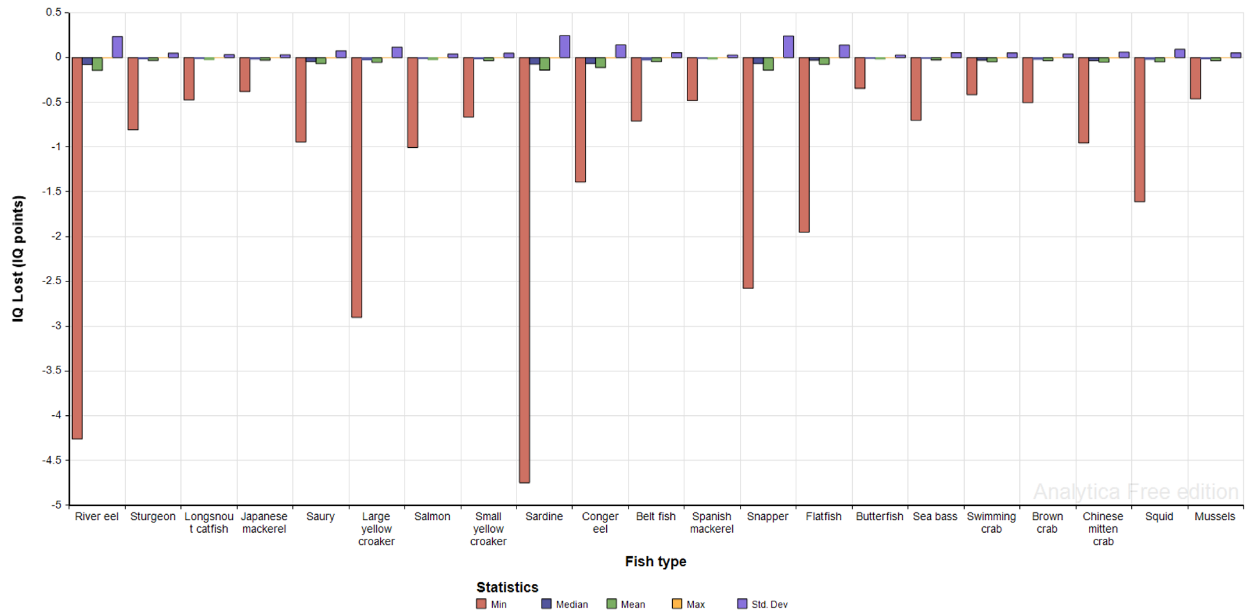


**Figure 17.** Statistics of IQ Loss (Central Estimate) (Shanghai). This figure demonstrates the central estimates of minimum, median, mean, and maximum IQ loss for 21 species of seafood in Shanghai due to dietary exposure to MeHg, along with their standard deviations.

## Comparisons

As shown in Figure 18, among the three locations studied in this research, Kuwait has on average the greatest mean IQ reduction caused by maternal dietary exposure to MeHg in fish consumption, with 0.44 IQ points in central estimate. The fact that it is almost four times that of Hong Kong (central estimate: 0.09) and eight times that of Shanghai (central estimate: 0.06) makes children in Kuwait more prone to neurological disabilities caused by prenatal intake of MeHg through fish consumption than their counterparts in Hong Kong and Shanghai. Additionally, a fish species in Kuwait can cause up to 2.49 IQ points reduction on average in central estimate, just short of that for Hong Kong and Shanghai combined (2.56 total, Hong Kong: 1.21, Shanghai: 1.35).

**Statistics of Average IQ Loss (Central Estimate)**

| | Minimum | Median | Mean | Maximum |
|---|---|---|---|---|
| Kuwait | -2.488660498 | -0.37536846 | -0.439200236 | -0.086008071 |
| Hong Kong, China | -1.210852721 | -0.055752472 | -0.09079731 | -0.002086778 |
| Shanghai, China | -1.345899488 | -0.029338577 | -0.055646983 | -0.000827877 |

**Figure 18.** Statistics of Average IQ Loss (Central Estimate). This shows the central estimate of the minimum, median, mean, and maximum IQ reductions on average for a fish species in Kuwait, Hong Kong, and Shanghai.

Between Hong Kong and Shanghai, fish species in Hong Kong are generally considered more dangerous than those in Shanghai in terms of IQ reduction. Not only does Hong Kong have a higher mean IQ reduction for each fish species on average, but it also has a higher median IQ reduction of 0.06 in central estimate, compared to Shanghai's 0.03. However, it is notable that fish species in Shanghai are more capable of causing higher IQ reductions on average compared with those in Hong Kong, since the maximum IQ reduction of average for each fish species in Shanghai is higher than in Hong Kong. Yet it still needs to be stressed that IQ reductions caused by MeHg in fish in Hong Kong and Shanghai are minimal compared with those in Kuwait.

## Conclusion and Discussion

This study conducted hazard identification, exposure assessment, dose-response relationship, and risk characterization regarding IQ reduction due to maternal dietary exposure to MeHg in Kuwait, Hong Kong, and Shanghai by establishing a risk assessment model.

The results demonstrated that all types of seafood reduced children's IQ to some extent, but most fish species had only mild effects. The mean and median IQ reduction for hamoor consumption was the largest in Kuwait and also in all three locations studied in this research. Frozen cod fillet was estimated to cause the largest IQ reduction in Hong Kong, with its mean, median, and maximum IQ reduction significantly higher than the rest of the 25 species in Hong Kong. River eel and sardine are speculated to be the more hazardous seafood types in Shanghai, due to their high mean and maximum IQ reductions. In general, fish species in Kuwait are more likely to inflict higher IQ reduction on local children, while most species in Hong Kong and Shanghai can be considered safe in terms of prenatal IQ reduction caused by MeHg in various types of seafood.

This research indicates that certain regulations may be needed to reduce the MeHg concentration in fish, thereby protecting the children from possible neurological disabilities. Also, pregnant women in coastal regions should be aware of the potential risk of consuming fish with high MeHg levels in their regions, such as hamoor in Kuwait, frozen cod fillet in Hong Kong, river eel and sardine in Shanghai, and therefore make more careful dietary choices.

This study has several advantages. First, uncertainty was included when constructing the model, thus increasing the validity of the result. For example, the average daily consumption of fish in Kuwait was estimated to have a geometric standard deviation of 1.11554572. Likewise, standard deviations were also taken into account in this study for the MeHg concentrations of all 15 types of seafood in Kuwait, 26 types of seafood in Hong Kong, and 21 types of seafood in Shanghai. Second, the IQ reductions due to maternal dietary exposure were compared between different types of seafood and different coastal regions. Instead of solely evaluating the risk of consuming one fish species, this study assessed the risks of numerous types of seafood common in the marketplaces, encompassing almost all types of fish available to the public in the three study locations. The general IQ reduction caused by MeHg through fish consumption is also compared between the three study locations, making this study not solely concentrated on one population, but more applicable to women of child-bearing age in many coastal regions in their seafood choice. Furthermore, IQ losses for consuming MeHg in different fish species were displayed quantitatively in terms of IQ points. Instead of using complicated and technical terms, this study used IQ points, a concept in everyday use, to demonstrate IQ reduction. Its application makes the results very direct and understandable to possible stakeholders, including the government and pregnant women in these coastal areas.

There are limitations in this study that need to be addressed. First, since no experiment was conducted in this study, the sample size of the seafood was small, making the MeHg concentration of the species more uncertain. Second, some of the values are used deterministically in this model. For example, although uncertainty has been considered, the body weight and daily fish consumption of women of child-bearing age in coastal areas are deterministic in this study. Third, different species of fish contain various nutrients, which may help the children grow in IQ maternally. However, the potential IQ gained from the nutrients was not considered in this research.

Based on the aforementioned analysis, there are several recommendations for future research. First. further studies can collect more seafood samples to increase the precision of the result. Second, future studies can divide the citizens in coastal areas into subpopulations by their body weight or average daily fish consumption, and then determine the IQ reduction for each of the groups. Last but not least, future studies can examine the nutrients in different fish species and assess their influence on the intelligence of children living in coastal regions.

Despite the limitations present in this study, it still has some significance that should be emphasized. This study assessed the IQ reduction of children in coastal areas due to maternal dietary exposure to MeHg in fish, and quantitively demonstrated how consumption of different types of seafood can affect children's IQ to different extents. It also compared the potential impacts of different fish species in Kuwait, Hong Kong, and Shanghai on children's IQ across the study locations. Finally, this research provided scientific evidence for pregnant women in coastal regions on their dietary choices, with the knowledge about the connection between MeHg exposures and IQ reductions in mind.

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