Concentration and Human Health Implications of Trace Metals in Fish of Economic Importance in Lagos Lagoon, Nigeria

Ngozi M. Oguguah,1 M. Onyekachi J. Ikegwu2

1 Department of Fisheries Resources, Nigerian Institute for Oceanography and Marine Research, Lagos, Nigeria.
2 Department of Food Science and Technology, Ebonyi State University, Abakaliki, Nigeria

Corresponding Author:
Ngozi M. Oguguah
Tel. +2348032642262
ngozimoguguah@yahoo.com

Introduction

Chemical contamination of food is considered to be one of the most significant sources of human health risk. The most significant sources of food borne diseases are microbiological and chemical hazards. Health risks due to consumption of food from aquatic ecosystems contaminated with hazardous chemicals including metals has increased globally, especially in developing countries like Nigeria.

Objectives. The concentration and human health implications of trace metals in fish of economic importance in Lagos lagoon were investigated by determining the degree of contamination with heavy metals of selected fish from Lagos lagoon and assessing the possible health risks associated with fish consumption.

Methods. Fish of economic importance including Caranx hippos, Chrysichthys nigrodigitatus, Elops lacerta, Galeoides decadactylus, Ilisha africana, Liza falcipinnis, Lutjanus goreensis, Mugil cephalus, Pseudotolithus senegalensis, Sarotherodon spp, Sphyraena spp, and Tilapia spp were bought from fishermen fishing in Lagos lagoon. The fish tissue samples were digested and analyzed in five replicates for heavy metals (lead, cadmium, iron, manganese and zinc) using a Varian AA600 atomic absorption spectrometer.

Results. There were considerable variations in the concentrations of heavy metals among different species. The twelve fish species collected from Lagos lagoon were found to contain various concentrations of heavy metals and the levels of accumulation of these heavy metals varied across different species. Lead, cadmium, and manganese were present in all the studied fish species at higher concentrations than the maximum allowable concentrations in fish recommended by the Food and Agricultural Organization (FAO) and World Health Organization (WHO). The target hazard quotient (THQ) estimated for individual heavy metals through consumption of different fish species was less than 1 for all individual heavy metal in all the fish species.

Conclusions. Controls on the dumping of wastes in the lagoon are needed, along with regular monitoring. Currently, no potential non-carcinogenic health risks from ingestion of a single heavy metal through consumption of these fish species was found.

Competing Interests. The authors declare no competing financial interests.

Keywords. heavy metals, target hazard quotient, hazard index; Lagos lagoon, Nigeria

J Health Pollution 13: 66-72(2017)
the consumption of contaminated fish by humans causes acute and chronic effects. Metals like cadmium (Cd), lead (Pb), mercury, barium, chromium, and arsenic have been reported to be extremely dangerous to human health, even at low levels of concentration, while essential metals (copper (Cu), cobalt, zinc (Zn), iron (Fe), calcium, magnesium, selenium, nickel and Mn) are required in very trace quantities for the proper functioning of enzyme systems, hemoglobin formation and vitamin synthesis in humans. Some of these heavy metals have neurotoxic and carcinogenic effects. Among various heavy metals, chromium and nickel are known to cause various pulmonary disorders, while high intake of Cu can cause liver and kidney damage. Cadmium is toxic to the cardiovascular system, kidneys, and bones, and excessive intake of Zn has negative effects on the immunological system (reduction in lymphocyte stimulation response) and cholesterol metabolism.

Fish are an integral component of the Nigerian diet because they are very affordable, especially for low income earners. Fish have been reported in several studies to be a source of heavy metals in humans through consumption. Although there have been several studies reporting enrichment of heavy metals in water, sediment and fish in various rivers, there have been few studies reporting the level of heavy metals in Lagos lagoon. In this context, it is important to monitor the concentration and potential human health risk associated with consumption of commonly consumed fish species in Nigeria. The present study aims to determine the degree of contamination with heavy metals of selected fish from Lagos lagoon and to assess possible health risks associated with fish consumption.

### Methods

#### Fish Collection

Fish samples were bought from professional fishermen fishing in the Lagos lagoon. The samples were immediately preserved in air sealed plastic bags for further analysis. Twelve fish species of economic importance were identified: *Caranx hippos* (Linnaeus, 1766), *Chrysichthys nigrodigitatus* (Lacepède, 1803), *Elopslacerta* (Valenciennes, 1847), *Galeoides decadactylus* (Bloch, 1795), *Ilisha africana* (Bloch, 1795), *Liza falcipinnis* (Valenciennes, 1836), *Lutjanus goreensis* (Valenciennes,1830), *Mugil cephalus* (Linnaeus, 1758), *Pseudotolithus senegalensis* (Valenciennes, 1833), *Sarotherodon spp*, *Sphyraena spp*, and *Tilapia spp*. Three samples of representative size of each species were used in the heavy metal analysis.

#### Fish Preparation

Fish samples were taken to the Physical and Chemical Laboratory of the Nigerian Institute for Oceanography and Marine Research in Lagos, Nigeria. Fish were washed with distilled water and 5 g of muscle tissue cut. The tissue was digested in analytical grade 5 ml HNO₃; 2ml H₂O₂. After digestion, the digest was filtered with Whatman filter paper and sample volume was raised to 50 ml using distilled water.

#### Metal Analysis

The samples were analyzed for Pb, Cd, Fe, Mn and Zn using a Varian AA 600 atomic absorption spectrometer. All reagents used during analysis were of analytical grade and deionized water was used throughout the study. The glassware was soaked in nitric acid for 3 days and rinsed with deionized water before use. For each analysis blank run, certified reference materials used as an internal standard were analyzed along with the samples in five replicates to eliminate any batch-specific errors. A multi-element standard solution was used to prepare a standard curve. Five standards with standard linear regression and internal standardization were prepared at levels ranging from 0–50 μg/L. All test batches were evaluated using an internal quality approach and validated if they satisfied the defined internal quality controls.

Data analysis was carried out using Statistical Package for the Social Sciences.
Table 1 — Mean Heavy Metal Concentrations in Twelve Species Collected from Lagos Lagoon, Nigeria

| Species                  | Pb (mg/kg) | Cd (mg/kg) | Fe (mg/kg) | Mn (mg/kg) | Zn (mg/kg) |
|--------------------------|------------|------------|------------|------------|------------|
| Caranx hippos            | 0.05±0.02  | 0.18±0.02  | 1.65±0.01  | 1.88±0.06  | 1.66±0.02  |
| Chrysichthys nigrodiatus| 0.03±0.03  | 0.04±0.02  | 1.71±0.02  | 0.98±0.05  | 3.91±0.08  |
| Elops lacerta            | 0.07±0.02  | 0.05±0.01  | 1.67±0.02  | 0.60±0.06  | 2.42±0.05  |
| Galeoides decadactylus   | 0.05±0.04  | 0.06±0.04  | 5.15±0.01  | 0.57±0.02  | 2.02±0.05  |
| Ilisha africana          | 0.04±0.03  | 0.13±0.04  | 1.54±0.02  | 0.31±0.02  | 2.07±0.04  |
| Liza falcipinnis         | 0.02±0.01  | 0.05±0.03  | 1.26±0.03  | 0.23±0.01  | 0.30±0.01  |
| Latjsanus gorenensis     | 0.07±0.02  | 0.08±0.02  | 0.87±0.03  | 0.02±0.01  | 1.84±0.02  |
| Mugil cephalus           | 0.06±0.02  | 0.05±0.01  | 1.14±0.02  | 0.10±0.02  | 1.75±0.02  |
| Pseudotolithus senegalensis | 0.14±0.01  | 0.13±0.03  | 1.09±0.02  | 0.10±0.03  | 0.57±0.01  |
| Sarotherodon spp         | 0.06±0.03  | 0.05±0.03  | 1.51±0.01  | 0.37±0.03  | 3.35±0.03  |
| Sphyraena spp            | 0.06±0.03  | 0.05±0.02  | 1.51±0.01  | 0.37±0.04  | 3.35±0.04  |
| Tilapia spp              | 0.13±0.04  | 0.02±0.01  | 3.35±0.02  | 0.27±0.01  | 3.58±0.03  |

All concentrations are µg/g ww
All means are ± SD

Table 2 — Environment, Feeding Habits and Importance of Twelve Species Collected from Lagos Lagoon, Nigeria

| Species                  | Environment       | Feeding habit                                      | Importance     |
|--------------------------|-------------------|---------------------------------------------------|----------------|
| Caranx hippos            | Marine; brackish  | Feeds on smaller fish, shrimp, and other invertebrates | Commercial    |
| Chrysichthys nigrodiatus| Freshwater        | Omnivorous, feed on seeds, insects, bivalves and detritus | Minor commercial |
| Elops lacerta            | Marine; freshwater; brackish; pelagic-neritic; dissent | Feeds primarily on small fishes, mainly cladopus, crustaceans and molluscs, large specimens also feed on insects | Commercial    |
| Galeoides decadactylus   | Marine; brackish; demersal; | Feeds on benthic invertebrates | Commercial    |
| Ilisha africana          | Marine; brackish; pelagic-neritic; | Feeds on small planktonic animals, like crustaceans | Commercial    |
| Liza falcipinnis         | Marine; freshwater; brackish; | Feeds on plankton and detritus | Commercial    |
| Latjsanus gorenensis     | Marine; freshwater; brackish; | Feeds mainly on fishes and bottom-dwelling invertebrates | Minor commercial |
| Mugil cephalus           | Marine; freshwater; brackish; benthopelagic; catadromous | Feeds on detritus, micro-algae and benthic organisms | Highly commercial |
| Pseudotolithus senegalensis | Marine; demersal | Feeds on fish, shrimps and crabs | West Africa |
| Sarotherodon spp         | Marine; brackish; demersal; | Feeds on aufwuchs and detritus | Commercial    |
| Sphyraena spp            | Marine; brackish; Freshwater | Feeds on fish and shrimps and epibythus, and some invertebrates | Commercial    |

Source - www.fishbase.org

Table 2 — Environment, Feeding Habits and Importance of Twelve Species Collected from Lagos Lagoon, Nigeria

Non-Carcinogenic Health Hazard and Carcinogenic Risk Estimation

The target hazard quotient (THQ) and daily intake of metals were calculated by Equations 1 and 2.\(^\text{30}\)

Equation 1

THQ = (EF × ED × FIR × C) / (RfD × WAB × AT)\(^n\)

The estimated daily intake of each heavy metal was calculated as:

Equation 2

Daily intake (mg kg\(^{-1}\)day\(^{-1}\)) = (EF × ED × FIR × C) / (RfD × WAB × AT)\(^n\)

Where, EF is the exposure frequency (350 days year\(^{-1}\)), ED is the exposure duration (54.5 years for adults), equivalent to the average lifetime (life expectancy for a Nigerian adult);\(^\text{31}\) FIR is the fish ingestion rate (kg person\(^{-1}\)day\(^{-1}\)) ; (0.02 kg person\(^{-1}\) day\(^{-1}\) for adults); C is the metal concentration in fish (mg kg\(^{-1}\)); RfD is the oral reference dose (mg kg\(^{-1}\) day\(^{-1}\)); WAB is the average body weight (kg), (60.7 kg for adults); and AT\(^n\) is the average exposure time for non-carcinogens (365 days year\(^{-1}\)×ED).\(^\text{31}\)

Equation 3 calculates an allowable daily consumption (CR\(_{\text{lim}}\)) of contaminated fish, based on a contaminant’s carcinogenic health effects, and is expressed in kilograms of fish per day:\(^\text{12}\)

Equation 3

CR\(_{\text{lim}}\) = (ARL × BW)/(CSF × C\(_m\))

For non-carcinogenic effects, based on the reference dose for each of contaminants, Equation 4 was used:
Equation 4
\[ \text{CR}_{\text{lim}} = \frac{(\text{RfD} \times \text{BW}) / \text{C}_m}{\text{BW}} \]

Where, \( \text{CR}_{\text{lim}} \) is the maximum allowable fish consumption rate (kg/d); ARL is the maximum acceptable individual life time risk level (1\(^6\), dimensionless); BW is the consumer body weight (kg); CSF is the cancer slope factor; \( \text{C}_m \) is the metal concentration in fish (mg kg\(^{-1}\)); and RfD is the oral reference dose (mg kg\(^{-1}\) day\(^{-1}\)).

If the value of THQ is above one (THQ>1), then the exposed population through consumption of fish may likely experience deleterious effects. The higher the THQ value, the higher the probability of hazard risk to the human body.

For the risk assessment of multiple heavy metals contained in fish, a total hazard index (HI) was estimated using Equation 5:

Equation 5
\[ \text{HI} = \frac{\text{THQ} (\text{Pb}) + \text{THQ} (\text{Cd}) + \text{THQ} (\text{Fe}) + \text{THQ} (\text{Mn}) + \text{THQ} (\text{Zn})}{5} \]

Where, THQ is the target hazard quotient of an individual element of heavy metals and HI is the total hazard index of the five metals investigated in this study.

Individual exposure assessment was estimated using Equation 6:

Equation 6
\[ \text{E}_m = \frac{\text{C}_m \times \text{CR} / \text{BW}}{\text{BW}} \]

Where, \( \text{E}_m \) is the individual exposure to chemical contaminants in the form of ingesting fish (mg/kg-d), \( \text{C}_m \) is the concentration of chemicals in the edible portion of fish (mg/kg), CR is the mean daily consumption rate of fish (kg/d), and BW is the body weight of an individual consumer (kg).

Table 3 — Target Hazard Quotient (THQ) for Different Heavy Metals and Hazard Index (HI) from Consumption of Twelve Fish Species Collected from Lagos Lagoon, Nigeria

Results

Metal Concentrations in Fish Species
Table 1 shows that there were considerable variations in the concentrations of heavy metals across different species. Zinc was present in the highest level in most of the fish species except for Caranx hippos and Pb was present the least. Manganese concentrations ranged between 0.02 and 1.88 µg/g ww with Caranx hippos having the highest Mn concentration. Cadmium concentrations ranged from 0.02 to 0.18 µg/g ww, with Caranx hippos having the highest Cd concentration (0.18 µg/g ww), while Tilapia spp had the lowest concentration at 0.02 µg/g ww. Lead concentrations ranged from 0.02 to 0.14 µg/g ww, with Pseudotolithus senegalensis having the highest Pb concentration. In this study, the highest concentration of Fe was 1.75 µg/g ww.

Table 2 presents the environment, feeding habits and importance of twelve species collected from Lagos Lagoon, Nigeria. Pseudotolithus senegalensis is the most economically important demersal fish in West Africa.

Non-Carcinogenic Health Hazard and Carcinogenic Risk
The health risk assessments are based on assumptions that most chemicals with non-cancer effects exhibit a threshold response. The THQ estimated for individual heavy metals for the different fish species are presented in Table 3. The results show that the THQ and HI values were less than 1 for all the heavy metals studied.

Discussion

Metal Concentrations in Fish Species
Fish muscle forms the main part of the human diet in terms of fish consumption. All the fish species in the present study contained Pd, Cd, Fe, Mn and Zn at different concentrations. These variations might be due to the level of bioaccumulation, which is a function of species and trophic transfer.34 Species at different positions in the food chain accumulate different concentrations of metals.35 In addition, it has been reported that metal speciation in the aquatic system, as well as pH and temperature, are also factors of metal accumulation.36

Zinc is an essential micronutrient.
smelting, electroplating and fertilizers have been found to contribute to the environmental concentration of Cd. Cadmium has been reported to cause kidney failure and softening of bones following long term or high dose exposure and high levels of Cd have been reported to cause prostate cancer. Lead is a ubiquitous pollutant which could have found its way into the Lagos lagoon through discharge of industrial effluents from various industries such as printing, dyeing, oil refineries, and textiles. These industries are densely located around Lagos State and some surrounding states.

Non-Carcinogenic Health Hazards and Carcinogenic Risk
The acceptable guideline value for THQ is 1. THQ values were less than 1 for all individual heavy metals in all the fish species in the present study, indicating no potential non-carcinogenic health risks from ingestion of a single heavy metal through consumption of these fishes. However, humans are often exposed to more than one pollutant and can suffer combined or interactive effects. The effect of one metal is supposed to be dependent on the others due to the competitive absorption of metal ions in specific tissues of concern. The risk associated with the carcinogenic effects of a target metal is expressed as the excess probability of contracting cancer over a lifetime of 70 years. However, THQ and HI are not direct measurements of risk because they do not define a dose–response relationship.

Epidemiological studies have shown that Cd correlates with increased incidences of cancer in humans, and belongs to Group 1 of the International Agency for Research on Cancer classification system, with sufficient evidence of carcinogenicity in humans.

Conclusions
The present study found that the twelve fish species collected from Lagos Lagoon contained various concentrations of heavy metals and the levels of accumulation of these heavy metals varied across the different species. Lead, Cd and Mn were present in all the fish species studied at higher concentrations than the maximum allowable concentrations in fish recommended by the FAO/WHO (0.05 mg/kg for Cd, 0.30 mg/kg for Pb and 2.5 mgd for Mn). The metals do not individually pose non-carcinogenic health hazards. Constant monitoring and greater enforcement of sewage disposal management should be adopted as the levels of Pb and Cd were high in sampled fish.

Acknowledgements
We are grateful to the staff and management of the Nigerian Institute for Oceanography and Marine Research Lagos, Nigeria for institutional support.

References
1. Agusa T, Kunito T, Yasunaga G, Ivata H, Subramanian A, Ismail A, Tanabe S. Concentrations of trace elements in marine fish and its risk assessment in Malaysia. Mar Pollut Bull 2005[cited 2017 Mar 9];51(8-12):896-911. Available from: http://www.sciencedirect.com/science/article/pii/S0025326X0500250X Subscription required to view.
2. Agusa T, Kunito T, Sudaryanto A, Monirith I, Kan-Atireklap S, Ivata H, Ismail A, Sanguinsin J, Muchtar M, Tana TS, Tanabe S. Exposure assessment for trace elements from consumption of marine fish in Southeast Asia. Environ Pollut 2007 Feb[cited 2017 Mar 9];145(3):766-77. Available from: http://www.sciencedirect.com/science/article/pii/S0269749106003526 Subscription required to view.
3. Hajeb P, Jinap S, Ismail A, Fatimah AB, Jamilah B, Abdul Rahim M. Assessment of mercury level in...
Concentration and Human Health Implications of Trace Metals in Fish in Lagos Lagoon, Nigeria

commonly consumed marine fishes in Malaysia. Food Control [Internet]. 2009 Jan [cited 2017 Mar 9];20(1):79-84. Available from: http://www.sciencedirect.com/science/article/pii/S0956713508000601 Subscription required to view.

4. Oyewo EO, Don-Pedro KN. Estimated annual discharge rates of heavy metals from industrial sources around Lagos; a West African Coastal Metropolis. West Afr J Appl Ecol [Internet]. 2003 [cited 2017 Mar 9];4(1):115-23. Available from: http://www.aajol.info/index.php/waja/article/view/45588

5. Hill MB, Webb JE. The ecology of Lagos Lagoon. II. The topography and physical features of Lagos Harbour and Lagos Lagoon. Philosophical Transactions Royal Soc Lond [Internet]. 1958 Sep 4 [cited 2017 Mar 9];241(683):319-33. Available from: http://www.jstor.org/stable/92530 Subscription required to view.

6. Singh J, Hewawasam H, Moffat D. Nigeria: strategic options for redressing industrial pollution [Internet]. Vol 1. Washington, D.C.: World Bank; 1995 Feb 1 [cited 2017 Mar 9];69 p. Available from: http://documents.worldbank.org/curated/en/287401468333530717/Nigeria-Strategic-options-for-redressing-industrial-pollution

7. Safahieh A, Monikh FA, Savari A. Heavy metals contamination in sediment and sole fish (Erythrylopsis orientalis) from Musa Estuary (Persian Gulf). World J Fish Mar Sci [Internet]. 2011 [cited 2017 Mar 9];3(4):290-7. Available from: https://doi.org/10.7179/wjfrms3(4)(11)/5.pdf

8. Tam NF, Wong YS. Spatial and temporal variations of heavy metal contamination in sediments of a mangrove swamp in Hong Kong. Mar Pollut Bull [Internet]. 1995 Apr-Dec [cited 2017 Mar 9];31(4-12):254-61. Available from: http://www.sciencedirect.com/science/article/pii/0025326X95001419 Subscription required to view.

9. Otitoju AA, Don-Pedro KN. Bioaccumulation of heavy metals (Zn, Pb, Cu and Cd) by Tympanotus fuscatus fuscatus var. radulae (L) exposed to sublethal concentrations in laboratory bioassay. West Afr J Appl Ecol [Internet]. 2002 [cited 2017 Mar 9];13(1):17-29. Available from: http://www.aajol.info/index.php/waja/article/view/45570/29053

10. Tuzen M. Determination of heavy metals in fish samples of the middle Black Sea (Turkey) by graphite furnace atomic absorption spectrometry. Food Chem [Internet]. 2003 Jan [cited 2017 Mar 9];880(1):119-23. Available from: http://www.sciencedirect.com/science/article/pii/S0308814602002649 Subscription required to view.

11. Otitoju AA, Don-Pedro KN. Integrated laboratory and field assessments of heavy metals accumulation in edible periwinkle, Tympanotus fuscatus fuscatus var radulae (L.), Ecotoxicol Environ Saf [Internet]. 2004 Mar [cited 2017 Mar 9];57(3):354-62. Available from: http://www.sciencedirect.com/science/article/pii/S0147651303001751 Subscription required to view.

12. Saha N, Zaman MR. Evaluation of possible health risks of heavy metals by consumption of foodstuffs available in the central market of Rajshahi City, Bangladesh. Environ Monit Assess [Internet]. 2013 May [cited 2017 Mar 9];185(5):3867-78. Available from: https://link.springer.com/article/10.1007/s10661-012-2835-2 Subscription required to view.

13. Gale NL, Adams CD, Wixson BG, Loftin KA, Huang YW. Lead, zinc, copper, and cadmium in fish and sediments from the Big River and Flat River Creek of Missouri’s Old Lead Belt. Environ Geochem Health [Internet]. 2004 Mar [cited 2017 Mar 9];26(1):37-49. Available from: https://link.springer.com/article/10.1023/B:EGHA.00000290935.89794.57 Subscription required to view.

14. Aladetohun NF, Sakiti NG, Babatunde EE. Copoepods parasites in economically important fish, Mugilidae (Mugil cephalus and Liza falcipinnis from Lac Nosuke Lagoon in Republic of Benin, West Africa. Afr J Environ Sci Technol [Internet]. 2013 Aug [cited 2017 Mar 9];7(8):799-807. Available from: http://www.aajol.info/index.php/aesj/article/view/93927

15. Aiyesami AF. Baseline concentration of heavy metals in water samples from rivers within Okitipupa Southeast Belt of the Nigerian Bitumen Field. J Chem Soc Nigeria. 200631(1)(2):30-7.  

16. Ubalua AU. Cassava wastes: treatment options and value addition alternatives. Afr J Biotechnol [Internet]. 2007 Sep [cited 2017 Mar 9];6(18):2065-73. Available from: http://www.academicjournals.org/journal/AJB/article-abstract/OE08838826

17. Caniñi M, Attí G. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environ Pollut [Internet]. 2003 Jan [cited 2017 Mar 9];121(1):129-36. Available from: http://www.sciencedirect.com/science/article/pii/S026974910200194X Subscription required to view.

18. Duruihe JO, Ogwuwegu MO, Egaruwugwu JN. Heavy metal pollution and human biotic effects. Int J Phys Sci [Internet]. 2007 May [cited 2017 Mar 9];2(5):112-8. Available from: http://www.academicjournals.org/IJPS/article-abstract/59CA35213127

19. Sapkota A, Sapkota AR, Kucharski M, Burke J, McKenzie S, Walker P, Lawrence R. Aquaculture practices and potential human health risks: current knowledge and future priorities. Environ Int [Internet]. 2008 Nov [cited 2017 Mar 9];34(6):1215-26. Available from: http://www.sciencedirect.com/science/article/pii/S0160412008000718 Subscription required to view.

20. Forti E, Salovaara S, Cetin Y, Bulgheroni A, Tessadri R, Jennings P, Pfaefler W, Prieto P. In vitro evaluation of the toxicity induced by nickel soluble and particulate forms in human airway epithelial cells. Toxicol In Vitro [Internet]. 2011 Mar [cited 2017 Mar 9];25(2):454-61. Available from: http://www.sciencedirect.com/science/article/pii/S088723331000305X Subscription required to view.

21. Tuzen M. Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey. Food Chem Toxicol [Internet]. 2009 Aug [cited 2017 Mar 9];47(8):1785-90. Available from: http://www.sciencedirect.com/science/article/pii/S0278691509001987 Subscription required to view.

22. Ten chemicals of major public health concern [Internet]. Geneva, Switzerland: World Health Organization; 2010 [cited 2017 Mar 9]. Available from: http://www.who.int/ipcs/assessment/public_health/chemicals_pbc/en/

23. Bernard A. Cadmium & its adverse effects on human health. Indian J Med Res [Internet]. 2008 Oct [cited 2017 Mar 9];128(4):557-64. Available from: https://www.researchgate.net/publication/23688123_Cadmium_and_its_adverse_effects_on_humans

24. Goldhaber SB. Trace element risk assessment: essentiality vs. toxicity. Regul Toxicol Pharmacol [Internet]. 2003 Oct [cited 2017 Mar 9];38(2):232-42. Available from: http://www.sciencedirect.com/science/article/pii/S0273232600020020X Subscription required to view.

25. Castro-Gonzalez MI, Mendez-Armenta M. Heavy metals: implications associated to fish consumption. Environ Toxicol Pharam [Internet]. 2008 Nov [cited 2017 Mar 9];26(3):263-71. Available from: http://www.sciencedirect.com/science/article/pii/S138268908000914X Subscription required to view.

26. Schneider W, editor. FAO species identification guide for fishery purposes: field guide to the commercial marine resources of the Gulf of Guinea [Internet]. Rome, Italy: Food and Agriculture Organization of the United Nations; 1990 [cited 2017 Mar 9]. 268 p. Available from: http://www.fao.org/docrep/009/00438e/00438e00.htm

27. Manual of methods in aquatic environmental research, part 9: analyses of metals and organochlorines in fish (FAO fisheries technical paper). Rome, Italy: Food and Agriculture Organization of the United Nations; 1984 Oct. p. 21-33.

28. Standard methods for the examination of water and...
30. Guidance for assessing chemical contaminant data for use in fish advisories. Vol 2: Risk assessment and fish consumption limits [Internet]. 3rd ed. Washington, D.C.: United States Environmental Protection Agency; 2000 Nov [cited 2017 Mar 9]. 383 p. Available from: https://www.epa.gov/sites/production/files/2015-06/documents/volume2.pdf

31. Guidance for assessing chemical contaminant data for use in fish advisories. Vol 2: Risk assessment and fish consumption limits [Internet]. 3rd ed. Washington, D.C.: United States Environmental Protection Agency; 2000 Nov [cited 2017 Mar 9]. 383 p. Available from: https://www.epa.gov/sites/production/files/2015-06/documents/volume2.pdf

32. Regional screening level (RSL): what's new [Internet]. Washington, D.C.: United States Environmental Protection Agency; 2016 May [cited 2017 Mar 9]. [about 15 screens]. Available from: https://www.epa.gov/risk/regional-screening-levels-what's-new-may-2016

33. Froese, R. and D. Pauly. Editors. FishBase. www.fishbase.org, version (10/2016). [accessed 2017 March]

34. Spry DJ, Wiener JG. Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review. Environ Pollut [Internet]. 1991 [cited 2017 Mar 9];71(2-4):243-304. Available from: http://www.sciencedirect.com/science/article/pii/026974919190034T?via%3Dihub Subscription required to view.

35. Ahmed K, Baki MA, Kundu GK, Islam S, Islam M, Hossain M. Human health risks from heavy metals in fish of Buriganga river, Bangladesh. SpringerPlus [Internet]. 2016 [cited 2017 Mar 9];5(1697)1-12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5047865/

36. Dhanakumar S, Solaraj G, Mohanraj R. Heavy metal partitioning in sediments and bioaccumulation in commercial fish species of three major reservoirs of river Cauvery delta region, India. Ecotoxicol Environ Saf [Internet]. 2015 Mar [cited 2017 Mar 10];113:145-51. Available from: http://www.sciencedirect.com/science/article/pii/S0147651314005442 Subscription required to view.

37. Heath AG. Water pollution and fish physiology. In Boca Raton, N. V., (2nd Eds). CRC press, Florida, USA 2000.

38. Ahmed K, Baki MA, Kundu GK, Islam S, Islam M, Hossain M. Human health risks from heavy metals in fish of Buriganga river, Bangladesh. SpringerPlus [Internet]. 2016 [cited 2017 Mar 9];5(1697)1-12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5047865/

39. Sivaperumal P, Sankar TV, Nair PG. Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. Food Chem [Internet]. 2007 [cited 2017 Mar 10];102(3):612-20. Available from: http://www.sciencedirect.com/science/article/pii/ S0308814606004341 Subscription required to view.

40. Moreno JA, Yeomans EC, Streifel KM, Brattin BL, Taylor RJ, Tjalkens RB. Age-dependent susceptibility to manganese-induced neurological dysfunction. Toxicol Sci [Internet]. 2009 Dec [cited 2017 Mar 10];112(2):394-404. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2777078/

41. Vannoor BT, Thomson BM. 2003/04 New Zealand total diet survey: agricultural compound residue, selected contaminants and nutrients [Internet]. Wellington, New Zealand: New Zealand Food Safety Authority; 2005 Dec [cited 2017 Mar 10]. 144 p. Available from: http://www.foodsafety.govt.nz/elibrary/industry/2003_04-Analyses_Environmental.pdf

42. Gray MA, Harrins 42A, Centeno JA. The role of cadmium, zinc, and selenium in prostate disease. In: Moore TA, Black A, Centeno JA, Harding JS, Trumm DA, editors. Metal contaminants in New Zealand: sources, treatments, and effects on ecology and human health. Christchurch, New Zealand: Resolutionz Press; 2005. p. 393-414.

43. Li J, Huang Z, Hu Y, Yang H. Potential risk assessment of heavy metals by consuming shellfish collected from Xiamen, China. Environ Sci Pollut Res Int [Internet]. 2013 May [cited 2017 Mar 10];20(5):2937-47. Available from: https://link.springer.com/article/10.1007/s11356-012-1207-3 Subscription required to view.

44. Sappington K, Fairbrother A, Wentzel R, Wood W. Development of a Framework for Metals Risk Assessment: EPA Framework for metals. Available from: http://www.epa.gov/sites/production/files/2015-09/documents/rags_a.pdf [accessed 2017 March]

45. Risk assessment guidance for superfund. Vol. I, Human health evaluation manual [Internet]. Washington, D.C.: United States Environmental Protection Agency; 1989 Dec [cited 2017 Mar 10]. 291 p. Available from: https://www.epa.gov/sites/production/files/2015-09/documents/volume2.pdf

46. Nordberg GF, Fowler BA, Nordberg M, editors. Handbook on the toxicology of metals. 4th ed. London: Academic Press; 2015. 1542 p.

47. Stewart BW, Wild CP, editors. World cancer report 2014 [Internet]. Lyon, France: International Agency for Research on Cancer; 2014 [cited 2017 Mar 10]. 619 p. Available from: http://publications.iarc.fr/Non-Series-Publications/World-Cancer-Reports/World-Cancer-Report-2014 Subscription required to view.

48. Summary and conclusions [Internet]. Joint FAO/WHO expert committee on food additives: seventy-third meeting; 2010 Jun 6-17; Geneva, Switzerland. Rome, Italy: Food and Agriculture Organization of the United Nations; 2010 Jun 24 [cited 2017 Mar 10]. 17 p. Available from: http://www.who.int/foodsafety/publications/chem/summary73.pdf