Short Communication

Economic Benefits of Reducing Methylmercury in Food: an Integrated Approach to Bridge the Gap between Food Toxicology, Public Health and Economy

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Abstract

Methylmercury is one of the most toxic chemical compounds, which raises concern for assessing its effects at local and global levels. The Minamata Convention is a worldwide action established in 2013 to redouble efforts against mercury pollution and its adverse effects on human health. During the last decade, there was an exponential increase in investigating the impacts of methylmercury on food toxicology, human health, economy, among others, although there is a lack of studies that link them. The present study proposes an integrated approach among food toxicology, public health, and economy, to reduce the amount of methylmercury in food. The information generated may allow local regulatory agencies and international organizations to identify which food groups should be focused, thus reducing dietary methylmercury exposure, and developing effective action plans against foodstuffs most harmful to human health.

Keywords: Methylmercury intake, food, human health, economic benefits, IQ reduction

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Introduction

Methylmercury (MeHg) is the most toxic compound formed from mercury (Hg), and it is distributed throughout all terrestrial and aquatic ecosystems around the world, even in food. This chemical compound makes up a problem of global concern because of its high toxicity, long persistence in the environment, its ability to biomagnify through food chains, and its significant adverse effects on health and environmental compartments, even at low exposure levels. As a consequence, it established the Minamata Convention in 2013 in order to promote global actions to protect human and environmental health from Hg and its compounds by encouraging plans that reduce environmental Hg and human exposure; the article 19 of this Convention encourages to assess the effects of MeHg on human health, the environment, society, and the economy [1].

MeHg can be transported over long distances, and its ubiquity in aquatic ecosystems makes global population can be potentially exposed [2]. Most people without occupational Hg exposure, is generally exposed to MeHg mainly through food intake, especially fish and seafood, which stands out as the most important sources of MeHg [3]. People feeding mainly on fish may exceed up to six times the tolerable weekly intake (TWI) of MeHg (1.3 µg/kg body weight, [4]). There is an increasing amount of research describing rice consumption as another important source of MeHg among people from China and other Asian countries [5-7], as further research is needed on dietary exposure through rice from other geographic regions [8].

There are foods that have an antagonistic effect on MeHg toxicity, such as those with high content of n-3 polyunsaturated fatty acids (PUFA), selenium, iodine, lycopene pro-anthocyanidins, antioxidants, and polyphenols, which can be found in vegetables (e.g., tomatoes) and crops (e.g. tea) [9, 10]. The mechanisms that act as potential protective effects of food on MeHg exposure and toxicity are not yet completely understood, but are a topic of growing interest among researchers [11-14]. For food toxicology, the majority of the studies have reported total mercury (THg) levels in different food products, and their human exposure through diet [15-17]. National dietary surveys of Hg concentrations in the general population have been conducted in France [15] and Korea [18]. In addition, some specific regions from developing countries such as Nepal [17], Peru [19], Ghana [20], and Suriname [21], are been considered.

Assessing the exposure and bioaccumulation in human populations is not a straightforward task, even though several biological samples (e.g., blood) can be collected to evaluate these factors. Among them, hair is a non-invasive matrix, easily sampled under regular procedures, and usually used to assess Hg exposure as there is a direct correlation between Hg daily intake and its concentrations in human hair [22]. Hair Hg burden is a standard tool for monitoring Hg among human population, as hair is a reliable indicator of internal dose [23] and Hg dietary intake [22]. Mercury is incorporated into the hair follicle during its formation, having a direct correlation with Hg levels in blood [24, 25]. Analytically, over 90% of the THg in human hair corresponds to MeHg [26, 27]. Besides, hair samples can be transported and stored at ambient temperature, thus facilitating any logistic tasks during fieldwork. During storage, Hg in hair remains unaltered over many years when samples are stored under dry and dark conditions [28]. The adverse effects of MeHg exposure on human health have a strong scientific basis [8, 16]. The evidence shows that prenatal MeHg exposure produces extreme fetal abnormalities and significant decreases of neurological and cognitive functions [29-31]. Available data suggest that moderated exposure to Hg can be associated with memory loss, less attention, lower language development, and reduction of visual-motor skills [32]. MeHg in pregnant women's hair has been directly correlated with infant intelligence quotient (IQ) loss, with 0.7 decrease of IQ per each part per million (ppm) increase of Hg levels in mother's hair [33].

Losing IQ due to Hg burden has been used to estimate the economic impact of human Hg exposure. This analysis is a key factor in promoting management plans and public policies for environment protection [34]. However, many developing countries and those with transition economies have limited data about Hg exposures and less any economic impacts of Hg contamination [35]. Some estimations about the economic effects caused by Hg exposure in developed countries have evidenced substantial economic costs, especially in terms of a lesser economic productivity. For instance, an estimated of US$5.1 billion loss was reported in USA during 2008 [36] from Hg exposure, whereas in the European Union the losses were as high as US$9 billion [37]. Trasande et al. (2016) reported US$77.4 million in lost economic productivity in 15 developing countries. Some studies also have showed a significant economic benefits when some measures were applied for preventing Hg contamination in USA and other regions [38, 39]. However, those studies are based on THg instead of MeHg, which can be more accurate.

Currently, there is no integrated approach that bridges the gap between human MeHg exposure through diet and the economic benefits derived from implementing reduction plans. Most approaches have only been addressed separately, such as human dietary exposure to Hg [15], or the relationship of Hg food levels with hair [22], or economic impacts due to prevention human Hg exposure [35]. Quantifying the costs of MeHg food contamination, i.e. the economic benefits derived from preventing MeHg food contamination may contribute to improve the Minamata Convention. This novel approach can be useful for local regulatory agencies and international organizations to assess the economic benefits of reducing MeHg concentrations

in food, as well as knowing which foods should be focused on MeHg reduction.

Data Collection for Estimating the Economic Benefits of Reducing Hg in Food

Consumption Data and Food Sampling

Data collection must follow strict protocols with clear available information about the scope of the study, and data usage of survey subjects having formal consent. The surveys must observe some requirements: i) a daily dietary count survey with a representative sample from the adult population (18-65 years, working age) is quite required; ii) it is recommended that selected individuals be visited at homes by trained interviewers; iii) the subjects must fill a record for seven consecutive days (one week) to describe their feeding habits as precisely as possible (participants must be instructed they may refuse to answer it); iv) food portions to be tested are suggested to be taken from photographs compiled from an accredited manual [40]; v) interviewers must know whether food stuff was consumed at home or elsewhere; vi) weight of each interviewed must be registered to calculate his daily MeHg consumption.

After the survey, the most consumed items must be selected, based on the food ingested. Staple foods should cover about 90% of the entire diet and then divided into 17 food groups, as suggested by some researchers [42]. Foods must be purchased in triplicate from local markets in the area to be studied.

Hair Sampling

From each interviewee (voluntarily agreed and accepted), a bundle of hair must be cut from the occipital portion of the head, near the scalp, placed in an identified plastic bag, and then stapled to prevent hair displacement. Hair samples must be stored at room temperature until analysis. Individual information about the purpose of the study must be provided, and participants must be instructed they might refuse to take part in their will. Everyone must be told that data got from the survey will be confidential. Any testing must be approved by the Bioethics Committee of the sponsoring institution.

Laboratory Analysis

Preparation of Food Samples

Any inedible parts of foodstuff must be removed, and then prepared according to the most typical forms of consumption. It is recommended that cooking methods be roasting, steaming, baking, and boiling with deionized water. Do not add more ingredients during cooking. Canned foods must be drained immediately after opening. Fresh foods (vegetables and fruits) must be washed with distilled water. All samples must be homogenized using a domestic food processor. It is recommended that each food item be processed by triplicate (using different brands), and each item analyzed by triplicate or at less by duplicate. After homogenization, all foodstuffs must be weighed according to the percentage defined within their own category. The samples must be stored in a cool and dry place until further analysis [41, 42].

Quantification of MeHg in Food and Hair

MeHg extraction procedure and subsequent analysis can be performed by Direct Mercury Analyzer (DMA) [43] or by new methods as based on Square Wave Anodic Stripping Voltammetry (SW-ASV) with a Solid Gold Electrode (SGE), which allows analyzing THg and MeHg *in situ* [44]. These lab techniques are cheap and rapid procedures very appropriate for massive Hg evaluations and monitoring, and they are proven to be high-quality techniques.

Hair samples must be cut into short segments (approximately 5 mm) and then washed with acetone and Milli-Q water, and dried overnight (oven, 60ºC). Exposure to MeHg can be assessed through THg concentration in hair, since over 90% of THg corresponds to MeHg [26, 27]. Thus, MeHg should be analyzed in 10% of the samples to corroborate this relationship. THg analysis can be analyzed through DMA-80 analyzer (Milestone, USA), following the US EPA method 7473 [45].

Analysis of the Economic Benefits of Reducing MeHg in Foods

The estimation of the economic benefits of MeHg reduction in foodstuff is through analysis of the MeHg ingested, which has been shown to have a direct correlation to MeHg in hair. Losing IQ has been used to estimate economic losses in productive populations. We propose that using data of IQ index in humans could help us estimate which foodstuff(s) have the greatest influence on the economic loss derived from MeHg burden. With these results, action plans can be developed according to which foods are more harmful to human health, and consequently to the economy. The data analysis needed is described as follows:

Estimate Daily Intake (EDI)

$$EDI = \sum_{i=1}^{n} \frac{(Fi \, x \, Cmi)}{W}$$

(1)

where, Fi is the consumption of a particular food group (g/day), Cmi is the concentration of MeHg in the composite food sample (mg/g), W is the body weight (Kg), and n is the total of food groups consumed [41].

Estimation of MeHg Intake by Food Group

Based on the fact that the highest Hg exposure is due to diet, the total MeHg hair levels are due to the total food consumption. The contribution of each food group to the total MeHg concentration in hair (MeHg fg) can be calculated as follows:

$$MeHg\,fg = \frac{MeHg\,h\,x\,(\frac{Cfi\,x\,IRfi}{W\,(kg)})}{\sum(\frac{Cfi\,x\,IRfi}{W})} \qquad (2)$$

where MeHg h is the concentration of MeHg in hair, C*fi* is the concentration of MeHg from a food group, IR*fi* is the radius of intake from a food group, and W is the body weight.

Any food group showing the highest MeHg levels must be deeper screened to identify which food into the group exhibited the highest MeHg levels. In the case, MeHg in food exhibited negative relationships with MeHg in hair; it would mean that those food items have an antagonistic effect on MeHg (i.e. a protective action against MeHg contamination).

Intelligence Quotient Loss

The MeHg levels obtained with Equation (2) can be used to estimate fetal exposure and subsequent infant IQ loss [33]. Coefficient of IQ loss due to prenatal Hg burden has been used for several studies estimating the benefits of reducing Hg exposure [35, 37, 46]. Subsequently these results can be classified into specific ranges (<0.5, 0.5-1, 1-2, 2-4, 4-8, 8-16 and >16), according to Trasande et al. [35].

Economic Analysis

The main impact on social costs incurred by IQ reduction is lesser productivity and therefore a loss of earning capacity [47]. Following the approaches of previous authors [36, 37, 48], each IQ point is valued in U.S. dollars by updating Trasande's estimate of US$19,269 of 2010 [35], using the U.S. general consumer price index [49]. The cost value must be multiplied by the relationship between the Gross Domestic Product (GDP) per capita, and the value can be adjusted by differences in purchasing power. The exchange rate conversion and GDP can be adjusted for price differences, purchasing power parity (PPP), and conversion rates based on a common set of international prices. It is also recommended to carry out all calculations after adjustment for productivity as the ratio of PPP-adjusted real GDP in each region to that of the United States as a benchmark. Finally, the region-specific value must be multiplied by the lost IQ points to estimate the impact of labor and productivity costs.

Modeling and Proposals for Action Plans

Regions to be studied must be classified according to their potential for presenting the greatest economic benefit of reducing MeHg in food, and then to determine which foods are influencing the dietary MeHg exposure. It is recommended to analyze different scenarios for reducing MeHg levels (100%, 50%, 25%, 10% and 5%), taking groups and foods, which exhibited greater economic losses. Once data is obtained, a proposal based on which foodstuff must be prioritized for MeHg reduction must be developed. Monitoring for assessing an effective MeHg reduction must be implemented on concordance with action plans (estimated time for expected MeHg reduction in foods influencing the most a lesser economy).

Discussion

The present integrated approach, which is based on food toxicology, public health and economy, may be useful to design plans to quantify the impacts of MeHg contaminated food on human health, and their effects on economy (Fig. 1). This model, as well as others that have quantified the economic impacts of THg, is based on the loss of productivity due to a decreased IQ index [35-38]. For public health, MeHg exposure at sub-lethal doses for a long time period can lead to immunosuppression [50]. This physiological problem enhances the severity of pathogens such as viruses and bacteria, which may include COVID-19 [51]. Negative health effects caused by Hg are of global concern [52]. Future research should quantify the indirect costs of MeHg exposure to health care services. This integrated approach incorporates adults between 18-65 years (working ages), assessing how much is the economic benefit of MeHg reduction over current production. The analysis of lesser IQ index in children and adolescents due to MeHg food intake can be used to evaluate future sceneries with novel feeding habits that warrant the less MeHg ingestion.

The lack of research linking food toxicology, human health, and economy explains the lack of understanding about the benefits than could be obtained by reducing MeHg levels in food. Some approaches have only reported some relationships based on THg [35, 36, 38, 39]. Studies based on MeHg are required to make a more precise estimation, because MeHg is the chemical stressor responsible for causing the major biological alterations (cognitive level, lesser IQ, immunosuppression, and other biological problems). Traditional MeHg analyzes are complex and not rapid (analytically), making massive monitoring and evaluation very expensive. However, new techniques are under full development, and can make MeHg analyzes much easier and affordable [43, 44].

Global food trade is an important factor affecting MeHg food exposure. The export/import of food

commodities among countries and geographic regions are causing MeHg in food to be less unrelated to environmental MeHg of the region. The homogeneity in the food supply by large supermarket chains can generate similar MeHg levels in foods from different regions [53]. The rate of food intake in each region may have the greatest influence on the differentiation between regions and therefore on the perceived economic benefits of reducing MeHg in food. In addition, the type of food consumed can vary from supply/demand to purchasing power of people, as observed by the National Institutes of Statistics of each country. It is necessary that this approach take into consideration the above-mentioned points to be implemented. Future research should address potential differences in MeHg dietary exposure according to socioeconomic level. Food quality and

MeHg concentrations may differ according to price of the product. This point, along with income level and population, can influence the economic benefits that would be perceived from reducing MeHg in food.

This approach will allow to spot areas of major MeHg exposure by food ingestion, and to identify which foodstuff (or groups) incorporates more MeHg to human body through diet. The tolerable Hg dietary intake is one of the major actions enforced by health organizations from countries that signed the Mercury Convention and WHO. It should be kept in mind that fish and shellfish may not necessarily be the food with the highest MeHg levels. The rate of food intake plays a key role in MeHg exposure in humans, therefore a population could be more exposed to MeHg from foods that have medium or low MeHg levels, but with
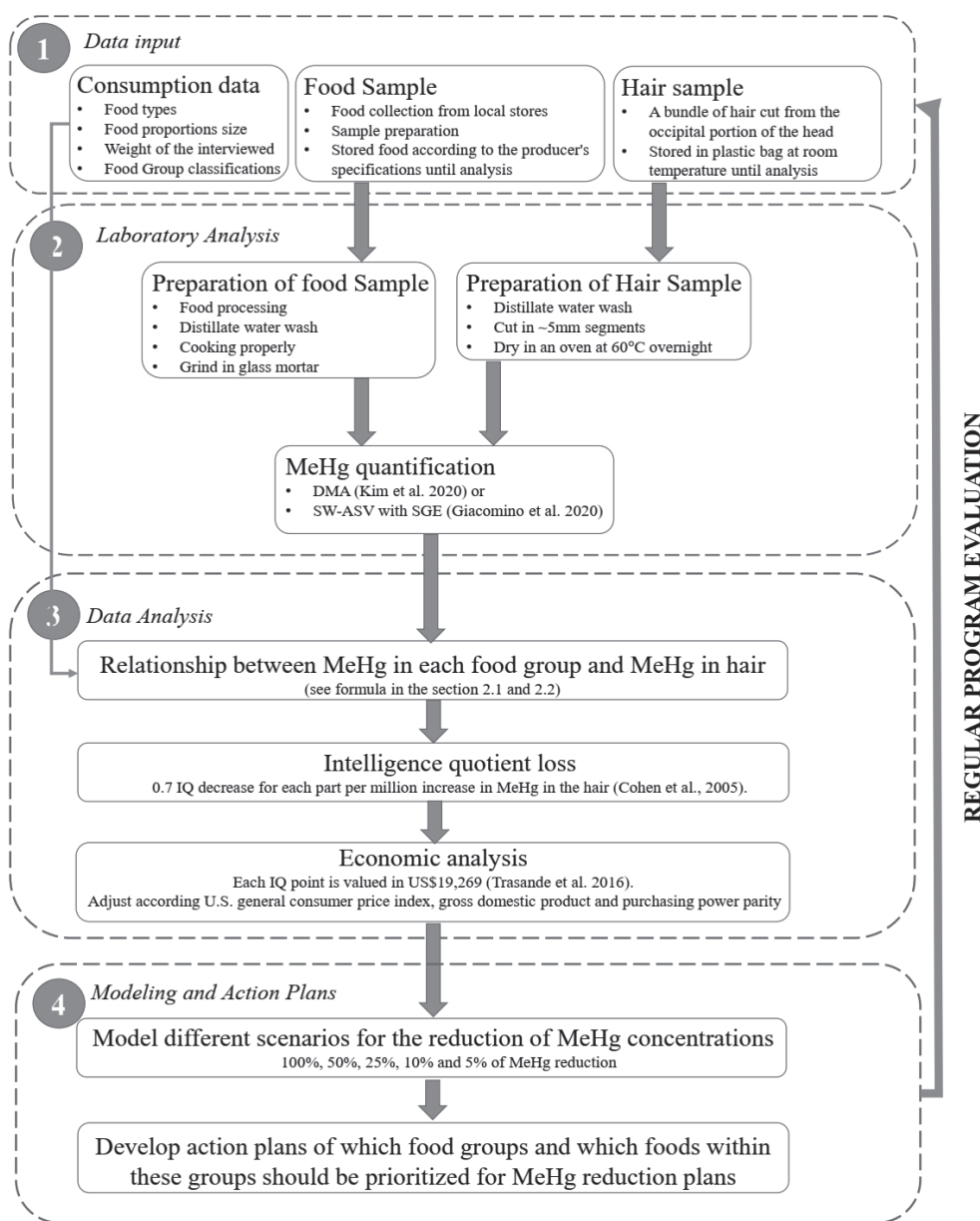

Fig. 1. Conceptual model for monitoring and reducing MeHg in foods to enhance economic and social benefits.

a higher rate of intake. This approach can be useful for government and regulatory agencies, but it needs to be formally addressed as part of health survey assessment by governments, and regularly evaluated to focus on those areas with MeHg levels are above threshold healthy recommendations.

In order to protect air and water quality and prevent soil contamination, it is necessary to emphasize the need to adopt rigorous control measures to reduce and eliminate mercury releases from large-scale mining operations [54]. Taking action on suspected mercury wastes must be enforced, as some wastes containing mercury are more difficult to identify without laboratory analysis. There are many industrial processes that use mercury or create waste streams commonly known to contain mercury, which may be identified for further investigation. We are taking about mercury contaminated recycled metals, industrial sludge, ash, contaminated soil, mining tailings and liquid wastes.

Finally, all the countries that signed the Minamata Convention on Mercury are required to cooperate more effectively with each other and with intergovernmental organizations to reduce and eliminate the use of mercury in artisanal and small-scale gold mining and processing activities. This cooperation must include a strong commitment toward education programs that encourages people´s capacity and the use of effective mechanisms to promote knowledge, including best environmental practices and viable alternative technologies.

Conclusions

Mercury represents risks for human beings, thus controlling mercury pollution is an issue at global and local scales. Our integrated approach proposed here may help to assess and monitor MeHg levels in food. Also, it brings forward a practical method to generate appropriate action plans focused on reducing MeHg by addressing the social and economic determinants of human health.

Interdisciplinary studies can certainly provide a more global approximation to solve Hg in food. Governmental and non-governmental entities are required to promote and finance research and/or monitoring programs that address natural, economic and social areas of knowledge.

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Conflicts of interest

The authors declare that they have not either financial or personal conflicts of interest that could have influenced this paper.

References

1. COULTER M.A. Minamata convention on mercury. International Legal Materials **55**, 582, **2016**.
2. ESTEBAN M., SCHINDLER B.K., JIMÉNEZ J.A., KOCH H.M., ANGERER J., ROSADO M., GÓMEZ S., CASTELEYN L., KOLOSSA-GEHRING M., BECKER K. Mercury analysis in hair: Comparability and quality assessment within the transnational COPHES/ DEMOCOPHES project. Environmental Research **141**, 24, **2015**.
3. WANG Z., HELLWEG S. First Steps Toward sustainable circular uses of chemicals: advancing the assessment and management paradigm. ACS Sustainable Chemistry & Engineering **9**, 6939, **2021**.
4. JULVEZ J., MENDEZ M., FERNANDEZ-BARRES S. Maternal consumption of seafood in pregnancy and child neuropsychological development: a longitudinal study based on a population with high consumption levels. American Journal of Epidemiology **183**, 169, **2016**.
5. LI M., SHERMAN L.S., BLUM J.D., GRANDJEAN P., MIKKELSEN B., WEIHE P.L., SUNDERLAND E.M., SHINE J.P. Assessing sources of human methylmercury exposure using stable mercury isotopes. Environmental Science & Technology **48**, 8800, **2014**.
6. LI P., FENG X., YUAN X., CHAN H.M., QIU G., SUN G., ZHU Y. Rice consumption contributes to low level methylmercury exposure in southern China. Environment International **49**, 18, **2012**.
7. ZHANG H., WANG D., ZHANG J., SHANG X., ZHAO Y., WU Y. Total mercury in milled rice and brown rice from China and health risk evaluation. Food Additives & Contaminants: Part B **7**, 141, **2014**.
8. HA E., BASU N., BOSE-O'REILLY S., DÓREA J.G., MCSORLEY E., SAKAMOTO M., CHAN H.M. Current progress on understanding the impact of mercury on human health. Environmental Research **152**, 419, **2017**.
9. GAGNÉ D., LAUZIÈRE J., BLANCHET R., VÉZINA C., VAISSIÈRE É., AYOTTE P., O'BRIEN H. Consumption of tomato products is associated with lower blood mercury levels in preschool children. Food and Chemical Toxicology **51**, 404, **2013**.
10. YANG H., XU Z., LIU W., WEI Y., DENG Y., XU B. Effect of grape seed proanthocyanidin extracts on methylmercury-induced neurotoxicity in rats. Biological Trace Element Research **147**, 156, **2012**.
11. CHOI A.L., MOGENSEN U.B., BJERVE K.S., DEBES F., WEIHE P., GRANDJEAN P., BUDTZ-JØRGENSEN E. Negative confounding by essential fatty acids in methylmercury neurotoxicity associations. Neurotoxicology and Teratology **42**, 85, **2014**.
12. DEROMA L., PARPINEL M., TOGNIN V., CHANNOUFI L., TRATNIK J., HORVAT M., VALENT F., BARBONE

F. Neuropsychological assessment at school-age and prenatal low-level exposure to mercury through fish consumption in an Italian birth cohort living near a contaminated site. International Journal of Hygiene and Environmental Health **216**, 486, **2013**.

13. DONALDSON S., VAN OOSTDAM J., TIKHONOV C., FEELEY M., ARMSTRONG B., AYOTTE P., BOUCHER O., BOWERS W., CHAN L., DALLAIRE F. Environmental contaminants and human health in the Canadian Arctic. Science of the Total Environment **408**, 5165, **2010**.

14. STRAIN J., YEATES A.J., VAN WIJNGAARDEN E., THURSTON S.W., MULHERN M.S., MCSORLEY E., WATSON G., LOVE T., SMITH T., YOST K. Prenatal exposure to methyl mercury from fish consumption and polyunsaturated fatty acids: associations with child development at 20 mo of age in an observational study in the Republic of Seychelles. The American Journal of Clinical Nutrition **101**, 530, **2015**.

15. LLOP S., BALLESTER F., BROBERG K. Effect of gene-mercury interactions on mercury toxicokinetics and neurotoxicity. Current Environmental Health Reports **2**, 179, **2015**.

16. BECKERS F., RINKLEBE J. Cycling of mercury in the environment: sources, fate and human health implications: a review. Critical Reviews in Environmental Science and Technology **47**, 693, **2017**.

17. THAPA D., SHARMA C., KANG S., SILLANPÄÄ M. The risk of mercury exposure to the people consuming fish from Lake Phewa, Nepal. International Journal of Environmental Research and Public Health **11**, 6771, **2014**.

18. PARK J.-H., HWANG M.-S., KO A., JEONG D.-H., KANG H.-S., YOON H.-J., HONG J.-H. Total mercury concentrations in the general Korean population, 2008-2011. Regulatory Toxicology and Pharmacolog*y* **70**, 681, **2014**.

19. DIRINGER S., FEINGOLD B., ORTIZ E., GALLIS J., ARAÚJO-FLORES J., BERKY A., PAN W., HSU-KIM H. River transport of mercury from artisanal and small-scale gold mining and risks for dietary mercury exposure in Madre de Dios, Peru. Environmental Science: Processes & Impacts **17**, 478, **2015**.

20. RAJAEE M., LONG R., RENNE E., BASU N. Mercury exposure assessment and spatial distribution in a Ghanaian small-scale gold mining community. International Journal of Environmental Research and Public Health **12**, 10755, **2015**.

21. PEPLOW D., AUGUSTINE S. Community-led assessment of risk from exposure to mercury by native Amerindian Wayana in Southeast Suriname. Journal of Environmental and Public Health **2012**, 1, **2012**.

22. SHAO D., KANG Y., CHENG Z., WANG H., HUANG M., WU S., CHEN K., WONG M. Hair mercury levels and food consumption in residents from the Pearl River Delta: South China. Food Chemistry **136**, 682, **2013**.

23. HUI Y., PING X., MIN S. Current status of hair analysis in forensic toxicology in China. Forensic Sciences Research **6**, 240, **2021**.

24. BJØRKLUND G., DADAR M., MUTTER J., AASETH J. The toxicology of mercury: Current research and emerging trends. Environmental Research **159**, 545, **2017**.

25. UNEP W. Guidance for identifying populations at risk from mercury exposure. Geneva: United Nations Environment Programme (UNEP), Division of Technology, Industry and Economics (DTIE), World Health Organization (WHO), Department of Food Safety, Zoonoses and Foodborne Diseases, Cluster on Health Security and Environment, **2008**.

26. XIE Q., WANG Y., LI S., ZHANG C., TIAN X., CHENG N., ZHANG Y., WANG D. Total mercury and methylmercury in human hair and food: Implications for the exposure and health risk to residents in the Three Gorges Reservoir Region, China. Environmental Pollution **282**, 117041, **2021**.

27. WANG Y., HABIBULLAH-AL-MAMUN M., HAN J., WANG L., ZHU Y., XU X., LI N., QIU G. Total mercury and methylmercury in rice: Exposure and health implications in Bangladesh. Environmental Pollution **265**, 114991, **2020**.

28. BASU N., HORVAT M., EVERS D.C., ZASTENSKAYA I., WEIHE P., TEMPOWSKI J. A state-of-the-science review of mercury biomarkers in human populations worldwide between 2000 and 2018. Environ Health Perspectives **126**, 106001–14, **2018**.

29. DEBES F., WEIHE P., GRANDJEAN P. Cognitive deficits at age 22 years associated with prenatal exposure to methylmercury. Cortex **74**, 358, **2016**.

30. LLOP S., BALLESTER F., MURCIA M., FORNS J., TARDON A., ANDIARENA A., VIOQUE J., IBARLUZEA J., FERNÁNDEZ-SOMOANO A., SUNYER J., JULVEZ J, REBAGLIATO M., LOPEZ-ESPINOSA M. Prenatal exposure to mercury and neuropsychological development in young children: The role of fish consumption. *I*nternational Journal of Epidemiology **46**, 10.1093/ije/dyw259, **2016**.

31. MIYASHITA C., SASAKI S., SAIJO Y. Demographic, behavioral, dietary, and socioeconomic characteristics related to persistent organic pollutants and mercury levels in pregnant women in Japan. Chemosphere **133**, 3, **2015**.

32. COUNCIL N.R. Toxicological effects of methylmercury. National Academies Press: **2020**.

33. JACOBSON J., MUCKLE G., AYOTTE P., DEWAILLY E., JACOBSON S. Relation of prenatal methylmercury exposure from environmental sources to childhood IQ. Environ Health Perspectives **123**, 827, **2015**.

34. UNITED NATIONS ENVIRONMENT PROGRAMME. Report on the Costs of Inaction on the Sound Management of Chemicals. https://wedocs.unep.org/20.500.11822/8412, **2013**.

35. TRASANDE L., DIGANGI J., EVERS D., PETRLIK J., BUCK D., ŠAMÁNEK J., BEELER B., TURNQUIST M., REGAN K. Economic implications of mercury exposure in the context of the global mercury treaty: hair mercury levels and estimated lost economic productivity in selected developing countries. Journal of Environmental Management **183**, 229, **2016**.

36. TRASANDE L., LIU Y. Reducing the staggering costs of environmental disease in children, estimated at $76.6 billion in 2008. Health Affairs **30**, 863, **2011**.

37. BELLANGER M., PICHERY C., AERTS D., BERGLUND M., CASTAÑO A., ČEJCHANOVÁ M., CRETTAZ P., DAVIDSON F., ESTEBAN M., FISCHER M. Economic benefits of methylmercury exposure control in Europe: monetary value of neurotoxicity prevention. Environmental Health **12**, 1, **2013**.

38. SUNDSETH K., PACYNA J., PACYNA E., MUNTHE J., BELHAJ M., ASTROM S. Economic benefits from decreased mercury emissions: Projections for 2020. Journal of Cleaner Production **18**, 386, **2010**.

39. TRASANDE L., SCHECHTER C., HAYNES K.A., LANDRIGAN P.J. Applying cost analyses to drive policy that protects children: mercury as a case study.

Annals of the New York Academy of Sciences **1076**, 911, **2006**.

40. GALAN P., HERCBERG S. Methods used in food consumption and dietary assessment studies. Cahiers de Nutrition et de Dietetique, France: **1994**.

41. MUÑOZ O., ZAMORANO P., GARCIA O., BASTÍAS J. Arsenic, cadmium, mercury, sodium, and potassium concentrations in common foods and estimated daily intake of the population in Valdivia (Chile) using a total diet study. Food and Chemical Toxicology **109**, 1125, **2017**.

42. KIM D., WOO H., JOO J. ET AL. Estimated long-term dietary exposure to lead, cadmium, and mercury in young Korean children. European Journal of Clinical Nutrition **68**, 1322, **2014**.

43. KIM T.-H., CHO M.-J., LEE Y., KIM J., HWANG J.-Y., LEE H.-E., KIM S.-H., CHOI J.-D., KANG G.-J. Methylmercury determination in fish by direct mercury analyzer. Journal of AOAC International **103**, (1), 244, **2020**.

44. GIACOMINO A., REDDA A., SQUADRONE S., RIZZI M., ABETE M, LA GIOIA C., TONIOLO R., ABOLLINO O., MALANDRINO M. Anodic stripping voltammetry with gold electrodes as an alternative method for the routine determination of mercury in fish. Comparison with spectroscopic approaches. Food Chemistry **221**, 737, **2017**.

45. EPA US. Method 1630, Methyl mercury in water by distillation, aqueous ethylation, purge and trap, and CVAFS. US Environmental Protection Agency, Washington, DC, **1998**.

46. PACYNA J.M., MUNTHE J., PANASIUK D. Socio-economic Costs of Continuing the Status-quo of Mercury Pollution: Final Draft August 14, 2008. Nordic Council of Ministers, **2008**.

47. RICE K., WALKER JR E., WU M., GILLETTE C., BLOUGH E. Environmental mercury and its toxic effects. Journal of Preventive Medicine and Public Health **47**, 74, **2014**.

48. ATTINA T.M., TRASANDE L. Economic costs of childhood lead exposure in low-and middle-income countries. Environmental Health Perspectives **121**, 1097, **2013**.

49. BLS. Bureau of Labor Statistics. U.S. Department of Labor. https://www.bls.gov/news.release/archives/cpi_01162014.pdf, **2014**.

50. BECKER D., SPEER K., KORSTIAN J., VOLOKHOV D., DROKE H., BROWN A., BAIJNAUTH C., PADGETT-STEWART T., BRODERS H. Disentangling interactions among mercury, immunity, and infection in a Neotropical bat community. Journal of Applied Ecololgy **58**, 879, **2021**.

51. ESPEJO W., CELIS J.E., CHIANG G., BAHAMONDE P. Environment and COVID-19: Pollutants, impacts, dissemination, management and recommendations for facing future epidemic threats. Science of the Total Environment **747**, 141314, **2020**.

52. BUDNIK L.T., CASTELEYN L. Mercury pollution in modern times and its socio-medical consequences. Science of the Total Environment **654**, 720, **2019**.

53. NG C.A., VON GOETZ N. The global food system as a transport pathway for hazardous chemicals: the missing link between emissions and exposure. Environmental Health Perspectives **125**, 1, **2017**.

54. BELL L., DIGANGI J., WEINBERG J. An NGO introduction to mercury pollution and the Minamata Convention on Mercury. IPEN (International Pollutants Elimination Network), Sweden, **2014**.