Animal Science Papers and Reports vol. 44 (2026) no. 2, 235-246
DOI: 10.2478/aspr-2026-0015
Institute of Genetics and Animal Biotechnology
of the Polish Academy of Sciences, Jastrzębiec, Poland

Health risk assessment of mercury exposure from freshwater fish consumption across socioeconomic groups in Poland: a toxicological analysis of specific consumption scenarios

Jarosław Chmielewski[1]*, Barbara Gworek[2], Magdalena Florek-Łuszczki[3], Jarogniew Łuszczki[4], Małgorzata Czarny Działak[5], Grzegorz J. Dietrich[6]

[1] Department of Public Health, Academy of Medical Sciences of Applied and Holistic Sciences, Jerozolimskie 133A, 02-304 Warsaw, Poland

[2] Department of Environmental Chemistry and Risk Assessment, The Institute of Environmental Protection - National Research Institute, Słowicza 32, 02-170 Warsaw, Poland

[3] Department of Medical Anthropology, Institute of Rural Medicine, Jaczewskiego 2, 20-090 Lublin, Poland

[4] Faculty of Medical Sciences, Medical University, Racławickie 1, 20-059 Lublin, Poland

[5] Faculty of Medicine, Collegium Medicum, Jan Kochanowski University, IX Wieków 19A, 25-317 Kielce, Poland

[6] Team of Biodiversity Protection. InLife Institute of Animal Reproduction and Food Research, Polish Academy of Sciences, Trylińskiego 18, 10-683 Olsztyn, Poland

(Accepted March 2, 2026)

This study aimed to assess the health risk associated with mercury (Hg) exposure resulting from the consumption of freshwater fish in Poland. The analysis focuses on differentiating risks between socioeconomic groups and a vulnerable population (children) using specific consumption scenarios. Total mercury (THg) concentrations in wild species (e.g., *Esox lucius*, *Sander lucioperca*) and farmed fish (e.g., *Cyprinus carpio*) were analyzed against European and global data. Dietary patterns were

*Corresponding author: j.chmielewski@ios.edu.pl

derived from the 2023 report by Statistics Poland (GUS), stratified by socioeconomic status (retirees, farmers, employees). The health risk was estimated using the Hazard Quotient (HQ) for chronic exposure and the percentage of Tolerable Weekly Intake (%TWI) for three consumption scenarios (S1: 150 g, S2: 300 g, S3: 450 g/week). Hg levels in Polish freshwater fish are comparable to European averages, with predatory species showing the highest bioaccumulation (*Esox lucius*: up to 0.45 mg/kg). Socioeconomic analysis revealed that retirees have the highest fish consumption (0.40 kg/month), resulting in the highest HQ (0.381), remaining below the safety threshold (HQ <1). However, the scenario-based analysis demonstrated that for children, even moderate consumption (S1) of predatory fish (pike, perch, zander) results in exceeding the TWI by 115–231%. While the general adult population in Poland remains at low risk of Hg toxicity, targeted dietary recommendations are urgently required for children, emphasizing the avoidance of predatory freshwater fish in favor of low-trophic species such as carp or bream.

KEY WORDS: methylmercury / food safety / risk assessment / socioeconomic factors / bioaccumulation / freshwater fish

Mercury (Hg) is widely recognized as one of the most critical environmental pollutants due to its persistence, mobility, and high toxicity [Olmedo *et al.* 2013, Cyran *et al.* 2019, Chmielewski *et al.* 2020, Chmielewski *et al.* 2023, Al-Sulaiti *et al.* 2023, Basta *et al.* 2023]. The World Health Organization identifies it among the top ten chemicals of major public health concern [WHO 2017]. Importantly, although Hg is released into the environment from natural sources, anthropogenic activities -primarily coal combustion and industrial processes - have significantly altered its global biogeochemical cycle [Gworek *et al*. 2017, Chmielewski *et al*. 2020, 2020a, Al-Sulaiti *et al*. 2023, Basta *et al*. 2023].

Unlike terrestrial food chains, aquatic systems promote Hg accumulation to levels that may be neurotoxic to humans, making fish effective bioindicators of environmental contamination [Dietrich *et al*. 2010, 2012, 2022, Olmedo *et al.* 2013, Domínguez-Morueco *et al*. 2022, Chmielewski *et al*. 2023, Basta *et al*. 2023]. Within these systems, inorganic Hg undergoes methylation mediated by sulfate-reducing bacteria in anoxic sediments, forming methylmercury (MeHg) [Zhao *et al*. 2024, Dietrich *et al*. 2022, Chmielewski *et al*. 2023]. This organic form is highly bioavailable and lipophilic, facilitating its passage across biological membranes.

Fish accumulate mercury through dietary exposure, with MeHg concentrations increasing progressively along the trophic chain via biomagnification. As demonstrated by the meta-analysis of Lavoie *et al*. [2013], long-lived predatory fish at the top of aquatic food webs can reach tissue concentrations up to 10^6 times higher than Hg concentration in surrounding waters. This phenomenon poses a direct threat to human health, as fish and seafood consumption represents the primary pathway of MeHg exposure [Wang *et al*. 2021, Brodziak-Dopierała and Fischer 2023, Domínguez-Morueco *et al.* 2022, Chmielewski *et al*. 2023].

Poland represents a unique study area within the European context due to its coal-based energy generation and traditional freshwater fish consumption. Historically, the country’s energy sector has relied heavily on coal combustion, contributing to atmospheric mercury deposition [Głodek and Pacyna 2009, Zyśk *et al*. 2015, Pyta *et al.*

2020]. Although emission controls have improved in recent decades, legacy mercury stored in sediments continues to be remobilized. At the same time, freshwater fish remain a traditional component of the Polish diet, even if dietary patterns are gradually shifting. According to data from Statistics Poland [GUS 2024], the consumption of both wild and farmed fish varies substantially across demographic groups.

The toxicological implications of Hg exposure are severe. MeHg is a potent neurotoxin capable of crossing the blood-brain barrier. As reported by Grandjean and Herz [2015], chronic exposure is associated with cognitive impairment in adults, while the developing nervous systems of fetuses and young children are particularly vulnerable. In response to these risks, the European Union has established strict Maximum Levels (MLs) for Hg, and the European Food Safety Authority Panel on Contaminants has defined Tolerable Weekly Intake (TWI) limits. However, standard monitoring programs – such as those conducted by the Chief Inspectorate of Environmental Protection (GIOŚ) – may prioritize regulatory compliance over the assessment of population-specific health risks [Gioś 2022].

Extensive evidence indicates that Hg is highly toxic to living organisms. Inorganic and organic Hg compounds exert cytotoxic effects on immune system cells. These compounds readily crosse the blood-brain barrier in the human body affecting the central nervous system. The primary site of its accumulation in the body is the cerebral cortex. Symptoms of Hg neurotoxicity include spontaneous tremors of the limbs or head, ataxia, sleep disturbances, depression, outbursts of anger, vision and hearing loss, weakened reflexes, and memory loss. Hg exposure has also been associated with an increased risk of neurodegenerative disorders, including amyotrophic lateral sclerosis, multiple sclerosis, Parkinson's disease, and Alzheimer's disease, and has been investigated in relation to neurodevelopmental disorders.

Beyond neurotoxicity, Hg also affects multiple organ systems. It has been reported to affect reproductive function in both women and men. By crossing the placenta, Hg can pose a risk to the developing fetus and lead to an increased number of miscarriages. Exposure to Hg is associated with an increased risk of hypertension, myocardial infarction, coronary dysfunction, and atherosclerosis. [Olmedo *et al.* 2013, Sura *et al.* 2018, Cyran *et al.* 2019, Pyta *et al.* 2020, Zulaikhah *et al.* 2020, Wang *et al.* 2021, Zrelli *et al.* 2021, Dietrich *et al.* 2022, Chmielewski *et al.* 2020, 2020a, 2020b, 2023, Basta *et al.* 2023].

Based on these premises, and considering the longstanding tradition of consuming predatory freshwater fish in Poland, it was hypothesized that while the general adult population maintains a safe exposure profile due to moderate average intake, specific vulnerable subpopulations – particularly children and high-intake consumers – may exceed toxicological safety thresholds when consuming wild predatory species, thereby necessitating targeted health risk monitoring.

Accordingly, this study aimed to conduct a comprehensive health risk assessment of Hg exposure from freshwater fish consumption in Poland. Specifically, the objectives were to: (1) compare Hg bioaccumulation levels in Polish freshwater fish with global benchmarks using data from Brodziak-Dopierała and Fischer [2023]; (2) estimate chronic exposure risk, expressed as the Hazard Quotient (HQ), across distinct socioeconomic groups; and (3) evaluate acute toxicological risk, expressed as the percentage of TWI (%TWI), for children and adults under defined consumption scenarios.

Materials and methods

Data collection and selection criteria

Data regarding total mercury (THg) concentrations in muscle tissue of freshwater and marine fish were compiled through a systematic review of peer-reviewed literature and national monitoring reports published between 2016 and 2023. The search focused on species originating from Polish inland waters (lakes, rivers) and aquaculture facilities. Key data sources regarding Hg contamination in Polish ichthyofauna were Łuczyńska *et al.* [2022], Brodziak-Dopierała and Fischer [2023] and Rajkowska-Myśliwiec and Protasowicki [2023].

The final dataset used for modeling includes:
– predatory freshwater species: Pike (*Esox lucius*), Zander (*Sander lucioperca*), Perch (*Perca fluviatilis*), Eel (*Anguilla anguilla*);
– non-predatory/Omnivorous freshwater species: Bream (*Abramis brama*), Roach (*Rutilus rutilus*);
– farmed species: Common Carp (*Cyprinus carpio*);
– imported marine species: Tuna (*Thunnus* spp.).

Socioeconomic consumption data

Dietary patterns were derived from the 2023 Household Budget Survey conducted by Statistics Poland [GUS 2024]. This official dataset provides average monthly fish and seafood consumption rates stratified by socioeconomic status. Six categories were analyzed: (1) Employees (manual), (2) Employees (non-manual), (3) Farmers, (4) Self-employed, (5) Retirees, and (6) Pensioners.

For toxicological modeling, monthly consumption data (kg/month) were converted into daily intake rates (CR, kg/day) by dividing by 30.4 days.

Health risk assessment models

The health risk assessment was performed using a deterministic approach, applying two complementary models recommended by the European Food Safety Authority [EFSA 2012] and the U.S. Environmental Protection Agency [USEPA 2023].

A. Chronic Systemic Risk (HQ)

The non-carcinogenic risk for the general adult population and specific socioeconomic groups was estimated using HQ. First, the Average Daily Dose (ADD) was calculated using Equation 1:

$$ADD = C \times CR \times EF \times ED / BW \times AT \quad (1)$$

where:
– C – concentration of Hg in fish (mg/kg wet weight);
– CR – consumption rate (kg/day) derived from GUS data [GUS 24];
– EF – exposure frequency (365 days/year);
– ED – exposure duration (70 years for adults);
– BW – body weight (standard adult weight: 70 kg);
– AT – averaging time (ED x 365 days).

HQ was calculated dividing the ADD by the reference dose (RfD) for MeHg (1 x 10^{-4} mg/kg/day) as provided in [USEPA 2023]:

$$HQ = ADD \times RfD \tag{2}$$

An HQ <1 indicates that adverse health effects are unlikely. Additionally, the Estimated Weekly Intake (EWI) was compared against the EFSA TWI of 1.3 µg/kg bw/week as established by the EFSA Panel on Contaminants [EFSA 2012].

B. ScenarioBased Toxicological Risk (%TWI)

To assess the acute risk in vulnerable populations, particularly children, the Estimated Weekly Intake (EWI) was calculated for both adults and children and compared with the TWI of 1.3 µg/kg bw/week established by the EFSA Panel on Contaminants [EFSA 2012].

Three specific consumption scenarios were modeled:
– scenario S1 (moderate): consumption of one standard portion (150 g) per week.
– scenario S2 (high): consumption of two portions (300 g) per week.
– scenario S3 (very high): consumption of three portions (450 g) per week.

These scenarios were applied to two demographic profiles:
1. Adult – body weight = 70 kg.
2. Child: body weight = 20 kg (representing a approx. 5-6-year-old child).

Chemical assumptions

For risk calculation, it was conservatively assumed that THg in predatory species consists of 95-100% MeHg. For non-predatory and farmed species, specific conversion factors were considered where applicable, consistent with the speciation ratios described by Bloom [1992]. This approach ensures a high level of consumer protection in the risk estimates.

Results and discussion

Hg is a toxic element characterized by a high bioaccumulation potential, and its concentration in fish is largely determined by the environmental conditions of their habitats [Zrelli *et al.* 2021, Hasanein *et al.* 2022]. Consequently, monitoring Hg contamination represents a major public health challenge in ensuring the safety of foods of animal origin as human exposure to Hg via fish consumption – driven by environmental loading and subsequent bioaccumulation – may pose a significant risk to consumer health [Zrelli *et al*. 2021, Al-Sulaiti *et al.* 2023, Basta *et al*. 2023, Żeber-Dzikowska *et al*. 2025, Chmielewski *et al*. 2025]

Bioaccumulation kinetics and trophic transfer mechanisms

Quantification of THg in fish muscle tissue revealed a pronounced interspecific variability driven by trophic ecology and physiological traits (Tab. 1). The observed concentration gradient supports the classic biomagnification paradigm within the aquatic food web. Apex predators – specifically pike (*Esox lucius*) and zander (*Sander lucioperca*) – exhibited the highest body burdens (0.10-0.45 mg/kg). This accumulation is chemically driven by the high affinity of MeHg for sulfhydryl (-SH) groups in myofibrillar proteins, leading to efficient retention in muscle tissue [Bloom 1992].

Although the recorded values in predatory species approach European regulatory limits in Poland, they align with the global biomagnification factors (BMF) reported for freshwater piscivores by Lavoie *et al.* [2013]. Interestingly, the absolute contamination levels in Polish ichthyofauna remain comparatively lower than those observed in oligotrophic systems in Scandinavia or North America. This attenuation can be mechanistically attributed to the "biodilution effect" characteristic of eutrophic waters [Soerensen *et al.* 2016]. Elevated primary productivity in Polish lakes increases phytoplankton biomass. As a result, the concentration of MeHg per unit of organic carbon available for uptake at the base of the food web is reduced, thereby limiting its transfer efficiency to higher trophic levels [Brodziak-Dopierała and Fischer 2023, Rajkowska-Myśliwiec and Protasowicki 2023].

In sharp contrast to other species, farmed Common Carp (*Cyprinus carpio*) exhibited minimal bioaccumulation potential, with Hg concentrations frequently remaining below the limit of quantification (<0.05 mg/kg). This favorable safety profile -corroborated by Łuczyńska *et al.* [2022] Brodziak-Dopierała and Fischer [2023] and Rajkowska-Myśliwiec and Protasowicki [2023]

Table 1. Concentrations of THg and MeHg in the muscle of fish from Polish waters against European and Global data (mg/kg wet weight)

Fish species	Environment	Poland (range THg)	Poland (MeHg % of THg)	Europe (range THg)	World (range THg)	EU limit reference
Pike (*Esox lucius*)	freshwater	0.10-0.45	75-95	0.15-0.70	0.20-1.20	usually < limit
Zander (*Sander lucioperca*)	freshwater	0.08-0.35	70-90	0.10-0.60	0.15-1.00	usually < limit
Perch (*Perca fluviatilis*)	freshwater	0.05-0.30	65-90	0.05-0.50	0.10-0.80	< limit
Eel (*Anguilla anguilla*)	coastal/ estuary	0.20-0.60	80-95	0.30-0.90	0.40-1.50	locally elevated
Roach (*Rutilus rutilus*)	freshwater	0.01-0.10	60-80	0.01-0.15	0.02-0.20	significantly <
Bream (*Abramis brama*)	freshwater	0.02-0.12	60-85	0.02-0.20	0.03-0.30	significantly <
Carp (*Cyprinus carpio*)	farmed	0.005-0.05	50-70	0.01-0.10	0.01-0.15	significantly <
Tuna (*Thunnus spp.*)	marine (import)	0.20-0.83	85-98	0.30-1.20	0.50-2.00	often near limit

– reflects the trophic decoupling inherent to intensive aquaculture. The reliance on formulated, quality-controlled feed and rapid biomass turnover (growth dilution) effectively limits the exposure duration and uptake of xenobiotics compared to wild populations reliant on natural food webs.

Socioeconomic determinants and risk-benefit analysis for adults

Stratification of dietary habits based on the 2023 Household Budget Survey by Statistics Poland [GUS 2024] highlighted marked disparities in fish consumption across socioeconomic groups (Tab. 2). Retirees and pensioners exhibited the highest intake (0.40 kg/month), exceeding that of employees by approximately 70%. This pattern likely reflects cultural preferences for traditional cuisine and the economic accessibility of freshwater species for older cohorts.

Table 2. Average monthly consumption of fish and seafood in Polish households by socioeconomic group in 2023

Socioeconomic group	Monthly consumption (kg/person)	Daily intake (g/day)
Retirees & pensioners	0.40	13.3
Farmers	0.32	10.5
Self-employed	0.32	10.5
Employees (non-manual)	0.24	7.9
Employees (manual)	0.24	7.9
National average	0.32	10.5

Despite elevated consumption rates, the deterministic risk assessment for adults (Tab. 3) indicates an adequate margin of safety. The HQ for the highest consumption group remained well below the threshold of toxicity (HQ <1; max 0.381). These findings suggest that MeHg exposure in the general adult population does not exceed RfD established by the U.S. Environmental Protection Agency [USEPA 2023].

Table 3. Calculated HQ for Hg exposure in different socioeconomic groups (Worst-Case Scenario: Hg = 0.20 mg/kg)

Socioeconomic group	Consumption rate (kg/day)	Average daily dose (ADD) (mg/kg/day)	Hazard quotient (HQ)	Risk interpretation
Retirees & pensioners	0.0133	3.81×10^{-5}	0.381	safe (HQ<1)
Farmers	0.0105	3.05×10^{-5}	0.305	safe (HQ<1)
Self-employed	0.0105	3.05×10^{-5}	0.305	safe (HQ<1)
Employees (total)	0.0079	2.29×10^{-5}	0.229	safe (HQ<1)
General population	0.0105	3.05×10^{-5}	0.305	safe (HQ<1)

From a public health perspective, the risk-benefit balance clearly favors fish consumption. The cardiovascular and neuroprotective properties of n-3 polyunsaturated fatty acids (PUFAs) outweigh the risk associated with low-level contaminant exposure [Mozaffarian and Rimm 2006]. Furthermore, biochemical interactions are relevant: freshwater fish often exhibit a favorable selenium-to-mercury (Se:Hg) molar ratio. Selenium sequestration reduces Hg bioavailability through the formation of biologically inert Hg-Se complexes, thereby mitigating mercury-induced oxidative stress [Adams and Duguay 2025]. Consequently, the dietary habits of Polish seniors should be viewed as nutritionally beneficial rather than hazardous.

Pediatric vulnerability and toxicokinetic disparity

In contrast to the adults, the scenario-based assessment for children (Tab. 4) reveals a pronounced toxicokinetic disparity. Due to lower body mass, higher metabolic rates, and greater gastrointestinal absorption efficiency, the consumption of predatory species by children results in a rapid exceedance of toxicological safety thresholds. A single moderate portion (S1: 150 g) of Zander or Pike corresponds to 173 and 231% respectively, of TWI established by EFSA.

Table 4. Estimated MeHg Intake expressed as % of EFSA TWI (%TWI) based on fish species and consumption scenario

Species	THg (mg/kg)	S1 adult (%)	S2 adult (%)	S3 adult (%)	S1 child (%)	S2 child (%)	S3 child (%)
Roach	0.05	8	16	25	29	58	87
Bream	0.08	13	26	39	46	92	138
Perch	0.20	33	66	99	115	231	346
Zander	0.30	49	99	148	173	346	519
Pike	0.40	66	132	198	231	462	692
Eel	0.50	82	165	247	288	577	865
Tuna	0.60	99	198	297	346	692	1038

S1 – 150g/week; S2 – 300g/week; S3 – 450g/week.
Values >100% (bold) indicate risk.

This heightened susceptibility is biologically underpinned by the functional immaturity of the blood-brain barrier (BBB) and the active phase of synaptogenesis. During neurodevelopment, the central nervous system exhibits a distinct *window of susceptibility* to MeHg neurotoxicity, where even low doses may disrupt neuronal migration and cortical cytoarchitecture [Grandjean and Herz 2015, EFSA Panel on Contaminants in the Food Chain 2012].

Our results strongly indicate that current general safety margins, while adequate for adults, are insufficient for pediatric population. The findings support a targeted revision of dietary guidelines that prioritize non-predatory aquaculture species (e.g., Carp) in pediatric nutrition for which TWI utilization remains low even in high-consumption scenarios.

The disparity in risk between age groups is illustrated in Figure 1. The heatmap shows that adults remain largely in the “safe zone” (green) even at higher consumption rates of most species, whereas children face immediate risk under comparable intake scenarios.

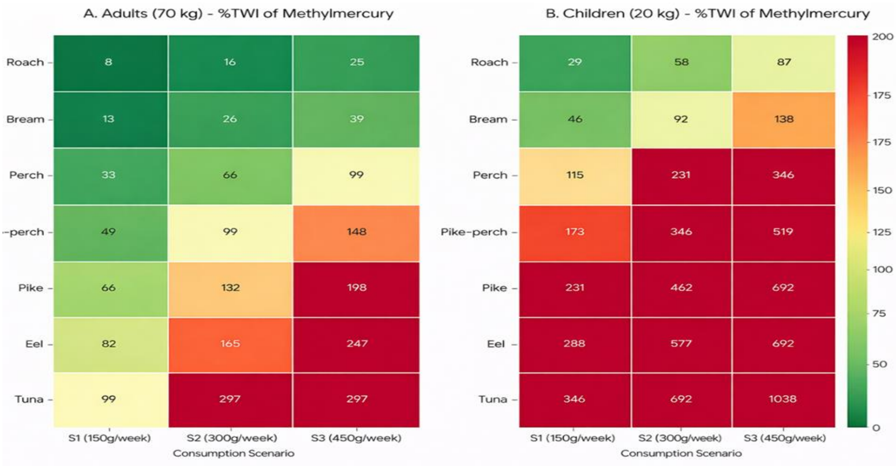

Fig. 1. Heatmap of toxicological risk expressed as %TWI of MeHg for adults (70 kg, panel A) and children (20 kg, panel B). The risk was assessed across three consumption scenarios: S1 (moderate: 150 g/week), S2 (high: 300 g/week), and S3 (very high: 450 g/week). Note: the color scale indicates risk levels: green (<100%) indicates safe exposure, while yellow to red (>100%) indicates the accepted EFSA safety threshold (1.3 µg/kg bw/week). Predatory species (e.g., pike, perch, tuna) pose a significantly greater risk to children than to adults.

The heatmap (Fig.1) highlights a pronounced contrast in toxicological safety between adults and children. Panel A (adults) is dominated by the green zone, indicating that even high consumption scenarios (S2, S3) for most freshwater species do not result in exceedance of the TWI. Elevated risk (yellow/red zones) emerges only under very high intake scenarios involving marine predatory species, such as tuna.

Conversely, Panel B (children) reveals a critical vulnerability. The consumption of predatory species acts as an immediate trigger for risk. For a child, even the lowest consumption scenario (S1: 150 g/week) of pike, perch, or pike-perch results in deep “red zone” values, exceeding the TWI by 200-300%. Notably, non-predatory species such as farmed carp remain in the safe zone across most scenarios for children, highlighting their suitability for pediatric diets compared to wild predators.

Conclusions

The bioaccumulation of Hg in Polish freshwater ichthyofauna reflects a distinct trophic dependency, where predatory species (*Esox lucius*, *Sander lucioperca*) exhibit significant biomagnification. Nevertheless, contamination levels generally remain within European background ranges and comply with EU regulatory limits. Socioeconomic analysis indicates that although retirees demonstrate the highest fish consumption rates, their chronic health risk remains negligible (HQ <1), supporting the continued nutritional inclusion of fish in geriatric diets.

In sharp contrast, a critical toxicological dichotomy is evident for the pediatric population. Scenario-based modeling proves that even moderate consumption of high-trophic level species results in immediate and substantial exceedance of TWI (>200%). These findings underscore the need for a shift from generalized dietary guidance toward age-stratified risk management. Public health strategies should therefore promote low – trophic level species such as farmed carp and bream – as safe alternatives, while restricting the consumption of predatory freshwater fish in pediatric diets.

Declaration

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The present research received no specific funding from any public, commercial, or non-profit funding agencies. Artificial intelligence (AI) was not used in the creation of this manuscript.

REFERENCES

1. ADAMS W.J., DUGUAY A., 2025 - Selenium–mercury interactions and relationship to aquatic toxicity: A review. ***Integrated Environmental Assessment and Management*** 21, 70-78.
2. AL-SULAITI M.M., AL-GHOUTI M.A., RAMADAN G.A., SOUBRA L., 2023 - Health risk assessment of methyl mercury from fish consumption in a sample of adult Qatari residents. ***Environmental Monitoring and Assessment*** 195, 617.
3. BASTA P.C., DE VASCONCELLOS A.C.S., HALLWASS G., YOKOTA D., PINTO D.D.O.D.E.R., DE AGUIAR D.S., OLIVEIRA-DA-COSTA M., 2023 - Risk assessment of mercury-contaminated fish consumption in the Brazilian Amazon: an ecological study. ***Toxics*** 11, 800.
4. BLOOM N.S., 1992 - On the chemical form of mercury in edible fish and marine invertebrate tissue. ***Canadian Journal of Fisheries and Aquatic Sciences*** 49, 1010-1017.
5. BRODZIAK-DOPIERAŁA B., FISCHER A., 2023 - Analysis of the mercury content in fish for human consumption in Poland. ***Toxics*** 11, 717.
6. CHMIELEWSKI J., GWOREK B., FLOREK-ŁUSZCZKI M., NOWAK-STARZ G., WÓJTOWICZ B., WÓJCIK T., SZPRINGER M., 2020 - Metale ciężkie w środowisku i ich wpływ na zdrowie człowieka (Heavy metals in the environment and their impact on human health). ***Przemysł Chemiczny*** 99, 50-57. In Polish, with English summary.
7. CHMIELEWSKI J., WÓJTOWICZ B., ŻEBER-DZIKOWSKA I., ŁUSZCZKI J. J., DZIECHCIAŻ M., SIERPIŃSKI R., SZPRINGER M., 2020a - Rtęć. Źródła uwalniania do środowiska, wskaźniki zanieczyszczenia, zagrożenia dla zdrowia ludzi i rola edukacji (Mercury. Sources of release into environment, pollution indicators, threats to human health and the role of education). ***Przemysł Chemiczny*** 99, 1227-1233. In Polish, with English summary.
8. CHMIELEWSKI J., SZPRINGER M., ŁUSZCZKI J.J., CZARNY-DZIAŁAK M., DUTKIEWICZ E., ZIĘBA E., NOWAK-STARZ G., 2020b - Zawodowe i środowiskowe narażenie na substancje i mieszaniny chemiczne działające szkodliwie na rozrodczość człowieka (Occupational and environmental exposure to substances and chemical mixtures that are toxic to human reproduction). ***Przemysł Chemiczny*** 99, 865-874. In Polish, with English summary.
9. CHMIELEWSKI J., DIETRICH G.J., WALOSIK A., ZIĘBA E., ŻEBER-DZIKOWSKA I., MOTYL M., GWOREK B., 2023 - Fish as bioindicators of mercury contamination in aquatic environments: an underestimated threat to consumer health. ***Journal of Elementology*** 28, 633-648.

10. CHMIELEWSKI J., GWOREK B., BĄK-BADOWSKA J., ZIĘBA E., SZENK P., ŻEBER-DZIKOWSKA I., 2025 - Food contaminated with pesticides and heavy metals – an underestimated public health threat. ***Journal of Elementology*** 30, 607-629.
11. CYRAN M., FLOREK-ŁUSZCZKI M., CZARNY-DZIAŁAK M., KRÓL H., SZPRINGER M., DZIECHCIAŻ M., CHMIELEWSKI J., 2019 - Wpływ środowiskowej i zawodowej ekspozycji na rtęć na poszczególne układy organizmu człowieka (Impact of environmental and occupational exposure to mercury on the systems of the human body) ***Przemysł Chemiczny*** 98, 1773-1177. In Polish, with English summary.
12. DIETRICH G.J., DIETRICH M., KOWALSKI R.K., DOBOSZ S., KAROL H., DEMIANOWICZ W., GLOGOWSKI J., 2010 - Exposure of rainbow trout milt to mercury and cadmium alters sperm motility parameters and reproductive success. ***Aquatic Toxicology*** 97, 277-284.
13. DIETRICH G.J., CIERESZKO A., KOWALSKI R.K., RZEMIENIECKI A., BOGDAN E., DEMIANOWICZ W., DIETRICH M., KUJAWA R., GLOGOWSKI J., 2012 - Motility and fertilizing capacity of frozen/thawed sperm of Siberian sturgeon after a short-time exposure of fresh semen to mercury and cadmium. ***Journal of Applied Ichthyology***, 28, 973-977.
14. DIETRICH G.J., FLOREK-ŁUSZCZKI M., WOJCIECHOWSKA M., WÓJCIK T., BĄK-BADOWSKA J., WÓJTOWICZ B., CHMIELEWSKI J., 2022 - Fish as bio-indicators of environmental pollutants and associated health risks to the consumer. ***Journal of Elementology*** 27, 879-896.
15. DOMÍNGUEZ-MORUECO N., PEDRAZA-DIAZ S., GONZALEZ-CABALLERO M.D.C., ESTEBAN-LOPEZ M., DE ALBA-GONZALEZ M., KATSONOURI A., CASTAÑO A. 2022. Methylmercury risk assessment based on European human biomonitoring data. ***Toxics*** 10, 427.
16. EFSA PANEL ON CONTAMINANTS IN THE FOOD CHAIN (CONTAM). 2012 - Scientific opinion on the risk for public health related to the presence of mercury and methylmercury in food. ***EFSA Journal*** 10, 2985.
17. EUROPEAN UNION 2023 - Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food. Off J Eur Union L119: 103.
18. GIOŚ (CHIEF INSPECTORATE OF ENVIRONMENTAL PROTECTION), 2022 - State of the environment in Poland based on the PMŚ results. GIOŚ, Warsaw.
19. GŁODEK A., PACYNA J.M., 2009 - Mercury emission from coal-fired power plants in Poland. ***Atmospheric Environment*** 43(35), 5668-5673.
20. GRANDJEAN P., HERZ K.T., 2015 - Trace elements as paradigms of developmental neurotoxicants: Lead, methylmercury and arsenic. ***Journal of Trace Elements in Medicine and Biology*** 31, 130-134.
21. GWOREK B., DMUCHOWSKI W., BACZEWSKA A.H., BRĄGOSZEWSKA P., BEMOWSKA-KAŁABUN O., WRZOSEK-JAKUBOWSKA J., 2017 - Air contamination by mercury, emissions and transformations-a review. ***Water, Air, & Soil Pollution*** 228, 123.
22. HASANEIN S.S., MOURAD M.H., HAREDI A.M.M., 2022 - The health risk assessment of heavy metals to human health through the consumption of Tilapia spp and catfish caught from Lake Mariut, Egypt. ***Heliyon*** 8, e09807.
23. LAVOIE R.A., JARDINE T.D., CHUMCHAL M.M., KIDD K.A., CAMPBELL L.M., 2013 - Biomagnification of mercury in aquatic food webs: a worldwide meta-analysis. ***Environmental Science & Technology*** 47, 13385-13394.
24. ŁUCZYŃSKA J., ŁUCZYŃSKI M.J., NOWOSAD J., KOWALSKA-GÓRALSKA M., SENZE M., 2022 - Total Mercury and Fatty Acids in Selected Fish Species on the Polish Market: A Risk to Human Health. ***International Journal of Environmental Research and Public Health*** 19, 10092.
25. MOZAFFARIAN D., RIMM, E.B., 2006 - Fish intake, contaminants, and human health: evaluating the risks and the benefits. ***Jama*** 296, 1885-1899.

26. OLMEDO P., PLA A., HERNÁNDEZ A.F., BARBIER F., AYOUNI L., GIL, F., 2013 - Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. ***Environment International*** 59, 63-72.
27. PYTA H., WIDZIEWICZ-RZOŃCA K., SŁABY K., 2020 - Inhalation Exposure to Gaseous and Particulate Bound Mercury Present in the Ambient Air over the Polluted Area of Southern Poland. ***International Journal of Environmental Research and Public Health*** 17, 4999.
28. RAJKOWSKA-MYŚLIWIEC M., PROTASOWICKI M., 2023 - Assessment of mercury bioaccumulation in the muscle of pike, bream and crucian carp in lakes in Poland. ***Animals*** 13, 697.
29. SOERENSEN A.L., SCHARTUP A.T., GUSTAFSSON E., GUSTAFSSON B.G., UNDEMAN E., BJÖRN E., 2016 - Eutrophication increases phytoplankton methylmercury concentrations in a Coastal sea - a Baltic sea case study. ***Environmental Science & Technology*** 50, 11787-11796.
30. STATISTICS POLAND (GUS), 2024 - Household Budget Survey in 2023. Statistics Poland, Warsaw.
31. SURA P., KOWALCZYK P., BIAŁA D., MARCIŃSKA K., WOŹNIAK D., MACURA B., SZCZEPANIK M., 2018 - Wpływ rtęci na układ odpornościowy (Mercury's effect on the immune system). ***Problemy Higieny i Epidemiologii*** 99, 310-317. In Polish, with English summary.
32. UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA), 2023 - Risk-based concentration table. *US EPA*, Washington DC.
33. WANG B., CHEN M., DING L., ZHAO Y., MAN Y., FENG L., FENG X., 2021 - Fish, rice, and human hair mercury concentrations and health risks in typical Hg-contaminated areas and fish-rich areas, China. ***Environment International*** 154, 106561.
34. WORLD HEALTH ORGANIZATION (WHO), 2017 - Mercury and health. Key facts. WHO, Geneva.
35. ZHAO W., GAN R., XIAN B., WU T., WU G., HUANG S., ZHANG Y., 2024 - Overview of methylation and demethylation mechanisms and influencing factors of mercury in water. ***Toxics*** 12(10), 715.
36. ZRELLI S., AMAIRIA S., CHAABOUNI M., OUESLATI W., CHINE O., NACHI MKAOUAR A., ZRELLI M., 2021 - Contamination of fishery products with mercury, cadmium, and lead in Tunisia: level's estimation and human health risk assessment. ***Biological Trace Element Research*** 199, 721-731.
37. ZULAIKHAH S.T., WAHYUWIBOWO J., PRATAMA A.A., 2020 - Mercury and its effect on human health: A review of the literature. ***International Journal of Public Health Science*** 9, 103-114.
38. ZYŚK J., ROUSTAN Y., WYRWA A., 2015 - Modelling of the atmospheric dispersion of mercury emitted from the power sector in Poland. ***Atmospheric Environment*** 112, 246-256.
39. ŻEBER-DZIKOWSKA I., GWOREK B., GOŹDZIEWSKA M., 2025 - Health risk resulting from pesticide residues in food of plant origin–a still valid challenge for health and ecological education. ***Annals of Agricultural and Environmental Medicine*** 32, 274-279.