



Ecotoxicological impact of mercury thermometers and the transition to safe alternatives

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Abstract. Mercury is a highly toxic element with significant environmental and human health implications due to its persistence, mobility, and capacity for bioaccumulation and biomagnification. This paper examines the ecotoxicological impact of mercury, with a particular focus on its release from mercury thermometers and its behavior within the environment. The study highlights the biogeochemical cycle of mercury, emphasizing its transformation into toxic organic forms such as methylmercury, which accumulates in aquatic food chains and poses serious risks to living organisms and humans. Major sources of mercury exposure are analyzed, including natural emissions, industrial activities, contaminated food consumption, and domestic incidents such as the breakage of mercury-containing devices. The paper also discusses the adverse effects of mercury on ecosystems and biological systems, particularly its neurotoxic and developmental impacts. Furthermore, the role of international regulations in limiting mercury use is explored, alongside the gradual phase-out of mercury thermometers. Safer and more sustainable alternatives, such as galinstan thermometers and digital technologies, are presented as effective replacements that reduce environmental risks while maintaining measurement accuracy. The findings underline the importance of transitioning to mercury-free technologies as a critical step in minimizing environmental pollution and protecting public health, supporting global efforts toward sustainable development and ecological preservation.

Keywords: mercury, ecotoxicology, mercury thermometers, environmental pollution, bioaccumulation, biomagnification, methylmercury, public health, environmental protection.

Introduction. In the context of increasing concerns regarding environmental protection and pollution reduction, the use of mercury has been restricted at the international level, with safer and more sustainable alternatives being promoted. The transition to digital thermometers or other types of mercury-free devices represents an important step in reducing the negative impact on ecosystems (Muniyandi et al., 2022).

The aim of this paper is to analyze the ecotoxicological impact of mercury originating from thermometers and to highlight the importance of adopting safe and environmentally friendly alternatives.

Mercury (Hg) is a liquid metal at ambient temperatures and pressures. It forms salts in two ionic states: mercury (I) and mercury (II). Mercury (II), or mercuric salts, are much more common in the environment than mercury (I) or mercurous salts (Petrescu-Mag & Oroian, 2015). These salts, if soluble in water, are bioavailable and considered toxic. Mercury also forms organometallic compounds, many of which have industrial and agricultural uses (Petrescu-Mag & Petrescu-Mag, 2010; Petrescu-Mag et al., 2010). Elemental mercury releases vapors that are only slightly soluble in water, but are problematic due to their easy transport in the atmosphere (Boening, 2000; Petrescu-Mag, 2025).

The biogeochemical cycle of mercury involves the movement and transformation of mercury through various environmental compartments, including the atmosphere, soil, and aquatic systems (Ielceanu, 2026), as shown in Figure 1. This cycle is complex and is influenced by both natural processes and human activities (Wu et al., 2024).

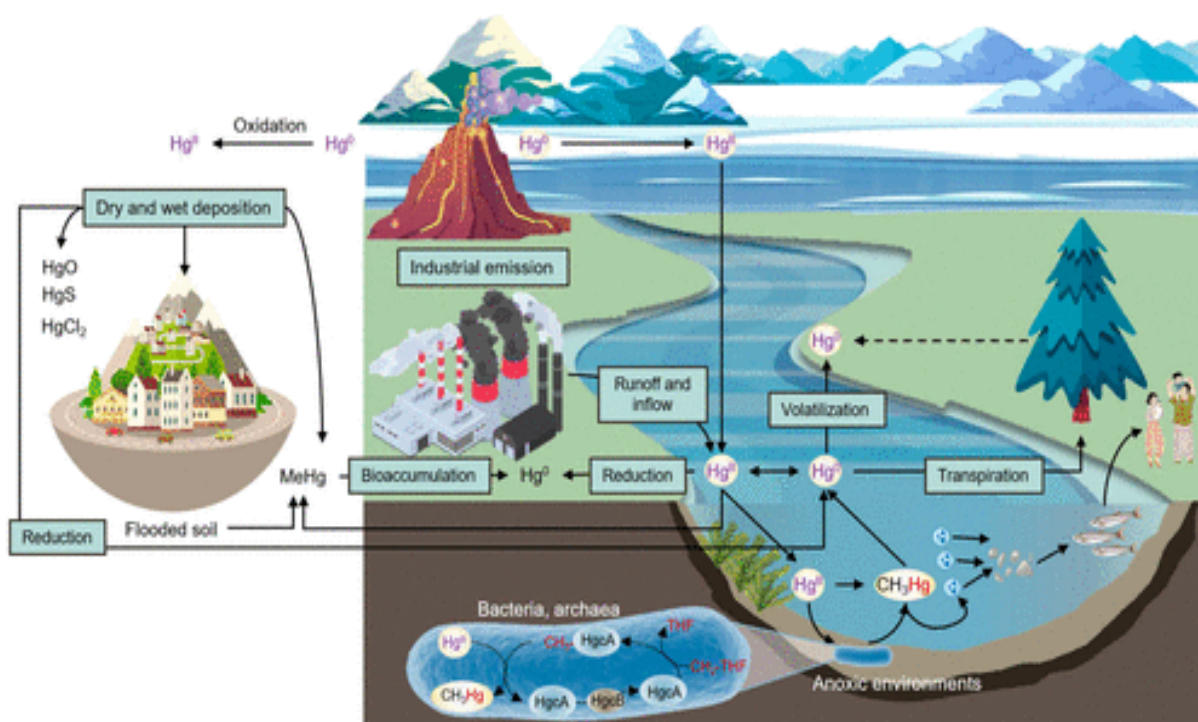


Figure 1. Biogeochemical cycle of mercury in the atmosphere, soil, and aquatic environment (Wu et al., 2024).

Sources of Mercury Exposure. The bulk of mercury exposure by humans comes from three major sources: the release of mercury vapor from dental fillings, consumption of contaminated fish, and occupational exposure (Basu et al., 2023; Pant et al., 2024). Mercury in nature is usually elemental mercury or sulfides, and occurs in the Earth's crust around 0.5 parts per million. Mercury can naturally be released to the atmosphere by such things as the discharge of gases from rocks, and through volcanic activity. Human activities, especially coal burning and mining (particularly for mercury and gold), also contribute significantly to atmospheric mercury levels (Basu et al., 2023; Pant et al., 2024).

Once in the atmosphere, elemental mercury eventually settles into bodies of water. There, microorganisms convert it into organic forms, such as methyl or ethyl mercury. These compounds are absorbed by small aquatic organisms, where they build up the food chain (Mastan et al. 2024). And so huge predatory fish such as tuna, swordfish and shark can have lots of mercury in their body tissues. Mercury is largely inhaled by humans through mercury vapor from workplace exposure and dental amalgam, and from meals with organic mercury.

A majority of mercury exposure is due to vapor from dental fillings and the body absorbs a good percentage of this. Less frequently, exposure can be due to accidental spills of mercury and is hazardous, especially if the mercury is agitated (e.g. through vacuuming). Organic mercury, especially methyl and dimethyl mercury, is predominantly obtained from biological sources such as fish found in fresh water and marine waters. Thousands of lakes have been closed to fishing due to contamination, and many ocean fish species have high levels of mercury also (Bernhoft, 2011).

In the context of the home, the breaking of mercury thermometers releases toxic vapors quickly into the air, which can be easily inhaled, especially in closed, poorly-ventilated spaces. This sort of exposure is dangerous, in large part because mercury vapors are readily absorbed through the respiratory system and can lead to nerve damage.

Additionally, the vapor emissions of amalgam fillings form part of chronic exposure to low levels of mercury, which may add up in the human body. Other major sources are pharmaceutical products and some vaccines that contain mercury compounds

in small concentrations, mostly used as preservatives. Such levels remain closely regulated, but they add to the overall exposure.

Moreover, products with mercury in them (a common source of contamination) are used to treat skin blemishes or for skin lightening, so they represent a large source of contamination, especially where rules are less stringent. Frequent use of such products may cause accumulation of mercury in the body. Similarly, poor disposal of waste that contains mercury (like batteries, electrical equipment, or medical products) also greatly pollutes soil and water. Microorganisms convert inorganic mercury to highly toxic organic forms in aquatic environments, including methylmercury.

These species are readily absorbed by aquatic organisms and then accumulate up the food chain to concentrations found in the upper level. Hence, the diversity of mercury sources, its mobility in the environment, and its bioaccumulation and biomagnification processes represent a significant risk to human health and ecosystem balance (Bernhoft, 2011) (Figure 2).

The Impact of Mercury on the Environment. Mercury pollution represents a major global issue due to its persistent nature, high mobility, and ability to transform into highly toxic chemical forms. Mercury is released into the environment through both natural processes, such as volcanic activity, rock weathering, and emissions from soil and water, and anthropogenic activities, including the combustion of fossil fuels, industrial processes, and the use of mercury-containing products. Once released into the atmosphere, mercury can remain in circulation for long periods and can be transported over great distances by air currents (Uddin et al 2024).

As a result, it can contaminate remote regions, including areas seemingly unaffected by direct human activity, such as Arctic ecosystems and the oceans. After deposition in soil or surface waters, mercury undergoes chemical transformations under the action of microorganisms, being converted into toxic organic forms such as methylmercury (Ielceanu, 2026). This form is easily absorbed by living organisms and progressively accumulates along food chains, a process known as biomagnification. Consequently, organisms at higher trophic levels, including humans, may be exposed to high concentrations of mercury even when the original source of contamination is distant. (Fagbenro & Olaleye, 2026).

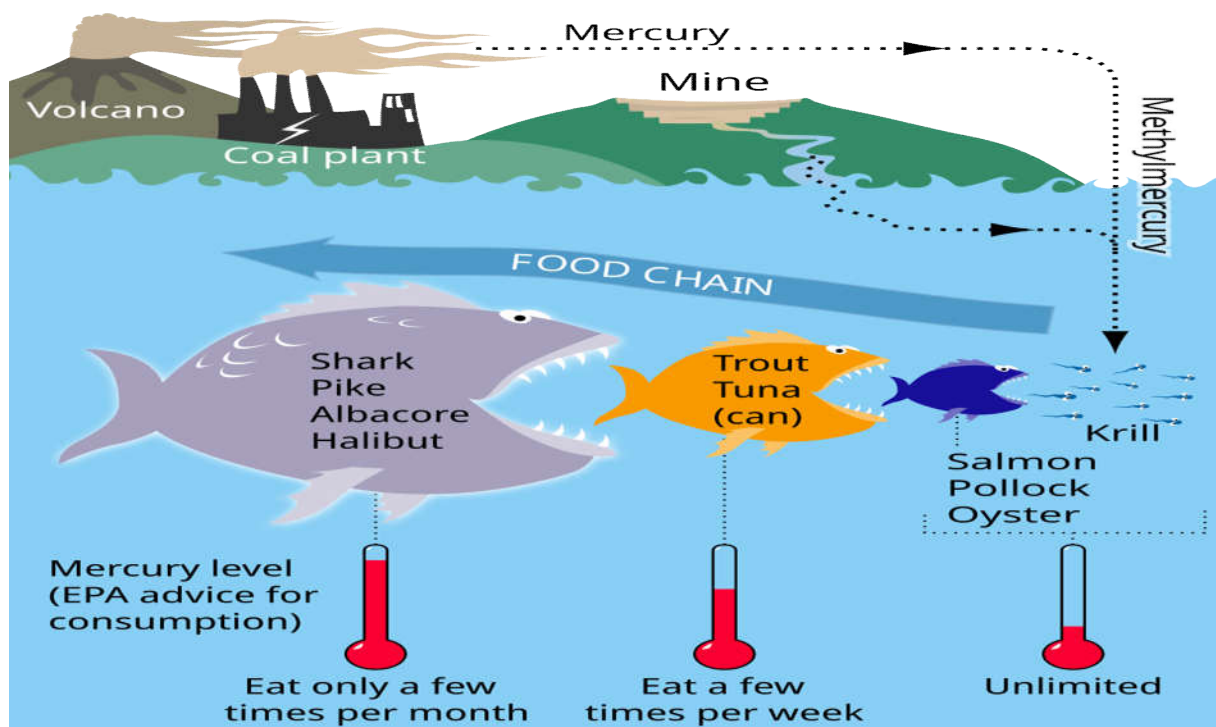


Figure 2. Mercury biomagnification through the food chain (U.S. EPA, 2023 - Mercury and the food chain).

The impact of mercury on living organisms is significant and diverse, affecting a wide range of life forms from microorganisms to plants and animals. This toxic metal disrupts essential metabolic activities and cellular functions, damaging enzymatic activity and biochemical homeostasis. Organic forms of mercury, especially methylmercury, are particularly toxic for aquatic organisms and finally for fish eaters (Elfidasari et al., 2022; Hiola & Badjuka, 2021).

Exposure to these forms may lead to developmental disorders, reproductive problems, reduced reproductive capacity, and behavioral alterations limiting species survival. In addition, methylmercury possesses potent neurotoxic effects on the nervous system of animals, resulting in impaired coordination, orientation, and response to stimuli. At the ecosystem level, such impacts can lead to declines in sensitive populations and ecological imbalances that may ultimately affect the function and stability of food chains (Boening, 2000).

The impact of mercury on the environment is complex and long-lasting, involving a series of interconnected processes such as global transport, chemical transformations, and accumulation in food chains. Due to its volatility, mercury can be transported through the atmosphere over very long distances, contaminating regions far from its original sources of emission.

Once deposited in soil or surface waters, mercury undergoes chemical and biological transformations, being converted into more toxic forms such as methylmercury. This form is easily absorbed by living organisms and progressively accumulates along food chains, leading to higher concentrations in organisms at upper trophic levels (Wang et al 2023).

Properties and Uses of Mercury Thermometers. Mercury thermometers are frequently used temperature measuring instruments in the medical field for their high reliability and accuracy of measuring temperature. These thermometers work according to the principle of mercury expanding due to heating and contracting due to cooling, giving an accurate temperature on a graduated scale.

A mercury thermometer is only possible if it is placed and subjected to a prolonged amount of time (several minutes) on its target area such as in an armpit, rectum, or oral cavity. Such quality guarantees a high degree of accuracy, but at the cost of a longer waiting time and discomfort for the patient, as well. Because the measured value is not always clear, the user needs to pay more attention.

The main disadvantage of these thermometers is the presence of mercury in the measurement system, which is a toxic substance that may put both the user and the individual at risk at the moment of accidental breakage of the thermometer.

Mercury thermometers were the gold standard of measurement of body temperature in medical practice for many years based on their reliability and precision. Their use in the body was extensive for monitoring and tracking the temperature of a patient, as well as temperature diagnosis and monitoring of fever. However, the time required to obtain a measurement was time-consuming and reading the measurements was very challenging despite their accuracy.

The use of mercury thermometers began to decrease due to developments in modern technology such as infrared thermometers. In global epidemics (SARS, Ebola, swine flu, COVID-19), quick, safe, and easy-to-use fever screening tools were required; hence their use declined. However, mercury thermometers remain the gold standard in accuracy, serving as a reference standard for other types of thermometers in comparative studies (Pecoraro et al., 2020).

International Regulations on Mercury and Thermometers. Mercury exposure to the poisonous metal and its impact on human and the surrounding environment has prompted international regulations on mercury use in thermometers in international regulations in international standards. With time, scientific investigations of mercury have revealed the physicochemical properties (especially at lower temperatures) like mercury's reactions in various measuring devices based on thermometers and reactivity.

These research results are used to inform the formulation of international laws regarding the use of regulation in the form of international regulatory decisions. The characterization of how mercury behaves at extreme temperatures (even freezing points) has not only been part of the regulation of mercury thermometers but has also become an integral part of mercury thermometers management. The narrow tube has tested the accuracy of the experimental data and found that mercury freezes more rapidly there than in the main reservoir, which is detrimental to flow and temperature control. While these developments were considered in international guidelines, their effects were known to raise concerns regarding the accuracy and safety of mercury thermometers at various temperatures.

Moreover, the studies involving mercury compression and contraction at low temperatures have revealed the limitations of this material (in its functioning as a measuring fluid in thermometers) in scientific or industrial settings, where accuracy is especially important. These observations supported the case for limiting or prohibiting mercury in measuring devices to opt for safer and more reliable alternatives. Hence, regulatory consideration has stemmed from the health and environmental hazards and technical constraints of mercury devices for measurement. These measures also resulted in the progressive elimination of mercury thermometers in numerous countries as well as the promotion of alternative options, and have contributed to worldwide exposure reduction of mercury and protection of global public health (World Health Organization, 2023).

Alternatives to Mercury Thermometers. The World Health Organization recommends the removal of mercury-containing devices and the dangers associated with exposure.

In this sense, liquid-in-glass thermometers using galinstan, in lieu of mercury, constitute the most viable alternative. Galinstan is a eutectic alloy of gallium, indium, and tin, which can retain a liquid state at room temperature and has a melting point of about -19° Celsius. Unlike mercury, the elements of galinstan are non-toxic to humans and the environment. From the viewpoint of metrological accuracy, galinstan thermometers were found to serve a valid purpose in both clinical and laboratory, comparable to mercury thermometers for determining body and fluid temperature, meaning they are an ideal tool for direct replacement (no requirement for adjustment to reading). But galinstan has a higher surface tension and is more likely to adhere to glass than mercury, a practical trade-off, requiring more mechanical force (stronger shaking) to reset the thermometer column.

A paradigm shift in technology has been achieved through the introduction of electronic devices that currently dominate the medical and industrial markets. These depend on sensors that have a predictable electrical resistance change with temperature. Thermistors (NTC/PTC) have been most commonly used household and clinical digital thermometers. They provide sensitivity over narrow temperature ranges and rapid response speeds but can drift over time if not calibrated regularly. RTDs (Resistance Temperature Detectors), which are usually made of platinum (sensors like Pt100), are extensively exploited for scientific measurement. RTDs are stable in the long term, and have higher linearity than mercury thermometers, and cover a much larger temperature range, ranging from -200°C to over 600°C .

Infrared thermopile sensor-based technology is an established method for quick non-contact measurements in medical triage and for high temperature production in industry. These instruments assess the heat-radiation of bodies and translate the temperature from them to an electrical signal in degrees Celsius. While they provide a great advantage in terms of cross contamination prevention and they take the temperature at the pulse of the moment, the performance of these devices may be affected by extrinsic factors including the emissivity of the measured surface, distance, and the angle of incidence. Consequently, although they are well-suited for quick examinations, contact digital thermometers are better in in-depth clinical studies for a definitive diagnosis.

Moving from mercury into more modern technological standards has been not just a necessary transition in nature for environmental reasons but a qualitative step in

metrology. Galinstan thermometers have the mechanical simplicity of traditional instruments, meaning they don't rely on batteries, but electronic and optical sensors (RTDs and IR pyrometers) automate the process, store data digitally and allow remote monitoring — overcoming the physical difficulties of liquid thermal expansion (Davies et al., 1986).

Mechanisms Linking Thermometer Use to Environmental Mercury Loads. Mercury thermometers contain elemental mercury in a fragile glass envelope. When thermometers break during use, storage, or disposal, mercury is released from a closed system into air, soil, and water, where it can enter the global mercury cycle and ultimately be transformed into more toxic forms such as methylmercury.

Mercury-containing thermometers are explicitly recognized as a source of elemental mercury spills and emissions into homes, hospitals, industry and landfills (Baughman, 2005; Kuepouo, 2013; Al-Sulaiti et al., 2022; Mostafalou & Abdollahi, 2013). Breakage of medical thermometers in Cameroonian hospitals produced an estimated 0.646 kg of mercury per year from a small sample, extrapolated to about 222.5 kg of mercury per year nationally from healthcare staff alone, directly discarded into the environment (Tetsopgang, 2023). National-scale trade and hospital consumption data suggest several tonnes of mercury were contained in thermometers over a few years, with breakage at all stages of the life cycle allowing transfer to air, soil, and water and creating local “hot spots” (Kuepouo, 2013). Poison centre data from the UK show that 67% of mercury-related calls involved thermometers, and half of these involved spills requiring cleanup, indicating frequent uncontrolled environmental releases in domestic and clinical settings (ICEAPCCT, 2009). Occupational studies in Chinese thermometer factories document high airborne mercury concentrations and urinary mercury in workers, driven by traditional production technologies; engineering controls and substitution with mercury-free thermometers markedly reduce workplace contamination and exposure (Xu et al., 2020; Bieser et al., 2023).

Once released, elemental mercury from thermometers behaves like other anthropogenic mercury: it volatilizes, is transported atmospherically, deposited to soils and waters, and then microbially transformed to methylmercury, which bioaccumulates and biomagnifies in aquatic food webs (Beckers & Rinklebe, 2017; Ray et al., 2025; De Almeida Rodrigues et al., 2019; Kim & Zoh, 2012; Al-Sulaiti et al., 2022; Mostafalou & Abdollahi, 2013; Duan et al., 2020). Environmental reviews stress that products containing mercury, including thermometers, contribute to the global mercury burden that ultimately drives methylmercury contamination of fish and associated human health risks (Beckers & Rinklebe, 2017; Ray et al., 2025; Kim & Zoh, 2012; Al-Sulaiti et al., 2022; Mostafalou & Abdollahi, 2013; Duan et al., 2020) (Table 1).

Table 1

Quantitative evidence from thermometer-related studies

<i>Context / pathway</i>	<i>Key quantitative finding (Hg)</i>	<i>References</i>
Cameroonian hospitals (broken medical thermometers)	~0.646 kg Hg/year from surveyed staff; extrapolated ~222.5 kg/year nationally disposed in hospitals	Tetsopgang, 2023
National consumption of medical Hg-thermometers, Cameroon	~2,430 kg Hg in thermometers over 5 years via trade data; up to ~8,603 kg/year inferred from on-site data	Kuepouo, 2013
UK poison centre calls	67% of mercury calls from thermometers; 50% involved spills requiring cleanup (environmental release)	ICEAPCCT, 2009
Factory lake contamination, India (thermometer plant)	Lake water 356–465 ng/L total Hg; sediments 276–350 mg/kg; fish 120–290 mg/kg Hg, attributed to factory emissions/wastes	Karunasagar et al., 2006.

The Kodaikkanal case in India provides direct environmental evidence: a thermometer factory's emissions and wastes were associated with markedly elevated mercury in lake water, sediments, and fish compared with reference lakes, demonstrating that thermometer manufacturing and related waste disposal can heavily contaminate aquatic systems (Karunasagar et al., 2006). Reviews and fate-transport analyses make clear that such point sources add to a larger pool of mercury that is redistributed globally, transformed into methylmercury, and taken up by aquatic organisms and humans through diet (Beckers & Rinklebe, 2017; Ray et al., 2025; De Almeida Rodrigues et al., 2019; Kim & Zoh, 2012; Al-Sulaiti et al., 2022; Mostafalou & Abdollahi, 2013; Duan et al., 2020). Regulatory and policy analyses (e.g., Minamata Convention-aligned strategies and EU directives) explicitly target mercury thermometers for phase-out on the basis that reducing their use and preventing spills will reduce environmental releases and associated health risks (Lin et al., 2025; Galappaththi & Suraweera, 2020; Clarkson et al., 2003; Al-Sulaiti et al., 2022; ICEAPCCT, 2009; Cox, 2018).

Conclusions. Mercury represents a significant environmental and public health concern due to its toxicity, persistence, and ability to bioaccumulate and biomagnify along food chains. The analysis presented in this paper highlights that even seemingly minor sources, such as mercury thermometers, can contribute to environmental contamination and human exposure, particularly in cases of improper handling or disposal.

The ecotoxicological impact of mercury is complex and far-reaching. Once released into the environment, mercury undergoes transformations into highly toxic organic forms, such as methylmercury, which readily accumulate in aquatic organisms and ultimately affect higher trophic levels, including humans. These processes pose serious risks to ecosystem stability, biodiversity, and human health, particularly through neurological and developmental effects.

Although mercury thermometers have historically been valued for their accuracy and reliability, their disadvantages—especially the risks associated with accidental breakage and mercury exposure—outweigh their benefits in the modern context. The emergence and widespread adoption of safer alternatives, such as galinstan-based thermometers and digital devices, provide effective and environmentally friendly solutions without compromising measurement accuracy.

International regulations and recommendations, particularly those promoted by global health and environmental organizations, have played a crucial role in reducing mercury use and encouraging the transition to safer technologies. This shift not only minimizes direct human exposure but also contributes to the broader goal of reducing environmental pollution.

Finally, replacing mercury thermometers with non-toxic alternatives is an essential step toward sustainable development and environmental protection. Continued efforts in regulation, public awareness, and technological innovation are necessary to further reduce mercury emissions and mitigate its long-term impact on ecosystems and human health.

Acknowledgement. An AI-powered search engine for research – Consensus (<https://consensus.app>, Consensus NLP, Inc.) – was used to summarize data and literature findings in the comparative table.

Authors Contributions. Alexandra Maria Chețan contributed to all aspects of the work.

Conflicts of Interest. The author declares that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the author upon reasonable request.

Funding. This research received no external funding.

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Received: 01 May 2026. Accepted: 01 June 2026. Published online: 01 June 2026.

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How to cite this article:

Chețan A. M., 2026 Ecotoxicological impact of mercury thermometers and the transition to safe alternatives. *AES Bioflux* 18(1):39-48.