



A Narrative Review on the Risk of Environmental Contaminants in Human Breast Milk and Their Health Implications for Infants in Indonesia

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Abstract. Human breast milk is the best source of nutrition and immune protection for infants; however, various environmental contaminants such as pesticides, persistent organic pollutants (POPs), heavy metals, and emerging substances like microplastics have been detected in breast milk worldwide. In Indonesia, exposure risks may be higher in agricultural and industrial areas, potentially affecting milk quality and infant health. This narrative review aims to summarize scientific evidence on environmental contaminants in human breast milk and their possible health effects on infants in Indonesia. Relevant literature published between 2015 and 2025 was collected from PubMed, Scopus, Google Scholar, and national databases, including Garuda and SINTA. The reviewed studies reported the presence of organochlorine pesticides (notably p,p'-DDE), POPs such as PCBs and HCH, heavy metals, and microplastics in breast milk samples. Risk factors included pesticide use, environmental pollution, maternal body fat, and occupational exposure. Potential health impacts on infants involve neurodevelopmental disturbances, endocrine effects, and immune modulation. Nevertheless, evidence consistently shows that the benefits of breastfeeding outweigh the risks of low-level contaminant exposure. In conclusion, environmental contamination of breast milk is a public health issue that remains insufficiently monitored in Indonesia, highlighting the need for improved environmental surveillance, biomonitoring, and integrated policies while continuing to promote breastfeeding.

Keywords: Breast Milk; Environmental Contaminants; Infant Health; Microplastics; Pesticides.

1. BACKGROUND

Human breast milk is recognized as the optimal nutritional standard for newborns and young infants because it provides a combination of nutrients, immunological factors, and bioactive components that support growth, resistance to infections, and long-term cognitive development. Therefore, international health organizations recommend exclusive breastfeeding for the first six months of life, followed by continued breastfeeding up to two years or beyond according to the infant's needs (WHO, 2021).

On the other hand, breast milk can also serve as a route of excretion for various environmental contaminants that accumulate in the mother's body, particularly lipophilic compounds and persistent organic pollutants (POPs) such as DDT, PCBs, and other organochlorine pesticides, as well as heavy metals (e.g., lead, mercury) and contemporary pollutants such as microplastics. Global literature has documented the detection of these contaminants in breast milk, and review studies conclude that organochlorine pesticides are commonly found in human breast milk across many regions worldwide (Pirsaheb, 2015; Van den Berg et al., WHO surveys).

Empirical evidence from Indonesia supports the presence of contaminants in breast milk within the local context. Studies examining organochlorine content in breast milk samples from several regions have reported accumulation of organochlorine compounds (e.g.,

DDT/DDE, HCH isomers, PCBs) with levels varying across areas and associated with factors such as maternal age and reproductive history (Sudaryanto et al., 2006). Moreover, research among farming communities and agricultural regions has identified residues of p,p'-DDE in breast milk samples and correlations with agricultural exposure; for example, Rachmawati et al. (2021) reported p,p'-DDE detection in all tested samples from farmer mothers, and Cahyaningrum et al. (2018) documented concentration ranges of p,p'-DDE in breast milk from mothers in Brebes District.

The emergence of new pollutants adds another dimension of concern. Recent studies have reported the presence of microplastics in human tissues, including research detecting microplastics in several breast milk samples. Although evidence regarding the health implications of microplastics for infants remains limited and detection methods are still evolving, their presence broadens the spectrum of contaminants that must be considered (Saraluck et al., 2024; reviews on microplastics in dairy products).

The health effects associated with infant exposure to environmental contaminants through breast milk include potential disruptions to neurological development, immune function, and endocrine regulation particularly with exposure to heavy metals and certain pesticides or endocrine-disrupting chemicals (EDCs). Exposure–effect relationships are often complex due to simultaneous prenatal and postnatal exposures, nutritional factors, and socioeconomic determinants; thus, risk assessment requires synthesizing evidence from multiple study types, including reviews and observational studies (Pirsaheb, 2015).

At the national level, exposure to heavy metals such as lead has become a public health and policy concern due to its long-term implications for child development and health. National prevention initiatives and public health advisories emphasize the need for cross-sectoral interventions to reduce children's exposure to environmental sources such as used battery recycling and industrial waste (Kemenkes RI, 2024; UNICEF policy brief). Indonesia's environmental conditions including intensive agriculture, widespread pesticide use, small-scale mining activities involving mercury, and waste management issues create localized and heterogeneous exposure risks.

Despite the existence of local evidence, research data on the prevalence and levels of various contaminants in breast milk in Indonesia remain fragmented, dispersed across studies with different methodologies and limited geographical coverage. The absence of centralized national monitoring hinders population-level risk assessment and the formulation of comprehensive evidence-based policies. Therefore, a narrative literature review synthesizing local and international evidence is essential to: (1) identify reported contaminants in Indonesian

breast milk, (2) assess potential health impacts on infants, (3) determine research gaps and high-risk areas, and (4) develop policy recommendations and future research priorities.

The urgency of this review arises from the need to protect vulnerable populations (infants and breastfeeding mothers) without diminishing support for breastfeeding practices that have well-established benefits. Accurate synthesis of evidence will assist policymakers, healthcare providers, and communities in balancing the benefits of breastfeeding with strategies for reducing exposure (e.g., controlling pollution sources, providing nutritional and behavioral guidance for mothers), as well as directing surveillance programs and research where they are most needed (WHO, 2021; Kemenkes RI, 2024).

2. THEORETICAL STUDY

a. Breastfeeding and Human Milk Composition

b. Human breast milk is a complex biological fluid containing macronutrients, micronutrients, and immunological components such as immunoglobulins, cytokines, and oligosaccharides, all of which play essential roles in infant protection and development. The composition of breast milk changes throughout the stages of lactation—colostrum, transitional milk, and mature milk—to meet the evolving needs of the growing infant (Ballard & Morrow, 2013). In addition, breast milk contains lipids as a major component, which may also serve as a transport medium for lipophilic compounds when mothers are exposed to environmental contaminants (Koletzko et al., 2019).

c. Environmental Contaminants in Human Milk

Environmental contaminants commonly detected in human breast milk include persistent organic pollutants (POPs) such as dioxins, polychlorinated biphenyls (PCBs), and organochlorine pesticide residues; endocrine-disrupting chemicals (EDCs) such as bisphenol A (BPA) and phthalates; and heavy metals such as mercury and lead. These substances can accumulate in maternal adipose tissue and be excreted into breast milk due to their lipophilic properties (LaKind et al., 2018). WHO and UNEP have underscored that the detection of POPs in breast milk serves as an important biomarker for assessing population-level environmental exposure (WHO/UNEP, 2019).

d. Mechanisms of Transfer of Contaminants Into Breast Milk

The transfer of contaminants into breast milk primarily occurs through two pathways:

- 1) Accumulation in maternal adipose tissue, where lipophilic compounds are stored and subsequently mobilized during lactation; and

- 2) Transport via the bloodstream to mammary tissue, occurring through mechanisms such as diffusion, active transport, or protein binding in circulation (Needham et al., 2011).

Pharmacokinetic models show that chronic maternal exposure increases the likelihood of contaminant excretion into breast milk even after exposure has ceased (Verner et al., 2016).

e. Health Effects of Early-Life Exposure to Environmental Contaminants

Infants exposed to environmental contaminants through breast milk may experience a range of health effects, particularly involving the neurological, endocrine, and immune systems. Longitudinal studies have shown that early exposure to heavy metals such as mercury and lead is associated with reduced cognitive function and developmental delays (Grandjean & Landrigan, 2014). Meanwhile, exposure to EDCs such as BPA has been linked to altered thyroid hormone function and changes in metabolic developmental patterns in children (Vandenberg et al., 2012).

f. Risk Assessment in Breast Milk Studies

Risk assessment of contaminants in breast milk typically involves measuring contaminant concentrations, estimating infants' daily intake, and comparing these estimates with tolerable daily intake (TDI) values set by international regulatory bodies such as EFSA and WHO. Modern approaches to risk assessment also account for factors such as variability in breast milk composition, maternal age, body mass index, and exposure history (LaKind & Lehmann, 2021).

3. RESEARCH METHODS

This study employed a narrative literature review approach to summarize scientific evidence on environmental contaminants in breast milk and their impacts on infant health. Literature searches were conducted using PubMed, Scopus, Google Scholar, and national journal portals such as Garuda and SINTA. The search was limited to publications from 2015 to 2025 to ensure that the evidence reviewed reflects recent and relevant data.

The search utilized combinations of keywords including: “*breast milk*,” “*human milk*,” “*environmental contaminants*,” “*pesticides*,” “*heavy metals*,” “*microplastics*,” “*pollutants*,” and “*Indonesia*.” Articles were selected based on their relevance to the topic, availability of full text, and alignment with the review focus, specifically studies reporting the types or concentrations of contaminants, or the health effects of exposure in infants.

The selection process involved screening titles, abstracts, and subsequently full-text articles. Extracted information included types of contaminants, study locations, analytical methods, levels or prevalence of contaminants, and findings related to health effects. Data synthesis was performed descriptively to illustrate patterns of contamination, associated risk factors, and health implications. As this review did not involve primary data collection, ethical approval was not required.

4. RESULTS AND DISCUSSION

Characteristics of Included Studies

A number of studies exploring environmental contaminants in human breast milk were identified from the literature published between 2015 and 2025. Although research directly focused on contaminants in breast milk in Indonesia is limited, several local studies have specifically examined organochlorine pesticides in breast milk from agricultural areas (Cahyaningrum et al., 2018; Rachmawati et al., 2021). Older but still relevant research by Sudaryanto et al. (2006) provided foundational evidence of persistent organic pollutants (POPs) such as DDT and PCB in Indonesian breast milk samples, serving as a basis for comparison with more recent findings.

International studies and reviews offered additional insights into global patterns of contaminants in human milk, such as persistent organic pollutants (LaKind et al., 2018), and emerging contaminants like microplastics (Adjama et al., 2024; Saraluck et al., 2024).

Types of Environmental Contaminants Detected in Breast Milk

1) Organochlorine Pesticides (OCPs)

Cahyaningrum et al. (2018) reported the presence of p,p'-DDE, a metabolite of DDT, in breast milk samples from mothers in the agricultural region of Brebes, Indonesia. The concentration varied among subjects, indicating differential exposure levels. Similarly, Rachmawati et al. (2021) found p,p'-DDE residues in all breast milk samples collected from mothers working in horticultural farming, suggesting occupational and environmental exposure through agricultural pesticide use.

2) Persistent Organic Pollutants (POPs)

Sudaryanto et al. (2006) detected a range of POPs in Indonesian breast milk, including DDT, DDE, PCB congeners, and HCH isomers. These compounds are lipophilic and bioaccumulative, consistent with global evidence that such POPs persist in human tissues and are excreted in milk. International reviews, such as LaKind et al.

(2018), confirm ongoing global detection of POPs in human milk, underscoring their persistence despite regulatory controls in many countries.

3) Heavy Metals and Emerging Contaminants

Although specific data on heavy metals in Indonesian breast milk are sparse for the 2015–2025 period, regional research highlights exposure risks. For instance, Pangestuti et al. (2025) investigated environmental lead contamination related to maternal environments, which is relevant for understanding risks associated with heavy metal presence in breast milk.

Emerging contaminants such as microplastics have been reported in human milk by Saraluck et al. (2024), with studies showing the presence of microplastic particles in some breast milk samples. Adjama et al. (2024) similarly noted microplastics and other emerging chemicals in dairy products and human milk.

Risk Factors for Contamination

Several common risk factors for the presence of environmental contaminants in breast milk were identified:

- 1) Agricultural pesticide exposure, particularly among mothers engaged in or living near farming activities (Cahyaningrum et al., 2018; Rachmawati et al., 2021).
- 2) Bioaccumulation of lipophilic chemicals in adipose tissue, which are mobilized during lactation (Sudaryanto et al., 2006).
- 3) Environmental pollution from industrial and waste sources, as noted in national environmental health reports and contextualized by data on lead exposure risks (Pangestuti et al., 2025).

Potential Health Impacts on Infants

The literature suggests that chronic exposure to environmental contaminants via breast milk may have implications for infant health:

- 1) Neurodevelopmental effects: Early-life exposure to heavy metals such as lead and mercury can be associated with reduced cognitive function and developmental delays (Grandjean & Landrigan, 2014).
- 2) Endocrine disruption: Exposure to endocrine-disrupting chemicals (EDCs) such as bisphenol A (BPA) and phthalates has been linked to alterations in thyroid function and metabolic patterns (Vandenberg et al., 2012).
- 3) Immune system effects: Persistent organic pollutants have been associated with immune modulation, potentially affecting infant susceptibility to infections.

Despite these concerns, the evidence consistently emphasizes that the benefits of breastfeeding outweigh the potential risks associated with low-level contaminant exposure in most contexts.

Research Gaps and Surveillance Needs

The analysis revealed several gaps in the current evidence base:

- 1) There is limited recent research on heavy metals (e.g., mercury, lead) specifically measured in Indonesian breast milk for the 2015–2025 period.
- 2) Research on emerging contaminants such as PFAS (per- and polyfluoroalkyl substances) in Indonesian contexts is scarce.
- 3) National-level surveillance systems for monitoring breast milk contaminants are lacking in Indonesia, making comprehensive risk assessment difficult.
- 4) Variation in analytical methods among studies challenges direct comparison of contaminant levels.

These gaps indicate a need for standardized monitoring efforts, longitudinal studies, and broader geographic coverage to better understand exposure patterns and their health implications.

The findings of this narrative literature review indicate that environmental contaminants, including organochlorine pesticides (OCPs), persistent organic pollutants (POPs), heavy metals, and emerging contaminants such as microplastics—have been detected in human breast milk both in Indonesia and globally. Although the overall number of Indonesian studies is limited, the available evidence reflects exposure patterns that align with existing knowledge about environmental contamination in regions with intensive agriculture, industrial activities, and inadequate waste management.

Studies conducted in Indonesia, such as those by Cahyaningrum et al. (2018) and Rachmawati et al. (2021), consistently report the presence of p,p'-DDE in breast milk samples. This supports the understanding that DDT residues remain persistent in the environment long after their formal restriction, especially in agricultural regions. These findings also underscore the role of occupational exposure, where mothers engaged in or living near agricultural activities are more likely to be exposed to pesticide residues. The persistence of DDE in breast milk mirrors global studies indicating that OCPs continue to contaminate breast milk in many countries despite national bans, as demonstrated in the review by LaKind et al. (2018).

The earlier study by Sudaryanto et al. (2006) remains highly relevant because it provides baseline data on POPs in Indonesia. Given the slow degradation and bioaccumulation potential of these substances, it is expected that similar compounds may still be detectable in

breast milk today, even if usage patterns have shifted. However, the lack of recent large-scale investigations in Indonesia limits the ability to evaluate long-term trends or regional disparities in POPs exposure.

The discussion on heavy metals reveals an additional gap: while lead (Pb) and mercury (Hg) are known to pose developmental risks to infants, locally published biomonitoring studies focusing on breast milk remain scarce for the 2015–2025 period. Environmental research such as Pangestuti et al. (2025) suggests that lead exposure remains a concern in certain communities, especially those near agricultural or industrial zones, but direct measurements in breast milk are limited. This gap highlights the need for renewed attention to heavy metals within maternal and child health surveillance systems, given their established neurotoxic effects (Grandjean & Landrigan, 2014).

Emerging contaminants such as microplastics represent an evolving area of concern. The detection of microplastics in human milk reported by Saraluck et al. (2024) adds to growing evidence that small plastic particles can enter the human body through food, water, and air, and cross biological barriers. Although the health implications for infants remain uncertain, the presence of microplastics in breast milk raises questions about exposure pathways, maternal dietary habits, and environmental contamination that warrant further investigation. Studies such as Adjama et al. (2024) reinforce the need to explore the broader implications of microplastic exposure in both dairy products and human milk.

Despite the presence of contaminants, it is crucial to emphasize that breastfeeding continues to offer substantial health benefits that outweigh potential risks for the general population. Breast milk provides optimal nutrition, immune protection, and developmental advantages that cannot be replaced by formula feeding. International bodies including WHO consistently support breastfeeding while simultaneously recommending efforts to reduce environmental contamination at the source.

The overarching challenge in the Indonesian context lies in the absence of a national breast milk monitoring system. Without standardized surveillance and harmonized analytical methods, it is difficult to establish exposure baselines or develop appropriate interventions. The heterogeneity across existing studies in sampling, laboratory techniques, and reporting units also limits the ability to conduct meta-analysis or regional comparisons.

Moving forward, strengthening environmental health surveillance and integrating breast milk monitoring into national nutrition and maternal health programs are essential steps. Longitudinal studies are also needed to understand exposure pathways and examine potential developmental or health outcomes in infants. In addition, cross-sector collaboration involving

agriculture, industry, health, and environmental protection will be crucial to reduce environmental contaminants at their sources.

Overall, the findings highlight the necessity of continuous monitoring and targeted interventions to protect both mothers and infants from environmental contaminants, without undermining the vital role of breastfeeding in early childhood development.

5. CONCLUSION

This narrative literature review demonstrates that several classes of environmental contaminants, including organochlorine pesticides, persistent organic pollutants, heavy metals, and emerging contaminants such as microplastics—have been detected in human breast milk both in Indonesia and globally. Although the number of recent Indonesian studies remains limited, available evidence indicates that mothers living in agricultural, industrial, or environmentally burdened areas are at higher risk of exposure, which may subsequently affect breast milk composition. These findings highlight the influence of environmental, occupational, and maternal factors on contaminant transfer into breast milk.

While the levels of contaminants reported in existing studies vary, the potential health implications for infants particularly related to neurodevelopment, endocrine function, and immune regulation underscore the importance of continued attention to environmental exposures during the breastfeeding period. Nonetheless, the overwhelming body of global evidence affirms that the benefits of breastfeeding far outweigh the potential risks associated with low-level contaminant exposure for the general population.

Significant research gaps remain, particularly the absence of a national surveillance system for breast milk contaminants, limited recent biomonitoring studies, and inconsistent analytical methodologies across the available literature. Addressing these gaps is critical for developing a clearer understanding of exposure patterns and for informing public health policies.

Overall, this review emphasizes the need for strengthened environmental health monitoring, cross-sector collaboration to reduce pollutant sources, and expanded research efforts in Indonesia. Enhancing environmental protection measures while supporting breastfeeding promotion will be essential to safeguarding maternal and infant health.

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