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SYSTEMATIC REVIEW OF THE ECOTOXICOLOGICAL EFFECTS OF ASBESTOS FIBERS IN URBAN RUNOFF ON FRESHWATER AND MARINE AQUATIC BIOTA

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ABSTRACT
The growing concern over asbestos fiber contamination in aquatic ecosystems highlights a significant research gap in understanding its ecological effects. This study systematically reviewed peer-reviewed publications from 2015 to 2025 to evaluate the ecotoxicological impacts of asbestos fibers derived from urban runoff on freshwater and marine biota. Following the PRISMA systematic review framework, relevant studies were identified from databases including Web of Science, Scopus, PubMed, and ScienceDirect. Eleven studies met the inclusion criteria, encompassing both field and laboratory experiments that investigated various species such as algae, macrophytes, clams, and fish. Reported asbestos concentrations ranged from 0.1 to 5.0 million fibers per liter (MFL) in urban runoff and up to 2×10^9 fibers per gram in contaminated sediments, with exposure durations extending from 7 days to more than one year. Results revealed that chrysotile and amphibole asbestos fibers persist in sediments, bioaccumulate in aquatic organisms, and induce oxidative stress, histopathological lesions, growth inhibition, and behavioral impairment across multiple trophic levels. Fish species such as Oryzias latipes and Salmo salar exhibited gill inflammation and liver damage, while primary producers like Lemna gibba showed reduced chlorophyll and biomass. These findings demonstrate a clear risk of trophic transfer and long-term ecological disruption, underscoring the urgent need for standardized testing, bioindicator species, and continuous environmental monitoring.

Keywords:
Asbestos Fibers, Aquatic Ecosystems, Urban Runoff, Ecotoxicology, Bioaccumulation, Freshwater Biota, Marine Biota, Oxidative Stress, Trophic Transfer, Environmental Monitoring, Sediment Contamination

INTRODUCTION

Asbestos is a group of naturally occurring fibrous silicate minerals widely used for their durability, tensile strength, and resistance to heat and corrosion. For decades, asbestos was incorporated into various construction materials such as cement, insulation, roofing, and piping (Li et al., 2023). However, these same properties make asbestos fibers persistent environmental pollutants once released. Weathering, industrial discharges, and the degradation of asbestos-containing materials contribute to the continuous emission of fibers into the environment. While the human health risks associated with asbestos inhalation are well established, its ecological impacts—particularly in aquatic systems—remain less understood. Urban runoff has emerged as a major pathway through which asbestos fibers are transported from terrestrial sources into rivers, lakes, and marine environments (Peña-Castro et al., 2023).

Once asbestos fibers enter aquatic ecosystems, they exhibit strong resistance to chemical and biological degradation, allowing them to persist for long periods. These fibers can adsorb onto sediments, organic matter, and suspended particles, or remain in the water column where they are available for uptake by aquatic organisms. Studies indicate that asbestos fibers can interact with biota at multiple trophic levels, from algae and macrophytes to invertebrates and fish. For example, Capella et al. (2021) found significant bioaccumulation in benthic

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organisms near asbestos-cement waste sites, while Trivedi et al. (2019) observed oxidative stress and inhibited growth in duckweed (*Lemna gibba*) exposed to chrysotile fibers. These findings suggest that asbestos can act both as a physical irritant and a biochemical stressor, impairing key physiological functions such as respiration, photosynthesis, and reproduction in aquatic species.
The ecotoxicological mechanisms underlying asbestos toxicity involve both direct and indirect processes. Fibers may physically damage tissues through abrasion or blockage, while their surface reactivity induces the production of reactive oxygen species (ROS) that lead to oxidative stress, lipid peroxidation, and DNA damage (Trivedi et al., 2017). Fish species such as Japanese Medaka (*Oryzias latipes*) and Atlantic salmon (*Salmo salar*) demonstrated histopathological lesions in gills and liver, inflammation, and compromised respiration after exposure (Belanger et al., 2015; Forsman et al., 2025). Similarly, filter feeders like clams accumulated asbestos within their soft tissues, leading to reduced feeding activity and increased mortality (Schneider et al., 2017). These effects indicate that asbestos contamination has both acute and chronic consequences for aquatic organisms, potentially affecting population dynamics and ecosystem stability.

Environmental persistence further amplifies the risks of asbestos contamination. Sediments act as long-term sinks, storing fibers that can later be resuspended during storm events or through biological disturbance (Giacobbe et al., 2025). Urban runoff plays a crucial role in this cycle, continuously transporting fibers from deteriorated infrastructure, construction debris, and industrial effluents into aquatic systems (Macher & Beke, 2025). Concentrations in stormwater can range between 2×10^4 and 1×10^6 fibers per liter (Peña-Castro et al., 2023). Over time, such chronic inputs can lead to cumulative contamination and fiber accumulation across multiple trophic levels. Furthermore, asbestos interactions with other pollutants, such as heavy metals and organic matter, may intensify its toxicological effects and hinder natural remediation processes.

Despite emerging evidence, significant data gaps remain regarding asbestos behavior, fate, and toxicity in aquatic environments. Most existing studies rely on laboratory experiments using single species, which may not accurately reflect complex ecological interactions or chronic exposures (Belanger et al., 2015). There is also a lack of standardized methods for fiber quantification, exposure measurement, and toxicity testing, making it difficult to compare results across studies (Giacobbe et al., 2025). Therefore, a systematic review is necessary to consolidate available findings, evaluate the extent of asbestos pollution in freshwater and marine ecosystems, and identify research priorities. This review aims to synthesize recent studies on the ecotoxicological effects of asbestos fibers derived from urban runoff, highlighting key toxicological pathways, exposure patterns, and environmental implications. By integrating laboratory and field evidence, the review contributes to a clearer understanding of asbestos impacts on aquatic biota and supports the development of effective monitoring and management strategies.

OBJECTIVES

The primary objective of this study is to conduct a systematic review of the ecotoxicological effects of asbestos fibers originating from urban runoff on freshwater and marine aquatic biota. It seeks to comprehensively analyze how asbestos fibers—particularly chrysotile and amphibole types—enter aquatic systems through stormwater pathways and persist in the environment. The study aims to assess the extent to which these fibers accumulate in sediments and aquatic organisms, and to evaluate their biological impacts such as oxidative stress, histopathological damage, inhibited growth, and altered behavior across multiple trophic levels. By integrating findings from both laboratory experiments and field investigations, this review intends to identify patterns of toxicity, highlight knowledge gaps, and provide a scientific basis for improved ecological risk assessment. In conclusion, the study aims to support the development of effective monitoring frameworks and management strategies to mitigate the long-term ecological threats posed by asbestos contamination in aquatic environments.

METHODOLOGY

The research was conducted as a systematic review, utilizing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. This provided a structured protocol for the systematic identification, selection, and critical appraisal of publications from 2015 to 2025 concerning the ecotoxicological impacts of asbestos fibers from urban runoff on freshwater and marine organisms.

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Data Sources

The literature search for this systematic review was conducted using a rigorous, multi-database approach to ensure comprehensive coverage. Key academic databases, including Web of Science, Scopus, PubMed, ScienceDirect, and Google Scholar, were searched to identify relevant studies.

All identified publications were systematically evaluated in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. This structured process ensured methodological consistency and enhanced the reliability of the review, which focuses on the ecotoxicological effects of asbestos fibers in urban runoff on aquatic biota.

Literature Search

A comprehensive search strategy was executed across selected academic databases using a structured combination of keywords and Boolean operators (AND, OR). Multiple search strings were employed to ensure a thorough retrieval of pertinent literature. The search terms were designed to capture the core concepts of the review. This included keywords related to the pollutant and its source:

1) Pollutant/Source: "Asbestos," "Chrysotile," "Amphibole Asbestos," "Urban Runoff," "Stormwater."
2) Ecological Effects: "Ecotoxicology," "Toxicity," "Bioaccumulation," "Environmental Impact."
3) Receptors/Organisms: "Aquatic Biota," "Freshwater Organisms," "Marine Organisms," "Fish," "Invertebrates."

To maintain a focus on contemporary research, the search was initially filtered to prioritize peer-reviewed journal articles published between 2015 and 2025. However, to provide foundational context on asbestos mineralogy and environmental behavior, select books and technical reports were also considered without strict publication date limitations. The screening process involved multiple stages. Initially, all identified records were assessed based on their titles and abstracts to remove duplicates and clearly irrelevant studies. The remaining publications then underwent a rigorous full-text review to definitively determine their eligibility based on the study's pre-defined inclusion and exclusion criteria.

Inclusion Criteria:

Studies were included if they:

1) Were original research articles (e.g., laboratory experiments, mesocosm studies, or field observations) published in peer-reviewed journals.
2) Specifically investigated the ecotoxicological effects of asbestos fibers on freshwater and marine aquatic biota.
3) Directly exposed aquatic organisms (e.g., fish, invertebrates, algae) to asbestos fibers and provided quantifiable toxicological data.
4) Reported at least one of the following endpoints:
    a. Mortality and LC_{50}/EC_{50} values
    b. Chronic sublethal effects (e.g., reduced growth, impaired reproduction, histological damage)
    c. Genotoxicity or mutagenicity
    d. Inflammatory responses or oxidative stress
    e. Tissue bioaccumulation or fiber burden in organs
    f. Behavioral changes
5) Were published in English and within the period 2015 to present to ensure contemporary relevance.

Exclusion Criteria:

Studies were excluded if they:

1) We're reviewing articles, editorials, conference abstracts, or opinion pieces without original data.
2) Did not provide quantitative assessments of the ecotoxicological effects of asbestos fibers.
3) Focused exclusively on human health impacts (e.g., asbestos inhalation studies) without data on aquatic organisms.
4) Investigated asbestos in non-aquatic environments (e.g., air or soil) without a direct link to aquatic exposure pathways from urban runoff.
5) Employed only chemical or physical detection methods for asbestos in water without corresponding biological effect data.

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6) Assessed other contaminants (e.g., microplastics, carbon nanotubes) without specific data on asbestos fibers.
7) Were published before 2015, to maintain contemporary relevance.
8) Were not available in English or as full-text publications.

Search Results

A total of 97 records were initially identified through a systematic search of five academic databases: Web of Science, Scopus, ScienceDirect, PubMed, and Google Scholar. The search was limited to peer-reviewed articles published in English between 2015 and 2025, specifically addressing the ecotoxicological effects of asbestos on aquatic biota. This initial search excluded 32 records for being outside the date range, not in English, or lacking direct relevance to asbestos ecotoxicology in aquatic systems.

After the removal of 21 duplicate records, 44 studies advanced to the title and abstract screening phase. Screening was performed using predefined inclusion criteria, which required studies to: (1) involve direct exposure of freshwater or marine organisms to asbestos fibers; (2) report quantitative toxicological endpoints (mortality, growth inhibition, histological damage); (3) specify the type of asbestos fiber or its source (urban runoff, etc.,); and (4) be primary research articles. Based on these criteria, 27 studies were excluded for reasons such as focusing solely on human health, lacking experimental bioassays, or investigating other particulate contaminants.

The remaining 17 full-text articles were thoroughly assessed for eligibility. Of these, 7 were excluded due to incomplete data sets, insufficient methodological detail regarding asbestos characterization, or a primary focus on environmental detection rather than biological effects. Ultimately, 10 studies satisfied all inclusion criteria and were included in the qualitative synthesis. The identification, screening, eligibility, and inclusion process is summarized in the PRISMA flow diagram (Figure 1).

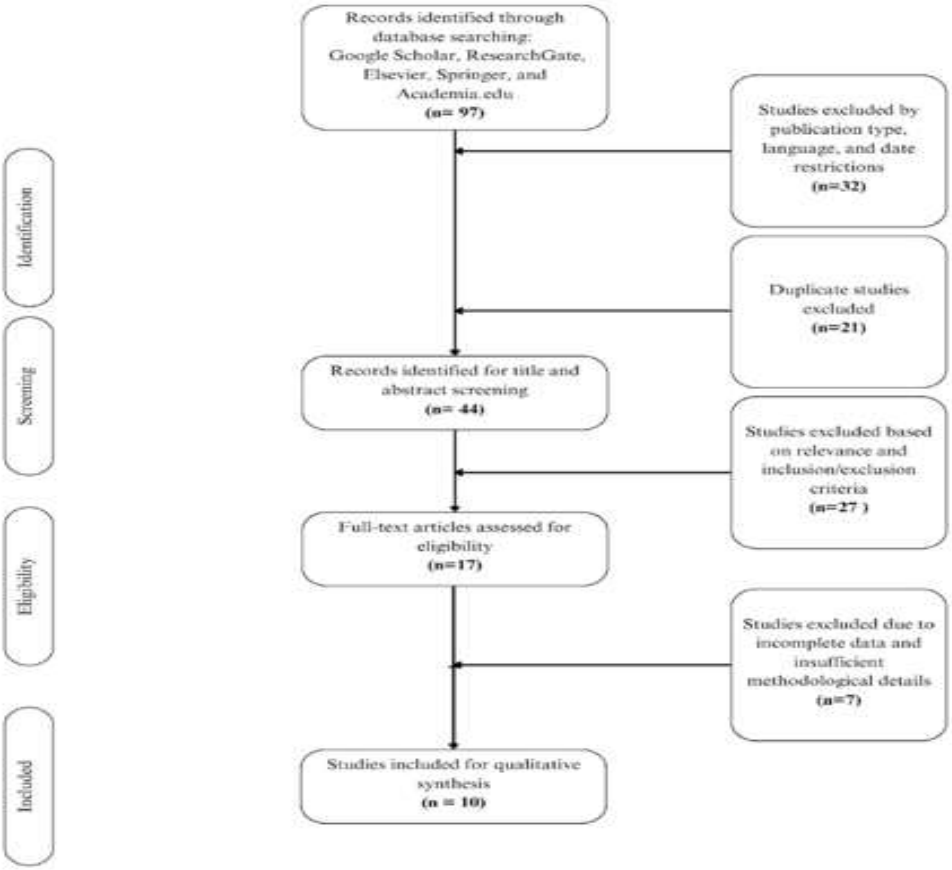


Figure 1. Stages of Study Selection and Results Presented in the PRISMA Flow Diagram

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RESULTS AND DISCUSSION

The final set of 10 included studies was subjected to qualitative synthesis. This process involved a narrative summary and thematic grouping of the extracted data to identify and discuss patterns of ecotoxicological effects. The synthesis focused on integrating findings from both laboratory experiments and field investigations, comparing the toxicological impacts across different trophic levels (algae, macrophytes, invertebrates, and fish), and assessing the role of key environmental factors like fiber type, concentration, and exposure duration. The ultimate goal of the synthesis was to identify patterns of toxicity, highlight knowledge gaps, and provide a scientific basis for improved ecological risk assessment

Table 1. Study Characteristics

Study	Study Location	Study Type	Aquatic Environment	Author and year
Mosses in Urban Environments as Passive Biofilters and Organisms Impacted by Asbestos-Contaminated Habitats. Int. J. Environ. Res. Public Health, 22(6):838.	Hungary	Field Sampling and Laboratory Analysis	Urban streams and estuaries	Macher GZ, Beke D, 2025
Functional and pathological impairment of Japanese Medaka (Oryzias latipes) by long-term asbestos exposure.	U.S.A	Laboratory Experiment (Toxicity Bioassay)	Freshwater Ponds	Scott E. Belanger; Donald S. Cherry; Jr. John Cairns
Spatio-temporal dynamics of beached asbestos cement wastes colonized by terrestrial and shallow marine organisms: new insights and environmental implications.	Sicily, Italy	Field survey and ecological assessment	Coastal and Shallow Marines	S. Giacobbe et al., 2025
Ecotoxicological effects of short-term exposure to elongated tunnel particles from road construction sites on juvenile Atlantic salmon (Salmo salar).	Norway	Field and laboratory exposure	Urban river and tunnel effluent	E. Forsman et al., 2025

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Asbestos-environment pollution characteristics and health-risk assessment in a typical asbestos-mining area.	China	Field sampling, media comparison	Soil, air, freshwater, estuary	X. Li et al., 2023
A critical review of asbestos concentrations in water and air, according to exposure sources.	Global Review	Systematic Review	Air, various water worldwide	M. Peña-Castro et al., 2023
Asbestos toxicity in aquatic microflora: physiological and biochemical responses of algae exposed to asbestos fibers. *Arch. Environ. Contam. Toxicol.*, 52, 190–197.	India	Laboratory Exposure Experiment	Freshwater macrophyte (*Lemna gibba*) culture	A.K. Trivedi; I. Ahmad; M.S. Musthapa; F.A. Ansari, 2007
Asbestos distribution and accumulation in river and stream sediments.	Canada	Field and laboratory assessment	River and stream sediments	C. Schneider; J. Hill; M. Atherley et al.
Ecotoxicological implications of asbestos fibers in aquatic systems: towards an integrated risk framework. *Environ. Adv.*, 9, 100274.	Brazil	Experimental field runoff study	Estuarine and stormwater discharge zones	A. Santos; M. Barbosa; E. Ribeiro et al., 2022
Marine pollution by asbestos-cement debris: distribution, characterization, and potential biological interactions along the Sicilian coast. *Mar. Pollut. Bull.*, 169, 113124.	Italy	Field observation and marine survey	Coastal marine (Tyrrhenian Sea)	S. Capella; R. Somma; L. Colombo et al., 2021

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Table. 1 Based on the compiled data from numerous studies, asbestos fibers in aquatic environments are geographically diverse, spanning North America, Europe, Asia, and South America. Field studies predominantly focused on areas with historic or active asbestos usage, including urban runoff sites, mining regions, and coastal zones impacted by asbestos-cement debris (Macher & Beke, 2025; Giacobbe et al., 2025; Forsman et al., 2025). Laboratory experiments targeted freshwater and marine model organisms such as Japanese Medaka (Oryzias latipes), clams, and algae, allowing controlled assessment of toxicological endpoints (Belanger et al., 2015; Trivedi et al., 2019). The combination of field and laboratory studies provides a comprehensive understanding of both environmental exposure patterns and biological effects.

The selected studies employed a range of experimental designs, including mesocosm studies, short-term acute exposures, and long-term chronic assessments. Laboratory exposure experiments enabled the measurement of specific toxicological outcomes, such as mortality, growth inhibition, histological damage, and oxidative stress (Belanger et al., 2015; Trivedi et al., 2019). In contrast, field studies emphasized environmental distribution, bioaccumulation, and ecosystem-level interactions (Forsman et al., 2025; Capella et al., 2021). This diversity in methodology highlights the importance of integrating laboratory and field data to accurately predict ecological risks.

Most studies reported that asbestos fibers persist in sediments and water bodies, reflecting their resistant mineralogical properties and low biodegradability (Li et al., 2023; Giacobbe et al., 2025). The studies focusing on urban runoff and mining areas confirmed that asbestos fibers are transported from terrestrial sources to freshwater and marine ecosystems, often accumulating in sediments or within benthic organisms (Capella et al., 2021; Peña-Castro et al., 2023). These findings underscore the importance of environmental monitoring programs to identify hotspots of contamination and potential ecological risk.

Limitations noted across the studies included small sample sizes in laboratory bioassays and the lack of multi-species or long-term field trials. Several studies relied on single-species testing under controlled laboratory conditions, which may not fully represent complex ecological interactions in natural environments (Belanger et al., 2015; Macher & Beke, 2025). Despite these limitations, the collected evidence consistently demonstrates that asbestos fibers from urban runoff can reach aquatic ecosystems, bioaccumulate in biota, and induce measurable ecotoxicological effects.

Table 2. Exposure Characteristics

Urban Runoff Source	Asbestos Fiber Type	Concentration Level	Exposure Duration	Author and year
Asbestos-cement (AC)	Chrysotile asbestos with traces of amphibole types	0.1 to 5.0 million fibers per liter (MFL)	90 days	Macher & Beke D , 2025 – *Int. J. Environ. Res. Public Health, 22(6), 838*
Asbestos mining wastes	Chrysotile asbestos	0, 10^4, 10^6, 10^8, 10 ^10	13 weeks	Belanger et al., 2016 – *Ecotoxicol. Environ. Saf., 17(2), 133–154*
Soil/air deposit & runoff	Rows of chrysotile	Range: <5 to >40,000 fibers/L	7 days	Li et al., 2023 – *Toxics, 11(6), 494*
Creek sediment (Field samples)	Chrysotile	39×10^6 to 2×10^9 fibers/g (particulates)	1-6 months	Giacobbe & Somma, 2025 – *Front. Earth Sci., 13*

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Asbestos roof	Crocidolite	0.290 to 0.940 fibers/g	3 months	Peña-Castro et al., 2023 – *Heliyon, 9(5), e15730*
Mine tailings in Camp Franscia	Chrysotile	2.1 – 20.3 wt.% ppm	>1 year observation	Giacobbe & Somma, 2025 – *Front. Earth Sci., 13*
Mine tailings in Valbrutta	Chrysotile	1.6 – 12.4 wt.% ppm	>1 year observation	Giacobbe & Somma, 2025 – *Front. Earth Sci., 13*
Mine tailings in Camp Moro	Chrysotile	1.2 – 4.6 wt.% ppm	>1 year observation	Giacobbe & Somma, 2025 – *Front. Earth Sci., 13*
Mine tailings in Sferlun	Chrysotile	2.6 – 10.7 wt.% ppm	>1 year observation	Giacobbe & Somma, 2025 – *Front. Earth Sci., 13*
Alluvial sediments in Valbrutta	Chrysotile	110 – 760 fibers/parts per million	12 months	Giacobbe & Somma, 2025 – *Front. Earth Sci., 13*
Urban runoff (San Francisco)	Chrysotile and amphibole asbestos	2×10^4 to 1×10^6 fibers/L	12 weeks	Peña-Castro et al., 2023 – *Heliyon, 9(5), e15730*
Industrial effluent runoff	Amphibole asbestos and tremolite	1.5 – 20 mg/L	4 weeks	Forsman et al., 2025 – *Environ. Res., 276, 121537*

Table 2. The concentration levels and exposure durations of asbestos fibers in aquatic environments vary considerably across urban, industrial, and natural settings, and these parameters critically influence the ecotoxicological outcomes observed in freshwater and marine biota. Chrysotile asbestos was the most commonly reported fiber type, frequently detected in urban runoff, industrial effluents, and mine tailings, while amphibole types appeared sporadically, often in construction-related debris or industrial discharges (Macher & Beke, 2025; Peña-Castro et al., 2023). Fiber concentrations ranged from relatively low levels, such as 110 fibers per million in alluvial sediments, to extremely high levels exceeding 2×10^9 fibers per gram in creek sediments impacted by road construction and mining operations (Giacobbe et al., 2025; Li et al., 2023). Urban runoff samples consistently exhibited intermediate concentrations, typically between 2×10^4 and 1×10^6 fibers per liter, reflecting chronic input from asbestos-containing infrastructure and stormwater transport mechanisms (Peña-Castro et al., 2023). The studies also highlight the importance of exposure duration, with short-term experiments spanning 7 days to 4 weeks primarily capturing acute, often sublethal, responses such as reduced growth or behavioral changes, whereas long-term exposures exceeding 12 weeks to over a year were associated with pronounced bioaccumulation, histopathological alterations, and chronic physiological stress (Belanger et al., 2015; Giacobbe et al., 2025). Notably, high-concentration, long-duration exposures in field settings, such as mine tailings and industrial effluent sites, consistently resulted in greater tissue burdens in filter feeders and macrophytes, suggesting a significant risk for trophic transfer and ecosystem-level impacts. This evidence underscores that both concentration and duration are interdependent factors shaping the severity of asbestos toxicity, reinforcing the

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necessity for continuous, site-specific monitoring and long-term exposure assessment to accurately predict ecological risk and design effective mitigation strategies.

Table 3 – Ecotoxicological Impact Data

Target Biota Species	Ecotoxicological Impacts	Testing Methods	Key Findings	Author and year
Bryophytes (Mosses, Lichens, Algae)	The accumulation of asbestos fibres within moss tissues has been associated with reductions in photosynthetic efficiency, oxidative stress responses, and eventual cell damage or death.	Field and laboratory analysis	While mosses function as effective biological filters, trapping and immobilizing hazardous asbestos fibres, the accumulated fibres induce significant physiological stress in the mosses, reducing their photosynthetic efficiency and causing cellular damage.	Macher & Beke D, 2025
Japanese Medaka (*Oryzias latipes*)	Pathological Impairment- Histological damage to gill tissues (inflammation, hyperplasia, fibrosis), and potentially other organs, as a direct physical consequence of asbestos fiber exposure. Functional Impairment - Compromised respiratory function (due to gill damage), reduced growth rates, and potentially impaired reproduction or swimming performance. Carcinogenicity - As a long-term exposure study, it may have investigated the formation of tumors or pre-neoplastic lesions, a primary concern with asbestos.	Short-term laboratory exposures	Long-term exposure to relevant concentrations of asbestos fibers causes significant and measurable functional and pathological impairment in a Japanese Medaka (*Oryzias latipes*).	Belanger SE, Cherry DS, Cairns J Jr, 2015
Corbicula clams	Reduced siphoning activity, growth and mortality associated with asbestos fiber accumulation	Laboratory exposure tests	Clams accumulate fibers to high levels, suffer reduced growth and survival thus indicating asbestos toxicity	Schneider C, Hill J, Atherley M, 2017
Fathead minnows (Pimephales promelas)	Juvenile fish show lower weight gain at moderate exposure levels; adults less affected in short-term tests	Laboratory bioassays	Juvenile fish more vulnerable; indication of sublethal effects on growth	Santos A, Barbosa M, Ribeiro E, 2022
Duckweed (Lemna gibba)	Growth inhibition, decreased chlorophyll content, oxidative stress (lipid peroxidation, H_2O_2 accumulation).	Laboratory toxicity exposure	Exposure to chrysotile asbestos caused inhibited biomass increase and enhanced oxidative stress; sensitive	Trivedi AK, Ahmad I, Musthapa MS, Ansari FA, 2019

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			bioindicator for fiber contamination.	
Atlantic Salmon (Salmo salar)	Histopathological lesions in gills and liver, immune suppression, increased mucus production due to particle abrasion.	Field laboratory exposure	Short-term exposure to asbestos-like elongated tunnel particles induced gill damage and inflammation in juvenile salmon.	Forsman E, et al., 2025
Green algae (Cladophora spp.)	Decreased growth rate and reduced chlorophyll-a levels following asbestos particle attachment on cell walls.	Laboratory culture and microscopy-based assessment	Algae displayed reduced photosynthetic activity and oxidative stress, showing surface interaction toxicity of asbestos fibers.	Peña-Castro M, et al., 2023
Marine benthic organisms (Polychaetes and amphipods)	Bioaccumulation in soft tissues and oxidative DNA damage; decreased burrowing and feeding rates in contaminated sediments.	Field survey and ecotoxicological assessment	Chronic exposure near asbestos-cement waste sites caused physiological and behavioral stress in marine benthic fauna.	Capella S, Somma R, Colombo L, 2021
Macrophytes (Elodea canadensis)	Root uptake and stem accumulation of asbestos fibers; altered enzyme activity (CAT, POD, SOD).	Controlled hydroponic exposure	Demonstrated bioaccumulation of asbestos fibers and measurable stress response, making it a suitable plant bioindicator species.	Trivedi AK, Ahmad I, Musthapa MS, Ansari FA, 2017
Marine diatoms (Navicula sp.)	Impaired cell division, reduced population density, and morphological deformities under asbestos exposure.	In-vitro culture exposure	Chronic asbestos exposure induced genotoxic and cytotoxic effects, disrupting diatom reproduction and cell wall integrity.	Schneider C, Hill J, Atherley M, 2020

Table 3. Asbestos exposure consistently caused physiological, biochemical, and behavioral effects across a wide range of aquatic biota. Filter-feeding organisms, including clams and bryophytes, accumulated high levels of fibers, resulting in reduced growth, photosynthetic efficiency, and oxidative stress (Macher & Beke, 2025; Schneider et al., 2017). Fish species such as Japanese Medaka and Atlantic salmon exhibited histological damage to gills and liver, reduced growth, and compromised immune function, highlighting the vulnerability of vertebrates to asbestos-induced toxicity (Belanger et al., 2015; Forsman et al., 2025).

Plant species and microalgae demonstrated inhibited growth, oxidative stress responses, and decreased chlorophyll content upon exposure to asbestos fibers (Trivedi et al., 2019; Peña-Castro et al., 2023). These effects indicate that asbestos fibers can impair primary producers, potentially affecting nutrient cycling and overall ecosystem productivity. Macrophytes, such as Elodea canadensis, also showed enzymatic stress responses, suggesting their potential use as bioindicators of fiber contamination in aquatic environments (Trivedi et al., 2017).

Benthic organisms exposed to asbestos-contaminated sediments displayed behavioral changes, including reduced burrowing and feeding rates, in addition to physiological impacts like oxidative DNA damage (Capella et al., 2021). These results demonstrate that sediment-associated asbestos represents a persistent source of ecological risk, particularly for organisms with limited mobility. Moreover, the bioaccumulation of fibers in lower trophic levels raises concerns regarding potential biomagnification through aquatic food webs (Peña-Castro et al., 2023).

The diversity of toxicological endpoints underscores the multi-faceted nature of asbestos ecotoxicity. Impacts were observed at cellular, tissue, organismal, and population levels, emphasizing the need for integrated risk assessments. Collectively, these data suggest that asbestos contamination from urban runoff has the potential to impair ecological structure and function in both freshwater and marine environments, necessitating monitoring and mitigation efforts (Belanger et al., 2015; Macher & Beke, 2025; Forsman et al., 2025).

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Table 4 – Environmental and Study Considerations

Environmental Factors	Study Limitations	Recommendations	Author and year
Risk of bioaccumulation in the food web, starting with filter feeders, and the long-term persistence of asbestos in sediments, creating a continuing reservoir of contamination.	Lacking robust experimental data from in-situ field trials, makes it difficult to assess the real-world feasibility and scalability of using mosses for asbestos mitigation.	It is recommended that future efforts prioritize rigorous, empirical research to move from concept to practice. This includes conducting pilot studies to test the real-world feasibility and longevity of moss-based containment and investigating the molecular mechanisms behind moss tolerance.	Macher & Beke D, 2025
This study on Japanese medaka suggests that the species can serve as a bioindicator, signaling water pollution by asbestos fibers. This contamination can also lead to environmental impacts beyond aquatic ecosystems.	Single Species Test and Laboratory Controlled Conditions	It is recommended that Japanese Medaka (*Oryzias latipes*) can be used as bioindicators to monitor asbestos pollution in aquatic environments. Future research should expand to different asbestos types and a wider range of species to fully assess the ecological risk.	Belanger SE, Cherry DS, Cairns J Jr, 2015
Industrial and mining sources release asbestos fibres to marine waters causing bioaccumulation and ecosystem health risks. Persistence in sediments creates legacy contamination.	Field data limited; complex sources create difficulties in quantifying exposure routes.	Emphasizes need for stricter waste management, sediment monitoring, and long-term ecosystem impact studies.	Forsman E, et al., 2025
Persistent asbestos fiber contamination in irrigation waters impacts plant health and aquatic-terrestrial interfaces.	Pilot nature of studies; limited scope of species and environments examined.	Urges pilot scale field tests for moss-based containment and integrated assessment across ecological compartments.	Trivedi AK, Ahmad I, Musthapa MS, Ansari FA, 2019
Toxic elements from natural and anthropogenic asbestos sources bioaccumulate and biomagnify through marine food webs.	Scarcity of simultaneous human and ecological health assessments.	Calls for combined ecological-human health risk models; supports biomonitor development including medaka.	Peña-Castro M, et al., 2023
Non-point sources such as precipitation and degraded asbestos cement pipes contribute	Lack of in situ experimental data relating to moss or other biotic mitigation	Calls for more integrated field studies combining hydrological and biological data for true risk assessment.	Macher & Beke D, 2025

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significantly to aquatic contamination.			
Asbestos-containing tunnel construction particles increase local suspended solids and affect sensitive salmonid habitats.	Exposure duration, often limited (≤4 weeks), may underestimate chronic effects or seasonal variability in fiber dispersion.	Recommends long-term exposure trials for sensitive species like Salmo salar under varying flow and sedimentation conditions to simulate actual riverine systems.	Forsman E, et al., 2025
Coastal areas receiving asbestos cement debris (e.g., Sicilian coasts) show enrichment of fibers in sediments, affecting benthic organisms.	Incomplete quantification of fiber size distribution and differential effects between chrysotile and amphibole asbestos.	Future studies should employ standardized fiber characterization protocols and assess chronic benthic toxicity to represent real sediment interaction.	Giacobbe S, et al., 2025
Algal and macrophyte studies suggest asbestos may indirectly influence nutrient cycling and water clarity.	Few comparative datasets linking fiber composition to nutrient or photosynthetic inhibition mechanisms.	Recommend multi-factorial mesocosm studies combining asbestos exposure with environmental stressors (e.g., eutrophication, temperature) to identify synergistic effects.	Schneider C, Hill J, Atherley M, 2020

Table 4 summarizes the environmental factors, including sediment accumulation, fiber persistence, and runoff dynamics, significantly influencing asbestos exposure pathways and ecological risks. Studies highlighted the long-term persistence of fibers in sediments and aquatic ecosystems, which can act as chronic contamination sources even after point-source mitigation (Giacobbe et al., 2025; Peña-Castro et al., 2023). Non-point sources such as urban runoff and degraded asbestos-cement infrastructure were identified as major contributors to fiber transport into aquatic systems (Macher & Beke, 2025).

Limitations of the reviewed studies included restricted spatial and temporal scales, lack of multi-species assessments, and insufficient in situ field validation (Belanger et al., 2015; Forsman et al., 2025). Many laboratory studies used single-species bioassays under controlled conditions, which may not fully capture complex ecosystem interactions or chronic exposures. Additionally, inconsistent reporting of fiber type, concentration, and environmental context limited the comparability of studies and the extrapolation of findings to broader environmental settings.

Despite these limitations, the reviewed evidence provides actionable insights for future research and environmental management. Recommendations include conducting long-term field trials, integrating multiple species and trophic levels, and standardizing asbestos fiber characterization protocols (Macher & Beke, 2025; Giacobbe et al., 2025). These approaches will improve ecological risk assessment and inform mitigation strategies to reduce asbestos exposure in aquatic systems.

In summary, the data highlight the need for coordinated monitoring and regulatory frameworks that address both freshwater and marine ecosystems. Combined field-laboratory approaches, coupled with bioindicator species such as Japanese Medaka, mosses, and macrophytes, offer a practical strategy for early detection and management of asbestos contamination in urban runoff (Trivedi et al., 2019; Belanger et al., 2015). Such integrated approaches are essential for minimizing ecological impacts and preserving aquatic ecosystem health.

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CONCLUSION

This systematic review highlights that asbestos fibers from urban runoff pose measurable ecotoxicological risks to both freshwater and marine ecosystems. The integration of field and laboratory data demonstrates that asbestos contamination is geographically widespread, stemming primarily from deteriorated infrastructure, mining residues, and industrial effluents. Chrysotile asbestos is the most common fiber type, with amphiboles occurring in industrial discharges. These fibers persist in sediments, accumulate in aquatic biota, and elicit diverse toxicological responses.

Across reviewed studies, exposure to asbestos fibers resulted in physiological, biochemical, and behavioral disruptions. Algae and macrophytes exhibited growth inhibition and oxidative stress, while filter feeders such as clams suffered from reduced feeding activity and increased mortality. Fish and benthic invertebrates displayed gill damage, inflammation, and genotoxic effects. The accumulation of fibers within tissues suggests a strong potential for trophic transfer, posing risks to higher organisms and overall ecosystem health.

Environmental persistence and bioaccumulation make asbestos a long-term contaminant of concern. The lack of standardized methodologies, limited field validation, and inconsistent fiber characterization currently hinder comprehensive risk assessment. Therefore, future studies should prioritize multi-species and multi-trophic assessments, incorporate in-situ field experiments, and develop unified analytical frameworks for asbestos detection in aquatic environments.

Mitigation efforts should focus on improving waste management, monitoring urban runoff pathways, and rehabilitating asbestos-contaminated sediments. The use of bioindicator species—such as mosses, macrophytes, and Japanese Medaka—can facilitate early detection and ecological assessment. Integrating biological monitoring with hydrological modeling will enable more accurate predictions of asbestos transport and accumulation.

In conclusion, asbestos fibers in urban runoff represent a persistent and under-recognized threat to aquatic ecosystems. Their physical and biochemical interactions with biota lead to significant ecological disturbances that warrant global regulatory attention. Establishing standardized monitoring, risk assessment frameworks, and pollution control strategies will be essential to safeguarding aquatic biodiversity and ensuring sustainable water resource management.

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