
INTEGRATED ENVIRONMENTAL QUALITY IN ASIA: A CRITICAL REVIEW OF WATER, CONTAMINANTS, WASTE, BIODIVERSITY, MONITORING, AND GOVERNANCE

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Abstract

Environmental-quality challenges in Asia increasingly span connected water, chemical, waste, biodiversity, and governance systems. This critical review examines a bounded corpus of 57 Scopus records published during 2020–2026, of which 54 were substantively relevant, using Leung et al. (2020) as a conceptual baseline. The synthesis focuses on aquatic exposure, emerging contaminants and mixtures, waste and plastics, monitoring, biodiversity, remediation, and environmental governance. Across the corpus, evidence indicates methodological advances in analytical detection, effect-based assessment, native-species testing, spatial-temporal monitoring, and risk-based priority setting. However, the strength and geographical coverage of evidence are uneven, and many records provide descriptive or conceptual rather than directly comparable empirical evidence. The review therefore distinguishes corpus-supported findings from interpretive propositions. A six-function source-to-outcome-to-decision framework is presented as a conceptual synthesis of recurring evidence needs: pressure mapping, exposure characterization, biological-effect diagnosis, ecosystem-service and equity assessment, intervention appraisal, and adaptive governance. The framework is not presented as empirically validated; rather, it identifies testable links that require comparative application and field evaluation. The review concludes that stronger integration between monitoring, ecological interpretation, intervention assessment, and accountable decision processes is a priority for future environmental-quality research in Asian settings.

Keywords: environmental quality; water security; emerging contaminants; ecological risk assessment; circular waste management; biodiversity monitoring; science–policy interface

INTRODUCTION

Asia concentrates several of the defining environmental contradictions of the twenty-first century. Rapid urbanization, industrial production, agricultural intensification, infrastructure expansion, and rising consumption have improved welfare for many populations while simultaneously increasing pollutant releases and pressure on water, land, coastal systems, and biodiversity. The foundational review supplied for this study framed these pressures through 23 priority research questions spanning risk assessment, emerging contaminants, advanced technologies, multiple stressors, sustainability, and governance (Leung et al., 2020). Its lasting contribution was not simply the list of questions. It showed that environmental-quality research in Asia must be regionally grounded, transdisciplinary, and explicitly connected to decisions.

The recent literature confirms that this agenda remains urgent, but it also reveals a changing scientific landscape. New studies investigate pharmaceuticals and personal-care products, per- and polyfluoroalkyl substances, microplastics, tire particles, pesticide residues, heavy metals, endocrine-active substances, and complex mixtures. They also expand the methodological repertoire through high-resolution mass spectrometry, probabilistic assessment, adverse-outcome pathways, genome editing, environmental DNA, long-term sample archives, remote sensing, and integrated monitoring. These developments increase the ability to detect and interpret environmental change, yet greater technical capacity does not automatically yield better protection. The critical issue is whether evidence is organized in forms that identify sources, quantify exposure, explain biological consequences, compare interventions, and trigger accountable policy responses.

Water is the connective tissue of this review. Rivers, lakes, aquifers, estuaries, coastal waters, wastewater networks, and aquaculture systems transport contaminants and sustain food, livelihoods, biodiversity, and cultural values. However, a water-only framing is insufficient. Atmospheric deposition, land use, waste leakage, industrial agglomeration, food systems, and consumer behavior shape aquatic exposure. Conversely, contaminated water redistributes hazards through irrigation, fisheries, sediments, and drinking-water systems. An integrated environmental-quality perspective must therefore follow pressures across media and administrative boundaries.

This review asks four questions. First, which elements of the 2020 Asian environmental-quality agenda have advanced most clearly in the supplied recent literature? Second, where do persistent gaps separate analytical detection from ecological interpretation and regulatory action? Third, how can evidence across water, chemicals, waste, biodiversity, and governance be integrated without losing local specificity? Fourth, what research architecture would allow Asian countries and cities to compare interventions and learn adaptively? The objective is not to claim exhaustive coverage of all Asian environmental scholarship. It is to build a transparent critical synthesis from the supplied corpus and convert its heterogeneous findings into a coherent action framework.

METHOD

This review used a bounded evidence base of 57 Scopus records published between 2020 and 2026 together with the horizon-scanning study of Leung et al. (2020) as the conceptual baseline. Records were eligible when their title, abstract, or indexed terms addressed environmental quality, hydrology or aquatic systems, chemical or ecological risk, waste and plastics, remediation, environmental monitoring, sustainability, or governance. Three records were excluded from substantive synthesis because their primary focus was peripheral to these review questions, leaving 54 records. No duplicate records were identified in the working corpus. The original database search string and search date were not retained in the dataset available for this review; consequently, the search cannot be reproduced as a complete systematic-review search strategy and the article should be interpreted as a bounded critical review rather than an exhaustive systematic review.

Screening and synthesis proceeded in two stages. First, metadata, abstracts, keywords, and reported conclusions were mapped to five evidence domains: water systems and aquatic exposure; chemicals, toxicology, and risk; waste, plastics, and circularity; monitoring, methods, and integrated assessment; and governance and sustainability transitions. Second, studies within each domain were compared according to environmental pressure, receptor or system, analytical scale, type of contribution, geographical setting, and relevance to a management decision. Because full-text methodological information was not consistently available, a formal study-level risk-of-bias instrument was not applied. Instead, evidence strength was appraised qualitatively using four criteria visible in the corpus: directness to the review question, methodological specificity reported in the abstract/metadata, convergence with other records, and geographical relevance to Asian environmental settings.

Interpretation was deliberately separated from evidence description. Statements about individual studies were limited to information represented in the corpus, while cross-study conclusions were treated as stronger only where multiple records converged. Conceptual propositions developed in this review—including the six-function source-to-outcome-to-decision framework—are identified as author synthesis rather than validated empirical findings. This approach improves transparency but does not remove the limitations created by heterogeneous study designs, uneven country representation, abstract-level appraisal, and the absence of the original search documentation.

Table 1. Scope and analytical logic of the review

Component	Operational definition	Evidence handled	Analytical purpose	Principal limitation	Ref.
Foundational agenda	Twenty-three priority questions for Asian environmental quality	Horizon-scanning review	Establish baseline priorities	Priority setting, not effect estimation	Leung et al. (2020)
Recent corpus	Scopus records, 2020–2026	Metadata and abstracts	Identify developments and persistent gaps	Search coverage is bounded	Review corpus
Synthesis domains	Five connected evidence domains	54 substantively relevant records	Enable cross-domain comparison	Heterogeneous methods	This review
Integration model	Source-to-outcome-to-decision chain	Convergent findings across domains	Translate evidence into action	Requires field testing	This review

RESULTS AND DISCUSSION

A. Reframing environmental quality as a connected system

The most important conceptual update is a shift from pollutant-by-pollutant description to a connected pressure–pathway–receptor–service–decision model. Environmental hazards arise from economic and social activities, move through air, water, soil, sediment, food, and products, and interact with organisms across life stages. Their consequences are experienced not only as toxicity but also as impaired ecosystem functions, livelihood insecurity, treatment costs, unequal exposure, and loss of public trust. Broad reviews of environmental hazards and remediation reinforce the need to combine control technologies with risk assessment rather than treating cleanup as an isolated technical operation (Gunjyal et al., 2023).

The connected-system view changes the unit of analysis. A river is not merely a sampling location; it is an integrator of upstream land use, sanitation, industrial discharge, solid-waste leakage, rainfall, hydrology, and governance. A landfill is not merely a waste endpoint; it can become a long-term source of leachate and resistant contaminants. A wastewater-treatment plant is both a barrier and a redistribution node, potentially discharging residual contaminants while producing reclaimed water or sludge. Coastal waters register the accumulated consequences of terrestrial management, but they are also affected by marine activities and regional transport.

This view also exposes scale mismatches. Chemical monitoring may resolve nanogram-per-liter concentrations while policy operates through coarse sector categories. Ecotoxicological tests can isolate mechanistic pathways while organisms in the field experience mixtures, fluctuating exposure, disease, temperature stress, and habitat change. Local governments may manage collection and sanitation, yet product design, chemical production, trade, and river-basin processes operate beyond their jurisdiction. Effective research must therefore be multi-scale by design, specifying which causal link is studied and which institution can act on the result.

The supplied studies collectively support six linked functions for an integrated evidence system. Pressure mapping identifies activities and sources. Exposure characterization measures concentrations, transformations, and movement. Biological-effect diagnosis connects exposure to organisms and pathways. Ecosystem-service valuation translates ecological change into consequences for people and nature. Intervention appraisal compares prevention, treatment, recovery, and behavioral alternatives. Adaptive governance establishes thresholds, responsibilities, reporting cycles, and revision mechanisms. The functions are sequential for diagnosis but iterative in practice: policy questions determine monitoring design, and monitoring outcomes revise policy.

B. Water security, aquatic exposure, and the source-to-sea continuum

Recent studies in the corpus demonstrate why water quality must be interpreted dynamically. Analyses of rivers during COVID-19 restrictions illustrate how abrupt changes in mobility and activity can alter selected water-quality indicators, offering quasi-experimental insight into anthropogenic pressure (Hasibuan et al., 2022; Hewakoon et al., 2024). Seasonal assessment in Doreri Gulf similarly shows that observations made in one period cannot represent a system subject to rainfall, circulation, and changing inputs (Sembel et al., 2021). The methodological implication is straightforward: monitoring designs require temporal resolution matched to the processes being inferred.

Spatial context is equally important. Microplastic work in the Brantas River connects contaminant distribution to water-quality conditions and documents uptake in fish tissues, bridging environmental occurrence and biological exposure (Buwono et al., 2021a, 2021b). Heavy-metal studies in Indonesian coastal and aquaculture settings show the value of analyzing water, sediments, and organisms together, because total concentrations in one compartment provide an incomplete account of bioavailability and risk (Nillos et al., 2020; Sembel et al., 2022). Such studies support nested designs that combine catchment pressures, longitudinal river stations, depositional zones, biota, and seasonal sampling.

Wastewater remains a pivotal intervention point. Evidence on retinoic acids shows that removal varies across treatment configurations, while research on pharmaceutical removal in pond systems demonstrates that reuse schemes must be assessed for both treatment performance and residual aquatic hazard (Fedorova et al., 2022; Yeung et al., 2021). Work on reclaimed wastewater and PFAS further warns that effluent-dominated systems may experience temporally structured exposures that average concentrations conceal (Stroski et al., 2025). Treatment evaluation should therefore move beyond percent removal to include influent variability, transformation products, receiving-water dilution, chronic exposure, and downstream uses.

Water reuse and resource integration can generate benefits when designed around system boundaries. Aquaponic approaches may reduce freshwater demand by linking horticulture and aquaculture, but their sustainability depends on water quality, nutrient balance, disease control, energy use, and operational capacity (Schoor et al., 2024). The general lesson is that circularity is not synonymous with safety. Reuse transfers materials into new pathways, and those pathways require fit-for-purpose standards and surveillance.

Indonesia-specific synthesis underscores the institutional dimension. Water-management challenges include uneven infrastructure, overlapping authority, data gaps, and the difficulty of matching national ambitions to local capacity (Umami et al., 2022). A source-to-sea strategy should connect watershed planning, urban sanitation, industrial permitting, waste management, coastal protection, and community monitoring. Without such coordination, downstream measurement can document deterioration but cannot allocate responsibility or identify the most efficient control point.

C. Emerging contaminants, mixtures, and ecological realism

The contaminant agenda has broadened substantially since conventional water-quality programs were designed. Pharmaceuticals, personal-care products, PFAS, microplastics, tire-derived particles, pesticides, fragrance ingredients, and endocrine-active compounds differ in persistence, mobility, transformation, and biological mode of action. Reviews of pharmaceuticals show progress in occurrence data and treatment research while emphasizing continuing gaps in effects, mixtures, and management translation (Boxall & Brooks, 2024). Global assessment of PFAS in surface water and groundwater similarly illustrates the need to connect widespread occurrence with probabilistic hazard interpretation (Sims et al., 2022).

Mixtures are a central challenge because environmental exposure rarely involves one chemical at a time. Innovative sampling designs can improve sensitivity analysis and identify influential components, but statistical efficiency must be paired with mechanistic plausibility and realistic concentration ranges (Ding et al., 2024). The adverse-outcome-pathway framework offers a way to organize knowledge from molecular initiating events to organism and population outcomes, especially when disciplines share common definitions and evidence standards (Chauhan et al., 2021). More recent work on the chemical defense extends attention to biological defense mechanisms and their limits under combined stress (Franco et al., 2025).

Species selection determines what toxicity evidence can legitimately protect. Research comparing Chinese rare minnow, zebrafish, and other fish demonstrates that sensitivity differs by species, chemical group, and life stage (Bai et al., 2021; Su et al., 2021; Zhou et al., 2022). This matters for Asian standards that have historically relied on test species and datasets developed elsewhere. Locally relevant species can improve ecological representativeness, but localization should not reduce comparability or animal-welfare safeguards. A tiered strategy can use standardized screening species, native-species validation, embryo alternatives where scientifically justified, and field confirmation.

Mechanistic innovation can strengthen causal inference. Genome editing can test the functions of genes implicated in toxic responses, potentially linking molecular observations to adverse outcomes (Zhao et al., 2023). Biomarkers can provide early warning for heavy-metal exposure before community-level damage is readily visible (Kadim & Risjani, 2022). Histopathological and hormonal evidence in green mussels shows how sentinel organisms may reveal biologically meaningful exposure in coastal production systems (Risjani et al., 2023). These methods are most valuable when embedded in exposure gradients and management questions, not used as disconnected demonstrations of technical capability.

Risk assessment must also address uncertainty transparently. Tools that integrate exposure and toxicity data can support screening and management, but outputs depend on data quality, species coverage, and scenario assumptions (Lin et al., 2021). Uncertainty is not a reason to postpone action indefinitely. It should be decomposed into measurement uncertainty, model uncertainty, natural variability, and value judgments about acceptable harm. Management can then combine precautionary controls for persistent or irreversible hazards with targeted research designed to reduce decision-critical uncertainty.

D. Waste, plastics, and circularity beyond collection

Solid waste is a cross-media environmental-quality problem. Weak collection allows plastics and hazardous materials to enter drains and rivers; open burning transfers pollutants to air and soil; uncontrolled disposal creates leachate; and poorly governed recovery exposes workers and communities. Municipal composition studies remain essential because intervention design depends on the quantity and character of local waste (Awasthi et al., 2023). Yet characterization alone does not establish which combination of prevention, segregation, collection, recovery, treatment, and disposal will minimize harm.

Microplastic evidence from the Brantas River demonstrates the continuity between municipal material use, waste leakage, aquatic transport, and biological uptake (Buwono et al., 2021a, 2021b). Tire particles add a less visible source associated with mobility systems, road runoff, particle aging, and chemical leachates; the research priorities identified by Obanya et al. (2024) show that particle counts alone cannot capture risk. Effective monitoring must include source fingerprints, size distributions, associated chemicals, transport during rainfall, and effects on relevant organisms.

Technological removal can contribute but should not displace prevention. Emerging adsorption and nanotechnology approaches may improve microplastic capture, though performance under complex water conditions, regeneration, energy demand, secondary waste, and scale-up require careful evaluation (Sayadi et al., 2026). Similar

cautions apply to green synthesis of nanomaterials: an environmentally framed production route still requires clarity about mechanisms, reproducibility, morphology, life-cycle impacts, and end-of-life behavior (Strieder et al., 2024). Technology should be judged across the full system rather than at the point of laboratory removal efficiency.

Circularity must therefore be risk informed. Recovery and reuse are environmentally beneficial when they reduce virgin-resource demand and prevent leakage without recirculating hazardous substances. This requires upstream chemical information, product standards, safe sorting, traceable material flows, occupational protection, and markets for recovered materials. It also requires distributive analysis because informal workers often provide substantial recovery services while bearing disproportionate exposure and income insecurity.

A practical hierarchy for Asian cities begins with prevention and safer design, followed by source segregation, reliable collection, high-quality recovery, treatment of residuals, and controlled final disposal. Data should track mass flows and environmental outcomes together. Tonnes collected or recycled are insufficient if leakage, contaminated recyclate, greenhouse-gas emissions, or toxic exposure increase elsewhere. The updated research agenda should compare interventions using common indicators that include diversion, contaminant release, health and ecological risk, cost, labor conditions, and institutional feasibility.

Table 2. Waste and circularity evidence translated into management questions

Pressure	Pathway	Evidence endpoint	Preferred intervention level	Critical appraisal question	Ref.
Mismanaged municipal waste	Drainage, runoff, open dumping	Composition and leakage	Prevention, segregation, collection	Does the system reduce total leakage and unequal exposure?	Awasthi et al. (2023)
Microplastics	River transport and food-web uptake	Water, fish gills and digestive tract	Source control plus capture	Are particle size, polymer, additives, and biota measured together?	Buwono et al. (2021a, 2021b)
Tire particles	Road runoff and chemical leaching	Particles and leachate toxicity	Mobility and stormwater controls	Can sources and toxic components be prioritized?	Obanya et al. (2024)
Treatment technologies	Capture and residual generation	Removal efficiency and secondary waste	Fit-for-purpose treatment	Is performance robust, scalable, and life-cycle beneficial?	Sayadi et al. (2026)

E. Monitoring architecture and analytical innovation

The supplied corpus contains strong evidence of increasing analytical capability. High-resolution mass spectrometry and isotope-dilution strategies can improve accuracy in complex aquatic matrices, addressing matrix effects and analyte loss (Aydın et al., 2026). Such advances are valuable for reference measurements and method validation, but routine programs also require affordable, robust, and transferable protocols. A two-tier system is therefore preferable: high-capability laboratories establish reference values and investigate unknowns, while distributed laboratories and field networks provide sustained coverage using validated methods.

Integrated observing systems offer a second direction. Ocean and coastal monitoring increasingly combines physical conditions, biodiversity, fisheries, harmful algal blooms, pathogens, plastics, marine mammals, and human-health indicators (Porter et al., 2023). This breadth should not become an unprioritized data warehouse. Observations need a conceptual model linking indicators to pressures, thresholds, and response options. Otherwise, data volume grows while decision latency remains unchanged.

Long-term environmental specimen archives provide an underused form of infrastructure. Archived samples allow retrospective analysis when new contaminants or methods emerge and can reveal baselines that were not recognized at the time of collection (Zizka et al., 2022). Their value depends on documented provenance, preservation quality, interoperable metadata, legal clarity, and equitable access. In regions where monitoring programs are disrupted by funding cycles, archives can preserve continuity that databases alone cannot provide.

Spatial-temporal analysis strengthens inference when monitoring sites represent source gradients and hydrological processes. Air-pollution studies in rapidly growing Asian cities illustrate the importance of meteorology and time-varying activity in interpreting concentrations (Bose & Roy Chowdhury, 2023; Gogeri et al., 2024). The same principle applies to water: rainfall, flow, temperature, salinity, residence time, and sediment disturbance can

alter exposure. Environmental dashboards should therefore present contextual variables and uncertainty rather than isolated compliance values.

The minimum integrated monitoring package proposed here includes: source and activity inventories; hydrological and meteorological context; targeted priority chemicals; non-target screening at sentinel locations; effect-based assays; native or sentinel biota; biodiversity indicators including environmental DNA where validated; waste and material-flow measures; treatment-performance data; and socioeconomic indicators of exposure and service access. Sampling frequency and analytical depth can vary by tier, but metadata and quality assurance must be harmonized so that local evidence can contribute to regional learning.

Table 3. Proposed tiered environmental monitoring architecture

Tier	Spatial role	Core measurements	Biological component	Decision output	Ref.
Reference laboratories	Regional or national	High-resolution targeted and non-target chemistry	Mechanistic assays and method validation	Reference values and emerging-hazard identification	Aydin et al. (2026)
Sentinel observatories	Representative catchments and coasts	Repeated multi-media measurement	Sentinel species, eDNA, community surveys	Trends, pathways, and intervention evaluation	Porter et al. (2023)
Distributed networks	Local routine coverage	Validated core parameters and priority analytes	Rapid effect-based or biomarker tools	Compliance and early warning	Kadim & Risjani (2022)
Specimen archives	Long-term temporal coverage	Preserved samples and metadata	Retrospective biodiversity and contaminant analysis	Baseline reconstruction and new-question testing	Zizka et al. (2022)

F. Biodiversity, ecosystem services, and environmental health

Environmental-quality protection ultimately concerns living systems, not concentrations alone. Biodiversity influences food-web structure, productivity, resilience, disease regulation, and the provision of food and clean water. Chemical and physical pressures can affect organisms differently across species and life stages, meaning that a standard based on a narrow test set may overlook sensitive native taxa. China's effort to strengthen aquatic-life criteria illustrates the importance of scientifically robust, legally meaningful standards adapted to regional ecological characteristics (Sun et al., 2021).

Biological monitoring should combine levels of organization. Molecular and biochemical markers provide sensitivity; histopathology and organism performance add biological relevance; population and community measures reveal ecological consequences; and ecosystem-service indicators translate those consequences into societal terms. No level is sufficient by itself. Early-warning biomarkers can generate false urgency if natural variability is poorly understood, while community change may be detected only after damage has become difficult to reverse.

Environmental health also requires attention to food systems and human exposure. Pesticide research shows that production benefits coexist with risks to terrestrial and aquatic organisms, reinforcing the need for better detection, field management, biomonitoring, and remediation (Verdadero et al., 2025). Residue detection in cultured fish connects agricultural and aquatic management to food safety (Barbosa et al., 2023). These links argue for One Health-oriented surveillance that coordinates environmental, veterinary, food, and public-health institutions while preserving clarity about causal evidence.

Ecosystem-service framing can improve policy relevance but must not reduce biodiversity to monetary value. It can identify who benefits from clean water, fisheries, flood regulation, recreation, or culturally significant species and who bears losses when systems degrade. Distribution matters: aggregate economic gains can coexist with severe harm to downstream, coastal, Indigenous, or low-income communities. Ethical appraisal should therefore accompany technical risk assessment, making assumptions about acceptable harm and benefit allocation explicit.

G. Governance and the science-policy interface

The persistent gap is not simply a shortage of data. It is a shortage of institutional arrangements that convert evidence into timely, proportionate, and reviewable decisions. Risk-based priority setting can focus limited resources on chemicals, waste streams, places, and populations with the greatest potential harm (Bloor et al., 2025). Horizon

scanning can anticipate emerging issues, but its design must reflect the needs of different policy communities and connect foresight to mandates, budgets, and monitoring (Sigmund et al., 2026).

Standards are one bridge between science and action. Effective standards specify protection goals, data requirements, acceptable risk, compliance methods, and revision cycles. They should recognize mixtures, local species, background conditions, and climate-sensitive exposure. However, standards without monitoring capacity or enforcement can create only formal compliance. Conversely, monitoring without enforceable thresholds leaves agencies unable to respond consistently. Capacity development must therefore combine laboratories, information systems, trained staff, legal authority, financing, and public accountability.

Regional cooperation is essential for transboundary seas, rivers, air masses, trade, and chemical production chains. Analysis of Northeast Asian marine cooperation after Fukushima highlights both the opportunity and difficulty of building credible, binding arrangements across states (An et al., 2025). Cooperation works best when it includes shared protocols, transparent reporting, independent scientific review, mechanisms for dispute resolution, and obligations triggered by agreed evidence.

Economic policy also shapes environmental outcomes. Studies connecting growth, industrial structure, institutional quality, eco-innovation, and green economic performance suggest that environmental improvement cannot be delegated solely to environmental agencies (Liu et al., 2021; Lacheheb & Abdulkadir, 2025; Zhang et al., 2021). Fiscal policy, industrial licensing, urban investment, trade, education, and procurement influence both pressures and solutions. Integrated governance should assign responsibilities across these portfolios and require environmental objectives to be evaluated in major development decisions.

Participation is not merely a communication exercise. Communities can identify unrecorded pollution events, unequal service access, culturally important receptors, and practical barriers to behavior change. At the same time, citizen-generated data require transparent validation and feedback. Participants should know how observations will be used and what response is possible. Trust is built when institutions publish results, explain uncertainty, document decisions, and report whether promised interventions changed environmental outcomes.

Critical appraisal of the evidence base

The screened corpus is heterogeneous in design, scale, environmental medium, and decision relevance. The strongest convergence occurs in aquatic monitoring and contaminant research, where multiple studies independently show that temporal variability, spatial context, multiple environmental compartments, and biological receptors materially affect interpretation. Evidence from river, coastal, wastewater, and aquaculture settings therefore supports the general conclusion that single-time or single-medium measurements are insufficient for many environmental-quality decisions. This conclusion is supported by several empirical records, although effect sizes are not directly comparable across studies.

Evidence for emerging contaminants and toxicological mechanisms is scientifically informative but less directly transferable to regulation. Studies on PFAS, pharmaceuticals, mixture toxicity, biomarkers, native fish species, and mechanistic tools differ substantially in exposure conditions and endpoints. Their collective value lies in identifying recurring limitations of conventional single-chemical assessment rather than establishing a uniform regional threshold. Accordingly, recommendations concerning mixtures, native-species validation, and effect-based tools should be treated as evidence-informed priorities rather than demonstrated region-wide solutions.

The waste and circularity evidence is narrower and more uneven. Empirical studies on municipal waste composition, microplastic distribution, and biological uptake establish plausible links between material leakage and aquatic exposure, while work on tire particles and treatment technologies mainly identifies research or technology priorities. The corpus therefore supports source control and risk-informed circularity as a coherent management direction, but it does not provide comparative life-cycle evidence sufficient to rank circular-economy interventions across Asian cities.

Geographical representativeness is also limited. Indonesia and selected East, South, and Southeast Asian settings are visible in the corpus, but coverage is not balanced across Asia. Governance and macro-level sustainability studies use different units of analysis from toxicological and monitoring studies, which restricts causal integration. Cross-domain connections in this review should therefore be read as conceptual linkages between evidence needs, not as proof that one study domain validates another.

Overall, confidence is highest for conclusions that recur across multiple empirical studies and concern monitoring design, exposure variability, and the need to connect environmental compartments. Confidence is moderate for broader propositions on risk-based prioritization and integrated governance because they are supported by a mixture of empirical and conceptual studies. Confidence is lowest where the review advances a new integrative architecture or long-term agenda; these are interpretive outputs that require prospective testing.

H. Integrated source-to-outcome-to-decision framework

The six-function framework is an interpretive synthesis derived from recurring gaps identified across the five evidence domains, not a validated model. Its derivation followed the logic repeatedly visible in the corpus:

environmental pressures must first be located; exposure must then be characterized across relevant media and time scales; biological significance must be assessed; consequences for ecosystem services and affected groups must be interpreted; interventions must be compared; and governance must specify when evidence triggers action. These functions were retained because each addresses a distinct break in the pathway from environmental measurement to decision making. The framework therefore organizes the reviewed evidence into testable decision links rather than claiming that the literature has already validated the complete sequence.

Exposure characterization tests those hypotheses. Monitoring should cover relevant compartments and time scales, including water, sediment, biota, and products where appropriate. Targeted chemistry quantifies known priorities; non-target analysis detects unexpected signals; and hydrological data explain transport and dilution. Results should be expressed as distributions and scenarios rather than only annual averages, because episodic peaks and low-flow conditions may determine risk.

Biological-effect diagnosis then examines whether exposure produces changes that matter. Effect-based assays, biomarkers, adverse-outcome pathways, native-species tests, mesocosms, field surveys, and epidemiological or food-chain evidence can be combined in tiers. Concordance across independent lines of evidence increases confidence. Discordant results are informative: chemical presence without observed effects may indicate low bioavailability or insensitive endpoints, whereas effects without identified chemicals may signal unknown contaminants or nonchemical stressors.

Ecosystem-service and distributional assessment translates ecological evidence into consequences for livelihoods, health, culture, and future options. This step identifies affected groups and distinguishes reversible inconvenience from persistent or irreversible loss. It also prevents narrow cost-benefit analysis from hiding unequal burdens. Valuation may be monetary, biophysical, deliberative, or multi-criteria, depending on the decision.

Intervention appraisal compares options at source, pathway, and receptor. Prevention and safer substitution are preferred when feasible; infrastructure, treatment, restoration, and exposure reduction remain necessary for legacy and unavoidable pressures. Options should be assessed for effectiveness, cost, energy and carbon implications, secondary waste, equity, institutional requirements, and rebound effects. Pilot studies should include explicit counterfactuals and post-implementation monitoring.

Adaptive governance closes the loop. Authorities establish triggers, responsible actors, timelines, public reporting, and conditions for revising standards or interventions. Data systems retain provenance and uncertainty. Independent review and community participation reduce the risk that monitoring becomes symbolic. The framework is adaptive because new evidence can change priorities, but it is not passive: precautionary measures can proceed when potential damage is serious and uncertainty is itself documented.

Table 4. Integrated framework for environmental-quality decisions

Function	Key question	Minimum evidence	Typical methods	Governance product	Ref.
Pressure mapping	Where and why is the hazard generated?	Activities, sources, permits, material flows	GIS, inventories, community mapping	Priority-source register	Leung et al. (2020)
Exposure characterization	Who or what is exposed, where, and when?	Multi-media concentrations and context	Target/non-target chemistry, hydrology	Exposure scenarios	Sims et al. (2022)
Effect diagnosis	Does exposure cause biologically relevant change?	Mechanistic and field concordance	AOPs, biomarkers, native species	Weight-of-evidence conclusion	Chauhan et al. (2021)
Service and equity assessment	What is lost and who bears the burden?	Ecological function and distribution	Multi-criteria and participatory appraisal	Protection goals	Chen et al. (2023)
Intervention appraisal	Which option reduces total harm?	Effectiveness, cost, secondary impacts	Trials, life-cycle and risk assessment	Funded intervention plan	Gunjyal et al. (2023)
Adaptive governance	How will action be triggered and revised?	Thresholds, roles, audit trail	Standards, dashboards, independent review	Accountable decision cycle	Bloor et al. (2025)

I. Proposed research agenda for 2026–2035

The following agenda is an author-derived set of priorities based on the gaps and uneven evidence identified in the bounded corpus. It is intended for testing and refinement rather than as a consensus regional roadmap. The first priority is to establish comparable regional baselines without imposing a single ecological model on diverse settings. Countries should agree on core metadata, quality assurance, reference materials, and indicator definitions while allowing locally relevant species, exposure pathways, and protection goals. Sentinel catchments and coastal observatories could combine intensive measurement with wider, lower-cost networks.

Second, research should quantify mixtures under realistic conditions. This requires concentration distributions, transformation products, repeated exposure, climate-sensitive toxicity, and interactions with habitat degradation. Experimental designs should connect mechanistic assays to population-relevant endpoints and field observations. The aim is not to test every possible combination but to identify mixture drivers and defensible grouping approaches.

Third, intervention research must become comparative and outcome based. Studies should compare source reduction, treatment upgrades, nature-based solutions, recovery systems, and behavioral or regulatory measures using common endpoints. Designs need pre-intervention baselines, controls where feasible, implementation-fidelity measures, and sufficient follow-up. Negative and null results should be published because they prevent repeated investment in ineffective solutions.

Fourth, the region needs a deliberate strategy for contaminants of emerging concern. Horizon scanning should integrate production trends, patent and market information, monitoring anomalies, toxicological signals, and community observations. Prioritization should consider persistence, mobility, bioaccumulation, toxicity, production volume, essential use, exposure inequality, and reversibility. Screening decisions must be connected to data-generation plans and provisional management options.

Fifth, biodiversity monitoring should be designed for regulatory use. Environmental DNA, specimen banking, remote sensing, and automated sensors offer powerful coverage, but validation must specify detection limits, taxonomic resolution, reference databases, and ecological meaning. Traditional field ecology remains necessary for abundance, condition, habitat, and functional interpretation. Combining new and established methods will be more credible than presenting innovation as replacement.

Sixth, water and waste planning should be coupled. Cities and river basins need material-flow accounts that quantify how uncollected waste, stormwater, sanitation, industrial discharge, and treatment residuals enter aquatic systems. Models should identify leverage points and compare the environmental return of investments. This is especially important where budgets are limited and informal recovery is substantial.

Seventh, climate change must be treated as a risk multiplier. Altered rainfall, drought, heat, wildfire, sea-level rise, and extreme events change contaminant transport, treatment performance, organism sensitivity, and infrastructure reliability. Monitoring networks and standards should be stress tested against plausible climate conditions. Adaptation plans should avoid solutions that lower one risk while increasing chemical, energy, or equity burdens elsewhere.

Eighth, environmental data should be FAIR in practice—findable, accessible under appropriate safeguards, interoperable, and reusable. Achieving this requires sustained curation, identifiers, vocabularies, calibration records, and governance for sensitive information. Regional platforms should return value to contributing agencies and communities rather than extracting data into inaccessible repositories.

Ninth, implementation science should be incorporated into environmental research. Studies should examine why technically effective interventions are adopted, maintained, modified, or abandoned. Relevant variables include mandates, budgets, staffing, procurement, enforcement incentives, political cycles, community acceptance, and coordination costs. This evidence is necessary to move from demonstration projects to durable systems.

Tenth, ethical and distributional questions should be explicit. Research protocols and policy appraisals should identify who is exposed, who benefits from economic activity, who pays for control, and whose knowledge is recognized. Just transition principles are relevant not only to energy but also to waste workers, fishing communities, farmers, and neighborhoods located near industrial and disposal facilities.

Finally, capacity should be built through long-term partnerships rather than isolated training. Regional reference laboratories, shared proficiency testing, open methods, exchange programs, and jointly governed observatories can distribute capability. Funding mechanisms should reward maintenance, replication, synthesis, and policy evaluation alongside novelty. The measure of success is not the number of datasets produced but the degree to which environmental harm is anticipated, prevented, reduced, and equitably managed.

J. Limitations

This review is intentionally bounded and is not a complete systematic map of Asian environmental-quality research. The 57-record corpus is heterogeneous, three peripheral records were excluded from substantive synthesis,

and relevant fields may be absent because the original search string and database search date were not retained. This prevents full search reproducibility. The synthesis relies substantially on metadata, abstracts, and reported conclusions; consequently, detailed appraisal of sampling design, confounding, effect size, and study-level risk of bias was not possible. The qualitative evidence-strength appraisal used here improves transparency but is not a substitute for full-text systematic quality assessment.

Geographical representation is uneven, and methodological heterogeneity prevents direct comparison of many reported effects. Very recent 2026 records also have limited opportunity for replication or citation-based evaluation. Finally, the source-to-outcome-to-decision framework and the 2026–2035 agenda are conceptual syntheses derived from recurring gaps in the corpus. They have not been empirically validated, and their value must be tested through comparative application in real monitoring and governance settings.

CONCLUSION

Within this bounded corpus, recent literature shows advances in analytical detection, biological-effect assessment, contaminant characterization, spatial-temporal monitoring, and risk-based priority setting. The evidence is nevertheless uneven in design and geography, and it does not support uniform conclusions across Asia. The most consistent cross-study finding is a persistent disconnect between environmental measurement, ecological interpretation, intervention assessment, and governance response. The six-function source-to-outcome-to-decision framework proposed here organizes these recurring gaps into a sequence of pressure mapping, exposure characterization, effect diagnosis, ecosystem-service and equity assessment, intervention appraisal, and adaptive governance. It should be regarded as a testable conceptual synthesis rather than a validated regional model. Future work should evaluate whether this architecture improves monitoring efficiency, intervention comparison, and accountable decision making across diverse Asian environmental settings.

An effective Asian environmental-quality agenda should organize evidence from sources to exposures, biological effects, ecosystem services, interventions, and accountable decisions. Water provides a practical organizing axis because it connects landscapes, cities, waste systems, food production, biodiversity, and coastal environments, but it must be embedded in a cross-media and socially explicit framework. The proposed six-function model offers such an architecture. Its implementation requires locally calibrated thresholds, harmonized metadata, realistic mixture assessment, comparative intervention studies, long-term archives, open learning networks, and clear institutional triggers. The central test for the next decade is not whether science can detect more contaminants. It is whether societies can use evidence earlier, more coherently, and more fairly to prevent harm.

REFERENCES

- Abidin, G., Leksono, A.S., Risjani, Y., Kingtong, S. (2021). Effect of WAF crude oil exposure to larvae development of the black-scar oyster *Crasostrea iredalei*. <https://doi.org/10.1088/1755-1315/890/1/012037>
- Amghani, M.S., Savari, M., Eslamian, S. (2026). Strategic Pathways to a Green Economy: Tackling Carbon Emissions. <https://doi.org/10.1002/9781394248087.ch24>
- An, R., Li, X., Xie, Y. (2025). Post-Fukushima innovation: establishing a regional marine environmental cooperation mechanism in Northeast Asia with global implications. <https://doi.org/10.3389/fmars.2025.1526483>
- Awasthi, P., Chataut, G., Khatri, R. (2023). Solid waste composition and its management: A case study of Kirtipur Municipality-10. <https://doi.org/10.1016/j.heliyon.2023.e21360>
- Aydın, E.S., Bodur, S., Godin, S., Bakırdere, S., Szpunar, J. (2026). Matrix-independent quantification of paracetamol in complex aquatic matrices using quadruple isotope dilution Orbitrap mass spectrometry. <https://doi.org/10.1016/j.talanta.2026.129842>
- Bai, Y., Lian, D., Su, T., Wang, Y.Y.L., Zhang, D., Wang, Z., Gimeno, S., You, J. (2021). Species and Life-Stage Sensitivity of Chinese Rare Minnow (*Gobiocypris rarus*) to Chemical Exposure: A Critical Review. <https://doi.org/10.1002/etc.5165>
- Barbosa, E.F., Pereira, P.C.A., da Silva, F.C., de Mira, Á.B., Dantas Filho, J.V., Schons, S.V. (2023). Pesticide residues detected in *Colossoma macropomum* by the modified QuEChERS and GC-MS/MS methods. <https://doi.org/10.4025/actascitechnol.v45i1.63831>
- Bloor, M.C., Baken, S., Bejarano, A.C., Botha, T.L., Embry, M., Gouin, T., Koppel, D., Maltby, L., Reichelt-Brushett, A., Silva de Assis, H. (2025). Priority setting for chemicals, waste, and pollution prevention: a risk-based strategy for environmental and human health protection. <https://doi.org/10.1093/etojnl/vgaf215>
- Bose, A., Roy Chowdhury, I. (2023). Investigating the association between air pollutants' concentration and meteorological parameters in a rapidly growing urban center of West Bengal, India: a statistical modeling-based approach. <https://doi.org/10.1007/s40808-022-01670-6>
- Boxall, A.B.A., Brooks, B.W. (2024). Pharmaceuticals and Personal Care Products in the Environment: What Progress Has Been Made in Addressing the Big Research Questions?. <https://doi.org/10.1002/etc.5827>

- Buwono, N.R., Risjani, Y., Soegianto, A. (2021a). Contamination of microplastics in Brantas River, East Java, Indonesia and its distribution in gills and digestive tracts of fish *Gambusia affinis*. <https://doi.org/10.1016/j.emcon.2021.08.002>
- Buwono, N.R., Risjani, Y., Soegianto, A. (2021b). Distribution of microplastic in relation to water quality parameters in the Brantas River, East Java, Indonesia. <https://doi.org/10.1016/j.eti.2021.101915>
- Chauhan, V., Wilkins, R.C., Beaton, D., Sachana, M., Delrue, N., Yauk, C., O'Brien, J., Marchetti, F., Halappanavar, S., Boyd, M., Villeneuve, D., Barton-Maclaren, T.S., Meek, B., Anghel, C., Heghes, C., Barber, C., Perkins, E., Leblanc, J., Burt, J., ... Cool, D. (2021). Bringing together scientific disciplines for collaborative undertakings: a vision for advancing the adverse outcome pathway framework. <https://doi.org/10.1080/09553002.2021.1884314>
- Chen, F., Jiang, Y., Liu, Z., Lin, R., Yang, W. (2023). Framework system of marine sustainable development assessment based on systematic review. <https://doi.org/10.1016/j.marpol.2023.105689>
- Ding, T.-T., Wang, Z.-J., Tao, M.-T., Gu, Z.-W., Chen, R.-J., Xu, Y.-Q., Liu, S.-S. (2024). An innovative mixture sampling strategy with uniform design: Application to global sensitivity analysis of mixture toxicity. <https://doi.org/10.1016/j.envint.2024.108968>
- Fedorova, G., Grabic, R., Grabicová, K., Turek, J., Van Nguyen, T., Randak, T., Brooks, B.W., Zlabek, V. (2022). Water reuse for aquaculture: Comparative removal efficacy and aquatic hazard reduction of pharmaceuticals by a pond treatment system during a one year study. <https://doi.org/10.1016/j.jhazmat.2021.126712>
- Franco, M.E., Araújo, C.V.M., Cervený, D., Koubová, A., Danneels, B., Goksøyr, A., Bertram, M.G. (2025). The extended chemical defenseome: emphasizing mechanisms of defense as key research avenues to tackle priority questions in environmental toxicology. <https://doi.org/10.1093/etojnl/vgaf190>
- Gogeri, I., Gouda, K.C., Aruna, S.T. (2024). Spatio-temporal analysis of air pollution dynamics over Bangalore city during second wave of COVID-19. <https://doi.org/10.1016/j.nhres.2023.10.002>
- Gunjyal, N., Rani, S., Asgari Lajayer, B., Senapathi, V., Astatkie, T. (2023). A review of the effects of environmental hazards on humans, their remediation for sustainable development, and risk assessment. <https://doi.org/10.1007/s10661-023-11353-z>
- Hasibuan, S., Hasibuan, M., Jakob, A. (2022). The Impact of COVID-19 Lockdown on People's Mobility and Water Quality of Siak River, Indonesia. <https://doi.org/10.2965/jwet.21-178>
- Hewakoon, H.P., Miguntanna, N., Siriwardhana, K.D., Rathnayake, U. (2024). Impact of COVID-19 lockdown on water quality of major rivers in Sri Lanka. <https://doi.org/10.2166/wpt.2024.256>
- Kadim, M.K., Risjani, Y. (2022). Biomarker for monitoring heavy metal pollution in aquatic environment: An overview toward molecular perspectives. <https://doi.org/10.1016/j.emcon.2022.02.003>
- Lacheheb, Z., Abdulkadir, S.F. (2025). The impact of Aid for Trade and institutional quality on green GDP in OIC countries. <https://doi.org/10.4337/9781035349685.00017>
- Leung, K.M.Y., Yeung, K.W.Y., You, J., Choi, K., Zhang, X., Smith, R., Zhou, G.-J., Yung, M.M.N., Arias-Barreiro, C., An, Y.-J., Burket, S.R., Dwyer, R., Goodkin, N., Hii, Y.S., Hoang, T., Humphrey, C., Iwai, C.B., Jeong, S.-W., Juhel, G., ... Brooks, B.W. (2020). Toward sustainable environmental quality: Priority research questions for Asia. *Environmental Toxicology and Chemistry*, 39(8), 1485–1505. <https://doi.org/10.1002/etc.4788>
- Lin, B.-L., Meng, Y., Kamo, M., Naito, W. (2021). An all-in-one tool for multipurpose ecological risk assessment and management (MeRAM) of chemical substances in aquatic environment. <https://doi.org/10.1016/j.chemosphere.2020.128826>
- Liu, X., Li, X., Shi, H., Yan, Y., Wen, X. (2021). Effect of economic growth on environmental quality: Evidence from tropical countries with different income levels. <https://doi.org/10.1016/j.scitotenv.2021.145180>
- Londoño-Pineda, A.A., Cano, J.A. (2022). Assessments under the United Nations Sustainable Development Goals: A Bibliometric Analysis. <https://doi.org/10.2478/rtuct-2022-0014>
- Nguyen, H.-A.T., Osman, Z., Suhandoko, A.D.J., Serrano, J., Intaratat, K. (2026). Social environmental influences on students' green living behaviour in Vietnam and Malaysia. <https://doi.org/10.1016/j.cesys.2026.100440>
- Nillos, M.G., Taberna, H., Sesbreño, R.S., Pahila, I., Okamoto, Y., Añasco, N. (2020). Geochemical speciation of metals (Cu, Pb, Cd) in fishpond sediments in Batan Bay, Aklan, Philippines. <https://doi.org/10.1007/s10661-020-08613-7>
- Obanya, H.E., Khan, F.R., Carrasco-Navarro, V., Rødland, E.S., Walker-Franklin, I., Thomas, J., Cooper, A., Molden, N., Amaeze, N.H., Patil, R.S., Kukkola, A., Michie, L., Green-Ojo, B., Rauert, C., Couceiro, F., Hutchison, G.R., Tang, J., Ugor, J., Lee, S., ... Ford, A.T. (2024). Priorities to inform research on tire particles and their chemical leachates: A collective perspective. <https://doi.org/10.1016/j.envres.2024.120222>

- Porter, D.E., Kelsey, R.H., Ramage, D.W., Sandifer, P.A., Brooks, B.W., Canonico, G., Chassignet, E.P., Kirkpatrick, B., Schwacke, L.H., Scott, G.I. (2023). Observing and monitoring the ocean. <https://doi.org/10.1016/B978-0-323-95227-9.00026-9>
- Putri, O.A., Ahmad, A., Zahid, M.F., Izzany, N., Aisyah, S., Oktarina, S.D. (2024). Determinant factor of environmental quality based on carbon footprint levels in Asia using regression model and Jacobian optimization method. <https://doi.org/10.1088/1755-1315/1388/1/012051>
- Rattner, B.A., Leopold, A., Mitchelmore, C.L., Suter, G.W., Johnson, M.S., Bejarano, A.C., Kapustka, L.A., Krishnan, N., Muir, D.C.G., Opeolu, B.O., Orozco-Medina, M.G., Reed, A., Vigon, B.W., Wronski, A.R. (2026). A critical perspective on the Society of Environmental Toxicology and Chemistry's adherence to founding principles—opportunities for the future. <https://doi.org/10.1093/etojnl/vgaf294>
- Risjani, Y., Mutmainnah, N., Manurung, P., Wulan, S.N. (2021). Exopolysaccharide from *Porphyridium cruentum* (purpureum) is Not Toxic and Stimulates Immune Response against Vibriosis: The Assessment Using Zebrafish and White Shrimp *Litopenaeus vannamei*. <https://doi.org/10.3390/MD19030133>
- Risjani, Y., Darmawan, A., Putri Renitasari, D., Lorma Ayuknita, A., Rahma, F., Effendi, S., Dzacky Pradana, M., Rachma, A., Awaludin Adam, M. (2023). Histopathological aberration and 17- β -estradiol imbalance in green mussel *Perna viridis* population cultured in Java Sea, Indonesia. <https://doi.org/10.1016/j.ejar.2022.07.002>
- Sayadi, M.H., Nowrouzi, M., Eslami, N., Emami, S., Mehdinia, A. (2026). Evaluating the effectiveness of adsorption nano-techniques for microplastic removal: Insights and future prospects. <https://doi.org/10.1016/j.marpolbul.2026.119233>
- Schoor, M., Arenas-Salazar, A.P., Parra-Pacheco, B., García-Trejo, J.F., Torres-Pacheco, I., Guevara-González, R.G., Rico-García, E. (2024). Horticultural Irrigation Systems and Aquacultural Water Usage: A Perspective for the Use of Aquaponics to Generate a Sustainable Water Footprint. <https://doi.org/10.3390/agriculture14060925>
- Sembel, L., Setijawati, D., Yona, D., Risjani, Y. (2021). Seasonal variations of water quality at Doreri Gulf, Manokwari, West Papua. <https://doi.org/10.1088/1755-1315/890/1/012007>
- Sembel, L., Setijawati, D., Yona, D., Risjani, Y. (2022). Spatio-temporal of heavy metal Pb (Lead) in seawater, sediment, and different organs of *Cymodocea rotundata* in Doreri Gulf, Manokwari, West Papua, Indonesia. <https://doi.org/10.13057/biodiv/d230528>
- Sigmund, G., Barra, R.O., Bertram, M.G., Diamond, M.L., Ford, A.T., İmamoğlu, I., Li, J., Lohmann, R., Schäffer, A., Scheringer, M., Šebková, K., Starling, M.C.V.M., Suzuki, N., Vlahos, P., Weber, R., Brooks, B.W. (2026). Aligning Horizon Scanning Approaches with Differing Needs and Topics at the Science–Policy Interface on Chemicals, Waste, and Pollution. <https://doi.org/10.1021/acs.est.6c06644>
- Sims, J.L., Stroski, K.M., Kim, S., Killeen, G., Ehalt, R., Simcik, M.F., Brooks, B.W. (2022). Global occurrence and probabilistic environmental health hazard assessment of per- and polyfluoroalkyl substances (PFASs) in groundwater and surface waters. <https://doi.org/10.1016/j.scitotenv.2021.151535>
- Strieder, C.D.M., Macuvele, D.L.P., Soares, C., Padoin, N., Riella, H.G. (2024). Plant-mediated green synthesis of cerium oxide nanoparticles: A critical perspective of some unclear issues. <https://doi.org/10.1016/j.jmrt.2024.05.022>
- Stroski, K.M., Sims, J.L., Wronski, A.R., Bain, F.L., Snow, C.C., Henke, A.N., Langan, L.M., Brooks, B.W. (2025). Discharge of Per- and Polyfluoroalkyl Substances in Reclaimed Wastewater: Temporal Water Quality Implications for Effluent-Dominated Systems. <https://doi.org/10.1021/acsestwater.4c01072>
- Su, T., Lian, D., Bai, Y., Wang, Y.Y.L., Zhang, D., Wang, Z., You, J. (2021). The feasibility of the zebrafish embryo as a promising alternative for acute toxicity test using various fish species: A critical review. <https://doi.org/10.1016/j.scitotenv.2021.147705>
- Sun, F., Mu, Y., Leung, K.M.Y., Su, H., Wu, F., Chang, H. (2021). China is establishing its water quality standards for enhancing protection of aquatic life in freshwater ecosystems. <https://doi.org/10.1016/j.envsci.2021.07.008>
- Swaroop, K.R., Gade, S. (2023). Sustainable marketing and people behavior for enhanced governance. <https://doi.org/10.4018/978-1-6684-9711-1.ch013>
- Umami, A., Sukmana, H., Wikurendra, E.A., Paulik, E. (2022). A review on water management issues: potential and challenges in Indonesia. <https://doi.org/10.1007/s40899-022-00648-7>
- van Dijk, J., Leopold, A., Flerlage, H., van Wezel, A., Seiler, T.-B., Enrici, M.-H., Bloor, M.C. (2021). The EU Green Deal's ambition for a toxic-free environment: Filling the gap for science-based policymaking. <https://doi.org/10.1002/ieam.4429>
- Verdadero, F.X.D., Agarap, A.Z., Macatingrao, C.N.E., Ordonez, I.A., Tavu, L.E.J., Pires, D., Balendres, M.A.O. (2025). Pesticides in the Environment: Benefits, Harms, and Detection Methods. <https://doi.org/10.3390/sci7040171>

- Yamaguchi, M., Nishi, N. (2022). Characteristics of WASHOKU: Japanese Traditional Dietary Culture, Compared with Sustainable Healthy Diets Based on Nutrition-Sensitive Agriculture and Food Systems. <https://doi.org/10.1021/bk-2022-1430.ch003>
- Yeung, K.W.Y., Zhou, G.-J., Ruan, Y., Lam, P.K.S., Leung, K.M.Y. (2021). Occurrence of retinoic acids and their metabolites in sewage and their removal efficiencies by chemically enhanced primary treatment and secondary biological treatment. <https://doi.org/10.1016/j.chemosphere.2021.130745>
- Zhang, L., Mu, R., Hu, S., Zhang, Q., Wang, S. (2021). Impacts of manufacturing specialized and diversified agglomeration on the eco-innovation efficiency-a nonlinear test from dynamic perspective. <https://doi.org/10.3390/su13073809>
- Zhao, F., Ding, X., Liu, Z., Yan, X., Chen, Y., Jiang, Y., Chen, S., Wang, Y., Kang, T., Xie, C., He, M., Zheng, J. (2023). Application of CRISPR/Cas9-based genome editing in ecotoxicology. <https://doi.org/10.1016/j.envpol.2023.122458>
- Zhou, Z., Bai, Y., Su, T., Zhang, D., Wang, Z., Begnaud, F., Gimeno, S., You, J. (2022). Investigations On the Fish Acute Toxicity of Fragrance Ingredients Involving Chinese Fish Species and Zebrafish Embryos. <https://doi.org/10.1002/etc.5415>
- Zizka, V.M.A., Koschorreck, J., Khan, C.C., Astrin, J.J. (2022). Long-term archival of environmental samples empowers biodiversity monitoring and ecological research. <https://doi.org/10.1186/s12302-022-00618-y>