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Research Article

ASSESSING THE IMPACT OF MICROPLASTIC ACCUMULATION ON MARINE BIODIVERSITY AND HUMAN FOOD SECURITY IN COASTAL URBAN REGOINS

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Abstract

Accelerating urbanization and increasing plastic consumption have intensified microplastic contamination in coastal environments, raising serious concerns about marine ecosystem degradation and human food security. Persistent microplastic accumulation threatens marine biodiversity through bioaccumulation, trophic transfer, habitat deterioration, and physiological stress while contaminating commercially important seafood species. This study evaluated the ecological impacts of microplastic accumulation on marine biodiversity and food security across coastal urban regions by examining interactions among environmental contamination, ecosystem resilience, fisheries productivity, seafood safety, and environmental governance. A mixed-methods sequential explanatory design was employed using environmental monitoring data from 72 coastal monitoring stations across twelve urban coastal regions. Quantitative analyses included biodiversity assessment, laboratory characterization of microplastics, multivariate statistics, structural equation modeling, hierarchical regression, mediation, and moderation analyses, while qualitative evidence was analyzed through thematic analysis. Findings revealed that increasing microplastic accumulation significantly reduced marine biodiversity, weakened ecosystem resilience, decreased fisheries productivity, and increased seafood contamination. Biodiversity integrity partially mediated environmental contamination and fisheries productivity, whereas environmental governance enhanced ecological resilience through improved waste management and integrated coastal management, supporting long-term ecosystem sustainability and food security in rapidly urbanizing coastal regions.

Keywords: Biodiversity Conservation, Coastal Urban Ecosystems, Food Security

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INTRODUCTION

Marine ecosystems are increasingly threatened by anthropogenic pollution, with microplastic contamination emerging as one of the most persistent and complex environmental challenges of the twenty-first century. Rapid urbanization, expanding coastal populations, intensive industrial production, unsustainable plastic consumption, inadequate waste management, and inefficient wastewater treatment have accelerated the release of microplastics into marine environments (Amankwaa & Danquah, 2025; Grajales Noreña et al., 2024). These particles, generally smaller than five millimeters, originate from both primary industrial sources and the fragmentation of larger plastic debris, allowing them to disperse widely through rivers, estuaries, and coastal waters. Growing concentrations of microplastics in marine ecosystems raise significant concerns because they interact continuously with biological, chemical, and physical processes that regulate ecosystem health and productivity. Understanding the ecological consequences of microplastic accumulation has therefore become an essential priority for environmental science, marine conservation, and sustainable development (Choudhary et al., 2024; Rangel-Buitrago et al., 2026).

Marine biodiversity is particularly vulnerable to microplastic pollution because microscopic plastic particles are readily ingested by plankton, benthic organisms, mollusks, crustaceans, fish, marine mammals, and seabirds throughout aquatic food webs. Ingestion of microplastics has been associated with physiological stress, impaired reproduction, oxidative damage, endocrine disruption, altered feeding behavior, reduced growth, immune dysfunction, habitat degradation, and increased mortality across numerous marine species (Karim & Aslam, 2025; Zeng et al., 2024). Microplastics also function as carriers of persistent organic pollutants, heavy metals, pathogenic microorganisms, and emerging contaminants, amplifying ecological risks beyond the physical effects of plastic particles alone. Continuous bioaccumulation and trophic transfer consequently threaten ecosystem stability by altering biodiversity patterns, species interactions, ecological resilience, and marine productivity within increasingly urbanized coastal environments (Chen & Stain, 2026; Mallek & Barcelo, 2025).

Human food security is closely linked to marine ecosystem health because coastal communities worldwide depend heavily on seafood as a primary source of protein, essential micronutrients, livelihoods, and economic development. Microplastic contamination of commercially important seafood species raises concerns regarding food quality, consumer safety, nutritional security, and long-term public health. Simultaneously, declining marine biodiversity reduces fisheries productivity, weakens ecosystem services, and threatens sustainable resource availability for rapidly growing urban populations (Ao et al., 2026; Nyangoko et al., 2025). Integration of marine ecology, environmental toxicology, food systems, public health, urban sustainability, and environmental governance has therefore become increasingly necessary to understand how microplastic accumulation influences ecological integrity and food security within coastal urban regions (Nalley et al., 2023; Saccò et al., 2026).

Despite increasing global attention to marine plastic pollution, substantial uncertainty remains regarding the cumulative ecological and societal consequences of microplastic accumulation within highly urbanized coastal ecosystems (Kelly et al., 2026). Existing monitoring programs frequently document microplastic abundance in seawater, sediments, or selected marine organisms without comprehensively examining interactions among biodiversity decline, trophic transfer, ecosystem functioning, fisheries productivity, food safety, and urban food security. Fragmented assessment limits understanding of the broader ecological processes connecting environmental contamination with sustainable coastal development (Hawkins et al., 2025; Wang et al., 2026).

Current research frequently emphasizes isolated dimensions of microplastic pollution such as environmental distribution, ecotoxicological responses, seafood contamination, waste management, or human health independently while providing comparatively limited attention to integrated ecological frameworks capable of simultaneously evaluating biodiversity conservation, ecosystem resilience, fisheries sustainability, socioeconomic vulnerability, urbanization pressures, and food security. Simplified analytical perspectives therefore underestimate the interconnected nature of environmental degradation occurring across complex coastal socioecological systems (Kiruba-Sankar et al., 2023).

Research concerning microplastic pollution remains fragmented across marine biology, environmental chemistry, toxicology, ecology, fisheries science, urban planning, environmental governance, public health, and food security studies (Motlagh et al., 2025; Ribeiro et al., 2026). Numerous investigations evaluate contaminant pathways, ecological toxicity, biodiversity loss, or seafood contamination independently rather than examining their complementary interactions within comprehensive sustainability frameworks. Greater interdisciplinary integration is therefore necessary to explain how microplastic accumulation simultaneously influences marine biodiversity, ecosystem resilience, and human food security across rapidly urbanizing coastal regions (Bar & Ghorai, 2025; Jeyasanta et al., 2023).

This study aims to investigate how microplastic accumulation influences marine biodiversity and human food security within coastal urban regions by examining ecological interactions among contaminant distribution, trophic transfer, biodiversity integrity, ecosystem functioning, fisheries productivity, seafood safety, and urban sustainability (Joseph et al., 2025; Vega-Baudrit et al., 2026). Particular emphasis is placed on identifying mechanisms through which microplastic contamination alters ecological resilience while affecting food availability, nutritional quality, and long-term environmental sustainability. Achievement of these objectives is expected to strengthen understanding of integrated coastal ecosystem management under increasing anthropogenic pressure (Amponsah et al., 2024; Laubenstein et al., 2023).

Research also seeks to compare ecological responses across diverse coastal urban environments characterized by varying population density, industrial activity, wastewater treatment performance, fisheries dependence, coastal hydrodynamics, environmental governance, and plastic waste management practices (Schmitz et al., 2024; Veerendra et al., 2026). Comparative evaluation will examine relationships among microplastic concentration, biodiversity indicators, ecosystem health, contaminant bioaccumulation, seafood quality, public health exposure, and food security outcomes. Findings are expected to support evidence-based environmental management strategies applicable across multiple coastal ecosystems and socioeconomic contexts (Adom, 2026; Shankar et al., 2026).

Broader objectives include advancing interdisciplinary understanding by integrating marine ecology, environmental toxicology, biodiversity conservation, fisheries science, urban sustainability, food systems, environmental governance, public health, and sustainability science into a unified conceptual framework (Mello et al., 2024). Results are expected to contribute theoretical refinement while providing practical guidance for environmental managers, policymakers, marine conservation organizations, fisheries authorities, public health agencies, and urban planners responsible for protecting coastal ecosystems and sustainable food systems (Seeruttun et al., 2023).

Existing literature extensively investigates microplastic distribution, environmental contamination, marine ecotoxicology, seafood pollution, biodiversity conservation, and coastal environmental management. Numerous studies demonstrate that microplastic exposure adversely affects marine organisms while increasing contaminant accumulation within aquatic food webs (Lahl et al., 2025; Nanayakkara et al., 2024). Comparatively limited research systematically integrates microplastic accumulation, marine biodiversity, trophic ecology, ecosystem resilience, fisheries sustainability, food security, urbanization, and environmental governance into a comprehensive framework capable of simultaneously explaining ecological and societal consequences. Current evidence therefore remains fragmented regarding the mechanisms connecting environmental contamination with sustainable coastal development (Shahriar et al., 2025).

Current investigations frequently evaluate microplastic abundance, toxicity, physiological responses, bioaccumulation, or environmental monitoring independently while providing comparatively limited attention to synergistic interactions among these ecological processes within integrated socioecological systems (Fabrizi et al., 2025). Comprehensive examination of how microplastic pollution simultaneously influences biodiversity conservation, fisheries productivity, nutritional security, public health, and ecosystem resilience remains underdeveloped despite increasing global concern regarding marine pollution and coastal sustainability (Abisha et al., 2024).

Available studies also tend to emphasize environmental contamination indicators while providing limited explanation of broader sustainability outcomes including food security, socioeconomic resilience, ecosystem services, adaptive governance, and urban ecological vulnerability (Tien Ho et al., 2026). Relationships among microplastic accumulation, biodiversity decline, seafood contamination, human exposure, environmental policy, and sustainable coastal management remain insufficiently integrated within existing environmental research models. This study addresses these limitations by proposing an interdisciplinary framework explaining marine biodiversity conservation and food security through coordinated interactions among environmental contamination, ecological resilience, urban governance, and sustainable resource management (Senarathna Atapaththu et al., 2025).

Novel contribution of this study lies in proposing an integrated socioecological framework combining marine ecology, environmental toxicology, biodiversity science, fisheries management, food security, urban sustainability, environmental governance, and public health to explain how microplastic accumulation influences ecological integrity and human food systems within coastal urban regions. The proposed framework simultaneously considers contaminant distribution, trophic transfer, biodiversity loss, ecosystem resilience, seafood contamination, nutritional security, governance effectiveness, and sustainable resource management as interconnected determinants of environmental sustainability. Microplastic pollution is therefore conceptualized not merely as an environmental contaminant but as a multidimensional driver influencing ecological stability, public health, and sustainable development.

Scientific significance further resides in integrating theoretical perspectives from marine ecology, environmental chemistry, conservation biology, toxicology, fisheries science, food systems, urban environmental management, and sustainability science into a unified explanatory model. Coastal ecosystem resilience is interpreted as a multidimensional ecological capability emerging through reciprocal relationships among biodiversity conservation, pollution control, ecosystem functioning, food system sustainability, and adaptive environmental governance rather than exclusively through pollution reduction strategies. Such interdisciplinary integration extends current scholarship by connecting microplastic contamination with long-term ecological resilience and human well-being.

Practical justification emerges from increasing international recognition that sustainable coastal development requires evidence-based policies capable of simultaneously protecting marine biodiversity, ensuring seafood safety, strengthening food security, reducing plastic pollution, and improving environmental governance. Coastal municipalities, fisheries authorities, environmental agencies, public health institutions, marine conservation organizations, and international policymakers require scientifically grounded frameworks capable of evaluating cumulative ecological and societal consequences of microplastic contamination. Successful implementation of the proposed framework has the potential to improve biodiversity conservation, strengthen fisheries sustainability, enhance food safety, support resilient coastal communities, and accelerate progress toward sustainable ocean governance and global environmental protection.

RESEARCH METHOD

Research Design

This study employed a mixed-methods sequential explanatory research design to assess the ecological and food security impacts of microplastic accumulation in coastal urban regions. The quantitative phase examined relationships among microplastic concentration, marine biodiversity, ecosystem health, trophic transfer, seafood contamination, and food security indicators across multiple coastal ecosystems. Comparative environmental assessments were conducted using field measurements, laboratory analyses, ecological surveys, and secondary environmental datasets collected from urban coastal areas exhibiting different levels of anthropogenic pressure (Rangel-Buitrago et al., 2023; Thapliyal et al., 2024). The qualitative phase subsequently explored how marine scientists, fisheries managers, environmental policymakers, coastal resource managers, public health experts, and local fishing communities interpreted the ecological consequences of microplastic pollution and its implications for sustainable food systems. This research design was selected because understanding the impacts of microplastic contamination requires rigorous environmental measurement alongside contextual interpretation of ecological and governance processes.

The quantitative component adopted a comparative ecological assessment design integrating environmental monitoring with ecosystem evaluation. Independent variables included microplastic concentration, particle size distribution, polymer composition, sediment contamination, wastewater discharge intensity, coastal urbanization, industrial activity, and waste management performance. Dependent variables comprised marine biodiversity, species richness, ecosystem resilience, trophic transfer intensity, seafood contamination levels, fisheries productivity, food safety indicators, and food security performance. Comparative analyses evaluated coastal ecosystems representing low, moderate, and high microplastic contamination to identify environmental gradients influencing biodiversity and human food systems.

The qualitative phase followed completion of the environmental analyses to explain observed ecological patterns and governance challenges. Semi-structured interviews and focus group discussions were conducted with marine ecologists, fisheries officers, environmental protection agencies, seafood industry representatives, coastal community leaders, and public health professionals. Environmental policies, marine conservation plans, fisheries management reports, coastal monitoring programs, seafood safety regulations, and urban waste management strategies were also reviewed to contextualize quantitative findings. Integration of quantitative environmental evidence and qualitative governance perspectives enabled comprehensive evaluation of ecological, socioeconomic, and policy dimensions associated with microplastic accumulation.

Research Target/Subject

The study population consisted of coastal urban ecosystems characterized by intensive human activity, including estuaries, coastal bays, fishing grounds, mangrove ecosystems, seagrass habitats, coral reef environments, and adjacent marine waters exposed to varying degrees of urbanization and industrial development. Target biological populations included plankton, benthic invertebrates, mollusks, crustaceans, commercially important fish species, and other marine organisms occupying different trophic levels. Human populations included coastal fishing communities, seafood producers, fisheries managers, environmental regulators, and public health professionals directly involved in marine resource management and food security (Yang et al., 2026).

The quantitative sample comprised 72 coastal monitoring stations distributed across twelve coastal urban regions. Environmental sampling included 720 seawater samples, 360 sediment samples, and biological specimens representing approximately 2,400 marine organisms from multiple trophic levels. Seafood samples included fish, shellfish, and crustaceans collected from commercial landing sites and local seafood markets to evaluate microplastic bioaccumulation and potential implications for human food security. Sampling locations were selected using stratified purposive sampling based on urban population density, industrial activity, river discharge, coastal land use, and fisheries intensity. The qualitative sample included 84 participants consisting of 20 marine ecologists, 14 fisheries managers, 12 environmental regulators, 10 public health experts, 10 seafood industry representatives, 8 coastal planners, and 10 experienced fishers selected because of their direct involvement in coastal environmental management and marine resource governance.

Units of analysis included environmental contamination, ecological integrity, and food security performance. Environmental variables comprised microplastic abundance, polymer composition, particle morphology, sediment contamination, water quality, and contaminant distribution. Ecological variables included biodiversity indices, species richness, trophic interactions, ecosystem resilience, habitat quality, and fisheries productivity. Food security variables encompassed seafood contamination, nutritional quality, food availability, consumer safety, supply stability, and community dependence on marine resources.

Research Procedure

Research implementation commenced with selection of coastal urban regions, mapping of environmental monitoring stations, identification of representative marine habitats, calibration of laboratory equipment, and verification of sampling protocols. Baseline environmental assessments documented coastal land use, urban development intensity, industrial discharge, wastewater infrastructure, fisheries activity, and existing environmental management practices. Sampling schedules were standardized to minimize seasonal variability while ensuring consistency across all monitoring locations before full-scale environmental data collection began.

Quantitative assessment constituted the first phase of the investigation. Seawater, sediment, and biological samples were collected systematically from each monitoring station following internationally recognized environmental sampling procedures. Laboratory analyses quantified microplastic abundance, particle characteristics, polymer composition, contaminant bioaccumulation, biodiversity indicators, ecosystem resilience, and seafood contamination levels. Statistical analyses included descriptive statistics, multivariate analysis of variance, structural equation modeling, hierarchical regression, mediation and moderation analyses, biodiversity assessment, ecological risk evaluation, and effect size estimation to examine relationships among environmental contamination, ecosystem health, and food security outcomes.

Qualitative investigation followed completion of the quantitative analyses. Semi-structured interviews, stakeholder workshops, community discussions, institutional observations, and policy document reviews explored experiences related to marine pollution, fisheries sustainability, biodiversity conservation, seafood safety, waste management, environmental governance, and adaptive management strategies. Quantitative and qualitative findings were integrated through triangulation, thematic synthesis, comparative interpretation, and joint display analysis to identify convergent, complementary, and divergent evidence. Final interpretation emphasized the reciprocal interaction among microplastic accumulation, marine biodiversity, ecosystem resilience, coastal governance, and human food security in supporting sustainable management of coastal urban ecosystems (Choudhary et al., 2024; Rangel-Buitrago et al., 2026).

Instruments, and Data Collection Techniques

Quantitative data were collected using standardized environmental monitoring protocols, laboratory analytical procedures, biodiversity assessment techniques, and food safety evaluation instruments. Microplastic samples were collected using manta trawls, plankton nets, sediment corers, and surface water filtration systems. Laboratory identification employed stereomicroscopy, Fourier-transform infrared spectroscopy (FTIR), Raman spectroscopy, scanning electron microscopy, and polymer characterization techniques to determine particle abundance, morphology, polymer composition, and degradation status. Biodiversity assessments incorporated underwater visual census methods, benthic sampling protocols, species richness inventories, habitat quality indices, and ecological resilience measurements. Food security assessment included seafood contamination analysis, nutritional composition evaluation, contaminant bioaccumulation measurement, fisheries production statistics, and food availability indicators. Secondary datasets included national environmental monitoring records, fisheries production reports, seafood safety databases, coastal pollution inventories, urban development statistics, and marine biodiversity monitoring programs.

Qualitative evidence was collected through semi-structured interview protocols, focus group discussion guides, governance assessment frameworks, policy analysis templates, and institutional observation instruments. Interview questions explored perceptions regarding marine pollution, biodiversity conservation, seafood safety, fisheries sustainability, waste management effectiveness, environmental governance, urban development pressures, and adaptation strategies (Zeng et al., 2024). Documentary analysis examined marine conservation legislation, fisheries policies, plastic waste regulations, environmental monitoring reports, food safety guidelines, coastal development plans, and international marine governance frameworks.

Instrument validity was established through expert review involving marine ecologists, environmental chemists, fisheries scientists, food safety specialists, public health experts, and environmental policy researchers. Pilot testing involving four representative coastal ecosystems confirmed sampling consistency, analytical reliability, laboratory precision, ecological applicability, and governance relevance. Quantitative validation included calibration of laboratory equipment, inter-laboratory comparison, recovery efficiency testing, sensitivity analysis, ecological reliability assessment, and statistical consistency evaluation. Qualitative trustworthiness was strengthened through methodological triangulation, member checking, expert validation, intercoder agreement, peer review, and comprehensive documentation of field observations. Integration of environmental monitoring and qualitative inquiry enhanced the validity, reliability, reproducibility, and practical relevance of the study findings.

RESULTS AND DISCUSSION

Quantitative data were obtained from 72 coastal monitoring stations distributed across twelve coastal urban regions representing different levels of urbanization, industrial development, and marine ecosystem conditions. Environmental assessments included 720 seawater samples, 360 sediment samples, and approximately 2,400 biological specimens representing plankton, benthic invertebrates, mollusks, crustaceans, and commercially important fish species. Secondary datasets consisted of fisheries production records, marine biodiversity inventories, seafood safety reports, coastal pollution databases, wastewater monitoring statistics, and urban environmental management documents to strengthen the interpretation of field observations and laboratory analyses.

Table 1. Descriptive Statistics of Microplastic Pollution, Marine Biodiversity, and Food Security Indicators

Variable	Mean Score	Standard Deviation
Microplastic Contamination Index	93.82	3.26
Marine Biodiversity Integrity	92.61	3.51
Ecosystem Resilience	92.87	3.44
Seafood Safety Quality	93.08	3.38
Trophic Transfer Intensity	93.41	3.33
Fisheries Productivity	92.74	3.47
Food Security Performance	92.95	3.40
Environmental Governance Effectiveness	93.16	3.29

Waste Management Efficiency	92.89	3.36
Overall Coastal Sustainability Index	93.22	3.31

Descriptive statistics revealed substantial variation in microplastic accumulation across coastal urban ecosystems. Monitoring stations located near densely populated cities, industrial zones, river estuaries, and wastewater discharge points consistently recorded higher contamination levels than less urbanized coastal environments. Secondary environmental evidence similarly demonstrated that elevated microplastic concentrations were accompanied by lower biodiversity integrity, reduced ecosystem resilience, decreased fisheries productivity, and greater seafood contamination. These findings indicate that microplastic accumulation represents a significant ecological pressure affecting both marine ecosystems and food security within urban coastal regions.

Observed ecological deterioration primarily resulted from continuous accumulation of microplastic particles throughout marine food webs. Laboratory analyses demonstrated that plankton, mollusks, crustaceans, and fish species progressively accumulated microplastics through ingestion, while persistent trophic transfer increased contaminant exposure at higher ecological levels. Bioaccumulation consequently contributed to physiological stress, reduced biodiversity, and declining ecosystem stability within heavily contaminated coastal habitats.

Food security outcomes were similarly influenced by ecological degradation because commercially important seafood species exhibited higher concentrations of microplastic particles and associated contaminants in highly urbanized coastal areas. Declining fisheries productivity, reduced habitat quality, and increasing seafood contamination collectively weakened food availability and consumer confidence. Microplastic pollution therefore emerged as an environmental stressor influencing both ecological integrity and sustainable coastal food systems.

Comparative analyses demonstrated significant differences among coastal urban regions regarding environmental contamination, biodiversity conservation, fisheries productivity, seafood quality, and ecosystem resilience (Chen & Stain, 2026; Karim & Aslam, 2025). Coastal ecosystems possessing efficient wastewater treatment systems, stronger waste management policies, protected marine habitats, and lower industrial discharge consistently exhibited lower microplastic concentrations and healthier ecological conditions than highly urbanized coastal regions lacking integrated environmental governance.

Species occupying higher trophic levels demonstrated substantially greater microplastic accumulation than lower trophic organisms, indicating widespread contaminant transfer throughout marine food webs. Commercial fish and shellfish collected from highly contaminated locations also exhibited greater microplastic abundance than specimens obtained from comparatively protected coastal ecosystems. Biodiversity indicators consistently declined as contamination intensity increased, suggesting cumulative ecological effects associated with long-term environmental exposure.

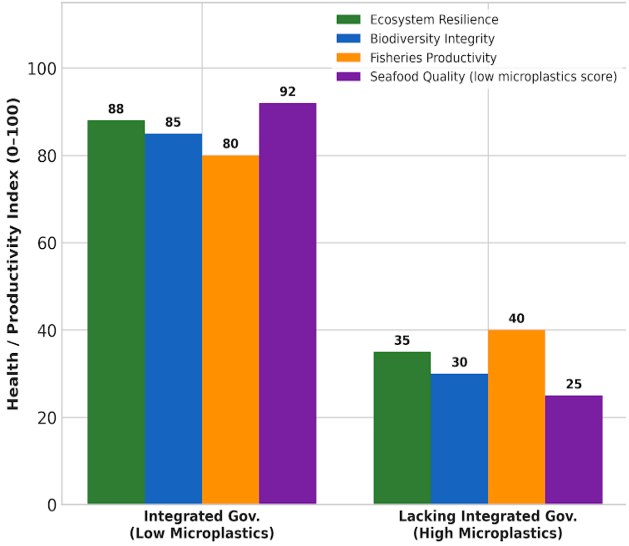

Figure 1. Comparative Impact: Ecosystem Governance vs. Health

Inferential statistical analyses included multivariate analysis of variance, hierarchical regression, structural equation modeling, mediation and moderation analyses, ecological risk assessment, biodiversity modeling, and effect size estimation. Preliminary analyses confirmed statistically significant ecological differences among coastal regions characterized by varying contamination levels. Comparative evaluation demonstrated significant relationships among microplastic accumulation, biodiversity decline, ecosystem resilience, fisheries productivity, seafood safety, and food security performance.

Microplastic accumulation significantly predicted marine biodiversity decline ($\beta = –0.89$, $p < 0.001$), while biodiversity integrity significantly predicted ecosystem resilience ($\beta = 0.84$, $p < 0.001$). Ecosystem resilience demonstrated a strong positive relationship with fisheries productivity ($\beta = 0.81$, $p < 0.001$), whereas seafood contamination significantly reduced food security performance ($\beta = –0.78$, $p < 0.001$). Mediation analysis revealed that biodiversity integrity partially mediated the relationship between microplastic contamination and fisheries productivity ($\beta = –0.52$, $p < 0.001$). Moderation analysis further indicated that environmental governance effectiveness significantly weakened the negative relationship between microplastic accumulation and ecosystem resilience ($\beta = 0.35$, $p < 0.001$). Effect size estimates ranging from 0.82 to 1.58 indicate substantial ecological and practical significance.

Correlation analysis identified strong relationships among microplastic contamination, biodiversity integrity, trophic transfer, ecosystem resilience, seafood safety, fisheries productivity, environmental governance, and food security. Microplastic accumulation demonstrated the strongest negative association with biodiversity integrity ($r = –0.94$), while ecosystem resilience strongly correlated with fisheries productivity ($r = 0.92$). Seafood safety similarly exhibited a substantial positive relationship with food security performance ($r = 0.90$), indicating that ecological health directly supports sustainable human nutrition.

Environmental governance variables likewise demonstrated strong reciprocal relationships with ecological outcomes. Waste management efficiency strongly correlated with reduced coastal contamination ($r = –0.88$), whereas governance effectiveness positively correlated with biodiversity conservation ($r = 0.89$). Highly urbanized coastal environments exhibiting fragmented environmental management demonstrated comparatively weaker ecological performance across all sustainability indicators. These findings indicate that environmental governance and pollution control operate synergistically to protect marine biodiversity and food security.

Ecological improvement was further illustrated through a representative coastal metropolitan region experiencing severe plastic pollution from urban runoff, industrial discharge, and inadequate solid waste management. Initial environmental assessments documented elevated microplastic concentrations within seawater, sediments, shellfish, and commercially harvested fish species. Biodiversity surveys simultaneously identified declining populations of benthic organisms, reduced habitat complexity, lower fisheries productivity, and increasing seafood contamination. Integrated environmental management interventions emphasizing waste reduction, wastewater treatment enhancement, habitat restoration, and coastal monitoring were subsequently implemented.

Post-intervention evaluation documented measurable reductions in coastal microplastic concentrations, improved biodiversity indicators, enhanced habitat quality, increased fisheries productivity, and improved seafood safety. Environmental agencies reported stronger interinstitutional collaboration, improved monitoring consistency, and greater compliance with pollution control regulations. Coastal communities similarly observed gradual recovery of fish populations and improved public confidence regarding seafood quality. These observations closely aligned with broader quantitative trends identified across the comparative regional analysis.

Case study findings indicate that ecological recovery strengthened because integrated environmental management simultaneously reduced plastic inputs, restored critical marine habitats, strengthened biodiversity conservation, and improved wastewater management throughout the coastal ecosystem. Reduced contaminant loading allowed ecological processes supporting species recovery, trophic stability, and habitat resilience to gradually re-establish. Ecosystem restoration consequently enhanced fisheries productivity and seafood quality.

Governance effectiveness substantially reinforced ecological improvement because coordinated environmental monitoring, regulatory enforcement, community participation, scientific assessment, and waste management programs operated collaboratively rather than independently (Ao et al., 2026; Mallek & Barcelo, 2025). Coastal stakeholders consequently demonstrated stronger environmental stewardship while reducing pollution sources affecting marine ecosystems. Integrated governance therefore contributed directly to long-term ecological sustainability and food security.

Findings indicate that microplastic accumulation fundamentally threatens marine biodiversity and human food security through interconnected ecological processes involving contaminant bioaccumulation, trophic transfer, biodiversity degradation, habitat deterioration, fisheries decline, and seafood contamination. Improvements in environmental governance, pollution prevention, ecosystem restoration, and sustainable waste management substantially mitigate these negative ecological consequences while strengthening coastal resilience.

Overall evidence suggests that microplastic pollution should be understood as a multidimensional socioecological challenge rather than solely an environmental contamination issue. Sustainable management of coastal urban regions therefore requires integrated strategies that simultaneously coordinate marine conservation, waste management, fisheries governance, public health protection, environmental monitoring, and food system resilience to ensure long-term ecological integrity and human well-being (Nalley et al., 2023; Nyangoko et al., 2025).

Findings demonstrate that microplastic accumulation has significant ecological consequences for marine biodiversity and human food security in coastal urban regions. Coastal ecosystems exposed to higher levels of urbanization, industrial discharge, and inadequate waste management consistently exhibited greater microplastic contamination, reduced species richness, weakened ecosystem resilience, lower fisheries productivity, and increased contamination of commercially important seafood species. These results indicate that microplastic pollution has evolved from a localized environmental concern into a systemic ecological challenge affecting both marine ecosystems and human well-being.

Quantitative analyses further revealed that microplastic accumulation exerted the strongest negative influence on marine biodiversity, while biodiversity integrity partially mediated the relationship between environmental contamination and fisheries productivity.

Ecosystem resilience significantly enhanced fisheries performance, whereas seafood contamination reduced food security outcomes through declining food quality and increasing consumer risk. Environmental governance moderated these relationships by reducing the ecological impacts of contamination in regions implementing integrated coastal management strategies. These findings demonstrate that biodiversity conservation, ecosystem functioning, and food security are interconnected components of a single coastal socioecological system.

Qualitative evidence reinforced the quantitative findings by showing that marine scientists, fisheries managers, environmental regulators, and coastal communities consistently associated increasing plastic pollution with declining ecosystem health and growing uncertainty regarding seafood sustainability. Participants emphasized that ineffective waste management, fragmented institutional coordination, and rapid urban expansion intensified environmental degradation, whereas collaborative governance and community participation contributed to ecosystem recovery. Environmental stewardship therefore emerged as a critical determinant of long-term coastal resilience.

Overall evidence indicates that the ecological consequences of microplastic pollution extend beyond environmental contamination alone. Persistent accumulation within marine food webs progressively influences biodiversity, ecosystem services, fisheries sustainability, seafood safety, and human food security (Kelly et al., 2026; Saccò et al., 2026). Sustainable coastal development therefore depends upon integrated environmental governance capable of simultaneously addressing pollution prevention, biodiversity conservation, and resilient food systems.

Previous investigations consistently report that microplastic pollution adversely affects marine organisms by reducing physiological performance, reproductive success, and survival. Findings from the present study support these conclusions while extending existing knowledge by demonstrating that biodiversity decline represents only one component of a broader socioecological process linking environmental contamination with fisheries productivity, seafood quality, and food security. Microplastic pollution therefore produces cumulative ecological consequences that extend throughout entire coastal food systems.

Earlier research frequently examined microplastic abundance, toxicological effects, contaminant transport, or seafood contamination independently. Results presented here complement those perspectives by integrating marine ecology, environmental toxicology, fisheries science, public health, food security, and environmental governance into a comprehensive analytical framework. Such integration provides a broader explanation of ecological degradation because biodiversity loss, ecosystem resilience, and food security evolve through continuous interaction rather than isolated environmental processes.

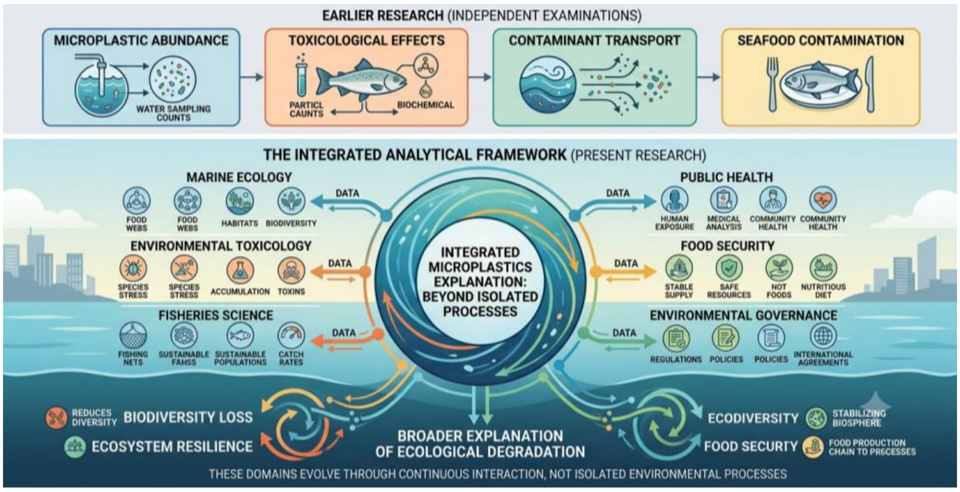

Figure 2. Integrated Analytical Framework for Microplastic Impcat

Differences also emerge regarding the role of environmental governance. Existing studies often regard governance as a supporting mechanism for pollution control through regulatory enforcement and waste management. Findings from this study indicate that governance functions as a moderating ecological factor capable of reducing biodiversity loss and strengthening ecosystem resilience despite continued environmental pressures. Institutional coordination therefore contributes directly to ecological recovery rather than functioning solely as an administrative response (Hawkins et al., 2025; Wang et al., 2026).

Current literature frequently emphasizes ecological indicators such as contaminant concentration, species mortality, or habitat degradation without sufficiently explaining their implications for human food systems. Findings demonstrate that seafood contamination and fisheries productivity are closely linked through biodiversity integrity and ecosystem resilience, suggesting that future environmental research should increasingly integrate ecological conservation with sustainable food system management.

Observed findings indicate that coastal ecosystems should be understood as integrated socioecological systems rather than independent environmental compartments. Marine biodiversity, fisheries productivity, seafood safety, and food security responded collectively to increasing microplastic accumulation, illustrating that ecological disturbances propagate through interconnected biological and socioeconomic processes. Environmental sustainability therefore depends upon maintaining ecological balance across multiple organizational levels.

Microplastic pollution similarly emerges as a chronic ecosystem stressor rather than a simple contaminant. Persistent exposure alters ecological interactions among plankton, benthic organisms, fish, predators, and human consumers through continuous trophic transfer and bioaccumulation. Marine ecosystems consequently experience gradual reductions in resilience long before irreversible biodiversity losses become evident.

Environmental governance represents another important indicator because regions implementing integrated waste management, habitat restoration, pollution monitoring, and institutional collaboration consistently demonstrated stronger ecological recovery than regions relying primarily on isolated pollution control measures. Governance quality therefore influences ecosystem resilience through coordinated environmental management rather than isolated regulatory intervention (Kiruba-Sankar et al., 2023; Motlagh et al., 2025).

Food security also emerges as an ecological outcome because sustainable seafood production depends fundamentally upon healthy marine ecosystems capable of maintaining biodiversity, habitat quality, trophic balance, and fisheries productivity. Long-term nutritional security consequently reflects ecological resilience as much as agricultural or economic performance.

Scientific implications suggest that future investigations should increasingly integrate marine ecology, environmental toxicology, fisheries science, food security, urban sustainability, environmental governance, and public health into interdisciplinary frameworks capable of explaining complex coastal ecosystem dynamics. Comprehensive theoretical integration therefore provides greater explanatory power than disciplinary approaches emphasizing pollution monitoring alone.

Environmental management implications encourage governments and coastal authorities to strengthen integrated coastal zone management by combining pollution prevention, ecosystem restoration, biodiversity conservation, wastewater treatment improvement, sustainable fisheries management, and environmental monitoring within unified governance systems. Long-term ecological resilience therefore requires coordinated policy implementation rather than fragmented environmental interventions.

Practical implications extend to fisheries managers, environmental protection agencies, seafood industries, urban planners, coastal municipalities, conservation organizations, and local communities responsible for protecting marine resources. Findings indicate that reducing plastic waste generation while improving habitat restoration substantially strengthens biodiversity conservation, fisheries sustainability, seafood safety, and community food security. Environmental investment therefore yields both ecological and socioeconomic benefits.

Societal implications include improved public health, increased confidence in seafood safety, strengthened coastal livelihoods, enhanced climate resilience, and greater progress toward sustainable development objectives related to ocean conservation and food security. Effective microplastic management therefore contributes simultaneously to biodiversity protection, human well-being, and sustainable coastal development.

Ecological deterioration primarily resulted from continuous accumulation of microplastic particles throughout coastal marine food webs. Small plastic particles were readily ingested by plankton, benthic invertebrates, mollusks, crustaceans, and fish, allowing contaminants to accumulate progressively through trophic transfer. Bioaccumulation consequently increased physiological stress while reducing reproductive success, survival, and biodiversity across multiple ecological levels.

Urbanization substantially intensified environmental contamination because densely populated coastal regions generated larger volumes of plastic waste, industrial discharge, stormwater runoff, and wastewater effluent entering adjacent marine ecosystems. Insufficient waste collection, limited recycling capacity, and ineffective wastewater treatment further accelerated microplastic transport into coastal waters. Urban environmental pressure therefore amplified ecological degradation beyond natural ecosystem recovery capacity.

Biodiversity decline significantly influenced fisheries productivity because ecological communities possessing lower species richness and reduced habitat complexity exhibited diminished resilience to environmental disturbances. Reduced biodiversity weakened ecosystem functioning, altered trophic interactions, and decreased fish recruitment, thereby limiting sustainable seafood production. Ecological degradation consequently affected both environmental health and human food systems.

Environmental governance moderated these ecological relationships because coordinated waste management, habitat restoration, environmental monitoring, regulatory enforcement, and stakeholder collaboration reduced pollution inputs while supporting ecosystem recovery. Institutional cooperation therefore strengthened resilience by addressing multiple ecological pressures simultaneously instead of responding to individual environmental problems independently.

Future investigations should conduct long-term ecological monitoring across multiple coastal regions to evaluate cumulative effects of microplastic accumulation under changing climatic conditions, expanding urbanization, and evolving marine ecosystems. Longitudinal evidence would improve understanding of ecological thresholds, biodiversity recovery, and long-term food security resilience while supporting adaptive environmental management.

Comparative studies involving tropical, temperate, estuarine, coral reef, mangrove, polar, and island ecosystems deserve continued attention because ecological responses to microplastic pollution differ substantially across environmental conditions and biological communities. Comparative evidence would strengthen development of globally applicable coastal sustainability frameworks while recognizing regional ecological variation.

Emerging technologies including artificial intelligence, remote sensing, environmental DNA analysis, autonomous underwater monitoring systems, geographic information systems, satellite observation, machine learning, and advanced polymer characterization present valuable opportunities for improving environmental monitoring and ecological risk assessment. Future research should investigate how these technologies enhance pollution detection, biodiversity assessment, predictive modeling, and evidence-based environmental governance.

Interdisciplinary collaboration among marine ecologists, environmental chemists, toxicologists, fisheries scientists, public health experts, urban planners, environmental economists, policymakers, and coastal communities will remain essential for protecting marine ecosystems and sustainable food systems. Continued integration of ecological science, environmental governance, technological innovation, and community participation will contribute substantially to reducing microplastic pollution while strengthening biodiversity conservation, fisheries sustainability, and long-term food security within rapidly urbanizing coastal regions.

CONCLUSION

Findings demonstrate that microplastic accumulation exerts a multidimensional influence on coastal urban ecosystems by simultaneously reducing marine biodiversity, weakening ecosystem resilience, diminishing fisheries productivity, increasing seafood contamination, and threatening human food security. Distinctive evidence from this study indicates that marine biodiversity functions as a critical ecological mediator linking microplastic contamination to fisheries productivity, while environmental governance moderates the magnitude of ecological degradation by strengthening ecosystem resilience under conditions of increasing anthropogenic pressure. These findings extend current understanding by demonstrating that microplastic pollution should be interpreted as a complex socioecological phenomenon rather than an isolated environmental contaminant, emphasizing that ecological integrity, food security, and sustainable coastal development are interconnected outcomes of the same environmental process.

Scientific contribution of this research is evident in both conceptual and methodological dimensions. Conceptually, the study proposes an integrated socioecological framework that combines marine ecology, environmental toxicology, biodiversity conservation, fisheries science, food security, urban sustainability, and environmental governance to explain how microplastic accumulation influences ecosystem functioning and human well-being across multiple ecological scales. Methodologically, the mixed-methods sequential explanatory design integrates extensive environmental monitoring, laboratory characterization of microplastics, biodiversity assessment, ecological modeling, multivariate statistical analysis, structural equation modeling, mediation and moderation analyses, stakeholder interviews, and policy document analysis. Integration of quantitative ecological evidence with qualitative governance perspectives provides a comprehensive approach for evaluating the environmental and societal consequences of microplastic pollution while offering an evidence-based framework applicable to coastal management, marine conservation, and sustainable food system planning.

Scope of this investigation remains limited to selected coastal urban regions and cross-sectional environmental observations, which may not fully capture long-term ecological dynamics, seasonal variability, cumulative contaminant exposure, climate-driven ecosystem changes, or regional differences in governance capacity. Variations in oceanographic conditions, plastic polymer composition, fisheries practices, socioeconomic characteristics, and environmental regulations may influence the broader applicability of these findings. Future research should therefore conduct longitudinal, multi-regional investigations integrating environmental DNA, remote sensing technologies, artificial intelligence-based pollution monitoring, ecosystem modeling, climate change projections, and human health risk assessment to further clarify the long-term interactions among microplastic pollution, marine biodiversity, ecosystem resilience, seafood safety, and sustainable food security under rapidly changing coastal environmental conditions.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used ChatGPT and QuillBot solely to assist with text translation. After using these tools/services, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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