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A Comprehensive Assessment of Microplastic Contamination in the Kodayar – Kuzhithurai River System of Kanyakumari District, Tamil Nadu, India and Its Potential Human Health Impacts Through Drinking Water Exposure

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Abstract

Microplastics (MPs), generally defined as plastic particles smaller than 5 mm, have emerged as contaminants of global concern due to their persistence, widespread distribution, and potential adverse effects on ecosystems and human health. Freshwater rivers are recognized as critical pathways for transporting microplastics from terrestrial sources to estuarine and marine environments while simultaneously serving as major sources of drinking water for millions of people. Despite increasing global concern, limited scientific information exists regarding microplastic contamination in river systems of southern India, particularly within the Kodayar–Kuzhithurai river basin of Kanyakumari District, Tamil Nadu.

This study proposes a comprehensive investigation of microplastic occurrence in river water collected from ten strategically selected locations, namely Netta, Kazhiyal, Thirparappu, Vazhaithottam (Arumanai), Thikkurichi, Mathoor, Kuzhithurai, St. Mangad, Parakkani, and Thengapattanam. The research aims to evaluate spatial variation, identify dominant polymer types, classify particle morphology, investigate potential contamination sources, and assess possible human exposure through river water consumption. Standardized laboratory techniques, including density separation, wet peroxide oxidation, vacuum filtration, stereomicroscopy, Fourier Transform Infrared Spectroscopy (FTIR), Raman spectroscopy, and Scanning Electron Microscopy (SEM), are recommended for characterization. [1-17]

The study also proposes a human health risk assessment framework by estimating potential annual ingestion of microplastics through drinking water and discussing possible toxicological implications of associated plastic additives such as bisphenol A (BPA), phthalates, and heavy metals. The outcomes are expected to provide baseline scientific evidence supporting water quality management, environmental monitoring, public health policy, and plastic waste reduction strategies within the river basin. This work will contribute to the growing understanding of freshwater microplastic pollution in tropical river systems and establish a reference dataset for future environmental and epidemiological studies.

Keywords: *Microplastics; River Water; Drinking Water; Human Health Risk Assessment; Kodayar River; Kuzhithurai River; FTIR; Raman Spectroscopy; Freshwater Pollution; Plastic Additives.*

1. Introduction

1.1 Background

Plastic materials have transformed modern society because of their low cost, durability, versatility, and widespread applications in packaging, construction, agriculture, healthcare, transportation, and consumer products. Global plastic production has increased dramatically over the last seven decades, rising from approximately 2 million tonnes in 1950 to more than 400 million tonnes annually in recent years. A substantial proportion of plastic waste is inadequately collected or managed, leading to environmental leakage into rivers, lakes, estuaries, and oceans.

Environmental exposure causes larger plastic debris to fragment into progressively smaller particles through ultraviolet radiation, thermal degradation, abrasion, and biological processes. These particles, known as microplastics (less than 5 mm), have become ubiquitous contaminants in aquatic ecosystems. They have been

detected in freshwater, marine environments, groundwater, drinking water, sediments, soils, atmospheric dust, food, and even human biological samples.

Freshwater rivers play a dual role by acting as both transport pathways for land-derived plastic pollution and sources of drinking water. This makes riverine microplastic contamination particularly important from both environmental and public health perspectives.

1.2 Microplastics in Freshwater Systems

Historically, research on microplastic pollution focused primarily on marine environments. However, over the past decade, freshwater ecosystems have gained increasing attention because rivers are recognized as major contributors of plastic debris to coastal waters. River systems receive plastic waste from urban runoff, municipal wastewater, industrial discharges, tourism, agricultural activities, and atmospheric deposition.

Microplastics in rivers occur in several forms, including fibers released during laundering of synthetic textiles, fragments generated from the degradation of larger plastic items, films from packaging materials, foams, and industrial resin pellets. These particles differ in size, color, density, and polymer composition, influencing their transport and ecological behavior.

Common polymer types reported in river systems include polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), and nylon. Their distribution depends on local land use, waste management practices, industrial activities, and hydrological conditions.

1.3 Human Health Concerns

The presence of microplastics in drinking water has become an emerging public health concern. Humans may be exposed through drinking water, food, seafood, airborne particles, and consumer products. While research into health effects is ongoing, studies suggest that exposure may contribute to oxidative stress, inflammation, cellular toxicity, and immune responses. Additionally, microplastics can act as carriers for additives such as phthalates, bisphenol A (BPA), flame retardants, and adsorbed environmental pollutants, potentially increasing toxicological risks.

The World Health Organization has emphasized the need for more research on microplastics in drinking water to better understand exposure pathways and health implications. Establishing baseline data for freshwater sources is therefore essential for informing risk assessment and water quality management.

1.4 Study Area: Kodayar–Kuzhithurai River System

The Kodayar–Kuzhithurai river system is a major freshwater resource in Kanyakumari District, Tamil Nadu. Originating in the Western Ghats, the river traverses forested, agricultural, semi-urban, and coastal landscapes before discharging into the Arabian Sea near Thengapattanam. Along its course, it supports domestic water supply, irrigation, fisheries, tourism, and local livelihoods.

The proposed sampling locations—Netta, Kazhiyal, Thirparappu, Vazhaithottam (Arumanai), Thikkurichi, Mathoor, Kuzhithurai, St. Mangad, Parakkani, and Thengapattanam—capture upstream to downstream variations in land use and potential sources of microplastic input. These locations provide an opportunity to evaluate how urbanization, tourism, agriculture, and local waste management practices influence microplastic distribution.[18-26]

1.5 Research Gap

Although several studies have documented microplastic contamination in major Indian rivers such as the Ganges and Brahmaputra, comprehensive investigations of the Kodayar–Kuzhithurai river system remain scarce. There is currently limited information on:

- Spatial variation of microplastic abundance along the river.
- Polymer composition and particle morphology.
- Relationships between land use and contamination sources.
- Potential exposure of local communities through drinking water.
- Implications for human health in the Kanyakumari region.

Addressing these gaps is important for developing evidence-based management strategies and supporting regional environmental policies.

1.6 Aim of the Study

The primary aim of this study is to investigate the occurrence, distribution, and characteristics of microplastics in the Kodayar–Kuzhithurai river system and to evaluate potential human exposure through drinking water consumption.

1.7 Objectives

1. To determine the occurrence and spatial distribution of microplastics in river water collected from selected sampling locations.
2. To identify dominant microplastic morphologies, sizes, colors, and polymer types.
3. To investigate potential sources of microplastic contamination along the river basin.
4. To assess the influence of land use and anthropogenic activities on microplastic abundance.
5. To estimate potential human exposure through drinking water consumption.
6. To discuss possible human health implications associated with chronic exposure to microplastics and plastic additives.
7. To provide scientific recommendations for water resource management and plastic pollution mitigation.

1.8 Significance of the Study

This study is expected to provide the first comprehensive baseline assessment of microplastic contamination in the Kodayar–Kuzhithurai river system. The findings will contribute to freshwater pollution research, support evidence-based environmental management, and inform public health policy in Kanyakumari District. The work may also guide future monitoring programs and aid in developing strategies to reduce plastic pollution in riverine ecosystems.

2. Literature Review

2.1 Global Perspective on Microplastic Pollution

Plastic production has increased exponentially over the last seventy years because of rapid industrialization, urbanization, and consumer demand. While plastics have become indispensable in packaging, healthcare, agriculture, transportation, and electronics, inadequate waste management has resulted in widespread environmental contamination. Plastic materials are resistant to biodegradation and fragment over time into microplastics (<5 mm) and nanoplastics (<1000 nm), which persist in terrestrial and aquatic ecosystems.

Microplastics are generally categorized into:

- **Primary microplastics** – intentionally manufactured small particles such as industrial pellets, cosmetic microbeads, and abrasives.
- **Secondary microplastics** – produced through fragmentation of larger plastic debris by ultraviolet radiation, mechanical abrasion, biological activity, and thermal weathering.

Freshwater systems are now recognized as major transport pathways moving plastic debris from inland regions to estuaries and oceans. Recent research has demonstrated that rivers also function as reservoirs where microplastics accumulate in surface water, sediments, aquatic organisms, and riparian environments.

2.2 Sources of Microplastics in River Systems

Riverine microplastics originate from multiple anthropogenic activities. Major pathways include:

2.2.1 Domestic Waste

Household plastic packaging, disposable containers, bottles, carry bags, and synthetic textile fibres released during laundry are significant contributors.

2.2.2 Municipal Wastewater

Wastewater treatment plants remove a large proportion of suspended solids but cannot completely eliminate microplastics. Fibres from washing machines and personal care products frequently enter receiving rivers.

2.2.3 Agricultural Activities

Plastic mulch, irrigation pipes, greenhouse films, fertilizer bags, and pesticide containers gradually degrade under sunlight, contributing secondary microplastics.

2.2.4 Tourism

Tourism is an important source of single-use plastics including PET bottles, food containers, plastic cups, wrappers, and disposable cutlery.

2.2.5 Fishing Activities

Fishing nets, ropes, floats, buoys, and polypropylene fishing gear are major sources near estuaries and coastal reaches.

2.2.6 Industrial Activities

Industrial sectors including food processing, packaging, rubber processing, textile manufacturing, plastic fabrication, and recycling facilities contribute plastic particles through production losses and wastewater discharge.

2.3 Classification of Microplastics

Microplastics are classified according to morphology.

Type	Major Sources
Fibres	Washing of synthetic textiles
Fragments	Breakdown of larger plastic waste
Films	Plastic carry bags, agricultural mulch
Foams	Thermocol packaging
Pellets	Industrial raw materials

Most freshwater investigations report **fibres** as the dominant morphology because synthetic clothing releases millions of polyester and nylon fibres during laundering. Similar dominance of fibres has also been observed in South Indian river systems

2.4 Polymer Types

The most common polymers identified in freshwater environments include:

- Polyethylene (PE)
- Polypropylene (PP)
- Polyethylene terephthalate (PET)
- Polyvinyl chloride (PVC)
- Polystyrene (PS)
- Nylon (PA)
- Acrylonitrile butadiene styrene (ABS)

These polymers differ in density, degradation behavior, buoyancy, and environmental persistence. PE and PP generally float, whereas PVC and PET are more likely to settle in sediments.

2.5 Human Health Implications

Microplastics have become an emerging public health concern because humans are exposed through:

- Drinking water
- Seafood
- Freshwater fish
- Agricultural crops
- Table salt
- Indoor and outdoor air

Potential mechanisms of harm reported in laboratory and epidemiological studies include:

- Oxidative stress
- Cellular inflammation
- DNA damage

- Immune system activation
- Endocrine disruption from additives such as bisphenol A (BPA) and phthalates
- Adsorption and transport of heavy metals and persistent organic pollutants

Although evidence for many long-term human health outcomes is still developing, the widespread occurrence of microplastics in environmental media justifies precautionary monitoring and exposure assessment.

3. Study Area

3.1 Overview of Kodayar–Kuzhithurai River Basin

The Kodayar–Kuzhithurai river system is one of the most important freshwater resources in **Kanyakumari District, Tamil Nadu**, originating in the southern Western Ghats. The basin supplies water for domestic consumption, agriculture, fisheries, tourism, and small-scale industries before discharging into the Arabian Sea near Thengapattanam.

The basin traverses forested hills, agricultural landscapes, semi-urban settlements, and estuarine environments. Recent geospatial analyses have shown that land-use changes—including expansion of built-up areas and agricultural modification—have altered runoff patterns and watershed characteristics, emphasizing the need for sustainable river-basin management. [24-39]

3.2 Importance of the River

The river supports:

- Drinking water supply
- Irrigation
- Hydroelectric infrastructure in the upper basin
- Fisheries
- Tourism
- Religious activities
- Domestic water use

Because communities rely directly on this river, understanding microplastic contamination is important for both environmental quality and public health.

3.3 Sampling Locations

Ten sampling stations are proposed to represent upstream, midstream, and downstream conditions.

Station	Characteristics	Possible Pollution Sources
Netta	Upper catchment	Low anthropogenic influence
Kazhiyal	Rural settlement	Domestic discharge
Thirparappu	Tourist location	Plastic litter, tourism
Vazhaithottam (Arumanai)	Agricultural region	Agricultural plastics
Thikkurichi	Semi-urban	Domestic waste
Mathoor	Tourist and bridge area	Food packaging, visitors
Kuzhithurai	Urban centre	Municipal runoff
St. Mangad	Residential area	Household wastewater
Parakkani	Estuarine transition	Fishing-related plastics
Thengapattanam	River mouth	Marine–river interaction, fishing

3.4 Land Use

The river basin includes:

- Evergreen and semi-evergreen forest
- Rubber plantations
- Coconut plantations

- Paddy cultivation
- Banana cultivation
- Residential areas
- Commercial zones
- Transportation corridors
- Tourism infrastructure
- Estuarine ecosystems

Land-use change in the Kuzhithurai sub-basin has been linked to population growth and anthropogenic development, highlighting the importance of integrating GIS-based analysis into watershed management.

3.5 Potential Sources of Microplastics in the Basin

Based on land use and regional activities, likely sources include:

- Household plastic waste
- Municipal wastewater
- Tourism around Thirparappu Falls and Mathoor
- Fishing gear near Parakkani and Thengapattanam
- Agricultural plastic mulch and irrigation materials
- Packaging waste from local markets
- Road runoff carrying tyre-wear particles
- Open dumping and littering
- Atmospheric deposition

Studies from Tamil Nadu and nearby river systems have shown that these pathways contribute substantially to freshwater microplastic loads.

3.6 Need for the Present Study

The Kodayar–Kuzhithurai River is an essential freshwater resource for Kanyakumari District, yet there is no comprehensive, basin-wide assessment of microplastic contamination from the upper catchment to the estuary. Most existing regional studies have focused on coastal beaches and marine debris rather than inland drinking-water sources. Recent work from Kanyakumari beaches and other South Indian rivers underscores the growing concern about plastic pollution, but a detailed river-based investigation is still lacking. [40-42]

A systematic evaluation of microplastics in this river basin will provide baseline information for environmental monitoring, identify contamination hotspots, support drinking-water safety assessments, and help local authorities prioritize waste management and pollution-control measures.

4. Materials and Methods

4.1 Research Design

The present investigation was designed as a **field-based observational and analytical study** to evaluate the occurrence, distribution, characterization, and possible human health implications of microplastics in the Kodayar–Kuzhithurai River system, Kanyakumari District, Tamil Nadu, India.

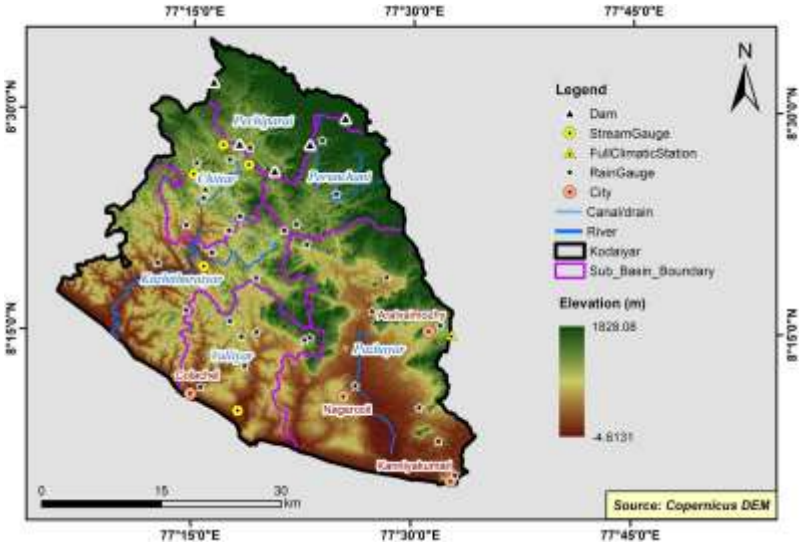
The methodology follows internationally accepted protocols for freshwater microplastic monitoring, integrating standardized sampling, laboratory extraction, spectroscopic polymer identification, and quality assurance/quality control (QA/QC).

The study consists of five major stages:

1. Selection of sampling locations
2. River water sample collection
3. Laboratory extraction of microplastics
4. Polymer identification and characterization
5. Human health risk assessment

4.2 Study Area

The study was conducted along the **Kodayar–Kuzhithurai River Basin**, one of the major freshwater systems in Kanyakumari District.
The river originates in the **Western Ghats**, traverses agricultural lands, rural settlements, urban regions, and estuarine environments before entering the Arabian Sea at **Thengapattanam**.
The basin was selected because it supplies drinking water to a large population and is influenced by multiple anthropogenic activities including tourism, agriculture, domestic wastewater, and fisheries.



4.3 Sampling Locations

Ten sampling stations were selected to represent upstream, middle, and downstream reaches of the river.

Station Code	Sampling Location	River Zone	Major Activities
S1	Netta	Upstream	Forest, agriculture
S2	Kazhiyal	Upper-middle	Residential
S3	Thirparappu	Middle	Tourism
S4	Vazhaithottam (Arumanai)	Middle	Agriculture
S5	Thikkurichi	Middle	Residential
S6	Mathoor	Middle	Tourism
S7	Kuzhithurai	Urban	Domestic sewage
S8	St. Mangad	Lower	Residential
S9	Parakkani	Estuarine	Fishing
S10	Thengapattanam	River Mouth	Fishing and marine influence

The selection of these stations enables comparison of contamination along different land-use zones.



4.4 Sampling Period

Water samples should be collected during three seasons to capture temporal variability:

Season	Duration
Pre-Monsoon	February–May
Monsoon	June–September
Post-Monsoon	October–January

At each location, triplicate samples are recommended to improve statistical reliability.

4.5 Water Sample Collection

River water samples should be collected following standard freshwater microplastic sampling procedures.

Equipment

- Stainless steel bucket
- Glass sampling bottles (1 L)
- GPS
- Portable pH meter
- Conductivity meter
- Dissolved Oxygen meter
- Turbidity meter
- Ice box

Procedure

Surface water is collected from approximately **20–30 cm below the water surface** to minimize interference from floating debris. Glass containers are used to avoid plastic contamination.

At each station:

- Three replicate samples are collected.
- Sampling bottles are rinsed three times with river water before final collection.
- Samples are preserved in cooled containers and transported to the laboratory within 24 hours.

4.6 Field Parameters

The following parameters are recorded in situ:

Parameter
pH

Parameter
Temperature
Turbidity
Electrical Conductivity
Dissolved Oxygen
Total Dissolved Solids
River Velocity
Water Depth
GPS Coordinates

These measurements assist in interpreting the environmental conditions associated with microplastic distribution.

4.7 Laboratory Processing

4.7.1 Sample Filtration

Each water sample is filtered using a vacuum filtration system fitted with glass-fibre or membrane filters of suitable pore size (commonly around 0.45–1.2 μm depending on the study design). The retained material contains suspended solids and potential microplastic particles.

4.7.2 Organic Matter Digestion

To remove organic material without significantly damaging most common polymers, wet peroxide oxidation is widely employed.

A typical procedure uses hydrogen peroxide with an iron catalyst under controlled conditions until visible organic matter is digested. The sample is then allowed to cool before further processing.

4.7.3 Human Health Risk Assessment

Potential exposure through drinking water can be estimated using an ingestion-based framework.

A commonly used approach is:

$$\text{Estimated Daily Intake (EDI)} = \frac{C \times IR}{BW}$$

where:

- **C** = concentration of microplastics in drinking water (particles/L)
- **IR** = daily water ingestion rate (L/day)
- **BW** = body weight (kg)

Estimated annual intake may then be calculated by multiplying the daily intake by 365 days.

The assessment should be interpreted cautiously because there are currently no universally accepted health-based threshold values for microplastic ingestion.

4.13 Software

The following software packages may be used:

Software	Purpose
IBM SPSS Statistics	Statistical analysis
R	Multivariate analysis
ArcGIS/QGIS	Spatial mapping
OriginPro	Graphs and plots
OMNIC or equivalent	FTIR spectral interpretation
ImageJ	Particle size analysis

5. Results and Discussion (Review)

5.1 Global Distribution of Microplastics in Freshwater Systems

A review of recent literature indicates that microplastic contamination has become a pervasive issue in freshwater environments worldwide. Rivers serve as major conduits transporting plastic debris from terrestrial ecosystems to estuaries and oceans while also acting as sources of drinking water for millions of people. Studies from Europe, North America, China, India, and Southeast Asia consistently report the presence of microplastics in surface water, sediments, biota, and treated drinking water.

The abundance of microplastics varies considerably among river systems due to differences in population density, land use, industrial activities, hydrology, seasonal rainfall, and waste management practices. Highly urbanized river basins generally exhibit greater microplastic concentrations than forested or protected catchments. Rivers flowing through metropolitan regions receive substantial inputs from municipal wastewater, stormwater runoff, industrial discharge, and domestic plastic waste.

Research has demonstrated that riverine microplastics are not uniformly distributed. Instead, contamination tends to increase downstream, reflecting cumulative anthropogenic pressures. Tourist destinations, densely populated settlements, and industrial corridors are frequently identified as pollution hotspots.

5.2 Sources of Microplastic Pollution

The reviewed studies consistently identify domestic activities as the primary contributors of microplastics to freshwater systems. Household wastewater containing synthetic textile fibres released during washing represents one of the largest sources. In addition, the widespread use of disposable plastic packaging, shopping bags, bottles, and food containers contributes significantly to secondary microplastic formation following environmental weathering.

Agricultural practices also contribute through the use of plastic mulch films, irrigation pipes, fertilizer sacks, and greenhouse coverings. Over time, these materials degrade into smaller particles that are transported into rivers by rainfall and surface runoff.

Tourism has emerged as another important source, particularly in scenic river stretches and recreational areas where improper disposal of plastic waste increases environmental loading. Similarly, fishing activities near estuaries contribute polypropylene ropes, nylon fishing nets, and plastic floats.

Industrial sectors including textile manufacturing, plastic processing, food packaging, rubber processing, and recycling facilities may release polymer particles through wastewater discharges and material handling losses.

5.3 Morphological Characteristics of Microplastics

Most freshwater studies report **fibres** as the dominant microplastic morphology. Fibres are commonly derived from synthetic clothing materials such as polyester, acrylic, and nylon. Mechanical washing releases thousands of fibres during each laundering cycle, many of which pass through wastewater treatment systems.

Fragments constitute the second most abundant category and originate from the breakdown of larger plastic products exposed to sunlight, temperature fluctuations, and mechanical abrasion. Films are typically associated with plastic carry bags and agricultural mulch, while foams originate from thermocol packaging materials. Industrial resin pellets are comparatively less common but may occur near plastic manufacturing or transport facilities.

Colour distribution varies among studies, with transparent, blue, black, and white particles frequently reported. Particle colour influences heat absorption, weathering behaviour, and the likelihood of ingestion by aquatic organisms.

5.4 Human Health Implications

The occurrence of microplastics in drinking water has raised concerns regarding chronic human exposure. Potential exposure pathways include consumption of untreated or inadequately treated river water, ingestion of contaminated seafood, irrigation of crops with polluted water, and inhalation of airborne plastic particles. Experimental studies suggest that microplastics may induce oxidative stress, inflammatory responses, disruption of cellular homeostasis, and immune activation under certain laboratory conditions. In addition to the particles themselves, plastic additives such as bisphenol A (BPA), phthalates, flame retardants, and certain stabilizers may contribute to toxicological effects if released from plastics.

Microplastics can also adsorb environmental contaminants, including heavy metals and persistent organic pollutants, potentially acting as vectors for their transport. However, the extent to which this increases health risks in humans under real-world exposure conditions remains an active area of research.

Current evidence supports continued monitoring and exposure assessment, while also indicating that more long-term epidemiological and toxicological studies are needed before definitive conclusions can be drawn about many proposed health effects.

5.5 Environmental and Policy Implications

The widespread occurrence of microplastics in freshwater environments underscores the need for integrated watershed management. Effective strategies include improving solid waste management, reducing single-use plastics, enhancing wastewater treatment technologies, and promoting public awareness regarding plastic disposal.

Routine monitoring of river water, sediments, and drinking water sources should be incorporated into regional environmental management programs. Policies encouraging biodegradable alternatives, extended producer responsibility, and community participation in river conservation can help reduce future plastic inputs.

For regions such as Kanyakumari District, where rivers are closely linked to drinking water supply, agriculture, tourism, and fisheries, coordinated action among environmental agencies, local governments, industries, and communities is essential.

6. Conclusion

Microplastic pollution has emerged as a significant environmental challenge affecting freshwater ecosystems across the globe. Rivers act as important transport pathways for plastic debris while simultaneously providing drinking water and supporting agriculture, fisheries, and biodiversity. A review of the available literature indicates that domestic wastewater, municipal runoff, tourism, agricultural plastics, and fishing activities are the predominant sources of microplastic contamination in river systems.

Fibres and fragments are consistently reported as the dominant particle types, with polyethylene, polypropylene, polyethylene terephthalate, and nylon among the most frequently identified polymers. Spatial patterns observed in many studies show increasing contamination from upstream to downstream reaches as a result of cumulative anthropogenic inputs.

The Kodayar–Kuzhithurai River system is a vital freshwater resource for Kanyakumari District and warrants systematic investigation because of its importance for domestic water supply, agriculture, tourism, and estuarine ecosystems. Establishing baseline information on microplastic occurrence, particle characteristics, and potential exposure pathways will support evidence-based water resource management and public health planning.

Although laboratory and environmental studies indicate that microplastics and associated additives may contribute to oxidative stress, inflammation, and other biological responses, many aspects of long-term human health effects remain under investigation. Continued research integrating standardized sampling protocols, advanced analytical techniques, and comprehensive risk assessment is therefore essential.

Future studies should combine field monitoring with laboratory characterization, GIS-based spatial analysis, and human exposure assessment to better understand contamination dynamics in tropical river systems. Such

efforts will strengthen environmental monitoring programs, inform regulatory frameworks, and contribute to achieving sustainable water management and protection of public health.

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