A Bibliometric Review of River Sediment Pollution Assessment for 2004-2023 using PRISMA Guidelines

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in

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Submitted by

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I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of my **Master of Engineering** in **Water Resources and Hydraulic Engineering (Six Semester)** in the Faculty Council of Interdisciplinary Studies, Law & Management, Jadavpur University during the academic session 2023-24.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

The rapid expansion of industry and the intensified use of fertilizers and pesticides have led to a substantial increase in pollutants entering rivers, causing elevated nutrient runoff that triggers eutrophication and harms aquatic life. In major natural aquatic systems around the world, such as those in downstream or agricultural regions, pollution primarily enters rivers through various nonpoint sources. Meanwhile, human-made impervious surfaces and heavily engineered waterways contribute point source pollution to the sediment systems within river basins. These systems are under increasing chemical stress from various contaminants, resulting in pollution levels that negatively affect both human health and ecosystems. Before evaluating different remediation technologies in detail and comparing the efficiency of different analytical methods, it is essential, to first prioritize a comprehensive assessment of the current state of emerging pollutants, focusing on their presence and impact on river sediments. This thorough evaluation is crucial for understanding the environmental impact, to identify pollutants that harm aquatic life, disrupting ecosystems, reducing biodiversity and providing valuable insights to enhance sediment management strategies. In the present study, a systematic approach has been applied for the literature review, starting with selecting relevant keywords and finding the most important articles through a screening process for 20 years spanning from 2004 to 2023 on River Sediment Pollution Assessments (RSPA), with the help of the search engine SCOPUS. This review mainly synthesizes research on various emerging sources of pollution that face river catchment mostly nowadays in river sediments. The 10 important river sediment contaminating parameter has been selected for this study namely, Polychlorinated Biphenyls (PCBs), Freely Dissolved Polychlorinated Biphenyls (FDPCBs), Total Suspended Solids (TSS), Particulate Organic Matter (POM), Total Organic Carbon (TOC), Total Organic Nitrogen (TON), Total Organic Phosphorus (TOP), Heavy Metal Concentration (HevMetC), Pesticide Concentration (PestC) and Ecotoxicity Test (EcoT). Out of 509 journal papers screened from SCOPUS, after thorough evaluation, 169 are found very relevant for inclusion in this study. This study provides a comprehensive assessment of sediment sources, pathways, and storage within river systems, with a focus on sediment management and the effects of local and global environmental changes. Contaminated sediments are a primary concern, as they often transport pollutants, complicating management strategies. The study involves a comprehensive evaluation through a three-stage sequential process: bibliometric examination, scientometric investigation, and qualitative valuation of such target contaminants as keywords, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyse) guidelines. This study systematically evaluates the current research landscape related to (RSPA) using the VOSviewer tool. This is followed by a quantitative analysis of the selected literatures, focusing on the most productive journals, commonly used keywords, influential authors, highly cited articles, and the countries most involved in the field. Key insights from the sample led to a qualitative evaluation, where past and current research trends are identified and discussed. The methods for the detection of pollutants have also been analysed along with the yearwise analysis of the published papers giving the in-depth current trend of the research regarding the RSPA. Finally, gaps in the past researches are highlighted, leading to recommendations for future studies with analytical directions. This bibliometric review aims to guide both new and experienced researchers working in this emergent field of RSPA.

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Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
AIP	Apatite Inorganic Phosphorus
APHA	American Public Health Association
BFRs	Brominated Flame Retardants
BMP	Best Management Practices
Bsi	Biogenic silica
CAC	Codex Alimentarius Commission
CD	Contamination Degree
mCD	Modified Contamination Degree
CF	Contamination Factor
CR	Cancer Risk
CUPs	Current-use pesticides
CV-AFS	Cold Vapour Atomic Fluorescence Spectroscopy
DDE	Dichlorodiphenyl-dichloro-ethylene
DDT	Dichloro-diphenyl-trichloroethane
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DL-PCBs/ dl-PCBs	Dioxin-like PCBs
DMeHg	Dissolved methyl Hg

DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
Dsi	Dissolved Silicon
EcoT	Ecotoxicity Test
EDI	Estimated Daily Intake
EF	Enrichment Factor
EOMsed	Extracted organic matter from sediments
EPA	Environmental Pollution Agency
ERI	Ecological Risk Index
ERL	Effect Range Low
ERM	Effect Range Median values
FAAS	Flame Atomic Absorption Spectrometry / Spectrophotometry
FDPCBs	Freely dissolved polychlorinated bi phenyls
FSS	Fine Sediment Fraction
GC-LRMS	Gas Chromatography-Low Resolution Mass Spectrometry
GC-ANCA	Gas Chromatography using an Automatic Nitrogen and Carbon Analyzer
GC–NICIMS	Gas chromatography–Negative Ion Chemical Ionization Mass Spectrometry
GC×GC -TOF	Two-Dimensional GC coupled with Time-of-Flight Mass Spectrometry
GFAAS	Graphite Furnace Atomic Absorption Spectrometry
HBCDs	Hexa-bromo-cyclodo-decanes
HCB	Hexa-chloro-benzene
HCH	Hexachlorocyclohexanes
HevMetC	Heavy Metal Concentration
HRGC-LRMS	High Resolution Gas Chromatography-Low Resolution Mass Spectrometry
HUPs	Historic-use pesticides
Igeo	Geoaccumulation Index
LC-MS/MS	Liquid Chromatography-Tandem Mass Spectrometry
LOD	Limits of Detection
LOQ	Limits of Quantification
MeHg	Methylmercury
MRL	Maximum Residual Limits
NBs	Nitrobenzenes
ng/g dw	Nano gram per gram, Dry Weight
NOAA	National Oceanic and Atmospheric Administration
NPOC	Non-purgeable organic carbon
NWQS	National Water Quality Standard
OP	Organophosphate
PAHs	Polycyclic aromatic hydrocarbons
PBBs	Polybrominated biphenyls
PBDD/Fs	Polybrominated dibenzo-p-dioxins and dibenzofurans
PBDEs	Polybrominated diphenyle ethers

PCBs	Polychlorinated bi phenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
PEL	Probable Effect Level
PestC	Pesticide Concentration
PFASs	Per- and poly-fluorinated alkyl substances
PLI	Pollution Load Index
POC	Particulate Organic Carbon
POM	Polyoxymethylene
POP	Persistant Organic Pollutant
PRS	Polluted River Stretches
RDS	Road-Deposited Sediments
RSPA	River Sediment Pollution Assessment
SIM	Single Ion Monitoring
SL	Sediment Load
SOM	Sediment Organic Matter
SPM	Suspended Particulate Matter
SQGQ	Sediment Quality Guideline Quotient
SS	Suspended Sediment
SSC	Suspended Sediment Concentration
SumTU	Sum of Toxic Units
TEF	Toxic Equivalency Factor
TEL	Threshold Effect Level
TEQ	Toxic Equivalency Quotient
THQ	Target Hazard Quotient
TOC	Total Organic Carbon
TOP	Total Organic Phosphorus
TOP	Total Organic Nitrogen
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WSR	Water and Sediment Regulation
WSRS	Water Sediment Regulation Scheme

Chapter 1

River and Fluvial Sediments: Pollution, Contamination and Environmental Impact

1.1. Introduction

In environmental engineering, the word "*environment*" can mean different things depending on the size and type of the problem being solved. It is not a fixed definition but rather a flexible concept that changes based on the situation, goal, and work being done. This variety in how "*environment*" is understood reflects the ever-changing nature of environmental engineering. Issues can range from big global problems like climate change to more specific, local ones affecting communities, cities, or regions.

The environment is composed of several interconnected components that together support life and maintain ecological balance. These components can be broadly categorized as the atmosphere, hydrosphere, lithosphere, biosphere, and anthroposphere. The *atmosphere*, a mixture of gases extending outward from the Earth's surface, includes the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. The *hydrosphere* encompasses all water on Earth, such as oceans, rivers, lakes, groundwater, and atmospheric water vapor, playing a crucial role in regulating climate, supporting ecosystems, and providing resources for human use. The *lithosphere*, the solid outer layer of the Earth, includes the crust and upper mantle, providing a habitat for living organisms and containing important resources like minerals and fossil fuels. The *biosphere* is the global sum of all ecosystems, including all living organisms and their interactions with each other and their environment. Lastly, the *anthroposphere* refers to the human-made environment, including settlements, infrastructure, technology, and cultural aspects, which closely interact with and significantly impact the natural components of the environment. These components are interconnected and interdependent, forming a complex web of relationships that sustain life on Earth. Human activities in the anthroposphere increasingly influence and alter natural systems, leading to environmental issues such as pollution, habitat destruction, climate change, and loss of biodiversity. Understanding and managing these components are crucial for sustainable development and the well-being of both ecosystems and human societies.

Pollution is commonly defined as the addition of a substance by human activity to the environment, which can cause injury to human health or damage to natural ecosystems. This definition excludes "natural pollution", although natural processes can also release harmful substances into the environment. There are different categories of pollution: chemical, physical, radioactive, biological, and aesthetic. For every natural act of pollution, for every undesirable alteration in the physical, chemical or biological characteristics of the environment, and for every incident that eroded the quality of the immediate or local environment, there were natural actions that restored that quality. Only in recent years has it become apparent that the sustaining and assimilative capacity of the environment, through

tremendous, is not, after all, infinite. Though the system has operated for millions of years, it has begun to show signs of stress, primarily because of the impact of humans upon the environment.

It was the Industrial Revolution that greatly accelerated the release of pollutants into the environment. The Industrial Revolution originated in the north of England in the late 18th/early 19th century and quickly spread to other regions of Europe and North America. Rapid industrialisation is still going on throughout the world, especially in the developing countries of Asia, Africa, and South America. The variety of pollutants and the extent of pollution are now greater than ever in history, and this trend looks set to continue through this century. Natural processes can no longer cleanse the environment of the enormous quantities of pollutants that are generated daily and the pollution is steadily accumulating in the air, the oceans, and the soil.

Rivers are crucial for transporting and storing weathered materials from continents to oceans, playing a significant role in the biogeochemical cycles and climate of Earth. They exist worldwide in all climatic zones. However, natural processes and human activities have significantly impacted river hydrology, sediment regimes, and contamination. Throughout the Quaternary period, river systems have experienced significant natural hydrological changes due to deglaciation and sea-level shifts. Human activities have left few rivers in a pristine state, with exceptions in Canada, Amazonia, the Congo Basin, and Siberia (Meybeck 2003).

River sediment pollution is a growing concern in developing countries, particularly in South Asia, where rapid industrialization, urbanization, and agricultural expansion have led to increased contamination of water bodies. In South Asia, where regulatory frameworks and enforcement mechanisms are often weak, the problem is exacerbated by inadequate wastewater treatment facilities and unregulated industrial discharge, contributing to the degradation of water quality and the decline of fisheries, which are vital for local livelihoods.

The Ganges River (Batabyal 2023) in India is heavily polluted with lead, cadmium, mercury from untreated industrial effluents, and pesticides from agricultural effluents (Behera et al. 2024) posing risks to both aquatic life and human health. Similarly, the Buriganga River (Majed et al. 2022), and Padma River (Fahad et al. 2024) of Bangladesh face severe chromium contamination from the leather industry, affecting biodiversity and public health. The Indus River (Khan et al. 2022) in Pakistan also suffers from sediment pollution due to agricultural runoff, leading to a decline in fish populations and threatening food security.

1.2. River as a Media of Fluvial Sediment

Fluvial sediments refer to materials transported by, suspended in, or deposited by a stream. These sediments are crucial sources of nutrients, contaminants, and other solid materials for downstream fluvial, estuarine, and coastal environments. Each year, millions of tons of sediment are transported to the oceans (Perry and Taylor 2009).

The term “fluvial” refers to anything related to a stream or river, including organisms that live in or around these water bodies or features created by rivers (Bates and Jackson 1980). Fluvial environments are present on every continent and in all climatic zones (Fig. 1.1). They are often categorized by climate: arid, semi-arid, temperate (cool), temperate (Mediterranean), and tropical. Additionally, rivers are classified based on their flow regimes into perennial

(flowing year-round), intermittent (flowing part of the year, usually during or after a wet season), and ephemeral (flowing occasionally). Intermittent and ephemeral rivers are common in Mediterranean and tropical climates, while perennial rivers are typically found in temperate regions.

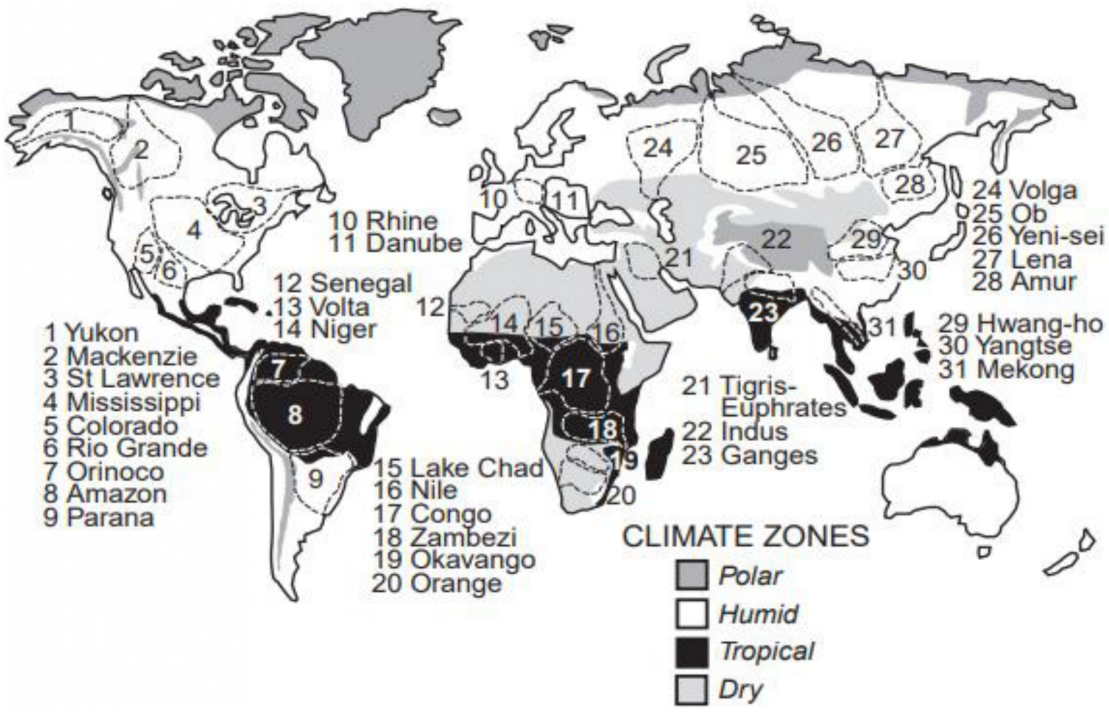


Fig. 1.1. Climatic zones and the largest river basins in the world (Perry and Taylor 2009).

A river system comprises interconnected river channels within a drainage basin primarily featuring channels and floodplains (Fig. 1.2a). In mountainous areas, channels are often incised into bedrock or alluvium with narrow floodplains, while in lowland areas, valleys are broader with extensive floodplains. Rivers are traditionally classified by their planform channel geometries into straight, meandering, braided, and anastomosing types, although these categories overlap and should be viewed as a continuum (Bristow 1996). Changes in channel geometry can result from variations in sinuosity and braiding due to factors like flow rate, sediment processes during floods, and land use.

Fluvial (often refer as alluvial) deposits exhibit diverse bedforms and sedimentary structures, including bars, islands, riffles, ripples, dunes, and various floodplain features (Bridge 2003). The traditional point-bar model for a meandering stream illustrates the different types of fluvial sedimentary deposits (Fig. 1.2b). These features help geomorphologists to understand river sedimentation history, contamination, and flood events. Human activities have significantly impacted fluvial sedimentary environments, often surpassing natural processes and contaminating the river sediment. Both natural and anthropogenic factors can lead to substantial modifications in fluvial sediment transport and deposition and enhance the pollution load to it.

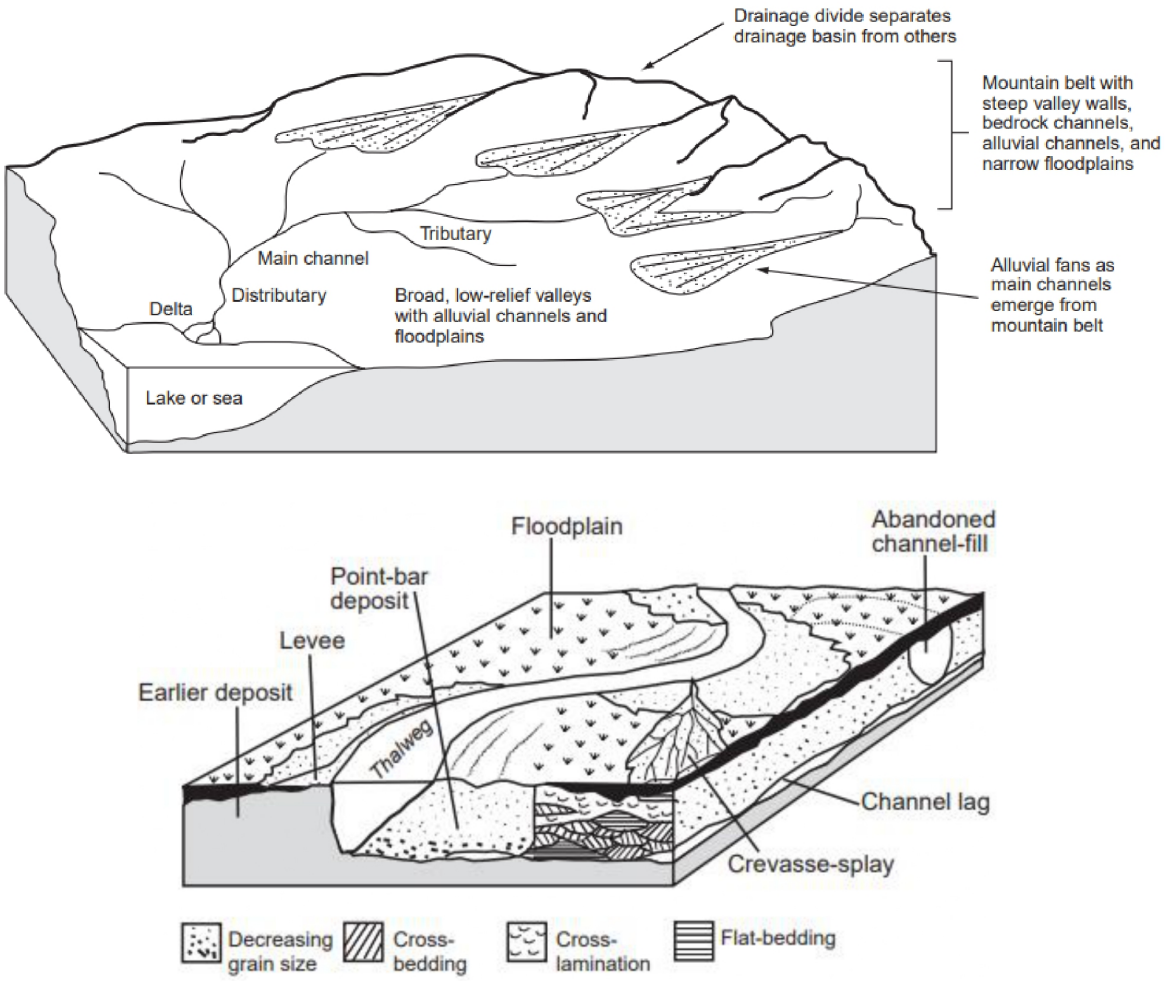


Fig. 1.2. (a) Plan geometry of a hypothetical river system and **(b)** classic point-bar model for a meandering stream, showing various types of fluvial sedimentary deposits (Perry and Taylor 2009)

1.3. Fluvial Sedimentary Environments and Accumulation Processes

Issues related to river basin disturbance differ between the developed world, with mainly temperate rivers, and the developing world, with predominantly arid, semi-arid, and tropical rivers. The developing world faces challenges like drought, irrigation, poverty, salinization, pesticide contamination, and desertification, impacting river systems. Conversely, the developed world focuses on managing and restoring river systems affected by contamination. Both will increasingly confront climate change impacts on river systems.

Fluvial sediments, transported by rivers, include bed load (coarse sediments of mean size greater than 0.0625 mm) and suspended load (fine sediments of mean size less than 0.0625 mm) (Knighton 2014), the latter comprising over 90% of sediment in a river. Sediments are sourced from physical erosion of banks and surface materials, and resuspension of fine channel-bed material. Their characteristics depend on size, shape, and provenance, which influence contaminant distribution. Sediment is derived from natural and anthropogenic activities like erosion, mining, and deforestation.

1.4. Sediment-Bound Contaminants

Contaminants in river systems originate from point sources (e.g., mine discharges, sewage) and diffuse sources (e.g., agricultural runoff). Contaminant concentrations are influenced by the natural background and anthropogenic additions. The primary contaminants include metals, inorganic compounds, nutrients, organic compounds, and radionuclides.

Sediment fingerprinting identifies sediment sources by comparing the properties of fluvial sediments with potential source materials. Tracers, which show conservative behavior during transport, are used to differentiate between sources. Multiple tracers are often employed for effective source apportionment. Table 1.1 lists the main types of sediment-bound contaminants found in river systems. These are grouped into metals and metalloids, inorganic compounds, nutrients, organic compounds and radionuclides.

Table 1.1. Types and sources of natural and anthropogenic inputs to fluvial sediments (Perry and Taylor 2009).

Category	Sources
Bedrock, Soil, Vegetation	Physical weathering occurs through natural erosion, forest fires, and tectonic uplift. Additionally, human activities such as deforestation, agriculture, mining, damming, engineering projects, and urbanization contribute to weathering processes.
Metallic and metalloid elements (Sb, As, Cd, Cu, Co, Cr, Pb, Hg, Ag, Tl, Sn, Zn)	Natural sources, industry, mining, acid mine drainage, sewage, agriculture, vehicle emissions, etc.
Chemicals, Pathogens, Oil	Urban runoff, parking lots, streets, sewage disposal.
Inorganic compounds (SO_4, PO_4)	Natural sources, mining, industry, acid deposition, and agriculture.
Nutrients (C, N, P, K)	Agricultural and urban runoff, wastewater.
Organic compounds (pesticides, herbicides, petroleum hydrocarbons, viruses, bacteria)	Agriculture, industrial processes, sewage, landfills.
Radionuclides (^{137}Cs, ^{129}I, ^{239}Pu, ^{230}Th)	Nuclear power, military, natural sources.

1.5. River Pollution-Causes and Effects

Rivers as one of the basic resources of surface water have Ecologic and notable economic value. The hydrochemical composition and quality of water and the sediments of river beds have always been influenced by natural (geologic) and unnatural (pollution) factors.

The polluting elements entry, based on natural and human activities is one of the most important issues which mankind faces today. Together with the fast industrial and economic growth and producing many kinds of chemical substances as well as the consumption increase, human enters many kinds of contaminants into nature which endangers both man and the

environment. The importance of water resources especially surface water for supplying water needs, declares the important need of maintaining them from pollution, by entering effluents into the main system, consisting of urban, industrial and agricultural sewage, they contain microbial and contaminants such as heavy metals and persistent organic pollutants, industrial chemicals, polychlorinated biphenyls (PCBs), as well as unintentional by-products of many industrial processes, especially polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDFs), commonly known as dioxins. Although some matter in low concentration acts as micro-nutrients in a food chain, their accumulation in high concentrations causes toxicities and adverse environmental effects and as a result endangers the water ecosystem and of course the consumers.

Measuring the heavy metals concentration alone, would not show their pollution intensity. The accumulation of metals and other toxic matters mentioned earlier in sediments provides researchers with suitable information about environmental conditions. Although sediments are the ultimate accumulation of contaminants in aquatic environments, in some cases, they can act as sources of contamination in water themselves. The contaminants remain in the sediment for quite a long time, but due to biological activities and physical and chemical changes they can enter the surface waters, therefore measuring the concentration of contaminants (heavy metals, PCBs, POPs, OCPs etc.) can show a real picture of aquatic environment pollution. To determine the pollution effect, the sources and concentrations of pollutants in the aquatic environment need assessment and monitoring. The amount of pollution in the aquatic environment can be determined by analysis of water, sediments and marine organisms.

1.6. History and Present Scenario of River Pollution in India

The National Water Quality Monitoring Programme (NWMP) has been carried out by the Central Pollution Control Board (CPCB) to evaluate the water quality of the aquatic resources of the nation. According to the report, rivers and static water bodies are particularly concerned about the organic and microbiological pollution of aquatic resources.

The CPCB initiated the exercise of identifying polluted river stretches (PRS) in the country since 2009 based on the river water quality monitored during the years 2002 - 2008 in 29 States/ Union Territories (UTs), and afterwards, reports were brought out in 2015 based on assessment of water quality data monitored during the years 2009-2012 in 27 States/ UTs and in 2018 based on water quality data of the years 2016 and 2017 in 31 States/ UTs. A total of 150 PRS on 121 rivers, 302 PRS on 275 rivers and 351 PRS on 323 rivers were identified and reported in the year 2009, 2015 and 2018.

As per CPCB 2022 reports, in the year 2015, 70% of rivers monitored (275 out of 390) were identified as polluted whereas, in the year 2022, only 46% of rivers monitored (279 out of 603) were identified as polluted.

1.7. Status of Polluted River Stretches in India

The water quality data for years 2019 and 2021 is analyzed by CPCB (2022) and monitoring locations exceeding the water quality criteria are identified as polluted locations. Water quality

data for the year 2020 has not been considered in the exercise as data generated in the year 2020 may not reflect the actual water quality as most commercial and industrial activities were restricted due to the lockdown in the country in light of the COVID 19 pandemic.

Based on the assessment according to the CPCB (2022) report, 311 polluted river stretches (PRS) have been identified on 279 rivers in 30 States and Union Territories (Fig. 1.3). The priority wise number of river stretches is given in Table 1.2. The PRS are categorized under five Priority Classes (I to V) based on the maximum Biochemical Oxygen Demand (BOD) level observed. The criteria for prioritization of the river are also depicted in Table 1.3.

Table 1.2. State-wise and priority wise number of Polluted River Stretches (PRS) in India (CPCB 2022).

Sl No.	State/Union Territory	Priority Class					Total number of PRS
		I	II	III	IV	V	
1	Andhra Pradesh	1			1	1	3
2	Assam	1				9	10
3	Bihar		1	2	7	8	18
4	Chhattisgarh		1		2	3	6
5	Daman And Diu, Dadra And Nagar Haveli			1			1
6	Delhi	1					1
7	Goa				1	5	6
8	Gujarat	6	1	1	1	4	13
9	Haryana	2	1				3
10	Himachal Pradesh	4			1	4	9
11	Jammu & Kashmir			2	4	2	8
12	Jharkhand			1	2	6	9
13	Karnataka	3			3	11	17
14	Kerala			1	2	15	18
15	Madhya Pradesh	2		1	5	11	19
16	Maharashtra	4	5	18	17	11	55
17	Manipur				2	11	13
18	Meghalaya	2			1	4	7
19	Mizoram				2	1	3
20	Nagaland			1		3	4
21	Odisha	1			3	3	7
22	Puducherry		1	1	1		3
23	Punjab	3				2	5
24	Rajasthan	2		1	4	7	14
25	Tamil Nadu	4	1	1	1	3	10
26	Telangana	1	1	2		5	9
27	Tripura					1	1
28	Uttar Pradesh	6		1	2	8	17
29	Uttarakhand	2	2	4		1	9
30	West Bengal	1	2	1	3	6	13
	Total	46	16	39	65	145	311

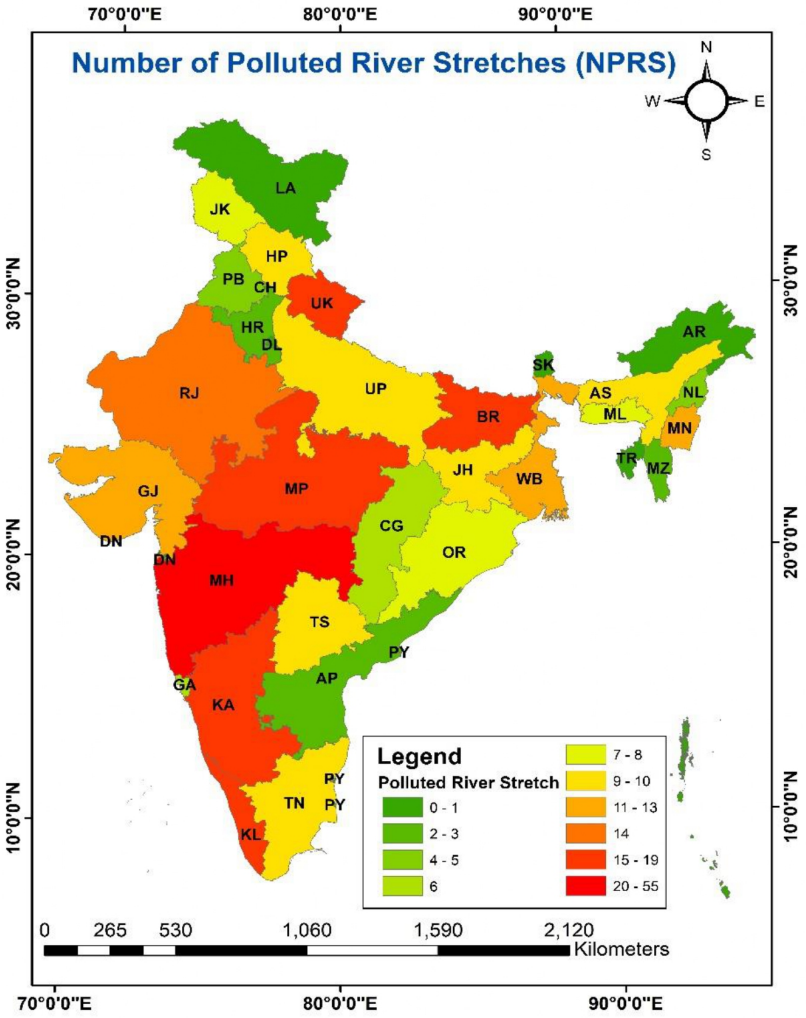


Fig. 1.3. Number of polluted river stretches identified in States/ UTs.

Table 1.3. Priority wise number of polluted river stretches (CPCB 2022).

Priority Class	Number of PRS	Condition of monitoring locations
I	46	Exceeding BOD concentration of 30 mg/ L
II	16	having BOD between 20 – 30 mg/ L
III	39	having BOD between 10 – 20 mg/ L
IV	65	having BOD between 6 – 10 mg/ L
V	145	having BOD between 3 – 6 mg/ L

It was also observed by CPCB that the state of Maharashtra has the highest number of polluted river stretches i.e. 55 followed by Madhya Pradesh (19), Bihar (18), Kerala (18), Karnataka (17), Uttar Pradesh (17), Rajasthan (14), Gujarat (13), Manipur (13), West Bengal (13), Assam (10), Tamil Nadu (10), Himachal Pradesh (9), Jharkhand (9), Telangana (9), Uttarakhand (9), Jammu & Kashmir (8), Meghalaya (7), Odisha (7), Chhattisgarh (6), Goa (6), Punjab (5), Nagaland (4), Andhra Pradesh (3), Haryana (3), Mizoram (3), Puducherry (3), Daman and Diu, Dadra and Nagar Haveli (1), Delhi (1) and Tripura (1).

1.8. Water Quality of Rivers in West Bengal

Water Quality of 26 rivers in West Bengal was monitored at 59 locations during the years 2019 and 2021, out of which, 40 locations on 13 rivers were found non-complying to the prescribed Water Quality Criteria with respect to BOD. The names of 13 polluted rivers are Barakar, Churni, Damodar, Dwarakeshwar, Dwarka, Ganga, Jalangi, Kansi, Mahananda, Matha Bhanga, Rupnarayan, Teesta and Vindyadhari. Details of polluted river stretches identified are given in Table 1.4.

Table 1.4. Number of polluted river stretches in West Bengal (CPCB 2022).

Sl No.	River	Polluted river stretch/ location	Max BOD observed (mg/l)	Priority class
1.	Barakar	Along Asansol	3.1	V
2.	Churni	Bijoypur to Ranaghat	20.8	II
3.	Damodar	Dishergarh to Burdwan	5.2	V
4.	Dwarakeshwar	Along Bankura town	3.8	V
5.	Dwarka	Along Tarapith	5.7	V
6.	Ganga	Behrampur to Haldia	8.0	IV
7.	Jalangi	Along Krishnanagar	6.2	IV
8.	Kansi	Along Midnapore	6.3	IV
9.	Mahananda	Along Siliguri	31.0	I
10.	Matha bhanga	Along Gobindapur	15.3	III
11.	Rupnarayan	Kolaghat to Geonkhali	3.7	V
12.	Teesta	Along Sevoke	3.8	V
13.	Vindyadhari	Haroa to Malancha	29.6	II

Chapter 2

Literature Surveys and Identification of Research Gaps

2.1. Literature Reviews

Several studies have been done assessing the **10 key parameters** namely Polychlorinated Biphenyls (PCBs), Freely Dissolved Polychlorinated Biphenyls (FDPCBs), Total Suspended Solids (TSS), Particulate Organic Matter (POM), Total Organic Carbon (TOC), Total Organic Nitrogen (TON), Total Organic Phosphorus (TOP), Heavy Metal Concentration (HevMetC), Pesticide Concentration (PestC) and Ecotoxicity Test (EcoT) on river sediment pollution assessment (RSPA).

Some recent and impactful studies on **PCBs** are Miglioranza et al. (2013), Mwanamoki et al. (2014), Brito et al. (2015), Kilunga et al. (2017), Barhoumi et al. (2019), Qiu et al. (2020), Lu et al. (2021), Iwegbue et al. (2022), etc. They evaluated the occurrence, distribution and ecotoxicological risk associated with PCBs along with some other persistent organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs).

Researches were done on **PestC** by Devault et al. (2009), Rasmussen et al. (2015), Ccanccapa et al. (2016), Etchegoyen et al. (2017), Cui et al. (2020), Arisekar et al. (2021), and others. They monitored the concentration, occurrence, and fate of some legacy pesticides and of some current use pesticides on RSPA.

Some recent and impactful studies on **HevMetC** were performed by Bere et al. (2016), Zhao et al. (2018), Li et al. (2020), Fan et al. (2021), Tepe et al. (2022), Ali et al. (2023), and others. They investigated the spatial distribution of heavy metals like Cd, Cr, Cu, Pb, Co, Ni, As, Zn, etc. with their possible potential sources and environmental, ecological, human and aquatic life risk assessment.

Researchers such as da Conceição et al. (2020), Laursen et al. (2023), and others studied the historical evolution of pollution level of **POM** in river bed sediments and identified their natural and anthropogenic sources in their respective studies.

Roig et al. (2015), Mata et al. (2020), How et al. (2023), and others assessed the ecotoxicological status (**EcoT**) of river sediment by different bioassay procedures.

Some recent impactful articles on **TOC**, **TON** and **TOP** were produced by Avilés et al. (2006), Ouyang et al. (2006), Jia et al. (2017), Fang and Lien (2021), de Morais et al. (2021) and many others.

The details of literature studies are given below:

Schulz et al. (2003) evaluated the influence of macrophytes on sedimentation and nutrient retention in the lower River Spree. The river stretches near the village of Freienbrink which is a part of the Muggelspree was studied. Sediment cores were analysed for TON and TOC with a thermal conductivity measuring analyzer (Vario EL, Elementar). The study observed that macrophytes significantly reduced flow velocities, thereby creating favorable conditions for

the settlement of organic seston (SPM). Sedimentation was influenced by both the speed of the water flow and the availability of seston. The spatial distribution of deposition corresponded to the flow regime. According to them, discrepancies between calculated and observed deposition can be explained by a high temporal and spatial variability of sedimentological parameters, such as seston concentration. Macrophytes enhance nutrient retention by promoting the sedimentation of organic seston. The retention through deposition is depended on the species composition of macrophyte stands. Deposition is the primary process responsible for phosphorus retention in the lower River Spree.

Avilés et al. (2006) examined the relationship between phosphorus concentration and other sediment properties. The study area was the River Guadalfeo of Southern Spain. Technicon Autoanalyser AAII was employed to evaluate TOP concentration in the collected sample. The study identified that the most abundant form of phosphorus was apatite inorganic phosphorus (AIP), which constituted 68% of the total phosphorus. This was followed by total organic phosphorus (OP), accounting for 29% of the total phosphorus. The study emphasized that the most significant self-cleansing mechanism for removing phosphorus from the water column was calcite-phosphorus co-precipitation. Lithology and sewage inputs were found to be less influential in determining phosphorus concentration.

Ouyang et al. (2006) investigated temporal and spatial distributions of sediment TOC and its relationships to sediment contaminants. TOC concentration was evaluated by Method 9060 (USEPA SW-846) which involves combustion followed by coulometric titration. Total organic carbon was determined using a high-temperature furnace to combust the material to carbon dioxide in an oxygen atmosphere. Significant temporal changes in sediment TOC concentrations were observed over the past century, reflecting variations in the characteristics and magnitude of inputs into the rivers. Meanwhile, high concentrations of contaminants, specifically total polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were detected in Cedar River sediments. However, no correlation was found between TOC and PAHs or PCBs. The study revealed that the southern part of the Ortega River received a higher load of TOC, whereas most hydrocarbons were concentrated in the Cedar River.

Zheng et al. (2008) evaluated the distribution of Hg, Pb, Cd, Zn, and Cu in the surface sediments and typical sediment profiles of the Wuli River, Cishan River, and Lianshan River. Surface sediment samples were collected from these rivers, flowing through Huludao City, a region in northeast China. The ecological risk of the sediments was assessed using two different sets of Sediment Quality Guideline (SQG) indices: effect range low/effect range median values (ERL/ERM) and threshold effect level/probable effect level (TEL/PEL). The concentrations of Pb, Cd, Zn, Cu, and Fe were analyzed using inductively coupled plasma atomic emission spectrometry (ICP-AES). For samples where ICP-AES was not sufficiently sensitive, total metal concentrations were determined using graphite furnace atomic absorption spectrometry (GFAAS). The study found that the potential acute toxicity in the sediment of the Wuli River may primarily be due to Hg contamination, stemming from previous sediment contamination related to chlor-alkali production. Hg was identified as the major contributor to toxicity, accounting for 53.3-93.2% and 7.9-54.9% of total toxicity in the Wuli River and Lianshan

River, respectively, followed by Cd. In the Cishan River, Cd was the primary contributor to sediment toxicity, accounting for 63.2-66.9% of the total toxicity.

Liu et al. (2009) monitored the heavy metal pollution and their fractionations in the surface sediments of the Yellow River in Lanzhou Reach. Surface sediment samples from Lanzhou Reach of Yellow River were collected and concentrations of heavy metals (As, Pb, Zn, Cr, Cu, and Mn) were measured by ICP-AES. The mean sediment concentrations (in μg/g dry weight) ranged from 13.68–48.11 (As), 26.39–77.66 (Pb), 89.80–201.88 (Zn), 41.49–128.30 (Cr), 29.72–102.22 (Cu), and 773.23–1459.69 (Mn). Spatial distribution showed that each heavy metal concentration remained almost constant in this reach. Correlation coefficients indicated that metals were not strongly associated with sediment sand content or organic carbon content (f_{oc}).

Salati et al. (2010) assessed the heavy metal (Cr, Mn, Ni, Cu, Zn, Pb, and Cd) concentrations and sediment of the Khoshk River, Shiraz, Southwest Iran, in order to identify polluted zones and to assess the anthropogenic influence on sediment contamination. Metals concentrations in water and sediments were determined using inductively coupled plasma mass spectrometry (ICP-MS). Urban sampling sites exhibited the highest geo-accumulation index (Igeo) and enrichment factor (EF) values for sediment samples. The abundance of heavy metals in sediments followed the order: Mn > Cr > Pb > Ni > Zn > Cu > Cd. According to the EF and Igeo values, sediments were particularly loaded with Cr, Zn, Pb, Cu, and Cd. The high Ni concentration in all sediment samples likely reflected the geochemical composition of the parent rock. While the elevated Cr levels in the Khoshk River were mainly attributed to anthropogenic activities, the influence of natural sources should also be considered. The study concluded that the primary sources of heavy metals in wastewater are traffic, businesses (such as car washes), building materials, auto workshops, and electroplating industries.

Kim et al. (2010) investigated the chemical forms and accumulation patterns of heavy metals in the sediments of the Kumho River, the main tributaries of the Nakdong River of Korea. The concentrations of heavy metals Cd, Co, Cr, Cu, Ni, Pb, and Zn were evaluated by ICP-AES and ICP-MS. The study assessed the concentrations, with Cd, Co, Cr, Cu, Ni, Pb, and Zn averaging 1.67, 20.9, 99.7, 125, 97.6, 149, and 298 ppm respectively, the sediments were classified as heavily polluted according to EPA guidelines. The heavy metal concentrations followed the order: Zn > Pb > Cu > Ni > Cr > Co > Cd. Alternately, the contamination levels based on the average Igeo (index of geo-accumulation) values ranked as Pb > Cd > Zn > Cu > Co = Cr > Ni. The concentrations of heavy metals generally increased downstream, except for Cd and Pb, with the highest levels found near industrial areas. The study indicated that industrial activity was the primary factor contributing to the increased concentrations of most heavy metals at downstream locations.

Aktar et al. (2011) assessed the levels of certain heavy metals in riverine water, sediment and muscles of two different fish species. Fish, water and sediment samples were collected on a monthly basis from the river Ganges (Ball, Howrah, Maheshtala, CETP STP, Middle 1, Middle 2). Standard procedures were used for quantitative estimation of heavy metals Cu, Cr, Cd, Pb

and Zn by atomic absorption spectrophotometer (AAS). The annual average concentrations of Cu, Cr, Cd, Pb, and Zn were found to be 0.15, 0.04, 0.03, 0.02, and 0.29 ppm, respectively. The accumulation order of these heavy metals at the impact points and the middle point was Zn > Cu > Cr > Cd > Pb for water and Cu > Zn > Cd > Cr > Pb for sediment. This data indicated that Cu accumulated the most in the riverine sediments, while Pb had the lowest annual average concentration. The pattern of accumulation suggested that deposition was highest for Zn and lowest for Cd in the muscles of both fish species. The heavy metal contamination in fish could be attributed to the indiscriminate discharge of polluted and untreated sewage sludge into the river. The levels of heavy metals in fish at certain locations were concerning. Therefore, proper care, maintenance, treatment, and disposal of sewage water and sludge were crucial.

Taghinia Hejabi et al. (2011) evaluated heavy metal pollution by determining the distribution and concentration of Cr, Cu, Fe, Mn, Ni, Pb and Zn in sediment besides analysis and distribution of Cr, Cu, Fe, Mn, Pb and Zn in water. River water and bed sediments were collected along the main stream of the River Kabini in Karnataka. Total metals (Cr+3, Cu++, Mn++, Ni++, Pb++, Fe+3 and Zn++*)* were determined by AAS after acid digestion. The study revealed that heavy metal concentrations in the Kabini River sediments exceeded those in background sediment samples. Hierarchical cluster analysis demonstrated significant interrelationships among groups of elements. Cu and Cr exhibited the highest pollution levels, with mean values of 161.033 mg/g and 441.14 mg/g, respectively. Higher concentrations of metals were observed near industrial effluent discharge points. The levels of Cr, followed by Zn and Ni are notably higher than the maximum background values in the Kabini River sediments, particularly at the points where paper mill effluents enter the river.

Hejabi et al. (2013) assessed the association of metal with various geochemical phases by sequential extraction of riverbed sediments of Kabini River, Karnataka, India. Total metals (Cu^{++}, Cr^{+3}, Fe^{+3}, Mn^{++}, Ni^{++}, Pb^{++}, and Zn^{++}) were determined by the AAS technique after acid digestion. The geochemical study indicated that heavy metals were present in the least mobilizable fraction in the overlying water. The results showed that Pb and Cr have a higher potential for mobilization from the sediment due to their higher concentrations in the exchangeable ion and sulfide ion-bound fractions. Additionally, Cu and Pb had the greatest percentage in the carbonate fraction, suggesting that the study area received inputs from urban and industrial effluents. Furthermore, Zn and Ni showed significant enrichment in the sediment, attributed to the release of industrial wastewater into the river. These trace metals pose a risk of contaminating the aquatic environment and entering the food chain.

Zahra et al. (2014) determined the accumulation, spatial and temporal distribution trends, and source identification of heavy metals in sediments of the Kurang and its tributaries. Sediment samples were collected from 21 sites during two years of monitoring in pre-monsoon and post-monsoon seasons (2007–2008). The total metal concentration of Cr, Mn, Co, Ni, Cu, Cd, Zn, Ca, Mg, Fe, K, Na, Pb, and Li was determined in triplicate in air/acetylene flame using Fast Sequential AAS. Heavy metal toxicity risk was assessed using Sediment Quality Guidelines (SQGs), specifically the effect range low/effect range median values (ERL/ERM) and the threshold effect level/probable effect level (TEL/PEL). In the post-monsoon season, higher

mean concentrations of Ni, Mn, and Pb were observed, while the pre-monsoon season showed a metal accumulation pattern in the following order: Zn > Mn > Ni > Cr > Co > Cd > Pb > Cu > Li. The enrichment factor (EF) and geoaccumulation index (Igeo) values indicated that sediments were loaded with Cd, Zn, Ni, and Mn. A comparison with uncontaminated background values revealed higher concentrations of Cd, Zn, and Ni compared to the respective average shale values. The concentrations of Ni and Zn were above the ERL values, with Ni concentrations exceeding the ERM values. The contamination of sediments was attributed to both anthropogenic and natural processes.

Devarajan et al. (2015) evaluated the effects of untreated hospital and urban effluent waters on the accumulation of toxic metals in the sediment receiving systems in the Cauvery River Basin (CRB). Cr, Co, Ni, Cu, Zn, As, Cd and Pb concentration in the river sediment was assessed by ICP-MS, and Hg contamination by AAS and TOC content was measured employing loss of ignition (LOI). Mortality (%), length of the surviving ostracods and growth inhibition were determined by using Ostracodtox kit F on benthic ostracod crustacean *Heterocypris incongruens* cysts. As per the study, metal concentrations in CRB sediments were lower than those in hospital outlet pipes (HOP), but both exceeded Sediment Quality Guidelines (SQGs) and the Probable Effect Concentration (PEC) for aquatic life. Ecotoxicity tests with ostracods showed mortality rates of 22–100% in HOP sediments and 18–87% in CRB sediments. The results of this study showed the variation of toxic metal levels as well as toxicity in sediment composition related to both the type of hospital and the sampling period. The method of elimination of hospital and urban effluents leads to the pollution of water resources and may place aquatic organisms and human health at risk.

Rasmussen et al. (2015) studied the samples from 19 Danish first and second order streams to compare the toxicity of legacy pesticides and their metabolites to those of contemporary pesticides in the streams situated in agricultural landscapes covering a range of agricultural intensity, local climate and soil types. The study area was surrounded by agricultural land and forest, there was no influence from wastewater treatment plants. Analysis of water samples has been done by GC-MS (for non-polar compounds) and LC-MS/MS (for polar and semi-polar compounds). Sediment has been sampled in two different methods, i.e. bed sediment was collected (top 1 cm) and suspended sediment was additionally collected. Sediment samples have been analysed by two separate GC/MS systems, one in negative chemical ionization (NCI) mode and one in electron impact (EI) mode. The study suggested that legacy pesticides can be highly significant contributors to the contemporary toxic exposure of stream biota, especially macroinvertebrate communities and that those communities were primarily exposed to legacy pesticides via the sediment. Pesticide concentrations in bed sediment and suspended sediment samples exceeded safety thresholds in 50% of the samples and the average contribution of legacy pesticides to the sum of toxic units, $SumTU_{C.riparius}$ was >90%. Among the legacy pesticides, the organophosphate, chlorpyrifos and organochlorines such as DDT and lindane were the strongest drivers of high SumTU for daphnia, fish and sediment dwelling invertebrates. The dominant source of legacy pesticides was the upper soil layers of the catchments, originating from past agricultural applications.

Roig et al. (2015) aimed to design a cost-effective methodology to study the ecotoxicological status of freshwater systems by applying a quality triad integrating chemical, physicochemical, biological and ecotoxicological data. Pore water and whole sediment samples were collected from the Ebro River basin of Spain. Heavy metal concentrations (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) from the samples were evaluated by ICP-MS. The ecotoxicity of whole sediment has been evaluated in *Vibrio fischeri* (using Microtox 500 Analyser), *Daphnia magna* (microbiotest Daphtoxkit), in the benthic diatom *Nitzschia palea* and *Chironomus riparius* (ASTM E 1706-05 method). Whole sediment bioassays had shown more toxicity than pore water tests. Among the different organisms used, *P. subcapitata* and *C. riparius* were the most sensitive in pore water and whole sediment, respectively. The evaluation of the ecotoxicological status showed high coincidences with the ecological status, established according to the WFD, especially when ecosystem disruption due to numerous stressors (presence of metals and organic pollution) was observed. The study concluded that when chemical stressors negatively impact ecosystem functioning, an ecotoxicological approach using appropriate bioassays in pore water and whole sediment can accurately detect these changes.

Zhao et al. (2015) investigated the distribution, enrichment, and sources of heavy metals in surface sediments of eight rivers on Hainan Island, China. The heavy metals analyzed, including As, Hg, Cd, Cr, Cu, Pb and Zn were measured using ICP-AES. The contamination indices, such as the Contamination Factor (CF), Enrichment Factor (EF), and Geo-accumulation Index (Igeo), indicated that the rivers on Hainan Island ranged from unpolluted to considerably polluted. The Wenlan River was found to be at a moderate to considerable pollution level, with the highest concentrations of Hg, Cr, and Zn. The Nandu, Changhua, Lingshui, Wanquan, and Zhubi rivers were categorized at low to moderate pollution levels, while the Beimen and Ningyuan rivers were relatively less polluted. The Nandu River had the highest levels of Cd and Pb, and the Changhua River had the highest levels of As and Cu. Principal component analysis suggested that the heavy metals Cd, Pb, Cr, and Zn were primarily from anthropogenic sources, while Cu, As, and Hg originated mainly from natural, lithogenic sources.

Ccanccapa et al. (2016) monitored 50 currently used pesticides in water and sediments of the Júcar and Turia Rivers in Ukraine. The sampling has been designed to perform large-scale and long-term (both complete basins, two consecutive years) monitoring to assess temporal trends of pollutants. Sampling was carried out after a month without rainfall events to avoid their influence. Pesticides were determined by liquid chromatography tandem mass spectrometry (LC–MS/MS). The study assessed that the mean concentrations of pesticides ranged from <LOQ up to 200 ng/L. Chlorpyrifos was the most frequent pesticide whereas imazalil, thiabendazole, tolclofos methyl, ethion and carbofuran were those found at higher concentrations. The temporal variations also indicated a strong relation between pesticide concentrations with hydrology, the higher the river flow, the higher the number and frequency of pesticides but at lower concentrations. At lower river flows higher pesticide concentrations were detected.

Fernandes et al. (2016) evaluated the advantages of combined analysis of trace elements (Cu, Co, Cr, Zn, Cd, Ni and Sc) with POM – through POC, PON, the C:N ratio and the stable isotopes $\partial^{13}C$ and $\partial^{15}N$ in order to identify their natural and anthropogenic sources in a tropical environment. Suspended sediments were collected at the Sorocaba River mouth, **a** watershed in the Sao Paulo State of Brazil. The particulate organic matter (POM) content in the sediment sample was calculated by multiplying the POC by 1.72. The study found that Zn was the most abundant trace element in the fine sediment fraction (FSS), followed by Cr, Cu, Ni, Co, Sc and Cd. There was a higher concentration of trace elements during the dry season, except for Sc and Co. The POM showed the same trend, with higher concentrations during the dry season. The calculated enrichment factors (EF) and geoaccumulation index (Igeo) indicated that most of the trace elements are of geogenic origin, except for Zn, which showed significant anthropogenic contributions (55%). A significant correlation found between the concentrations of Zn and POM indicated that the main anthropogenic source of Zn is related to this domestic sewage.

Anim et al. (2017) quantified the amounts of PCBs and brominated flame retardants (BFRs). The study area spanned the Brisbane River, measuring about 70.5 km long between Karana Downs and the Port of Brisbane. The gas Chromatography-tandem mass spectrometry (GC-MS/MS) method was used for the detection of the concentration of PCBs. The study provided some of the first data on the levels of certain BFRs and PCBs in sediments from the Brisbane River estuary. It had been observed that the target compounds were regularly detected but at relatively low levels compared to similar studies elsewhere, with the contaminants fairly evenly distributed along the river. The amounts of PCBs in the sediment were found to be significantly influenced by land use, especially urbanization. Regardless of the ban on persistent organic pollutants (POPs), a suite of Poly Brominated Diphenyl Ethers (PBDEs), PCBs, and Hexa-bromo-cyclodo-decanes (HBCDs) had been present in estuarine sediment at measurable concentrations.

Baqar et al. (2017) assessed the occurrence, ecological risk, and spatial-temporal variations of PCBs in the water and surface sediments in the river Ravi and its three tributaries in Pakistan, i.e., Nullah Deg, Nullah Basantar, and Nullah Bein. GC-MS was adopted for the evaluation of the concentration of PCBs. Among the total studied PCB congeners, PCB-114 was found to be the most prominent one in sediments during both seasons, whereas PCB-37 and PCB-66 had been the most dominant congeners during pre-monsoon and post-monsoon seasons, respectively. The Nullah Deg had been found as the most contaminated tributary of River Ravi due to the reception of industrial and urban wastewater in the study area. Ecological risk assessment reflected considerable potential ecological risk with an ERI value of 95.17 during the pre-monsoon season and moderate potential ecological risk with an ERI value of 49.11 during the post-monsoon season. Also, the WHO-TEQ values were found higher than previous studies from Pakistan and other parts of the world.

Etchegoyen et al. (2017) studied the occurrence, concentration, and fate of pesticides in surface water and bottom sediments of the principal tributaries and main watercourse of the Paraguay-Paraná River. The main point sources of pollution are untreated domestic or industrial effluents or those along with diffuse inputs from agriculture runoff, livestock, resource extraction, and

urban landfills. Twenty-three pesticide (such as OCls, DDT, HCH etc.) compounds were analyzed by GC-μECD. The ranges of total measured pesticide concentrations in water and sediments have been found as 0.004–6.62 μg/l and 0.16–221.3 μg/kg dw, respectively. Endosulfans, cypermethrin, and chlorpyrifos have been evaluated as the most frequently detected compounds and those at the highest concentrations in both environmental compartments and quantitatively the most relevant. All concentrations detected in water were over the recommended guidelines for the protection of aquatic biota. The partitioning indicated a higher affinity for the sediments. Agricultural activity is the source of pesticide-pollution loads, transported by tributaries that reach the main watercourse and alter the quality of the aquatic ecosystem.

Jia et al. (2017) analyzed the historical record of sedimentary nutrients and the mechanism of controlling algae blooms. Sediment cores were collected in the upstream, estuary, and central regions of the Xin'an Reservoir. The inorganic carbon (IC) content was determined by the hydrochloric acid titration method and all samples were measured for TOC and TN using a Euro Vector elemental analyser. The nutrient data revealed varying patterns, suggesting that nutrient sources differ across regions. TOC levels significantly increased from 1.42% at the bottom to 5.97% at the surface in the lacustrine zone. Horizontally, TN and TP in surface sediments exhibited a trend of increasing from the riverine zone to the lacustrine zone, indicating nutrient accumulation in the central reservoir. Despite the deep depth of the reservoir and recent fishery policies, algae blooms in the Xin'an Reservoir have rarely occurred. However, the high TOC flux, the potential bioavailability of nutrients, and occasional local algae blooms indicated a potential risk of eutrophication in the reservoir.

Kilunga et al. (2017) evaluated the occurrence and spatial distribution of toxic metals, POPs, and PAHs in sediments from three main rivers draining the capital city of Kinshasa from tropical urban rivers, Kinshasa, Democratic Republic of the Congo. In addition, the degree of sediment pollution by heavy metals was evaluated using the geo-accumulation index (Igeo) and Enrichment Factor (EF) calculation. PCBs, PAHs, and PBDEs were analyzed using GC-MS/MS, and the concentration of heavy metals was determined using ICP-MS. The majority of the sediments contained four harmful heavy metals, namely Cu, Zn, Cd, and Pb. The results showed that the contamination level was greater than in other Congo River basins. When compared to the other two rivers under investigation, the Makelele River had come out as the most polluted and had significant concentrations of PCBs, DDTs, and PAHs, which had called for limiting the input sources and taking crucial action to stop future contamination of the food chain. The concentrations of PBDEs were found higher in investigated rivers compared with some values detected in many rivers from Sub-Saharan Africa. It had also been noted that PAHs represented the highest contributor to organic micro-pollutants pollution in these rivers. Findings suggested that these rivers had been heavily polluted and might pose a great risk to human health and the aquatic environment.

Lu et al. (2017) studied seven sites in the River Thames and its tributaries to find out to what extent the freshwater of River Thames bed sediments were contaminated with Hexa-chloro-benzene (HCB), seven PCBs, and six PBDEs; to assess whether this contamination could be linked to local sewage effluent discharge; and to examine whether POPs contamination could

be correlated to the depth of the sediment sample. The purified sample extracts were analyzed on a gas chromatograph coupled with a mass spectrometer (GC-MS), and the instrument was run in EI (electron impact) and SIM (single ion monitoring) mode. The highest sediment concentrations of POPs had been found in an urbanized tributary, The Cut and Littlemore Brook. In the majority of cases, the concentrations of the studied chemicals were found to be higher in the sediment samples collected from downstream of the STW (sewage treatment works) than in those collected from upstream. A wide variation in the concentrations of PCBs, PBDEs, and HCB with depth had been observed for the sediment sample from the site at Littlemore Brook Upstream. The concentrations of the chemicals were found to be higher in the second layer of the sediment core than in other layers.

Adeyinka et al. (2018) investigated the presence and concentration of selected PCBs—PCB 28, PCB 77, PCB 101, PCB 52, PCB 153, PCB 105, PCB 138, and PCB 180—in soil, sediment, and surface water samples of the Msunduzi River during the winter and spring seasons. The study area had passed through highly industrialized areas as well as rural and agricultural areas and was the main source of water for the greater region of KwaZulu-Natal, South Africa. Assessment of PCB contamination had been done by GC-MS. The study concluded that surface water contained a lower concentration of PCBs (winter 0.68–22.37 ng/mL and spring 2.53–35.69 ng/mL) compared to sediment (winter 76.53–397.75 ng/g and spring 20.84–443.49 ng/g) and that the winter samples had shown higher total concentrations of PCBs (214.21–610.45 ng/g) compared to the spring season (30.86–444.43 ng/g). In all the sampling sites selected for this study, Du Toit had been found to have the highest PCB concentration levels, and the lowest was found to be after chlorination at the Darvill wastewater treatment plant.

Sevin et al. (2018) evaluated selected POPs, including some PCBs, PBDEs, and organochlorine pesticides (OCPs), from water and sediment samples collected from 12 stations in the Ankara River for 12 months. Regions 1–6 represented the rural section and 7–12 the urban sections. GC-MS had been adopted for the analysis of concentration. Among the tested POPs in water, p,p'-DDE had been found as the most detected contaminant in water samples. Concentrations of POPs in general had much higher concentration in sediment samples compared to water. They had been found in sediment at a frequency of 13 samples for PCB101, four samples for PCB28, and two samples for PCB138 and PCB153. No PCB residues had been detected in water samples. However, PCB101 had been found as the most common contaminant in sediment. No differences between urban and rural regions had been observed.

Abd Wahab et al. (2018) assessed the spatial and temporal variations of Dissolved Oxygen (DO), total suspended solids (TSS) and Suspended sediment concentration (SSC). The water samples were collected from 29 sampling stations for the dry season and wet season along the Terengganu River Basin, which represents water quality levels from downstream, upstream and middle stream. For evaluation of TSS gravimetric method was adopted. The study observed the range of DO (2.11 mg/L – 8.07 mg/L), TSS (0.4 mg/L – 128.2 mg/L) and SSC (0.07 mg/L – 25.6 mg/L). The distribution of land use and land cover activities influenced the level of water quality in watersheds. Water quality analysis showed that TSS and SSC were higher in the dry season but DO were higher in the wet season. The increasing suspended solid

could lead to an increase in the turbidity and the odours and colour of water. Law enforcement was expected to be carried out, especially to illegal land use activists around the Terengganu River Basin.

Zhao et al. (2018) evaluated the spatial distribution of grain size and heavy metals (As, Cd, Cr, Cu, Hg, Pb, and Zn) of river sediments in the Pearl River Delta (PRD), and assessed the potential ecological risk of heavy metal pollution via geo-accumulation index (Igeo) and mean probable effect level quotients (M-PEL-Q). River sediment samples from the Beijiang River, Dongjiang River, Xijiang River, and Tianjiang River of PRD had been collected and evaluated. The heavy metal concentrations in the sediment samples were measured using various analytical methods: As and Hg were measured using Atomic Fluorescence Spectrometry (AFS), Cd and Cu were measured using ICP-MS, Cr, Pb, and Zn were measured using X-ray Fluorescence (XRF). The mean elemental concentrations were observed in the sediments as follows: As (18 mg/kg), Cd (0.84 mg/kg), Cr (55 mg/kg), Cu (43 mg/kg), Hg (0.1 mg/kg), Pb (45 mg/kg), and Zn (136 mg/kg). The maximum concentrations of As, Cr, Cu, Hg, Pb, and Zn occurred in the Beijiang River, whereas the maximum Cd concentration occurred in the Xijiang River. Most heavy metal concentrations were much higher than those in the nearby areas. The results of the Igeo analysis showed that the surficial sediments were moderately to heavily polluted with Cd and moderately polluted with As.

Babut et al. (2019) assessed an up to date diagnosis of the contamination of Saigon River sediments by a range of historical and emerging chemicals on Saigon River in Ho-chi-minh city (HCM), Vietnam. 30,000 small industrial production units and more than 800 large-scale factories located in 15 industrial zones in HCM city. Concentrations of organic contaminants, including PBDEs, PFASs, DDT, PCBs, PAHs, and insecticides, in bed sediments from the Saigon River and adjacent canals had been assessed. PCBs, PAHs, PBDEs concentration were measured by GC-MS/MS and PFASs concentration by LC-MS/MS. The Saigon River's bed sediments exhibit a low level of contamination from various organic pollutants, possibly as a result of the river's strong tidal influence and the monsoon season discharge of pollutants from urban surfaces. The Can Gio mangrove, which offers significant ecological services, is one downstream depositional location that may be impacted by this pattern of pollution transmission.

dos Santos et al. (2019) evaluated the Road Deposited Sediment (RDS) metal enrichment ratio between the end of the wet season and the middle of the dry season. Twenty samples (road deposited sediment, n=8; drainage system, n=6; river sediment, n=6) were collected in two sampling campaigns, in August 2017 (end of the rainy season) and in December 2017 (dry season). Bed sediment samples from the Pitimbu River were collected. Fe, Mn, Zn, Cu, Pb, Cr and Ni concentrations were analyzed in Flame Atomic Absorption Spectrometry (FAAS). The study found that contamination of road-deposited sediments (RDS) is an ongoing and cumulative process, primarily influenced by the density of vehicular traffic. The contamination by heavy metals such as Zn, Cu, Mn, Cr, and Pb was mainly attributed to vehicular activities, including wear of moving parts, oils, brake linings, and exhaust emissions. The Geo-accumulation Index indicated that the RDS was moderately polluted with Cu and slightly

polluted with Zn and Pb. The enrichment ratios of heavy metals in the RDS - Cr (1.3x), Cu (2.6x), Fe (3.3x), Mn (1.5x), Pb (1.5x), and Zn (2.1x) - highlighted the ongoing nature of the contamination. Effective management strategies, such as traffic control measures, road sweeping and maintenance, and public awareness, suggested essential to prevent degradation of the aquatic system due to the cumulative nature of river sediment contamination.

Zanardi-Lamardo et al. (2019) investigated PAHs, PCBs, and OCPs in surface sediments of the Hooghly estuary in order to assess distribution patterns, identify potential sources and infer their potential ecological impact on the local residing biota. Sampling stations were established along the Hooghly estuary and the Sundarban region. GC/MS had been adopted for the quantification of the contaminants. Concentrations of Σ17PAH, Σ182PCB and Σ6DDT ranged from 15.4 to 1731, not detected (nd) to 13.5 and nd to 8.97 ng/g dw, respectively. The study revealed that the concentration of the majority of the PCB congeners was below the detection limit, while an overall relative abundance of DDT and PAH concentrations was found at all sampling stations, which reflected recent development in West Bengal and also dominated by agriculture and multifarious industries in the past. Diagnostic ratios suggested that major sources of PAHs are combustion processes, DDTs are input by agriculture, antifouling paints and public health campaigns, and organochlorines are predominantly from industrial origin. Heavier PCB congeners suggest local sources and short range transport of such chemicals.

Abd Wahab et al. (2019) assessed the sedimentation problem especially the formation of TSS and annual sediment load (SL) taking 29 main sampling stations that are located around the basin representing the length of the Terengganu River. The research was performed during the wet season (January 2016) and dry season (July 2016). The gravimetric method was used to analyse the TSS measured in mg/L. The results showed that the highest average of TSS (mg/L) was 67.2 (wet season) and 128.2 (dry season) which are class III. While the highest turbidity was 43.57 (wet season) and 21.57 (dry season) which are Class II based on the National Water Quality Standard (NWQS). The highest annual average estimation for annual SL flow out from the Terengganu River Basin was 6,846.709 tonnes/km^2/year (Manir River Basin) the lowest in the Pauh River Basin is 2.850 tonnes/km^2/year. The contributors to sedimentation problems are from unsustainable land use such as sand mining activities which effectively trap the bed sediments, backflow that carries out high sediments, as well as sedimentation produced due to the river bank erosion. The study suggested the sedimentation management methods including land use settlement, cliff erosion problems, settlement and negotiable of uncontrolled development operations in Terengganu River and the integration of river management methods based on integrated river basin management in Terengganu River Basin is recommended.

Wang et al. (2019) studied the Pearl River Delta (China) to investigate the depth distribution of PCBs in urban, rural and reclamation-affected river sediment cores, to identify the possible sources of PCBs in the three types of river sediments; and to assess the risks of PCBs in river sediments. A gas chromatograph coupled with a micro-ECD equipped with an HP-5 fused silica capillary column was used to evaluate the PCB concentration and the potential adverse biological effects of PCBs in sediments were assessed by sediment quality guideline quotient (SQGQ). The study discovered that the majority of PCBs in river sediments in the Pearl River

Delta had come from Aroclor 1242, 1248, 1254, and 1016. It also discovered that PCBs had a positive correlation with sand content and microbial biomass carbon and that a new sediment quality guideline quotient (NSQGQ) that takes the threshold effects level (TEL) into account could be a better way to assess the ecotoxicological risks associated with PCBs. Light PCBs (i.e. tetra-, tri-, and penta-PCBs) accounted for a higher proportion at all sampling sites. PCBs had been found largely accumulated in surface sediments, showing a decrease with depth along sediment cores.

Xu et al. (2019) analyzed the effects of sulfate on PCB dechlorination rate, extent, pathway, preferences and dechlorinating-related microorganisms and the influence of fatty acids on PCB dechlorination in sulfate-amended sediment microcosms on the Hudson River and Grasse River. PCBs had been quantified with Hewlett Packard gas chromatograph coupled with a micro-electron capture detector (μECD). The study concluded that dredging may not be necessary for PCB remediation if PCBs in sediments are dechlorinated by microorganisms. In the sediment microcosms, sulfate slightly reduced PCB dechlorination; however, adding fatty acids significantly boosted dechlorination in the Grasse sediment. The effectiveness of fatty acid supplementation to stimulate PCB dechlorination under sulfate-reducing conditions largely depends on the sediment geochemistry.

Cui et al. (2020) investigated the occurrence and fate of nine target pesticides (four historic use pesticides-HUPs: simazine, atrazine, isoproturon and permethrin and five current-use pesticides-CUPs: metaldehyde, chlorpyrifos, chlortoluron, epoxiconazole and cypermethrin) in water, sediment and soil within the catchment environment of the River Ugie catchment, Scotland. GC/MS has been used for pesticide analysis with selected ion mode (SIM). Concentrations of target pesticides in water, sediments and soils were 4.5–45.6 ng/L, 0.9-4.6 ng/g dw and 1.7–8.0 ng/g dw, respectively. Concentrations of chlortoluron, metaldehyde, isoproturon, and atrazine were detected in sediment samples while all other pesticides were below the limit of detection (LOD). Concentrations of pesticides in water were found to be significantly influenced by season, while concentrations of pesticides in riverine sediments showed significant spatial heterogeneity, indicating spatial and temporal associations with pesticide use. Sediment-water exchange showed that the sediment acts as an important secondary emission source particularly for the historic-use pesticides (HUPs), while current local application and sediment emission are both major driving forces for current-use pesticides (CUPs) in the riverine environment.

da Conceição et al. (2020) assessed the historical evolution of pollution levels of trace elements and POM in riverbed sediment from the lower course of the Piracicaba River, Brazil. The trace element concentration (Cd, Cr, Cu, Ni, Pb, Zn and Sc) was measured by ICP OES. Gas chromatography using an Automatic Nitrogen and Carbon Analyser (GC-ANCA) with the direct combustion of sediment, was adopted to determine the percentage of particulate organic carbon (POC) and particulate organic nitrogen (PON) and their respective $\delta^{13}C$ and $\delta^{15}N$ isotopic signatures. The particulate organic matter (POM) content in the sediment sample was calculated by multiplying the POC by 1.72. The study evaluated that Zn was the most abundant trace element in the sediment core, followed by Cr, Cu, Ni, Pb, Sc, and Cd. The assessment of

trace metal pollution revealed that most trace elements were of geogenic origin, except for Cu and Zn. According to Brazilian sediment quality guidelines, Pb posed no potential toxic effect. Cu, Cr, and Zn levels were intermediate to the Threshold Effect Level (TEL) and Probable Effect Level (PEL), while Cd and Ni concentrations exceeded the PEL limits. Elemental and isotopic analyses of carbon (C) and nitrogen (N), along with the C/N ratio, indicated that the anthropogenic origin of particulate organic matter (POM) in the sediment core was mainly due to domestic sewage.

Iwegbue et al. (2020) determined the concentrations, spatial distribution patterns, sources and risks of PCBs in sediments from water bodies around oil production facilities in the Escravos River Basin. 28 PCB congeners, including 12 dioxin-like PCBs and 7 indicator PCBs, were determined in sediments. GC–MS was used to determine the concentrations of PCBs in the sediments. Also, the TOC content of the samples was evaluated according to the Walkley and Black wet oxidation method. The concentrations of Σ28 PCB in sediments ranged between 226 and 31,900 ng/g with a median concentration of 2300 ng/g. Generally, the concentrations of PCBs in sediments around oil production facilities, e.g. wellheads, flow stations, and truck lines, were greater than those found in sediments collected around residential communities and dockyards. Among the 28 congeners that were analyzed, lower chlorinated (2- Cl to 5-Cl) PCBs dominated higher chlorinated (6-Cl to 10-Cl) PCBs in these sites. Both low and high chlorinated PCBs are related to local sources and contaminated areas. The lower chlorinated PCBs are products of dechlorination but are generally not prone to further dechlorination. The median concentrations of PCB homologues in sediments from this river basin followed the sequence: hexaPCBs>penta PCBs>tetra-PCBs>hepta-PCBs>tri-PCBs>di- PCBs>deca-PCBs>octa-PCBs>nona-PCBs. The homologue distribution pattern reflects those of the Aroclor 1254 composition. The risk assessment of PCBs in sediments from this river basin suggested very high potential risks for both organisms and humans.

Köse et al. (2020) assessed some heavy metal concentrations (Zn, Cu, Ni, Cr and Pb) in sediment samples and in the tissues of Carassius gibelio and Capoeta. Sediment samples were collected from 14 stations selected on areas seasonally (2015–2016). Also, cyprinidae species, Capoeta baliki were caught from Dam Lakes and Sakarya River. Cr, Ni, Cu, Zn, and Pb levels in sediment samples and in the tissues of fish were analyzed in samples by Analytic Jena ContrAA 700 (high-resolution continuum source AAS). The study revealed that heavy metal concentrations were higher in the gills and liver of fish compared to their muscle tissue. Specifically, Zn levels in the muscle of Carassius gibelio from Yenice Dam Lake exceeded the permissible limits established by Turkish legislation and the FAO. Moreover, Cr and Ni concentrations in sediment samples were found to be higher during the rainy season than in the dry season, with levels exceeding sediment quality guidelines.

Li et al. (2020) studied the distribution, pollution levels, and potential sources of heavy metals in the trans-Himalayan Koshi River (KR). They used ICP-MS to measure concentrations of trace metals, including Cr, Co, Ni, Cu, Zn, Cd, and Pb. The study found no significant spatial differences in heavy metal concentrations between the upstream and downstream areas, although Cd and Pb levels were higher in the upstream region. The average heavy metal

concentrations in the KR sediments were comparable to natural background levels and were below sediment guideline values. Pollution assessments using the geo-accumulation index (Igeo), enrichment factor (EF), and pollution load index (PLI) indicated minimal anthropogenic influence, except for slight contamination by Cd, Pb, and Cu at some sites. Principal component analysis revealed that Cr, Co, Ni, and Zn were mainly derived from the parent rock, while Cu, Cd, and Pb had both natural and anthropogenic sources.

Mata et al. (2020) evaluated the contamination level and potential risks at a part of a large and important river in Central Africa, the Congo River. Surface sediments were collected from seven stations located in the Maluku-Kinsuka section, in the vicinity of Kinshasa. The toxicity test of sediment samples was performed using the Ostracodtox kit, on benthic ostracod crustacean, and Heterocypris incongruens cysts following the manufacturer's recommendations. Besides toxicity test concentration of heavy metal contaminations (Sr, Cr, Co, Ni, Cu, Zn, As, Cd, Pb and Hg) also had been evaluated by ICP-MS and Advanced Mercury Analyser. The study indicated elevated metal concentrations in sediments from the four densely populated areas (Kinkole, Kauka fishermen, Demoulin, and Chanic). These levels surpassed sediment quality guidelines (SQGs) and probable effect levels (PEL), with geo-accumulation index (Igeo) and enrichment factor (EF) values indicating heavy to extreme pollution and severe to extremely severe enrichment of the analyzed metals. Ostracods exposed to these sediments experienced 100% mortality after just six days of incubation, demonstrating sediment toxicity and the potential risks to aquatic life.

Ndunda et al. (2020) studied the spatial and temporal trends of polychlorinated biphenyls in water and sediment over the Nairobi River, covering upstream, midstream, and downstream, in order to offer knowledge for the appropriate management of Kenya's aquatic systems. GC-ECD was adopted for the evaluation of the concentration of PCBs. Nairobi River recorded high levels of PCBs compared with what had been reported in the past along the Kenyan coast and Lake Victoria. The total concentration of PCB in water in all three sites (upstream, midstream, and downstream) in March exceeded the recommended level of 500 ng/L for total PCBs in drinking water, which raises concerns due to the risk they pose to the human population. The dry season recorded the highest ΣPCB in sediments while the rainy season recorded the highest ΣPCBs in water, with levels exceeding the WHO water quality guidelines. High levels of PCBs were found downstream, which is indicative of the fact that human activities that increase down the river are a contributing factor to PCB load.

Urbaniak et al. (2020) assessed the potential for the application of Hudson River sediment as a plant growth medium by mixing it with various proportions of soil. Hudson River sediment samples were collected for the assessment. CNS analyser was used to quantify TOC, total nitrogen (TN) and sulphur, trace elements were measured by employing ICP-OES and PCBs were evaluated by GC-MS method. The ecotoxicity of the growth medium was evaluated using the following battery of bioassays: Phytotoxkit, Ostracodtoxkit, and Microtox. Bioassays were conducted in accordance with the standard protocol suggested by the respective manufacturer of the test kits. The ecological risk assessment of six trace elements and PCBs in the sediment indicated a medium to moderate risk, emphasizing the need for ecotoxicological testing before

using it as a growth medium. Ecotoxicity tests on the soil/sediment mixture showed that it was non-toxic or mildly toxic to the crustacean *Heterocypris incongruens* and the bacterium *Aliivibrio fischeri*. Based on the physicochemical and ecotoxicological analyses, the sediment was deemed suitable for use as a growth medium for non-edible plants.

Arisekar et al. (2021) assessed the distribution of pesticides and assessed the ecological and human health risks associated with pesticide residue concentration in the Thamirabarani River, the only perennial river of Tamil Nadu, India. Water, sediment and Rohu fish samples were collected from four main areas of interest around the Thamirabarani river basin and analysed by GC/MS. It has been observed that endosulfan, aldrin, and endrin were the predominant OCPs present in water, sediments, and fish. The total pesticide contamination in sediment samples ranged from ND to 16.79 mg/kg. The calculated daily intakes of endosulfan, aldrin, and endrin were above the Codex Alimentarius Commission- acceptable daily intake guidelines (CAC-2020). However, the concentration of pesticides in sediments has been found below the Sediment Quality Guidelines (SQG). The average concentration of pesticides in fish (Labeo rohita) was also below the maximum residual limits (MRL) set by the CAC. The human health risk assessment showed that children and adults exposed to pesticides in water and sediments through ingestion and dermal contact could have higher cancer risks than inhalation.

de Morais et al. (2021) evaluated the elemental and molecular features of the extractable organic matter (OM) of sediments taken from the Piracicaba River, at the confluence region and from the Tiete River. The total carbon (TC) content of the sediment samples was assessed using the dry combustion method. The extracts were acidified and measured using an elemental analyser (TOC-V Shimadzu) for Non-purgeable organic carbon (NPOC) and total organic nitrogen (TON). The average yield of alkaline extraction was 40.71% ± 5.52% of OM present in the bulk sediments. Extracted organic matter from sediments (EOMSed) from the Tiete River exhibited the highest average concentrations of non-purgeable organic carbon (NPOC) and total organic nitrogen (TON) and the lowest average NPOC/TON molar ratios. The high degree of eutrophication in the Tiete River indicated a substantial input of simple organic matter with nitrogenous structures. The humic-like component in EOMSed was the most abundant in both rivers. EOMSed from the Tiete River also featured enhanced biological activity due to the greater contribution of microbial-derived products and the presence of small molecules and nitrogenous structures.

de Filho et al. (2021) assessed the levels and spatial distribution of a suite of heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, Zn, Al and Fe) in surface sediments collected from five estuarine channels in the Parnaíba River Delta and evaluated the heavy metal contamination of the sediments using the geochemical indices and potential ecological risk indices. Trace metal concentration was assessed by flame atomic absorption spectrophotometry (FAAS), also enrichment factor (EF) and geo-accumulation index (Igeo) were used as the quantitative measurement of sediment contamination by Cu, Cd, Cr, Pb, Ni and Zn. Several factors account for the low concentrations of metals, including the minimal anthropogenic activities near the Parnaíba River Delta, the high hydrodynamics, and the sediment texture, as sandy sediments are less likely to retain contaminants compared to finer sediments. The sediments in the Igaracu River

exhibited higher percentages of fine particles and organic matter, making this region potentially more susceptible to urban contamination from Parnaíba city.

Fan et al. (2021) evaluated spatial and seasonal variations in heavy metals of river-delivered sediments and unravel potential pollution sources of the heavy metals. The riverbed sediment and suspended particulate matter (SPM) samples were collected from major tributaries and different locations of the mainstream of Minjiang River, SE China. Pb, Cd, Cr, Mn, Mo, Zn, V, Co, Ni, and Cu concentrations were evaluated by using ICP-MS. Enrichment factor (EF), geo-accumulation index (Igeo) and potential ecological risk index (ERI) were calculated to evaluate anthropogenic influences of heavy metals in sediments. The results showed that SPM samples exhibit higher concentrations of heavy metals compared to paired riverbed sediment samples. Concentrations of heavy metals such as Cd, Zn, Cr, V, Co, Ni, and Cu were higher in upstream SPM samples compared to those in downstream regions, whereas Pb, Mn, and Mo did not display this spatial variation. Most heavy metals, including Pb and Zn, had elevated concentrations during flood seasons and relatively lower concentrations during dry seasons, indicating hydrologic control. However, Cr and Mn exhibited high concentrations in certain dry season samples, suggesting episodic anthropogenic input events.

Fang and Lien (2021) evaluated the distribution, speciation transformation and partition of Hg within the Danshuei River Estuary (DRE) by analyzing different Hg species, including the total Hg and methyl Hg (MeHg) in water and sediment samples. TOC from the sediment sample was evaluated by the Horbia Carbon analyser. The analyzed results indicated that the DRE is contaminated by Hg, and the evidence of Hg sediment is more significant than that of the dissolved Hg. Most of the sedimentary total Hg concentrations exceeded the biological effects range low value of NOAA guidelines (ERL, Hg 150 ng/g). The sediment total Hg (STHg) concentrations inversely and positively correlated with the grain size and TOC content, respectively, suggesting that sediment Hg distributions were strongly influenced by both parameters. However, the sediment MeHg concentrations were generally relatively low, at 0.5% of the sediment total Hg pool. The dissolved methyl Hg (DMeHg) concentration positively correlated with Chl.a in the estuary, indicating that phytoplankton significantly influences DMeHg levels.

Wang et al. (2021) investigated the sediment pollution status and potential sources of heavy metals. Sediment cores were collected from the upstream, downstream and Shajing tributaries of Maozhou River. Concentrations of trace metals (Cr, Ni, Cu, Zn, Cd and Pb) were evaluated by ICP-MS. The study found that the average concentrations of Cr, Ni, Cu, Zn, Cd, and Pb were generally higher than the soil background values in Guangdong Province, the average values in Chinese lacustrine sediments, and the second-class standards for marine sediments. These average concentrations were 0.447 to 15.1 times greater than those found in Chinese lacustrine sediments. Moreover, the upper sediment layers (0–2.00 m) showed significantly worse heavy metal pollution compared to the lower layers (2.00–4.00 m), likely due to rapid industrial development in recent years. The ecological risk of the Maozhou River was considerably higher than that of other river sediments in Guangdong Province, particularly for Cu, Cd, and Ni. The potential ecological risk indexe (ERI) for heavy metals in the Maozhou

River sediments ranked as follows: Cu > Cd > Ni > Cr > Zn > Pb, aligning with the enrichment factor (EF) and geo-accumulation index (Igeo) proxies. Consequently, the study concluded that the Maozhou River is heavily polluted.

Tepe et al. (2022) identified the levels of HevMetC and their possible sources in the Turnasuyu stream sediments to assess the environmental, ecological, and human health risks of the sediments. HevMetC (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, Pb) were determined using an ICP-MS. The average concentrations of heavy metals in the sediments, were measured in mg/kg, following this order: Fe > Al > Mn > Pb > Zn > Cu > Co > Cr > Ni > Cd > As. The highest concentrations were found for Fe, Al, and Mn, while the lowest concentration was for As. Except for Pb, all metal concentrations were within the sediment quality guideline (SQG) limits. The mean Pb concentration was 60.23 mg/kg, exceeding the average levels in the Earth's crust. Environmental risks were assessed using the enrichment factor (EF), geo-accumulation index (Igeo), and contamination factor (CF). Cd exhibited moderate enrichment in the EF index, while Pb showed significant enrichment. The Igeo index indicated that Cd levels ranged from unpolluted to moderately polluted, and Pb levels were moderately polluted. The CF index showed moderate contamination for Cd and noticeable contamination for Pb. The study concluded that the Turnasuyu Stream sediments were not highly contaminated based on those assessments.

Bissassa et al. (2021) evaluated the physico-chemical, geochemical and mineralogical parameters of the water and sediments of the Oued Fez and its tributaries and the Sebou River. Eight sampling sites were selected along the Oued Fez River (upstream), urban catchment output, Oued Fez–Sebou River confluence and its tributaries and the Sebou River. As, Cd, Cr, Cu, Ni, Pb and Zn concentrations were analysed by ICP-AES. The enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF), contamination degree (CD), modified contamination degree (mCD) and pollution load index (PLI) were used to evaluate the intensity of heavy metal pollution in the sediments. A decreasing trend in heavy metal concentrations was identified as follows: Zn > Cu > Pb > Cr > As > Ni > Cd, with a mobility sequence of Cu > Pb > Zn > Ni > Cr. Comparing the total heavy metal concentrations in the sediments of the Oued Fez and Sebou River with previous studies revealed a reduction in the harmful and polluting impact of the Oued Fez on the Sebou River. This improvement was attributed to the construction of wastewater treatment plants (WWTPs). The assessment of heavy metals was carried out using environmental indices and sediment quality guidelines (SQG). The results suggested that the presence of heavy metals in the sediment primarily originates from anthropogenic activities. These findings, along with comparisons to previous studies, highlighted the significant role of WWTPs and sanitation networks in enhancing the water quality of the middle Sebou River.

Chowdhury et al. (2022) assessed the presence of PCBs in sediments of the Turag River, Dhaka, Bangladesh, which is one of the most industrially polluted (directly affected by garments, textile, pharmaceuticals, chemicals, pesticides, jute, metal industries, tobacco, ink, pulp and paper mills, food processing, tanneries, etc.) rivers surrounding Dhaka in Bangladesh. Six PCB congeners namely PCB 10, PCB 28, PCB 52, PCB 138, PCB 153, and PCB 180 had been analyzed in surface sediments by GC-ECD at nine sampling sites. PCB 180 was found to

be the most conspicuous one in sediments during both pre and post-monsoon seasons. The mean concentration of ΣPCBs in pre-monsoon (69.33 ng/g dw) was found higher than in post-monsoon (6.42 ng/g dw). The Ecological Risk Index(ERI) value indicated high potential ecological risk during pre-monsoon and low potential ecological risk during post-monsoon. The levels of total sedimentary PCBs reported from developed countries (China, England, France, Italy, and South Africa) were generally a little comparable to or higher than the levels of total PCBs in the present study. Whereas, the levels of total PCBs on the river sediments from developing countries (Egypt, Vietnam, Romania and Mexico) were generally comparable to or lower than the total PCBs levels in the present study.

Iwegbue et al. (2022) investigated the characteristic concentrations of 28 PCBs congeners, their spatial distributions, sources, and associated risks to the ecosystem in sediments of some rivers in the Niger Delta of Nigeria. Identification and concentration of 28 PCBs were measured by Gas chromatograph -mass selective detector with selected ion monitoring mode and besides this, the pH values, electrical conductivity (EC) and total organic carbon content (TOC) of the sediments were measured by standard methods (Radojevic and Bashkin 1999). The concentrations of PCBs in these river sediments had been found relatively higher than those reported in sediments from many parts of the world which signifies poor regulation and enforcement, continuous emissions from old electrical equipment and improper management and disposal of PCB-containing wastes in Nigeria.

Xue et al. (2022) evaluated the impact of water and sediment regulation (WSR) on the concentration and transport of dissolved heavy metals in the middle and lower reaches of the Yellow River. Dissolved heavy metals, including Cu, Pb, Ni, Cd, Cr, As, and Mn, were measured using ICP-MS. The study found that changes in the oxidation-reduction environment of the Xiaolangdi reservoir during the WSR process significantly impacted the concentrations of dissolved Cu, Cd, Pb, Cr, and As at the Xiaolangdi station, while the concentration of dissolved Ni remained mostly unaffected. At the Lijin station, the dissolved heavy metal content initially increased and then decreased in the first stage due to the release of heavy metals from resuspended sediments. In the second stage, the heavy metal content gradually decreased as they adsorbed onto fine particles discharged from the reservoir. During the WSR period, the dissolved heavy metal flux accounted for 16.9–33.4% of the annual total. The WSR process altered water and sediment transport, with dissolved heavy metal concentrations at the Xiaolangdi station mainly influenced by water and sediment discharge from the reservoir, while at the Lijin station, they were largely affected by sediments resuspended from downstream riverbeds and the scheduling mode of the Xiaolangdi reservoir. The WSR process had a substantial short-term impact on dissolved heavy metal transport. Human intervention, particularly WSRS operations, significantly alters the natural states of both the mainstream and estuarine environments of the Yellow River.

Ali et al. (2023) assessed the impact of heavy metals on the morphological characteristics of aquatic microorganisms in potentially contaminated water in River Swat and River Kabul. Five sample sites were selected from both River Swat and River Kabul and from each river, ten samples of water and sediment were collected. Concentrations of Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were assessed by the AAS method. The Cd concentration was higher than the

Environment Canada standard (0.68 mg/kg) for samples 1 and 5, while samples 2, 3, and 4 were found in the range. Similarly, Cd concentration exceeded the NOAA limit (1.2 mg/kg) for sample S1, while S2, S3, S4, and S5 were within the limits. Additionally, all the samples were found within the permissible limit of USEPA (>6 mg/kg). Among the selected heavy metals, in sediment samples, the highest concentration of heavy metals was reported for Fe and Mn in both River Swat and River Kabul sediments. The comparative analysis of heavy metals in both rivers revealed that heavy metals concentration in River Kabul was higher than in River Swat. River Swat is situated at a high altitude with low anthropogenic intervention, while River Kabul flows in low-lying areas and passes through the major cities, where municipal and industrial effluents are thrown in the river.

How et al. (2023) assessed whether river sediment with a high concentration of heavy metals could be restored using microbial bioleaching. River sediment samples were collected from a contaminated site and an unpolluted reference site from Erren River. Concentrations of eight metals including As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn had been evaluated by ICP-OES because they are the most common metals/metalloids regulated by sediment quality guidelines globally. The residual ecotoxicity of the microbially remediated sediment was tested using the soil nematode *Caenorhabditis elegans*. For the mortality assays, age-synchronous young-adult wild *C. elegans* were incubated in the sediment for 24 h at 20°C without feeding, and for the growth, reproduction, and germline apoptosis assays, age-synchronous larvae were incubated in the sediment for 96 h at 20°C with food. They showed that river sediment with high heavy metal concentrations, especially highly bioavailable Cu, Ni, and Zn could be restored using microbial bioleaching with simple settings. Acidophilic sulfur-oxidizing Acidicaldus sp. SV5 effectively bioleached Cu, Ni, and Zn from the contaminated sediment. C. elegans ecotoxicity testing could be used as screening tool in combination with chemical-based and bioavailability-relevant ecological safety assessment of sediment samples for better decision making.

Song et al. (2023) elucidated the effect of eutrophication on the retention process and estimated the overall retention quantity of each biogenic element in all reservoirs of the entire catchment and the impact of reservoir retention on the annual flux into the sea. Four typical reservoirs Pengshui, Wuqiangxi, Three Gorge, and Danjiangkou were selected based on their different water resident times and corresponding sediment cores were collected from each reservoir. The study analysed the total organic carbon (TOC), total organic nitrogen (TON), biogenic silica (BSi), grain size, and 210Pb chronology of collected sediment cores. TOC and TON were evaluated by an elemental analyzer (Vario Macro cube). The results showed that the average annual sedimentary retention of TOC and TON in the four reservoirs increased by 16% and 18% after dam construction and rapid eutrophication. The retention increments accounted for 20.6%, 7.0%, 8.8%, and 12.1% of the total flux of TOC, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP) and dissolved silicon (DSi) into the sea during the same period, respectively. The retention of TOC and DSi in reservoirs led to a decrease in their annual flux into the sea by 67.2% and 61.4% in 2016 compared to 1960. However, the retention of DIN and DIP increased their annual flux by 6.4-fold and 4.2-fold in 2016 compared to 1960, which was attributed to the substantial emission of fertilizer and sewage in the downstream catchment area of dams.

Spriņģe et al. (2024) assessed how the urban stream syndrome appears in a small stream in Marupite, Riga, Latvia. Samples were analysed with inductively coupled plasma spectrometer (ICP-OES) with optical detection. The study found significant variation in heavy metal concentrations, with higher levels downstream, especially near traffic areas. Metals like Cu, Pb, Fe, Zn, Ni, Cr, Mn, Co, and Cd often exceed environmental quality limits specified in various regulatory enactments. Phytotoxicity tests using *Spirodela polyrhiza* revealed significant negative effects of heavy metals on plant development. The results confirmed that the stream was characterized by urban stream syndrome, both according to the increased concentrations of heavy metals in sediments and the results of the Spirodela phytotoxicity test.

Zhang et al. (2024) evaluated the essential characteristics and spatial distribution of six major metal elements (Cr, Ni, Cu, Zn, As and Pb) in regional aquatic sediments and fish in different seasons. Samples were collected from five urban rivers of Xi'an, China (Weihe, Bahe, Chanhe, Fenghe and Heihe Rivers). The concentrations of major six heavy metals (Cr, Ni, Cu, Zn, As, Pb) in the sediments were measured by ICP-MS and ICP-AES method was used to determine the Hg content in sediments. The findings revealed that influenced by human activities, the heavy metal content in sediments during the wet season was ranked as follows: Cr > Zn > Pb > Ni > Cu > As. In the dry season, the ranking was: Zn > Cr > Cu > Ni > Pb > As. The potential ecological risk indices for sediment heavy metal concentrations in both seasons were well below the thresholds. Based on the estimated daily intake (EDI), target hazard quotient (THQ), total target hazard quotient (TTHQ), cancer risk (CR), total cancer risk (TCR), and the permissible safety limits set by the agencies, the consumption of the examined fish was considered safe for human health.

Zou et al. (2024) investigated the composition and driving factors of the microbial community in the sediments of two PCB-contaminated urban rivers, the Dasha River (DSH) and the Maozhou River (MZH), located in the Pearl River Delta. The concentration of PCBs was determined using a gas chromatograph-mass spectrometer. Besides PCBs the other environmental factors including total carbon (TC), TOC, total nitrogen (TN), total phosphate (TP), total sulfur (TS), ammonium (NH_4^+), and nitrate (NO_3^-) were also measured by TOC-analyser and spectrophotometric method. The study revealed significant community differences between the two rivers, largely driven by environmental factors. Metagenomic analysis detailed the composition and abundance of halogenated aromatic biodegradation genes, primarily associated with Proteobacteria, Desulfobacterota, and Chloroflexi. Network analysis showed strong interactions among these microbes in each river, suggesting a cooperative approach to PCBs biodegradation, and highlighting these interactions as a common survival strategy and metabolic mode in contaminated rivers.

2.2. Research Gaps

The trend and gaps in the researches on River Sediment Pollution Assessment (RSPA) particularly combining the 10 important parameters were unassessed to the best of our knowledge. Also, the methodology of assessing some less concerned parameters which are becoming threats to the aquatic health was unconsidered and neglected. This one is probably

the first review study based on literatures on RSPA, to draw attention to such an overlooked assessment. Some research gaps are mentioned below:

- Among 205 works of literature on the evaluation of Polychlorinated Biphenyls (PCBs), only 77 literatures have been found on river sediment, out of which only one was done from India. Considering the current pollution status of river stretches in India, more research should be conducted.
- None of the work was found assessing contamination of Freely Dissolved Polychlorinated Biphenyls (FDPCBs) on river sediment.
- Very less number of literature found on Pesticide Concentration (PestC), and Total Organic Nitrogen (TON) evaluation overall.
- Plenty of literatures had done work assessing part of Particulate Organic Matter (POM) such as Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC), Nitrous Oxide (N_2O), Total Nitrogen (TN), Total Organic Carbon (TOC), C and N stable isotope ($\delta^{15}N$ and $\delta^{13}C$), C/N ratios. Literature evaluating POM as a complete quantity by analytical method was very few. In majority of POM was measured by multiplying POC with the van Bemmelen Factor of 1.724. It was based on the assumption that organic matter in soil contains about 58% carbon by weight, which can give an idea about the concentration but this will not measure the exact quantity of POM in the sediment sample.
- Research on evaluating Total Organic Phosphorus (TOP) concentration in river sediment was very rare. During the last 20 years of our study span from 2004 to 2023, the TOP concentration in river sediment was evaluated only twice in 2006 and 2015. One of which was on wetland and the other one on river sediment.
- In heavy metal analysis, most of the literatures focused on assessing the contamination levels of Cr, Mn, Ni, Cu, Cd, Zn, and Pb. Assessments of other toxic metals like Hg, As (metalloid), Fe, K, and Co were very few.
- Most of the literature assessed ecotoxicity using the Microtox kit, which examines toxicity in *Aliivibrio fischeri*, a rod-shaped bacterium. In addition to the Microtox kit, the Phytotoxkit should be utilized to evaluate the toxicity of soils, sediments, and liquid samples by examining their effects on plant growth.

Chapter 3

Research Objectives and Framework of Analysis

3. Research Objectives and Methodology

3.1. Objectives of the Study

To provide a thorough idea about the **River Sediment Pollution Assessment** (**RSPA**) from the articles published in the last two decades (2004-2023). The target contaminants in our review study are **10 parameters** which are Polychlorinated Biphenyls (PCBs), Freely Dissolved Polychlorinated Biphenyls (FDPCBs), Total Suspended Solids (TSS), Particulate Organic Matter (POM), Total Organic Carbon (TOC), Total Organic Nitrogen (TON), Total Organic Phosphorus (TOP), Heavy Metal Concentration (HevMetC), Pesticide Concentration (PestC) and Ecotoxicity Test (EcoT). The present study involves a comprehensive evaluation through a three-stage sequential process: bibliometric examination, scientometric investigation, and qualitative valuation of such target contaminants as keywords (i.e. parameters). The main objectives are as follows:

- The main goal of this study is to systematically evaluate the current research landscape related to RSPA.
- To identify the most influential literature sources and the subject areas that had made highly impactful contributions in their respective fields.
- To highlight the most frequently used keywords in the field of RSPA where at least any of the 10 selected parameters were used.
- Extensive co-author analysis on the field of RSPA, to identify the most productive and influential researchers.
- To recognize the articles receiving the highest number of citations and discuss the key research areas associated with these influential articles.
- To give a brief idea about the objectives, main findings and limitations of published articles.
- Identify and discuss the countries actively contributing to the research domain of RSPA, noting the significant contributions from developing countries.
- To identify the most harmful contaminants and significant methodology adopted by the authors to evaluate the mentioned contaminants in the RSPA.
- To summarize the trend in publications on selected keywords (i.e. parameters) in the RSPA.

3.2. Methodology of the Review Study

The main objective of the study is to assess the current state of the research on river sediment pollution assessment (RSPA) by employing a methodical approach. A comprehensive review has been conducted using a three-stage approach: Bibliometric search, Scientometric analysis, and Qualitative assessment. For this, 10 parameters are selected to execute the review study analysis as they have a significant contribution towards river sediment pollution. The comprehensive workflow recommended in *Preferred Reporting Items for Systematic Reviews and Meta-Analysis* (PRISMA) (Page et al. 2021) is shown in Fig. 3.1. The approaches utilized in each of the three stages will be elucidated in the subsequent sections.

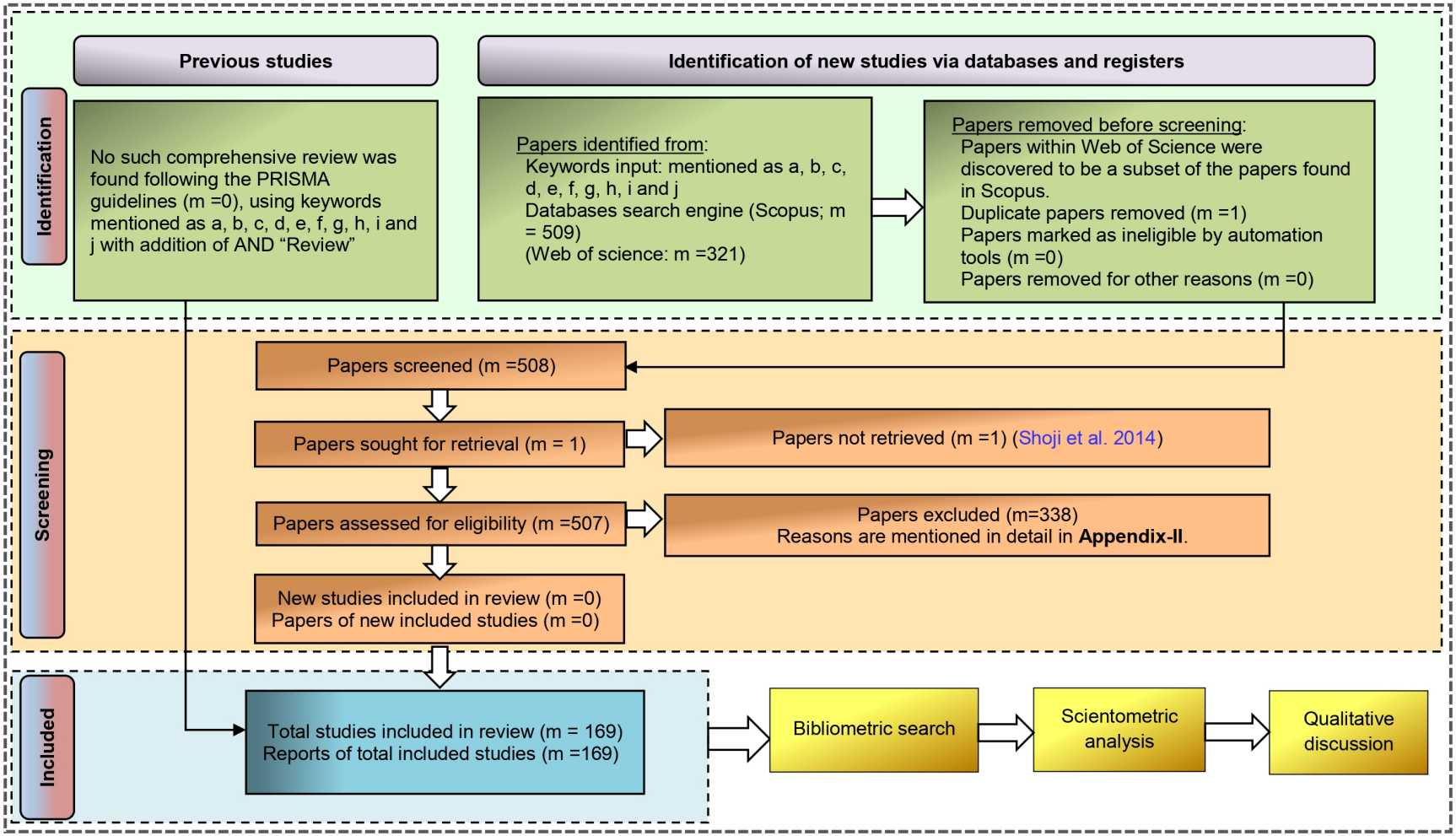
3.2.1. Bibliometric Search

The bibliometric analysis follows the PRISMA methodology which works on four independent levels. In this technique, among the four stages, the first step is to identify the available literature works. For this, keywords need to be entered in various databases such as SCOPUS, Web of Science, Dimensions, Science Direct, Google Scholar, PubMed, etc., and the records to be extracted. The research primarily focuses on river sediment characteristics, thus keywords are selected such that they must include the phrases "river" and "sediment" together with specific parameters, to get correct search results. A comparative analysis has been conducted between a few well-known search engines to ascertain which one yields more precise and accurate results (refer to Table 3.1).

Literatures published in less recognized journals may be indexed in "DIMENSION", however, this is very less whenever using either "WOS" or "SCOPUS". Table 3.1 depicts the same.

Table 3.1. Comparative analysis of search results among Web of Science, SCOPUS and DIMENSIONS.

Combination of Keywords	**Number of Search Results**		
	WOS (All fields)	**SCOPUS** (title-abs-key)	**DIMENSIONS** (title-key)
"River" AND "Sediment" AND "PCBs"	1368	1338	1439
"River" AND "Sediment" AND "Freely Dissolved PCBs"	2	2	4
"River" AND "Sediment" AND "TSS"	455	609	527
"River" AND "Sediment" AND "Particulate Organic Matter"	455	479	415
"River" AND "Sediment" AND "TOC"	1224	1339	1205
"River" AND "Sediment" AND "Total Organic Phosphorus"	2	4	4
"River" AND "Sediment" AND "Total Organic Nitrogen"	23	26	23
"River" AND "Sediment" AND "Heavy Metal Concentration"	144	932	870
"River" AND "Sediment" AND "Pesticide Concentration"	13	118	94
"River" AND "Sediment" AND "Ecotoxicity Test"	5	16	14
Total search results	2321	3523	4595



Note: **a**= "River" AND "Sediment" AND "PCBs; **b**= "River" AND "Sediment" AND "Freely Dissolved PCBs"; **c**= "River" AND "Sediment" AND "Pesticide Concentration"; **d**= "River" AND "Sediment" AND "Particulate Organic Matter"; **e**= "River" AND "Sediment" AND "TOC"; **f**= "River" AND "Sediment" AND "Total Organic Phosphorus"; **g**= ""River" AND "Sediment" AND "Total Organic Nitrogen"; **h**= "River" AND "Sediment" AND "TSS"; **i**= "River" AND "Sediment" AND " Heavy Metal Concentration" ; **j**= "River" AND "Sediment" AND "Ecotoxicity Test".

3.1. Flow diagram showing the representation of the three-step literature review process.

For the bibliometric search "SCOPUS" was chosen as the database. It is recognized as a prominent search engine among scholars and academicians due to its comprehensive coverage of a wide range of academic journals and its inclusion of more up-to-date articles compared to alternative search engines (Chadegani et al. 2013)

The phrase entered in the "*Search within*" field as keywords and in the fields of "*Search documents*" as the combination keywords e.g., "River" AND "Sediment" AND "PCBs", a result of 374 published documents were retrieved.

The next phase of the PRISMA methodology involved the evaluation of the collected literature employing inclusion-exclusion criteria. The screening process was conducted with careful consideration of the scope of this research. To ensure adherence to various criteria, we utilized the available filters in "SCOPUS". As most of these studies were done in the last 20 years (Fig. 4.1), therefore considering the fact this study was done in the last two decades (2004-2023). Further, the study area was restricted to "*Environmental Science*", "*Agricultural and Biological Sciences*", "*Earth and Planetary Sciences*", "*Chemistry*" and "*Engineering*" as the scope was limited to these areas only for the current review study. To prioritize the inclusion of more comprehensive and substantial material, the decision was made to omit conference papers and book chapters and instead focus on published articles.

Another filter was applied in the "*source title*" field, selecting sources that have published more than three articles for this study. Lastly, only articles published in the English language were included in the analysis.

The third step of the PRISMA technique was the "eligibility" criterion, where the previously screened articles were examined according to the scope of the investigation. The title, abstract, and keywords were checked to confirm the articles fell under the content of our research. Our aim of this search study is to find out the most widely used methods which were mentioned among the filtered articles which help to measure the concentration of particular parameters in the river sediment. After screening each, all irrelevant articles were excluded. The duplicate articles were also excluded from the extracted data. The details of the cause for rejection based on the scope of the present study are given in Table 3.4.

The fourth and final step was to use a single or combination of keywords to be present in the articles mandatorily by using the "included" function. With the help of Boolean operators such as "AND" or "OR", the combination of keywords was used to search the articles efficiently according to the requirement. In total, 509 articles were selected for scientometric analysis following the screening process, including 205 articles specifically on PCBs.

The details of keywords and screening steps involved for each parameter in this review study with available article results have been illustrated in Tables 3.2-3.11.

For PCBs at first 374 search results were screened, then the results turned to 286 as the study span was confined to 2004-2023, (as the year 2024 is still ongoing, so the inclusion of 2024 may not provide fixed search results). The rest of the 88 literatures were published from 1980 to 2003. Then after the *language* was set to only English, 15 were found to be in Chinese and one in Polish language. Since the *subject area* is limited to five specific areas (as mentioned earlier), the results exclude the works of literature published in comparatively less important subject areas and are reduced to 268 articles. By setting the *Document type* as only article, the search engines excluded six conference papers, one book chapter, and one review article from 268 and made it 260.

Table 3.2. Search results according to filter application by step for PCBs.

Filters	Criteria	Number of search results
Search documents	"River" AND "Sediment" AND "PCBs"	
Search within	Article title, Abstract, Keywords	1337
	Keywords	374 ✓
Year	2004-2023	286
Language	English	270
Subject Area	Environmental Science	268
	Agricultural and Biological Sciences	
	Earth and Planetary Sciences	
	Chemistry	
	Engineering	
Document Type	Article	260
Source Type	Journal	260
Source Title	Articles greater than 3	205

Note: ✓ denotes the selected search criteria for keywords.

Lastly, the *source title* having articles greater than three publications from the source has been taken as a final screen (exclusion of source title list has given Appendix I). A total of 205 (refer to Table 3.2) have been screened for the next step of analysis of the contamination of PCBs on RSPA. The selection of articles for all other parameters was conducted similarly as described in Table 3.2 for PCBs.

Table 3.3. Search results according to filter application by step for Freely Dissolved PCBs.

Filters	Criteria	Number of search results
Search documents	"River" AND "Sediment" AND "Freely Dissolved PCBs"	
Search within	Article title, Abstract, Keywords	2 ✓
	Keywords	0
Year	All	2
Subject Area	All	2
Document Type	Article	2
Language	English	2
Source Type	All	2

Table 3.4. Search results according to filter application by step for TSS.

Filters	Criteria	Number of search results
Search documents	"River" AND "Sediment" AND "TSS"	

Search within	Article title, Abstract, Keywords	608
	Keywords	55 ✓
Year	2004-2023	48
Language	English	45
Subject area	Environmental Science	44
	Agricultural and Biological Sciences	
	Earth and Planetary Sciences	
	Chemistry	
	Engineering	
Document Type	Article	33
Source Type	Journal	33
Source Title	ALL	33

Table 3.5. Search results according to filter application by step for POM

Filters	**Criteria**	**Number of search results**
Search documents	"River" AND "Sediment" AND "Particulate Organic Matter"	
Search within	Article title, Abstract, Keywords	479
	Keywords	159 ✓
Year	2004-2023	145
Language	English	143
Subject Area	Environmental Science	140
	Agricultural and Biological Sciences	
	Earth and Planetary Sciences	
	Chemistry	
	Engineering	
Document Type	Article	131
Source Type	Journal	130
Source Title	Papers Greater than 3	55

Table 3.6. Search results according to filter application by step for TOC

Filters	**Criteria**	**Number of search results**
Search documents	"River" AND "Sediment" AND "TOC"	
Search within	Article title, Abstract, Keywords	1338
	Keywords	48 ✓
Year	2004-2023	41
Language	English	40
Subject Area	Environmental Science	40
	Agricultural and Biological Sciences	
	Earth and Planetary Sciences	

	Chemistry Engineering	
Document Type	Article	38
Source Type	Journal	38
Source Title	All	38

Table 3.7. Search results according to filter application by step for Total Organic Nitrogen

Filters	**Criteria**	**Number of search results**
Search documents	"River" AND "Sediment" AND "Total Organic Nitrogen"	
Search within	Article title, Abstract, Keywords	26 ✓
	Keywords	1
Year	2004-2023/All	23
Language	English	17
Subject Area	Environmental Science Agricultural and Biological Sciences Earth and Planetary Sciences Chemistry Engineering	17
Document Type	Article	13
Source Type	Journal	13
Source Title	All	13

Table 3.8. Search results according to filter application by step for Total Organic Phosphorus

Filters	**Criteria**	**Number of search results**
Search documents	"River" AND "Sediment" AND "Total Organic Phosphorus"	
Search within	Article title, Abstract, Keywords	4 ✓
	Keywords	1
Year	2004-2023	4
Language	English	2
Subject Area	Environmental Science Agricultural and Biological Sciences Earth and Planetary Sciences Chemistry Engineering	2
Document Type	Article	2
Source Type	Journal	2
Source Title	All	2

Table 3.9. Search results based on filter application by step for Heavy Metal Concentration.

Filters	Criteria	Number of search results
Search documents	"River" AND "Sediment" AND "Heavy Metal Concentration"	
Search within	Article title, Abstract, Keywords	932
	Keywords	230 ✓
Year	2004-2023	225
Language	English	216
Subject Area	Environmental Science	211
	Chemistry	
	Agricultural and Biological Sciences	
	Engineering	
	Chemical Engineering	
Document Type	Article	185
Source Type	Journal	185
Source Title	Papers Greater than 3	126

Table 3.10. Search results according to filter application by step for Pesticide Concentration.

Filters	Criteria	Number of search results
Search documents	"River" AND "Sediment" AND "Pesticide Concentration"	
Search within	Article title, Abstract, Keywords	118
	Keywords	24 ✓
Year	2004-2023	24
Language	English	22
Subject Area	Environmental Science	22
	Chemistry	
	Agricultural and Biological Sciences	
	Engineering	
	Chemical Engineering	
Document Type	Article	24
Source Type	Journal	22
Source Title	Papers Greater than 3	22

Table 3.11. Search results according to filter application by step for Ecotoxicity Test.

Filters	Criteria	Number of search results
Search documents	"River" AND "Sediment" AND "Ecotoxicity Test"	
Search within	Article title, Abstract, Keywords	16 ✓
	Keywords	3

Year	2004-2023	15
Language	English	14
Subject Area	Environmental Science	14
	Agricultural and Biological Sciences	
	Earth and Planetary Sciences	
	Chemistry	
	Engineering	
Document Type	Article	13
Source Type	Journal	13
Source Title	All	13

Table 3.12. Summary of all search results before and after application of the filter option in "SCOPUS".

Parameters	**Author Keywords**	**Number of search results**	
		Before Filter	**After Filter**
Polychlorinated biphenyls	"River" AND "Sediment" AND "PCBS"	374	205
Freely Dissolved PCBs	"River" AND "Sediment" AND " Freely Dissolved PCBS"	2	2
Total Suspended Solids	"River" AND "Sediment" AND "TSS"	55	33
Particulate Organic Matter	"River" AND "Sediment" AND "Particulate Organic Matter "	159	55
Total Organic Carbon	"River" AND "Sediment" AND "TOC"	48	38
Total Organic Phosphorus	"River" AND "Sediment" AND "Total Organic Phosphorus"	2	2
Total Organic Nitrogen	"River" AND "Sediment" AND "Total Organic Nitrogen"	26	13
Heavy Metal Concentration	"River" AND "Sediment" AND "Heavy Metal Concentration"	230	126
Pesticide Concentration	"River" AND "Sediment" AND "Pesticide Concentration"	24	22
Ecotoxicity Test	"River" AND "Sediment" AND "Ecotoxicity Test"	3	13
	Total search results	923	509

Table 3.12 provides an overview of the ultimate search findings for this review investigation, encompassing precise keyword terms for every parameter in "SCOPUS" separately, both before and after the implementation of filters. This demonstrates that significant work was done on PCBs, POM, and HevMetC compared to other parameters in the domain of RSPA.

Articles are then studied thoroughly to further screen the papers in such a way that, the study must be on measuring river sediment contaminating parameters (10 parameters mentioned earlier).

Articles are then studied thoroughly to further screen the papers in such a way that, the study must be on measuring river sediment contaminating parameters (10 parameters mentioned earlier). For these screenings, some criteria have been taken which are precisely mentioned in Appendix II (exclusion criteria) and Appendix III (inclusion criteria). In general, as the sediment sample from the river is our concern, sediment samples from other water bodies like sea, pond, creek, bay, lagoon, wetland, and lake are not included; rivers affected by mining industries are also excluded and the articles worked on sample other than sediment, like surface water, air sample, mussel, crab, fish, was not included in the present review study. But there is some exception, for TSS measurement water sample was considered and ecotoxicity testing (EcoT) different macro-invertebrate (crustaceans, Daphnia magna), or bacteria (Vibrio fischeri) sampling was taken into consideration. After screening 169 articles are selected for Scientometric analysis. The general exclusion causes are given in Table 3.13.

Table 3.13. The general reasons why some articles are not selected for further analysis.

Sl. No.	Reason of exclusion
1.	Sea sediment /coastal sea /ocean sample
2.	Lake sediment sample
3.	Mine nearby study site
4.	Fish sample/Crab/Clam sample
5.	Sample from Lagoon area
6.	Sample from Creek
7.	Bird egg sample
8.	Mussel sample
9.	Stream water sample
10.	Dolphin Sample
11.	Air sample
12.	Sample is adult white sucker
13.	Nuclear power plant accident/Radio-nuclides
14.	Bay sample
15.	Cave sediment
16.	Wetland Sample
17.	Pond sample
18.	Partially insufficient data

3.2.2. Scientometric Analysis

The scientometric analysis using bibliometric mapping, also known as scientific mapping, was the second phase in the review process. It helps in finding the intellectual connection among the dynamically changing aspects of scientific research (Cobo et al. 2011). A scientometric software named VOSviewer (Leiden University, Netherlands) has been used. VOSviewer is a freely available tool, with VOS, the acronym for “visualization of similarities”, offering the functionality needed to visualize the scientometric networks (Hosseini et al. 2018). The

detailed functionality of VOSviewer can be acquired from van Eck and Waltman (2010). The advantages of selecting VOSviewer over other tools are tabulated in Table 3.14.

Table 3.14. Description of applicability for all the available bibliometric analysis tools.

Specification	VOSviewer	CiteNetExplorer	Gephi	SankeyMATIC	NodeXL	Citespace
Software Requirements	Linux, Windows, and MacOS	Linux, Windows, and MacOS	Linux, Windows, and MacOS	Web-based, no installation needed	Windows	Windows, MacOS, and Linux
Programming Knowledge Required	None	None	None	None	None	None
Data Import	SCOPUS, Clarivate Analytics, Web of Science, PubMed, Dimensions	SCOPUS, Clarivate Analytics, Web of Science, PubMed, Dimensions	Formats including CSV, GraphML, GEXF, Pajek	Manual entry, spreadsheet import	Formats including CSV, Excel, GraphML, Pajek	Formats including CSV, Excel, RIS, BibTeX, PubMed
Multiple File Loading	Yes	Yes	Yes	No	Yes	Yes
API Support	Yes	Yes	Yes	No	Yes	Yes
Spreadsheet Export	Yes	Yes	Yes	Yes	Yes	Yes
Dictionary Creation	Yes	Yes	Yes	No	Yes	Yes
Temporal Analysis	Yes	Yes	Yes	No	Yes	Yes
User Experience	Highly flexible and responsive	Flexible and user-friendly	Customizable and powerful	Simple and intuitive	User-friendly with extensive features	Flexible and comprehen-sive
Visualization Tools	Offers various tools	Comprehensive visualization options	Extensive visualization capabilities	Focused on Sankey diagrams	Offers various tools	Rich set of visualization tools

As shown in Table 3.14, “VOSviewer” offers several advantages for scientometric analysis. It is compatible with Linux, Windows, and MacOS, requiring no programming knowledge, making it accessible to a wide range of users. The software supports data import from multiple sources like “SCOPUS”, “Clarivate Analytics”, “Web of Science”, “PubMed”, and “Dimensions”, and allows loading multiple files simultaneously. It also includes API support, spreadsheet export, and dictionary creation features. “VOSviewer” provides temporal analysis and a variety of visualization tools, ensuring a highly flexible and responsive user experience.

The statistics of using the same has been given in Table 3.15. A total of 9,062 published documents utilizing VOSviewer can be found in "SCOPUS" by searching with the **TITLE-ABS-KEY** ("VOSviewer"). Specifically, in 2023 alone, there are 3,078 articles in SCOPUS based on "VOSviewer". The investigation further expanded for other tools and the results are tabulated in Table 3.15 to show their applicability in recent days.

Table 3.15. Table for recent research trends of different bibliometric tools.

Tool	**Total Documents**	**Documents in 2023**	**Keywords Used for Search as** TITLE-ABS-KEY
VOSviewer	9062	3078	"VOSviewer"
CiteNetExplorer	2	0	"CiteNetExplorer"
Gephi	941	147	"Gephi"
SankeyMATIC	2	1	"SankeyMATIC"
NodeXL	280	24	"NodeXL"
Citespace	6304	1937	"Citespace"

3.2.3. Qualitative Discussion

Qualitative analysis and their relevant discussions were the last steps of the scientometric analysis, which involved an in-depth analysis of the existing methodologies adopted in developing RSPA, recognizing various gaps in the research topic and proposing effective future directions to the research involving the domain of water quality indexing.

Chapter 4

Results and Insights from Scientometric Analysis

4. Results of Scientometric Analyses

4.1. Literature Sample Overview

Figure 4.1 shows the distribution of published literatures, until the year 2023. The data showed an overall trend of the research outputs in the domain of River sediment pollution assessment (RSPA). The database used for this review observed that the first literature on RSPA was published in 1980. It was observed that very few literatures were published until the beginning of the 21st century. Post the year 2004, there has been a steep rise in the publication of the literatures. In the past decade, i.e., from the year 2013, quite a good number of literatures have been published. This is indicative of the growing research in this domain, and it is expected that these numbers will go even higher in the upcoming years, owing to the development of newer methodologies and an everlasting wide range of scope in this domain of research. Hence this study is on the researches done during 2004-2023 as most of the research has been done in this time zone (refer to Fig. 4.1).

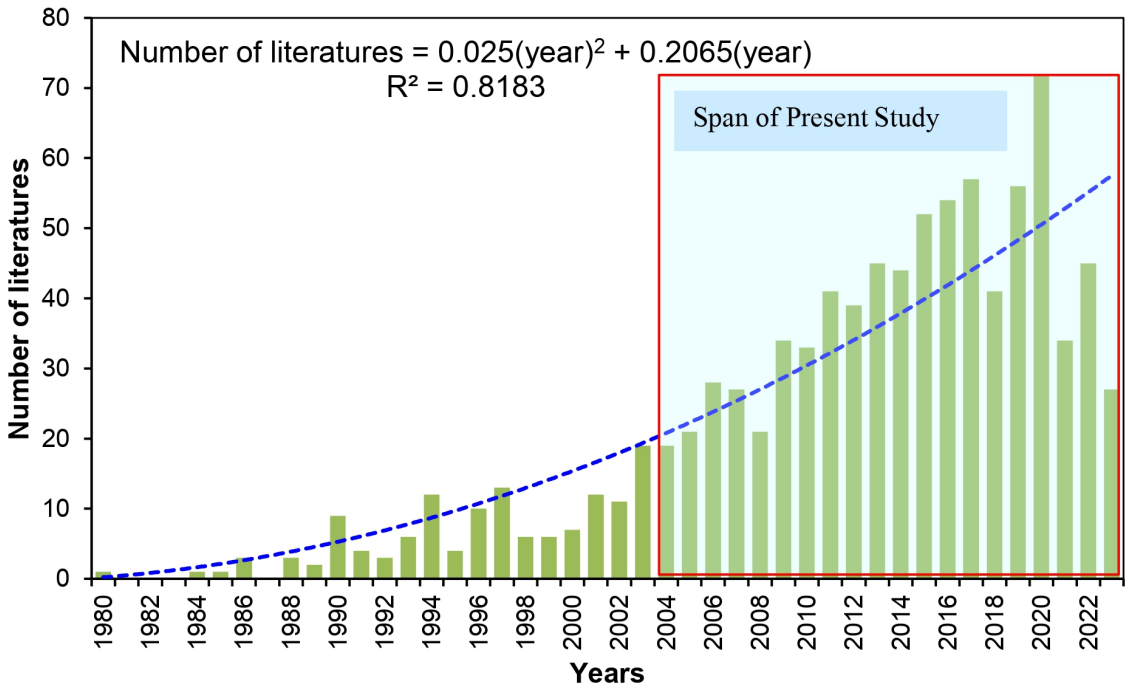


Fig. 4.1. Yearly Distribution of the number of published literatures on mentioned parameters in the review domain of River Sediment Pollution Assessment (RSPA).

The domain of RSPA is primarily focused on *Environmental Science* and *Agricultural and Biological Sciences* (Fig. 4.2). Thus, there exists a huge scope for engineers and scientists worldwide, specializing in *Environmental Science* and *Agricultural and Biological Sciences* work in the domain of RSPA.

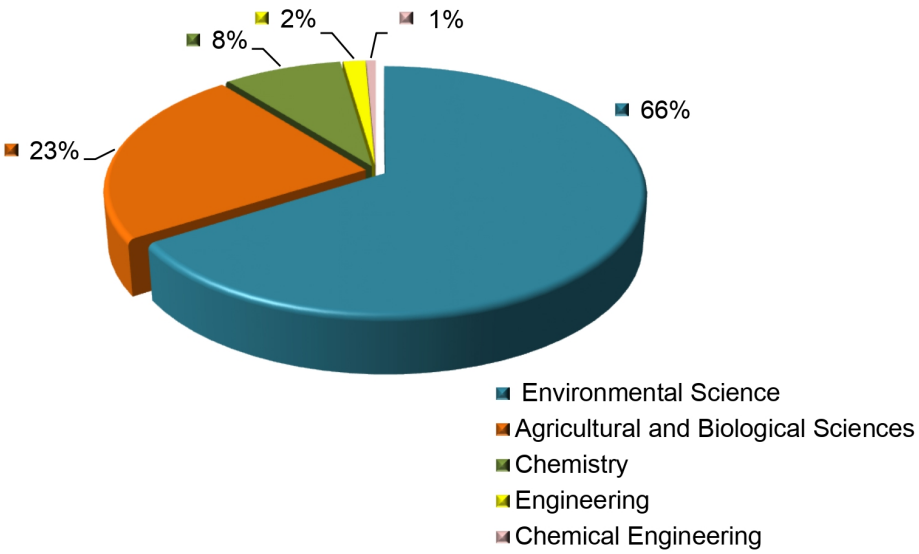


Fig. 4.2. Subject area wise published literatures on the domain of River Sediment Pollution Assessment (RSPA).

4.2. Science-Mapping of Literature Sources

The current study assessed and mapped the literature sources that were used to publish articles in the RSPA area. For analysis in VOSviewer, at least three articles and 50 citations were set as the threshold. As a result, 13 journals out of 32 met the tolerance criteria in total. Figure 4.3(a) displays the clusters of journal sources, their links, and the ways in which they are related to one another. It is important to keep in mind that not all relevant journals may be shown in Fig. 4.3(a). Therefore, Table 4.1(a) provides a more comprehensive quantitative analysis of the journal sources and their significance.

Larger font and node sizes indicate more published articles contributed from that journal in the network representation of the journal sources, as seen in Fig. 4.3(a). This is because the sizes of the fonts and nodes are proportionate to the number of publications from that specific journal. Moreover, the colors of the clusters and connecting lines show how closely related the different journals are to one another in terms of mutual citations. In the field of research, citations are highly valued since they are seen as a standard gauge of the impact of studies conducted in that specific area of study (van Eck and Waltman 2014).

From Fig. 4.3(a), it is visible that the node size of *Chemosphere*, *Science of the Total Environment* and *Environmental Monitoring and Assessment* are larger than others and of almost the same size, which resembles that they published more literatures than other sources.

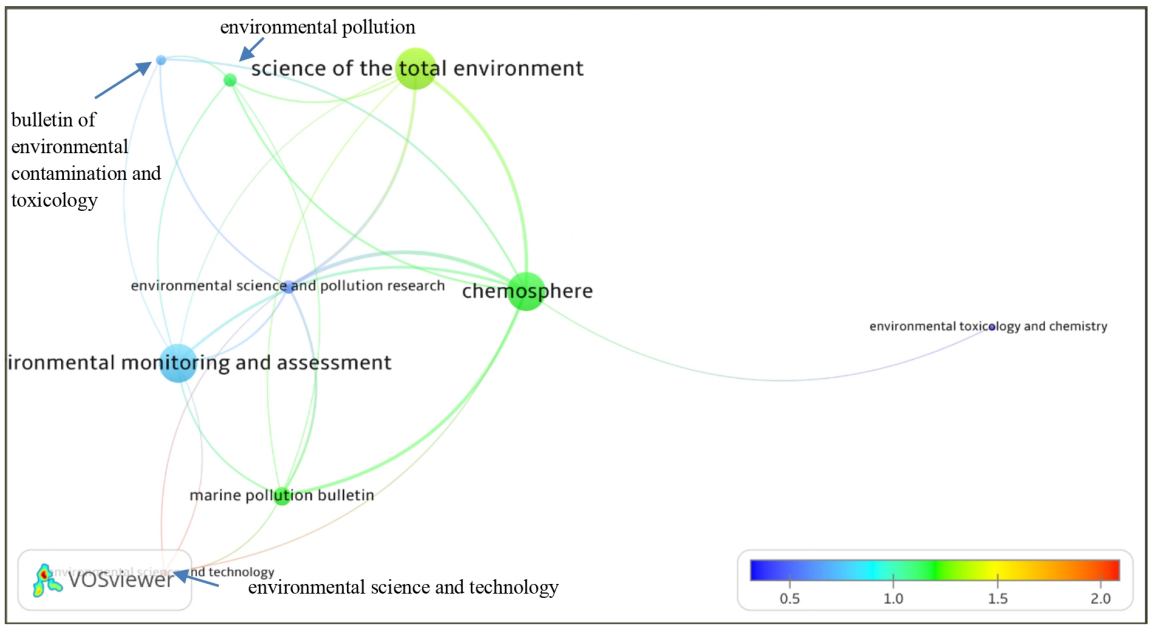


Fig. 4.3(a). Mapping of mainstream literature publishing sources on the field of River Sediment Pollution Assessment (RSPA).

Additionally, these journals also have some network of connecting lines, some of which are dense some of which are not. Dense connecting lines indicate their closeness with respect to the published articles. Here Chemosphere has a dense connection with *Science of the Total Environment*, *Marine Pollution Bulletin*, *Environmental Science and Pollution Research* and *Environmental Monitoring and Assessment*. For better understanding refer to Fig. 4.1(b). A more quantitative assessment has been reported in Table 4.1(a).

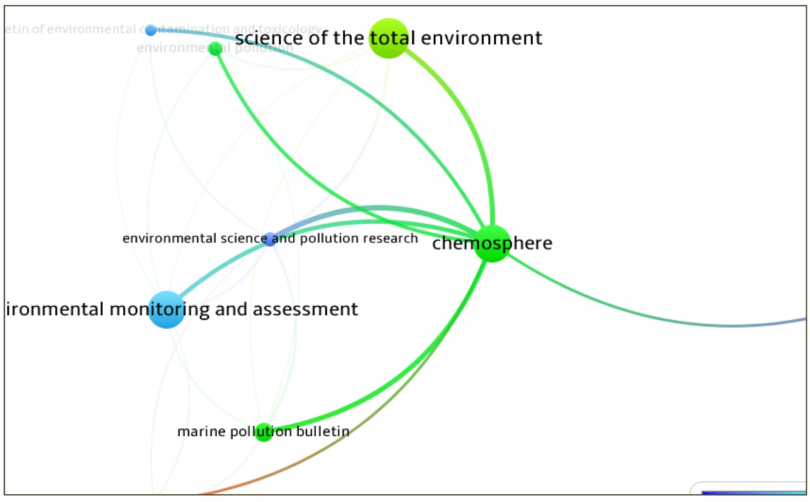


Fig. 4.3(b). Closer view of connecting lines of other sources with journal "Chemosphere".

The total number of published literatures, the total number of citations, the **average citations (avg. cit.)**, the **normalized citations (norm. cit.)** and the **average normalized citations (avg. norm. cit.)** are the five parameters for each journal, and they are listed in Table

4.1(a). While the former two parameters are found to be highly correlated to each other in general, the other three parameters are relatively non-aligned with the other two, i.e., the journals governed by a high number of publications or citations may not necessarily display a higher average citation score. Journals like *Environmental Monitoring and Assessment* and *Chemosphere* both published the same number of literatures (26) but have different impacts on the research field as their avg. norm. cit. was found to be different, which was 0.78 and 1.18, respectively. This also justifies that the number of documents published is not related to the avg. norm. cit. The avg. norm. citation received for that particular journal is significant in demonstrating the impact of a journal and comparing it to the other journals. *Environmental Science and Technology* has the highest avg. norm. cit. value of 2.32, in spite of only three published journals, which makes this journal as the most influential journal with considerable research contribution in the area of RSPA.

Table 4.1(a). Quantitative Assessment of journals publishing in domain RSPA.

Sources	Docu-ments	Citations	Avg. Citations*	Norm. Citations**	Avg. Norm. Citations***
Environmental Science and Technology	3	190	63.33	6.96	2.32
Science of the Total Environment	28	1622	57.93	36.66	1.31
Marine Pollution Bulletin	12	595	49.58	14.36	1.20
Chemosphere	26	1445	55.58	30.60	1.18
Environmental Pollution	9	1125	125.00	10.27	1.14
Environmental Monitoring and Assessment	26	871	33.50	20.22	0.78
Bulletin of Environmental Contamination and Toxicology	7	212	30.29	4.99	0.71
Environmental Science and Pollution Research	9	229	25.44	5.53	0.61
Environmental Toxicology and Chemistry	4	54	13.50	1.40	0.35

Note

*Avg. Cit. are calculated by dividing the total number of citations received by the total number of documents published in that journal.

**Norm. Cit. was automatically calculated in VOSviewer.

***Avg. Norm. Cit. represents the normalized citation per article and is calculated by dividing the Norm. Cit. by the number of published documents. The same calculation steps have been applied to Table -5-7 as well.

The formula used in Excel to calculate correlations =CORREL($E$2:$E$9,B2:B9) say for column E2-E9 and B2-B9

Table 4.1(b). Correlation of citation matrix for data given in Table 4.1(a).

Correlation	Docu-ments	Citations	Avg. Citations	Norm. Citations	Avg. Norm. Citations
Number of Total Documents	1				
Number of Total Citations	0.84	1			
Number of Avg. Citations	0.03	0.51	1		
Number of Norm. Citations	0.93	0.92	0.20	1	
Number of Avg. Norm. Citations	-0.03	0.18	0.50	0.22	1

Table 4.1(b) shows that *total. cit.* and *norm. cit.* greatly correlate with *documents* published, as it is 0.84. Whereas on the other hand *avg.cit.* and *avg.norm.cit.* both do not correlate with the value of *total documents*, as the correlation values are very low, indicating they are not linked to each other and have to be analyzed separately.

4.3. Co-occurrence of Keywords

In the process of doing keyword analysis, the use of "*author keywords*" and "*fractional counting*" was taken into account inside the *VOSviewer* software. A total of 44 out of 522 keywords were extracted with the boundary condition that the minimum number of occurrences of keywords is three. The repetitive parameters and those having closer resemblance were removed. Finally, 27 keywords were chosen, and they were ordered in Table 4.2 based on how frequently they appeared.

Table 4.2. Keywords in the domain of RSPA according to their occurrences.

Keywords	Occurrences	Keywords	Occurrence
Sediment	53	River Sediment	4
PCBs	34	Spatial Distribution	4
Heavy Metals	28	Surface Sediment	4
Risk Assessment	10	TOC	4
PBDEs	9	Toxic Metals	4
PCDD/Fs	9	Water Quality	4
Pesticides	8	Concentration	3
Bioaccumulation	7	Dioxins	3
Fish	7	Enrichment Factor	3
Water	7	Macroinvertebrates	3
Ecological Risk	5	Phosphorus	3
Organochlorine	5	Pollution Assessment	3
PAHs	5	POPs	3
Pollution	5	Sediment Quality	3
Ecotoxicity	4	Sedimentation	3
Monitoring	4	Total Suspended Solid (TSS)	3

In this area of research, keywords such as "*Sediment*", "*PCBs*", "*Heavy Metals*", and "*Risk Assessment*" indicated higher occurrence frequency (Table 4.2), which is also seen in

Fig. 4.4(a). It is clear from the keyword analysis that *Heavy Metals* and *PCBs* are the most problematic as well as influencing parameters in the domain of RSPA.

In Fig. 4.4(a), seven sets of clusters (represented by different colours) were formed among the keywords according to their closeness. For example, here, cluster one (refer to Fig. 4.4(a)) contains six keywords such as "TOC", "phosphorus", "sedimentation", "total suspended solid", "water quality" and "sediment quality" etc. which are hence closely related to one other. In addition, it is worth noting that keywords originating from distinct clusters may exhibit strong and resilient interconnections.

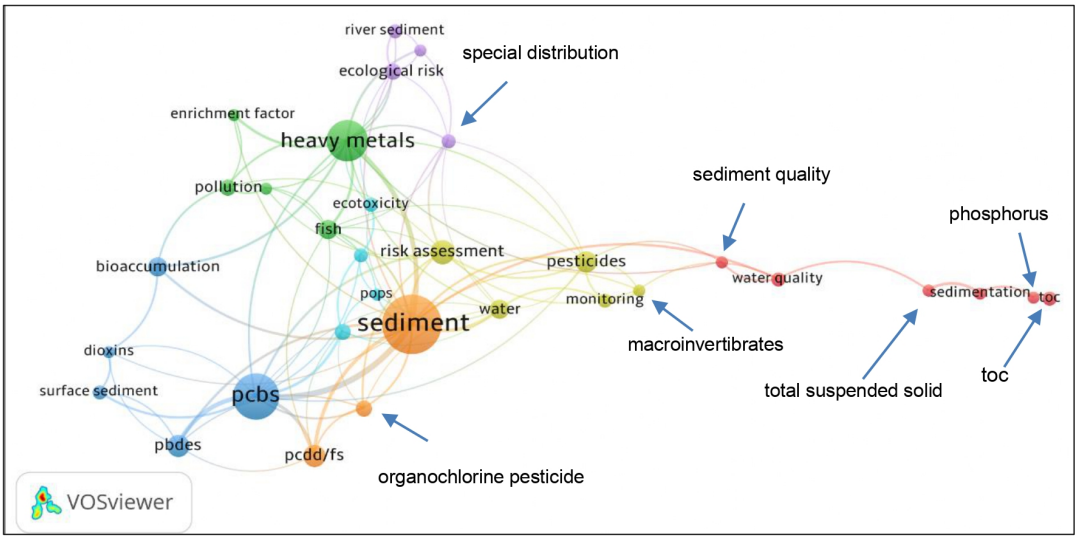


Fig. 4.4(a). Mapping of relevant keywords that have frequently occurred in the published literatures.

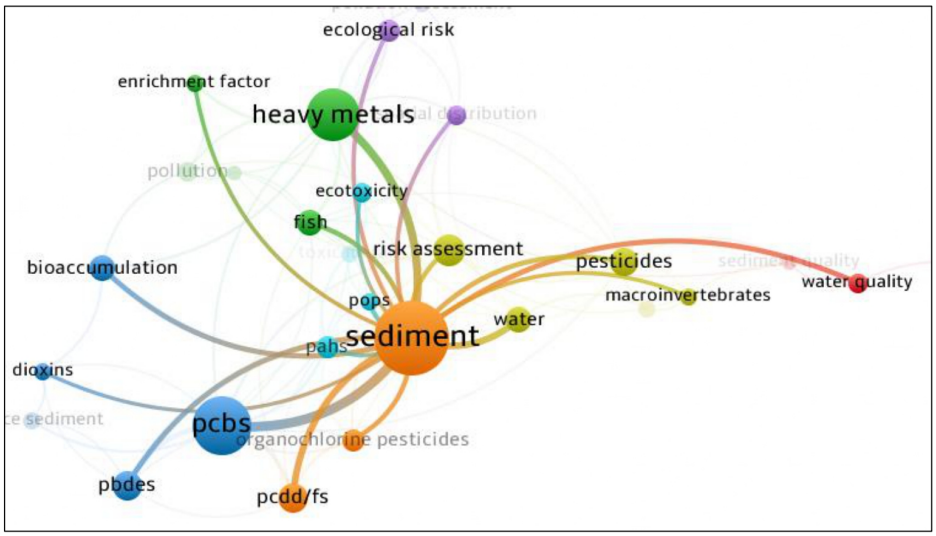


Fig. 4.4(b). A closer view of connecting lines of other keywords with "sediment" keyword.

Figure 4.4(b) shows the status of the connection with the keyword sediment with other keywords. Thicker the line resembles a strong connection which could be based on the

frequency of citations or collaborative research. Thicker lines imply stronger connections or more citations, while thinner lines imply weaker connections.

4.4. Active Countries in the Research

A comprehensive investigation has been conducted via *VOSviewer* to ascertain the respective contributions of several nations in this particular field. For the analysis, a selection of at least five papers and fifty citations per nation have been considered. Out of a total of 52 nations, 14 nations meet the specified requirements. Table 4.3(a) provides a detailed depiction of the specific situation of the nations involved in the study domain of RSPA.

Table 4.3(a). Active countries in the research domain of River sediment pollution assessment (RSPA).

Country	Documents	Citations	Avg. Citations	Norm. Citations	Avg. Norm. Citations
Spain	5	574	114.80	10.78	2.16
China	50	3201	64.02	59.81	1.20
Pakistan	8	720	90.00	9.21	1.15
South Korea	8	442	55.25	8.64	1.08
Germany	6	430	71.67	5.99	1.00
France	10	477	47.70	9.88	0.99
India	10	426	42.60	9.83	0.98
United Kingdom	7	390	55.71	6.59	0.94
United	23	1013	44.04	18.22	0.79
Switzerland	7	261	37.29	5.50	0.79
South Africa	8	193	24.13	5.52	0.69
Brazil	11	272	24.73	7.38	0.67
Taiwan	10	283	28.30	6.24	0.62
Japan	6	218	36.33	2.00	0.33

Table 4.3(b). Correlation of citation matrix for data given in Table 4.3(a).

Correlation	Docu-ments	Citations	Avg. Citations	Norm. Citations	Avg. Norm. Citations
Number of Total Documents	1				
Number of Total Citations	0.96	1			
Number of Avg. Citations	0.00	0.26	1		
Number of Norm. Citations	0.97	0.99	0.19	1	
Number of Avg. Norm. Citations	0.06	0.27	0.88	0.26	1

Table 4.3(a) lists the total number of publications from each country along with the avg. cit., norm. cit. and avg. norm. cit. *China* significantly contributes to this research domain, having more than 50 published articles which got 3201 citations. But the most impactful

research in this domain had been done by *Spain* having the highest avg. norm. cit. of 2.16. Spain published only five literatures which gained a total of 574 citations. Other countries like *China*, *Pakistan*, *South Korea* and *Germany* also had significant contributions as they have a higher rate of avg. Norm. Cit. of 1.20, 1.15, 1.08 and 1.00 respectively, which indicate a stronger influence in terms of research significance/efforts. The contribution of our country *India* also commendable.

Visual analysis of Fig. 4.5 explains the enormous research contribution by countries like China, Spain, United States, France, United Kingdom, South Korea, Pakistan, Switzerland, Brazil, Germany, Taiwan and Japan in this domain. It shows that China has a connection with 13 other countries in the case of the research domain of RSPA. Among all the connected lines few of them are much thicker which are connected with Pakistan, United States and South Korea implying a stronger connection with China.

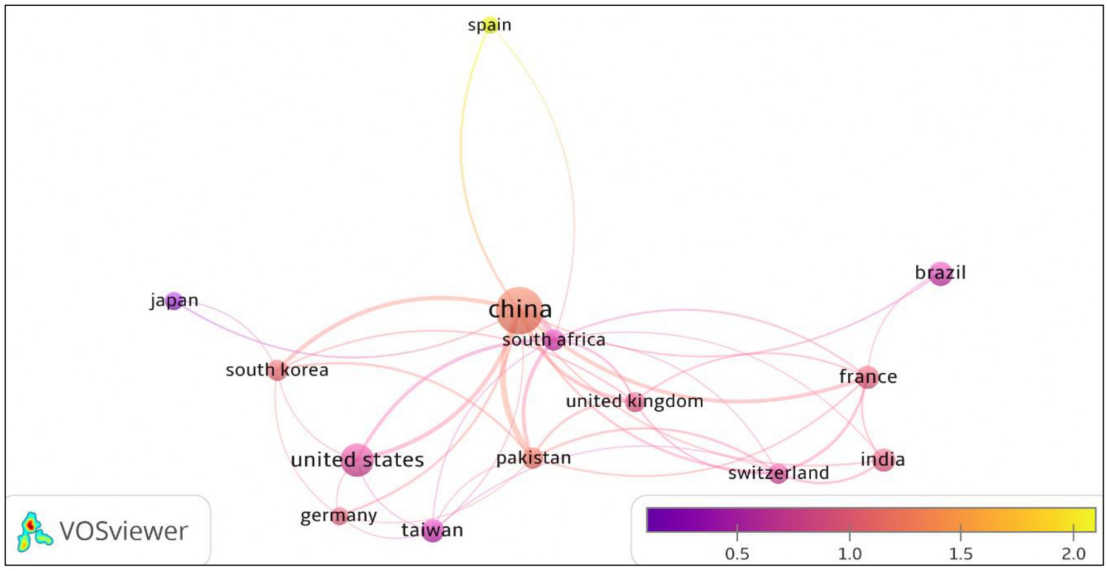


Fig. 4.5. Mapping of the countries that are most active in the research domain.

4.5. Co-authorship Analysis

To get an idea about the individual researchers working on RSPA, the co-authorship analysis was carried out, where minimum two numbers of published articles and 100 citations per researcher were made mandatory to find out the most impactful researchers working in this area. 41 among the total of 814 researchers met this criterion and 22 out of them were connected. Table 4.4(a) shows the co-authorship analysis of the most impactful researchers.

Table 4.4(a) lists the different author's contributions quantitatively. The table is listed according to the number of average normalised cited articles per researcher. Lu Q. and Zhang Q. published a greater number of articles than others which resembles their good productivity in the research area of RSPA. Fang W., He Z., Mai B., Wang S., Liang Z. and Liang Y. had maximum avg. norm. cit. value of articles, which reflects their good impact and contribution to the research domain.

Table 4.4(a). Co-authorship analysis in the research domain of River sediment pollution assessment (RSPA).

Authors	Documents	Citations	Avg. Citations	Norm. Citations	Avg. Norm. Citations
Fang W.	2	130	65.00	5.98	2.99
He Z.	2	130	65.00	5.98	2.99
Mai B.	2	130	65.00	5.98	2.99
Wang S.	2	130	65.00	5.98	2.99
Liang Z.	3	421	140.33	8.07	2.69
Liang Y.	2	127	63.50	5.05	2.53
Zhang Z.	3	615	205.00	7.25	2.42
Lu Q.	4	198	49.50	7.54	1.89
Xu J.	2	153	76.50	3.39	1.69
Zhang Q.	4	249	62.25	6.13	1.53
Li H.	2	186	93.00	2.91	1.46
Zhang P.	2	125	62.50	2.89	1.44
Wang J.	3	109	36.33	4.31	1.44
Li M.	3	106	35.33	3.85	1.28
Zhao L.	2	205	102.50	2.55	1.27
Zhang H.	2	145	72.50	2.40	1.20
Huang J.	2	455	227.50	2.24	1.12
Wang Y.	3	197	65.67	3.30	1.10
Zhao X.	2	125	62.50	2.08	1.04
Jiang G.	3	156	52.00	2.87	0.96
Zhang Y.	3	114	38.00	2.39	0.80
Chen P.	3	120	40.00	2.01	0.67

Table 4.4(b) shows the correlation among different research results criteria. Documents published hold negative and low values with both avg. cit. and avg. norm. cit., signifies no such relation. For example, Chen P. has gained gain minimum average normalized citation of 0.67 by publishing three articles. Whereas Fang W., He Z., Mai B., and Wang S. have gained a maximum average normalized score of 2.99 by publishing two articles each individually.

Table 4.4(b). Correlation calculations from data given in Table 4.4(a).

Correlation	Docu-ments	Citations	Avg. Citations	Norm. Citations	Avg. Norm. Citations
Number of Total Documents	1				
No of Total Citations	0.20	1			
No of Avg. Citations	-0.16	0.91	1		
No of Norm. Citations	0.34	0.36	0.15	1	
No of Avg. Norm. Citations	-0.25	0.14	0.14	0.81	1

A total of six different clusters were formed among all the 22 researchers, which explains a good area of the research domain (Fig. 4.6). Also, the closeness and dense connecting lines among the nodes indicate the closer association among the researchers in their field of research.

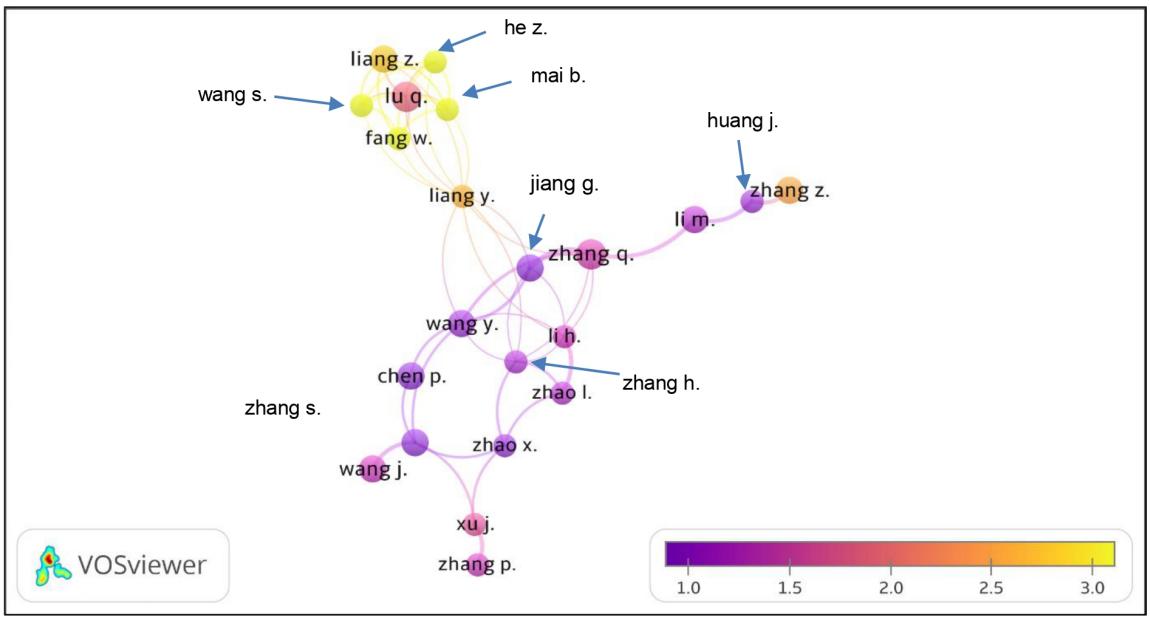


Fig. 4.6. Mapping of the most productive and influential authors contributing to the area of the research.

4.6. Citation of Articles

The citation of articles indicates the impact of that publication on that particular research area. To get an idea about the most influential published articles in the area of polluting parameters in river sediment, the minimum number of citations per document was set as 50. With that, 52 papers matched the criteria out of which 18 are found to be interconnected, are tabulated in Table 4.5, along with their normalized citation values.

Table 4.5. Co-authorship analysis in the research domain of River sediment pollution assessment (RSPA).

Authors	Citation	Norm. Citation	Authors	Citation	Norm. Citation
Eljarrat et al. (2005)	148	2.6195	Miglioranza et al. (2013)	75	1.2273
Barhoumi et al. (2019)	77	2.2427	Liu et al. (2007)	73	1.1587
Zheng et al. (2008)	291	2.0935	El-kady et al. (2007)	65	1.0317
Zhang et al. (2004)	444	1.9646	Zhang et al. (2010)	82	1.0195
He et al. (2006)	110	1.841	Mwanamoki et al. (2014)	90	0.9485
Kilunga et al. (2017)	74	1.7666	Wang et al. (2007)	51	0.8095
Kim et al. (2009)	80	1.6918	Syed et al. (2014)	76	0.8009
Zhao et al. (2010)	123	1.5293	Doong et al. (2008)	98	0.705
Wang et al. (2016)	63	1.3846	Koh et al. (2004)	156	0.6903

The overlay visualization is shown in Fig. 4.7 with respect to normalized citation values. Zhang et al. (2004), Eljarrat et al. (2005), He et al. (2006), Zheng et al. (2008), Kim et al. (2009), Zhao et al. (2010), Kilunga et al. (2017) and Barhoumi et al. (2019) have very high normalized citations compared to others, indicating highest impact in the research domain. Apart from this, the rest of the authors contribute considerably to the research domain of RSPA.

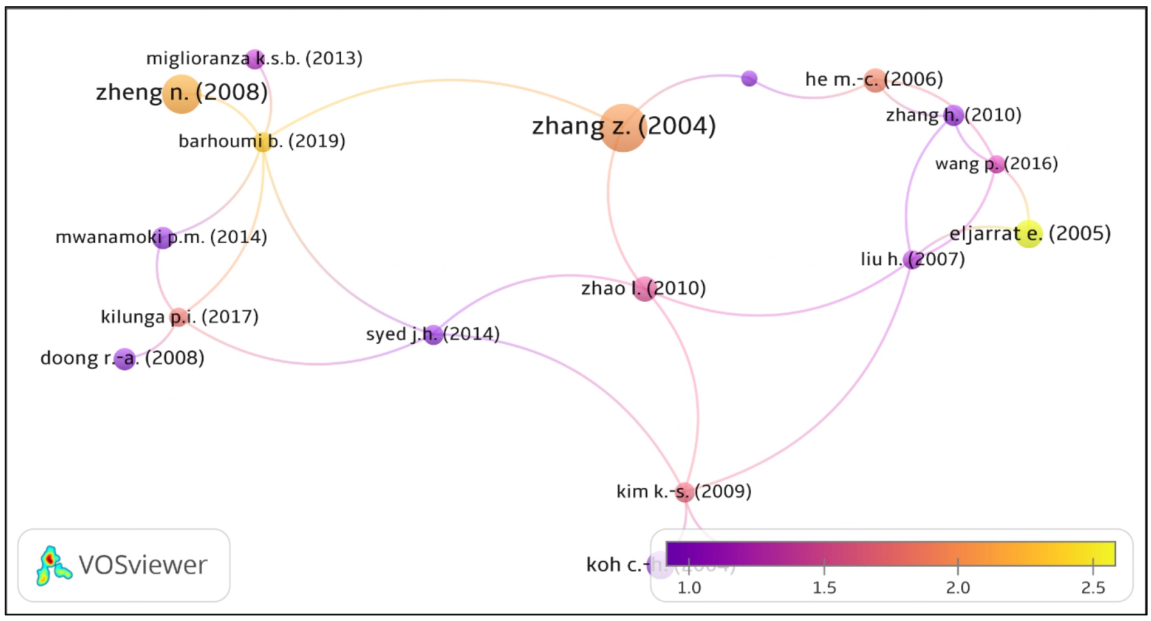


Fig. 4.7. Science mapping of the most influential publications in the research field of RSPA.

Chapter 5

Results and Insights of Qualitative Analysis

5. Discussions on Qualitative Analysis

The study was continued with a qualitative assessment following the scientometric method analysis in order to have a deeper understanding of the state of research for each article on the area of **river sediment pollution assessment** (RSPA). This made it easier to recognize the constraints that exist and to comprehend the current research methodology and key factors influencing the research topic. As a result, based on the advancements made in research thus far, this appraisal offered guidance for the future.

5.1. Polychlorinated Bi Phenyls (PCBs) in RSPA

5.1.1. Background and Present Scenario of PCBs Pollution

PCBs belong to a broad family of man-made organic chemicals consisting of 209 congeners known as persistent organic pollutants (POPs). These chemicals were first produced in 1929 and gained widespread use as insulators in transformers and capacitors, as well as additives in sealants and heat transfer agents, due to their durability and low flammability. PCB production continued domestically in the United States until 1979 when the U.S. Environmental Protection Agency (EPA) banned their manufacture under the Toxic Substances Control Act (TSCA). The global ban on PCBs was later reinforced by the Stockholm Convention in 2001. PCBs are introduced into the environment by anthropogenic activities such as incineration of PCBs containing waste; burning of many materials that may contain chlorine and wood treated with pentachlorophenol as well as uncontrolled landfills and hazardous waste sites. When PCBs are transported into the aquatic environment through diverse paths, they tend to deposit on the surface sediments and a small portion of PCBs adsorbed on the suspended particulate matter in water (Mechlińska et al. 2010). The process of urbanization, industrialization, and medium to large-scale landfills using industrial sludge, open burning of industrial and municipal waste, e-waste, etc., and many other polluting activities on riverbanks might be the key sources of PCBs in this River. PCBs were classified as human carcinogens in 2013 by the *International Agency for Research on Cancer* (IARC) (Brito et al. 2015).

PCBs exhibit a strong affinity for suspended solids (organic matter) and are highly insoluble in water. As a result, PCBs tend to accumulate in much higher concentrations in sediment and biota compared to water. Sediments can also act as significant sources of PCBs through desorption, diffusion, and potential re-suspension into the water column. The primary method for removing PCBs is the removal of contaminated sediments.

5.1.2. Different Forms of PCBs in Atmosphere

PCBs present in the atmosphere are identified by different terms, i.e. Congeners, Aroclor, Dioxin-like PCBs (DL-PCBs) and PCB-homolog.

***Congeners*:** PCB congeners are the individual chemical compounds within the broader group of PCBs. There are 209 possible congeners, each distinguished by the number and positions of chlorine atoms attached to the biphenyl rings. Congeners can have between 1 and 10 chlorine atoms. These structural differences affect their physical, chemical, and toxicological properties. Some congeners are more toxic, stable, or likely to bioaccumulate than others.

***Aroclors*:** Aroclors were not a single PCB congener but rather a complex mixture of multiple congeners. PCBs are mixtures of different congeners of chlorobiphenyl. Commercial PCB mixtures are known as aroclors. The aroclors are characterized by four-digit numbers. The first two digits refer to the number of carbon atoms in the phenyl ring (12 in the biphenyl skeleton) and the last two digits give the percentage of chlorine by mass in the mixture. For example, Aroclor 1242 contains approximately 42% chlorine by weight. Physical properties vary depending on the composition of the PCB mixture (the exception is Aroclor 1016, which has a biphenyl structure and is 41% chlorine by weight).

The Aroclors were widely used in industrial and manufacturing settings primarily as insulating fluids and coolants in electrical equipment and machinery. For example, Aroclor 1242 is a clear mobile liquid. Aroclor 1254 is a light yellow, viscous liquid. Aroclor 1260 is a light yellow, soft sticky resin.

***Dioxin-like PCBs*:** DL-PCBs are a subset of PCBs that possess a specific arrangement of chlorine atoms, making them structurally similar to dioxins (a group of chemically related compounds that are POPs). This structural similarity allows them to bind to the aryl hydrocarbon receptor (AhR) in cells, which is the same mechanism by which dioxins exert their toxic effects.

DL-PCBs are more toxic than non-dioxin-like PCBs due to their ability to activate the AhR pathway. This activation can lead to similar toxic effects as dioxins, including cancer, reproductive and developmental problems, immune system damage, and endocrine disruption. Due to their higher toxicity, DL-PCBs are often regulated and monitored separately from other PCBs. They are included in the toxic equivalency factor (TEF) system used to assess the risk of exposure to mixtures of dioxins and DL-PCBs.

Among the 209 PCB congeners, 12 are considered to have dioxin-like properties due to their structural similarity to dioxins and their ability to activate the AhR. These dioxin-like PCBs include: PCB 77, PCB 81, PCB 105, PCB 114, PCB 118, PCB 123, PCB 126, PCB 156, PCB 157, PCB 167, PCB 169 and PCB 189.

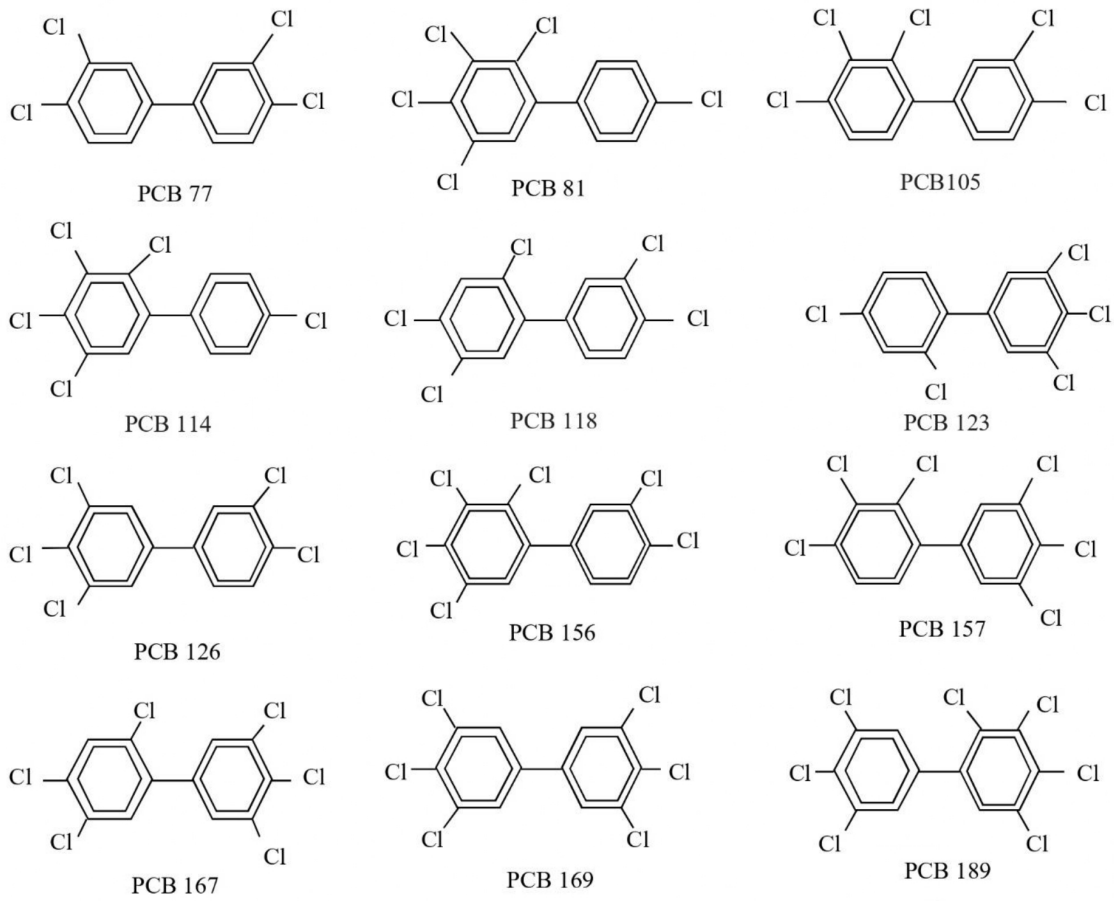


Fig. 5.1. Dioxin-like Polychlorinated Biphenyls (DL-PCBs).

***PCB-Homologs*:** PCBs can also be categorized by degree of chlorination. The term "homolog" is used to refer to all PCBs with the same number of chlorines (e.g., trichloro-biphenyls). Homologs with different substitution patterns are referred to as isomers. For example, the dichlorophenyl homolog contains 12 isomers.

The homolog groups are named based on the number of chlorine atoms:

1. **Monochlorobiphenyls:** one chlorine atom (PCB 1 to 3)
2. **Dichlorobiphenyls:** two chlorine atoms (PCB 4 to 15)
3. **Trichlorobiphenyls:** three chlorine atoms (PCB 16 to 39)
4. **Tetrachlorobiphenyls:** four chlorine atoms (PCB 40 to 81)
5. **Pentachlorobiphenyls:** five chlorine atoms (PCB 82 to 127)
6. **Hexachlorobiphenyls:** six chlorine atoms (PCB 128 to 169)
7. **Heptachlorobiphenyls:** seven chlorine atoms (PCB 170 to 193)
8. **Octachlorobiphenyls:** eight chlorine atoms (PCB 194 to 205)
9. **Nonachlorobiphenyls:** nine chlorine atoms (PCB 206 to 208)
10. **Decachlorobiphenyls:** ten chlorine atoms (PCB 209)

5.1.3. Sources of PCBs Pollution

***Industrial Discharges*:** Factories that used PCBs in electrical equipment, transformers, and capacitors might have released PCBs into rivers through improper disposal or leaks. Many industries, especially older ones, might have used PCBs without adequate pollution control measures.

***Improper Disposal*:** Inadequate waste management practices have led to the improper disposal of PCB-containing equipment and waste. This often results in PCB contamination of soil and water bodies.

***Legacy Pollution*:** Even after the ban on PCBs in many countries, including India, existing PCB-containing materials and equipment continue to pose a risk. Improper handling and storage of these legacy materials contribute to ongoing pollution.

5.1.4. Analysis According to the Source of Articles and Methods Adopted on PCBs

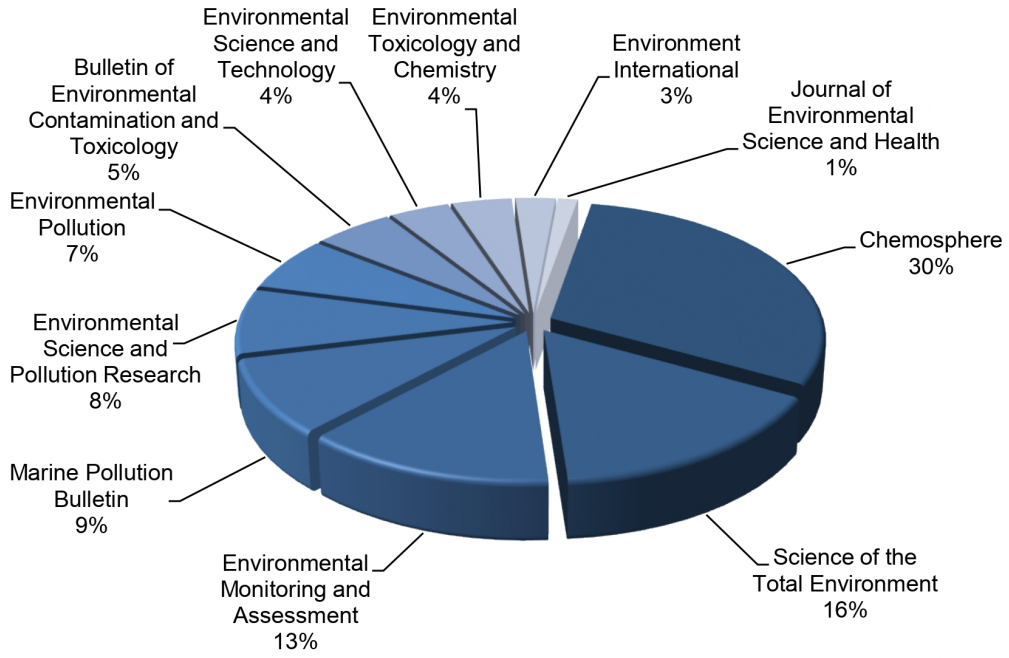


Fig. 5.2. Visual representation in terms of the contribution of article source, for evaluating PCBs on assessing river sediment pollution during the time span of 2004-2023.

From the graphical representation of Fig. 5.2 the contribution of various sources in the field of river sediment pollution by PCBs has been clearly reflected. *Chemosphere* contributes the highest (30%) among all the other sources. The contribution of *Science of the Total Environment* is 16%, and *Environmental Monitoring and Assessment* has a 13% contribution.

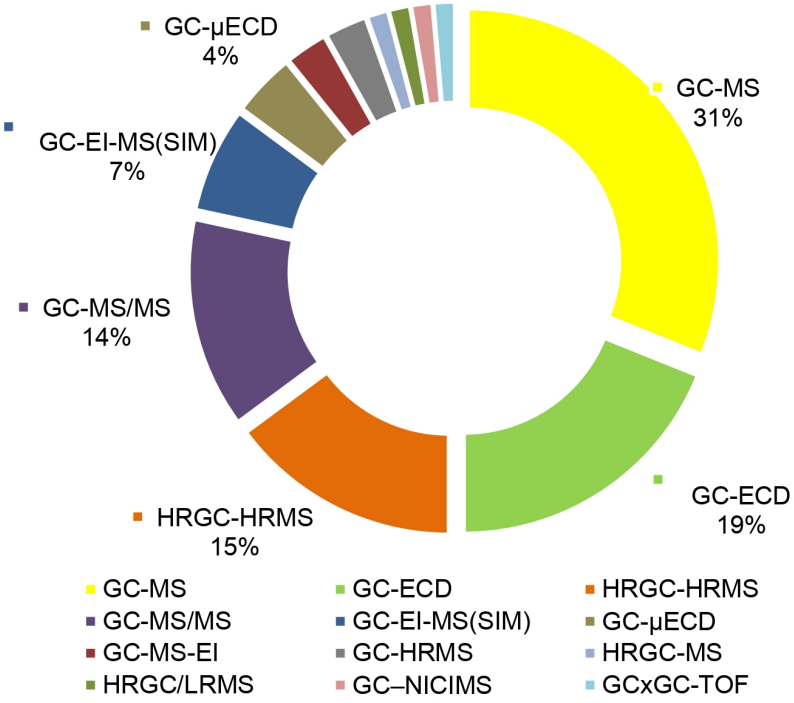


Fig. 5.3. Visual representation of methods adopted for evaluation of PCBs on RSPA during the time span of 2004-2023.

Table 5.1. PCBs measurement methods adopted in the literatures.

Abbreviation	Method Name
GC-MS	Gas Chromatography Mass Spectrometry
GC-ECD	Gas Chromatography coupled with Electron Capture Detector
HRGC-HRMS	High Resolution GC-High Resolution MS
GC-MS/MS	Gas Chromatography-Tandem Mass Spectrometry
GC-EI-	GC-MS with an Electron Impact-Selected Ion Monitoring mode
GC-μECD	Gas Chromatography coupled with Micro Electron capture
GC-MS-EI	GC-MS with an Electron Ionization
GC-HRMS	Gas Chromatography-High Resolution Mass Spectrometry
HRGC-MS	High Resolution Gas Chromatography-Mass spectrometry
HRGC–LRMS	Gas chromatography-Low Resolution Mass Spectrometry
GC-NICIMS	GC-Negative Ion Chemical Ionization Mass Spectrometry
GC×GC -TOF	Two-Dimensional GC coupled with Time-of-Flight Mass

Through the qualitative analysis, Fig. 5.3 represents the various methods according to their frequency of usage in different articles during the time span of 2004-2023. Gas chromatography-mass spectrometry (GC-MS) has the highest measurement frequency of 31% among all other methods (Brito et al. 2015, Barhoumi et al. 2019, Aziza et al. 2021). GC-ECD has 19%, HRGC-HRMS and GC-MS/MS both have 15% and 14% frequency, respectively. All other methods which have been rarely used in different articles are tabulated in Table 5.1.

5.1.5. Different Methods adopted for PCBs Evaluation in RSPA.

Gas Chromatography (GC)

Gas chromatography is an analytical technique applicable to gas, liquid, and solid samples (components that are vaporized by heat). If a mixture of compounds is analyzed using a GC system, each compound can be separated and quantified**.** Gas chromatography differs from other forms of chromatography in that the mobile phase is a gas and the components are separated as vapors. A schematic diagram of a gas chromatograph has been shown in Fig. 5.4.

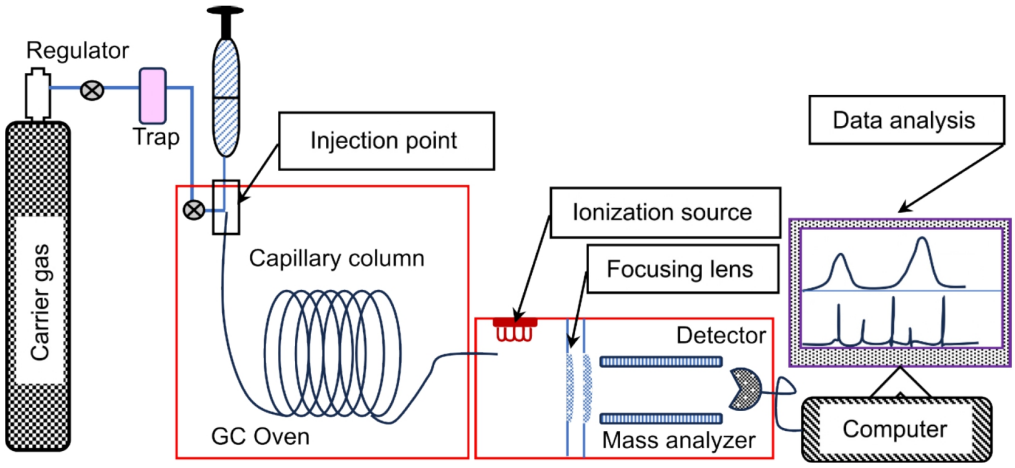


Fig. 5.4. Schematic drawing of a Gas Chromatograph.

The mobile phase (or "moving phase") is a carrier gas, usually an inert gas such as helium or an unreactive gas such as nitrogen. Helium remains the most commonly used carrier gas in about 90% of instruments although hydrogen is preferred for improved separations. The stationary phase is a microscopic layer of liquid or an inert solid support, inside a piece of glass or metal tubing called a column.

The sample is either a gas or a liquid that is vaporized in the injection port. The pressure is applied and the mobile phase moves the analyte through the column.

When a mixed solution sample is injected into the GC system, the compounds contained in the sample, including the solvent components, are heated and vaporized within the sample injection unit. GC oven provides heat to vaporized material right after injection. Additionally, it keeps the column heated to continue the gaseous molecules traveling through. Its temperature could vary from room temperature to 300°C.

With the GC system, the mobile phase, referred to as the carrier gas, always flows in sequence from the sample injection unit to the column, and then to the detector. The target components that were vaporized in the sample injection unit are transported by the carrier gas to the column. While a compound travels through the column with the mobile phase, it spends some time sticking to the stationary phase that is bonded to the column, different compounds spend different lengths of time stuck on the stationary phase. The exact time that a compound spends interacting with the stationary phase will depend on its chemical composition. It also depends on their boiling point or their size. The component having a low boiling point or

smaller size elutes faster from the column to the detector. The data recorded by the detector is transmitted to a computer that produces a two-dimensional plot called a *chromatogram,* which shows different retention times of different components. By comparing the generated retention time with the reference retention time of the respective component, the identification and concentration of a particular component will be evaluated.

There are many types of detectors with varying detection methods and limits. They may also be combined. A particularly powerful technique arises when a GC is coupled with a mass spectrometer (MS).

Mass Spectrometry (MS)

Mass spectrometry is an analytical technique that separates ionized particles such as atoms, molecules, and clusters by using differences in the ratios of their mass to their respective charge (mass/charge; m/z), and can be used to determine the molecular weight of the particles. A schematic diagram of a mass spectrometer has been shown in Fig. 5.5.

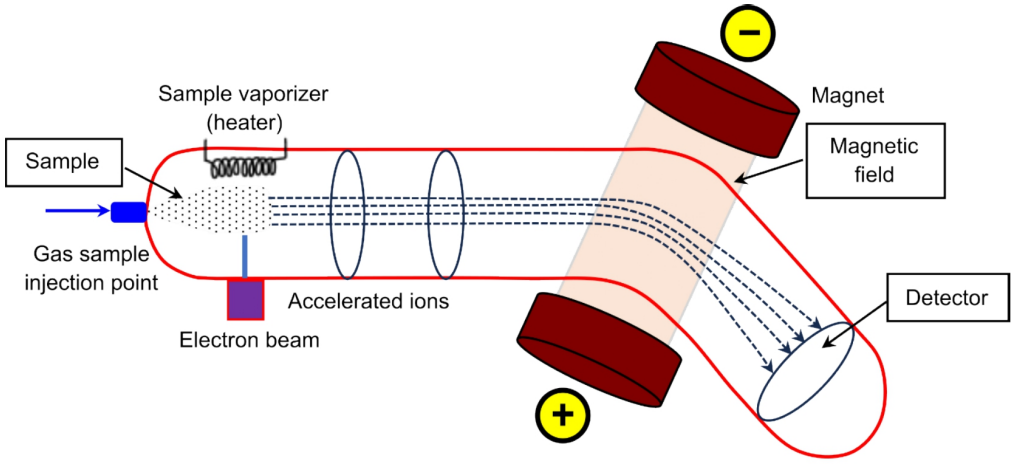


Fig. 5.5. Schematic drawing of a Mass Spectrometer

There are four key stages to a mass spectrometer-

***Ionization*:** Molecules in a sample are vaporized (converted to the gas phase by heating). Then, an electron beam bombards the vapors, which converts the vapors to ions. Because mass spectrometry measures the mass of charged particles, only ions will be detected, and neutral molecules will not be seen. The bombarding of the sample is done by the electrons. When the sample passes through the *electron stream* between the cathode and anode, electrons with high energy knock electrons out of the sample**,** resulting in a positively charged ion.

***Acceleration*:** Next, the ions are sorted according to mass in two stages – acceleration and deflection. *Acceleration* is simply attraction. The positive ions created in the ionization stage accelerate towards negative plates at a speed dependent on their mass. In other words, lighter molecules move quicker than heavier ones.

***Deflection*:** Magnetic field deflects ions based on its charge and mass. If an ion is heavy or has two or more positive charges, then it is least deflected. If an ion is light or has one positive charge, then it is deflected the most. So, ions of different masses travel through the spectrometer at different speeds.

***Detection*:** When an ion hits the detector, the charge is neutralized, and this generates an electrical current. This current is proportional to the abundance of the ion; these are sent to the computer to provide a spectrum. A mass spectrum is generated, which shows the different m/z values of ions present, and their relative abundance**.**

Low Resolution Mass Spectrometry (LRMS)

Low Resolution Mass Spectrometry is a mass spectrometry technique where the instrument is designed to detect and measure ions with relatively low mass accuracy and resolving power. This means the instrument can differentiate ions that are about 1 Da ("Dalton" a unit of mass commonly used in mass spectrometry) apart but may not be able to distinguish ions that are closer in mass.

***Advantages*:** LRMS instruments are generally less expensive than HRMS instruments, easier to operate and maintain. They offer faster analysis times due to lower data complexity.

***Limitations*:** Limited ability to distinguish between ions with very similar masses. Lower mass accuracy compared to HRMS, which may affect the identification of compounds in complex mixtures.

Electron Ionization-Selected Ion Monitoring (EI-SIM)

Electron Ionization-Selected Ion Monitoring is a combination of electron ionization (EI) and selected ion monitoring (SIM) used in mass spectrometry. This method is highly effective for analyzing complex mixtures with enhanced sensitivity and specificity.

***Electron Ionization (EI)*:** This is a common ionization technique used in MS. In EI, electrons bombard the molecules, causing them to ionize and fragment.

A beam of high-energy electrons is directed at the molecules of the analyte in the gas phase. These electrons are produced by heating a filament (similar to the filament in a light bulb) in a vacuum chamber.

When the high-energy electrons collide with the analyte molecules, they impart enough energy to eject one or more electrons from the molecules, forming positively charged ions (cations). The process can also cause the molecules to break apart into smaller fragments

The resulting ions and fragments are then accelerated into a mass analyser, where they are separated based on their mass-to-charge ratio (m/z). The pattern of the ions and fragments can be used to deduce the structure and identity of the original molecules.

***Selected Ion Monitoring (SIM)*:** In SIM mode, the mass spectrometer is set to detect only specific (m/z values) that are characteristic of the target analytes. During the analysis, the mass

spectrometer continuously monitors and records the abundance of these selected ions, ignoring other ions. The data collected is then used to quantify the amount of the target analytes in the sample. Since only a few specific ions are monitored, the method is highly sensitive and allows for the detection of low-abundance compounds in complex matrices by focusing on the ions of interest.

Combining these techniques with the GC-MS method allows for high sensitivity and specificity in analyzing complex samples, making GC-MS-EI-SIM a powerful tool.

Negative Ion Chemical Ionization Mass Spectrometry (NICIMS)

Negative Ion Chemical Ionization Mass Spectrometry is a specialized mass spectrometry technique that enhances the detection of compounds that can easily gain an electron and form negative ions. It is particularly effective for analyzing electronegative compounds such as halogenated organics, certain pesticides, and other substances with high electron affinity.

***Working Principle*:** In this method, a chemical ionization (CI) source is used. A reagent gas (often methane, ammonia, or isobutane) is introduced into the ionization chamber and ionized by an electron beam to produce reagent ions. The analyte molecules capture low-energy electrons from the reagent gas ions, forming negative ions. This process is efficient for compounds with high electron affinity. The reagent ions can also react with the analyte molecules to form negative ions through various ion-molecule reactions. The formed negative ions are then directed into the mass analyser, where they are separated and detected based on their mass-to-charge (m/z) ratios. The resulting mass spectrum provides information on the presence and concentration of the target compounds.

Electron Capture Detector (ECD)

The ECD is an example of a selective GC detector (Fig. 5.6). The operation of an ECD is based on the capture of secondary electrons by electronegative compounds that are eluting from the column. High-energy electrons, or beta particles, are provided in an ECD by a radioactive source such as ^{63}Ni or ^{3}H that is housed in the detector. As the beta particles are produced, they collide with the carrier gas (inert gasses like N_2 or Argon) and lead to the release of a large number of secondary electrons. When only the carrier gas is passing through this detector, a consistent supply of the secondary electrons is created. These secondary electrons are collected at a positive electrode and the flow of current continues within the instrument. When a chemical (sample) with electronegative groups elutes from the column, some of these secondary electrons are captured and fewer reach the electrode. The resulting change in current flow is used to detect and measure the amount of analyte that was eluted from the column. As the number of electrons is reduced (generally captured by the electro-negative sample), the amount of current is also reduced. The response is measured as the drop in current, not as an increase as with the other detectors.

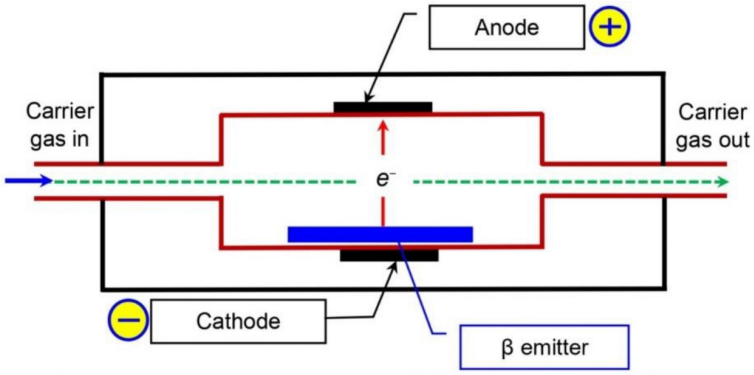


Fig. 5.6. Schematic diagram of Electron Capture Detector.

An ECD can provide both selective and sensitive detection for chemicals that contain electronegative groups. This includes chemicals that contain halogen atoms (I, Br, Cl, and F) or nitro groups ($-NO_2$). It also includes chemicals that are polynuclear aromatic hydrocarbons, anhydrides, or conjugated carbonyl compounds, along with many others. Derivatization with reagents containing polychlorinated or polyfluorinated groups can be used with some chemicals to also allow them to be monitored with an ECD.

Argon and nitrogen are usually employed as the carrier gases for a GC system with an ECD. Some methane is also usually combined with these carrier gases to produce a steady stream of secondary electrons and provide as Table detector response. It is important that these gases be pure and dry because the presence of oxygen and water can foul this type of detector.

Micro Electron Capture Detector (μECD)

The Micro Electron Capture Detector is a highly sensitive detector used primarily in gas chromatography (GC) for detecting trace amounts of electron-absorbing compounds. It is especially effective for halogenated compounds, making it ideal for detecting pesticides, polychlorinated biphenyls (PCBs), and other halogenated organics.

***Working Principle*:** This method uses a radioactive source, commonly nickel-63 (Ni-63), which emits beta particles (electrons). These electrons ionize the carrier gas (often nitrogen) passing through the detector, producing a steady stream of low-energy electrons. When an analyte with high electron affinity enters the detector, it captures some of these free electrons, forming negatively charged ions. The decrease in the number of free electrons reduces the current measured between a pair of electrodes in the detector. This reduction in current is proportional to the concentration of the electron-capturing compounds in the sample. The detector generates a signal based on the change in current, which is then recorded and analyzed. The signal intensity corresponds to the amount of electron-absorbing substance in the sample.

High Resolution Gas Chromatography - High Resolution Mass Spectrometry (HRGC-HRMS)

High-resolution gas chromatography-high resolution mass spectrometry is an advanced analytical technique used for compound identification and quantification. The key differences between GC-MS and HRGC-HRMS lie in the resolution and sensitivity of the mass spectrometry component. HRGC-HRMS provides enhanced capabilities for resolving complex mixtures and identifying compounds accurately at trace levels compared to conventional GC-MS. Here are the key differences between the two:

***GC-MS*:** In conventional GC-MS, the mass spectrometer typically has a lower resolution compared to high-resolution mass spectrometry (HRMS). This means it can distinguish ions with different masses but may not resolve closely spaced peaks with high precision. Typically uses a quadrupole or ion trap mass analyser, which provides good sensitivity and selectivity but lower resolution compared to HRMS.

***HRGC-HRMS*:** HRMS offers significantly higher resolution in mass spectrometry. It can separate ions that differ in mass by very small increments, enabling more accurate identification of compounds in complex mixtures. HRGC often employs columns with longer lengths and smaller internal diameters than conventional GC columns. These design features contribute to increased resolution by enhancing the separation efficiency of the analytes.

Tandem mass spectrometry (MS/MS)

Tandem mass spectrometry is an advanced technique used in mass spectrometry that involves multiple stages of mass analysis. Basically, it combines two different types of MS separation techniques to separate the compounds in a sample twice based on their mass-to-charge ratio (m/z) for improved resolution. GC-MS/MS systems typically consist of a gas chromatograph coupled with two mass spectrometers, often using triple quadrupole (QqQ) or hybrid quadrupole-TOF (Q-TOF) configurations for high sensitivity and selectivity. The tandem mass spectrometry configuration enhances sensitivity, enabling the detection and quantification of compounds at lower concentrations. GC-MS/MS integrates two stages of mass spectrometry:

***First stage (MS1)*:** In GC-MS/MS, the first mass spectrometer selects and ionizes molecules based on their mass-to-charge ratio (m/z). This initial mass spectrometry stage provides sensitive detection and quantification of target compounds separated by gas chromatography.

***Second stage (MS2)*:** The selected ions from MS1 are further fragmented using collision-induced dissociation (CID) or other fragmentation techniques in the second stage. This fragmentation generates a unique pattern of daughter ions, which allows for more precise identification and structural elucidation of the compounds of interest.

Two-Dimensional Gas Chromatography coupled with Time-of-Flight Mass Spectrometry (GC×GC-TOF)

Simple MS uses a magnetic field, quadrupole, or ion trap to filter ions based on their mass-to-charge ratio (m/z), where time-of-flight mass spectrometry (TOF-MS) measures the time it takes for ions to travel a fixed distance, where lighter ions reach the detector faster than heavier ones, allowing for mass determination.

GC×GC-TOF, or two-dimensional gas chromatography coupled with TOF-MS, is an advanced analytical technique that combines the enhanced separation capabilities of comprehensive two-dimensional gas chromatography (GC×GC) with the high-speed, high-resolution detection of TOF-MS (Fig. 5.7). This powerful combination provides detailed analysis of complex mixtures, making it ideal for applications requiring high sensitivity, resolution, and the ability to analyze a wide range of compounds.

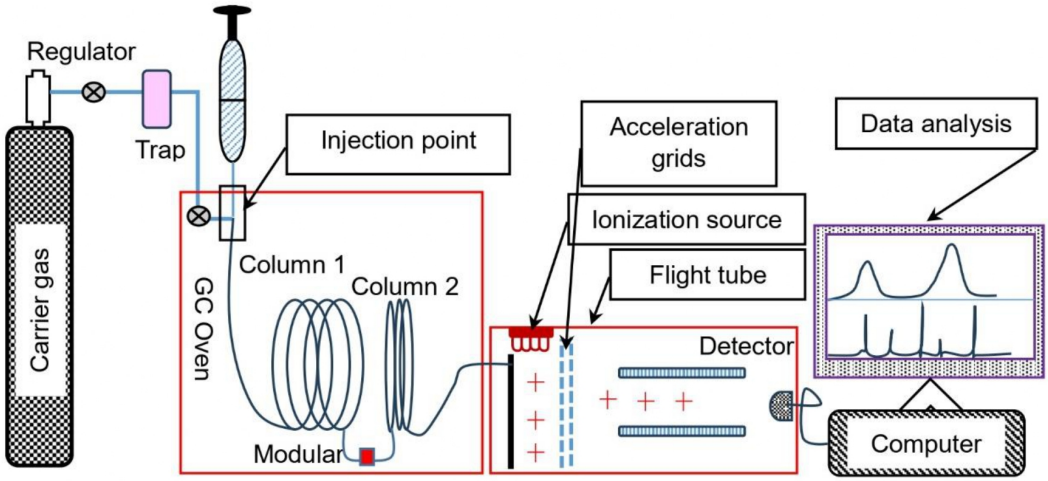


Fig. 5.7. Schematic diagram of GC × GC – TOF.

***Working Principle*:** In this method, the sample is injected into the first GC column, where it undergoes separation based on volatility. The effluent from the first column enters a modulator, which periodically traps and refocuses the analytes before injecting them into the second column. The analytes are further separated in the second GC column, which separates compounds based on another property (e.g., polarity), providing additional resolution. This two-dimensional separation process significantly enhances the resolution and peak capacity, allowing for better separation of complex mixtures.

As the analytes elute from the second column, they enter the TOF mass spectrometer, where they are ionized. The accelerated ions enter a field-free drift region or flight tube. Since all ions have the same kinetic energy, their velocities depend on their mass-to-charge ratio (m/z). The time it takes for an ion to reach the detector is directly proportional to its mass-to-charge ratio. As the time it takes for ions to travel a fixed distance and since lighter ions travel faster than heavier ones, the mass-to-charge ratio (m/z) of each ion can be determined with high accuracy.

The main findings and limitations of PCBs are given in Table 5.2.

Table 5.2. Main findings and limitations of literatures on PCBs.

Auth-ors	Main Findings	Limitations
Zhang et al. (2004)	❖ The concentrations of PCBs in sediments varied from 0.78 to 8.47 ng/g, dw, which was higher than those in surface water. ❖ In sediment, the predominant compounds were PCB28, PCB31 and PCB153, which accounted for 71% of total PCBs in sediment. ❖ Study concluded that the PCBs came from the residues from the former application and due to their resistance to degradation in the environment, PCBs could be continuously detected for many years.	❖ Study focused on only 12 selected PCB congeners and 16 PAHs quantification, which may overlook other significant congeners. ❖ Surface water and sediment samples from the Tonghui River were only studied, which limited the study area. ❖ To identify the sources, behaviour and fate of the micropollutants and make the risk assessment of these contaminants further study needs to be conducted.
Covaci et al. (2005)	❖ This study showed a relatively steady state for PCBs and DDTs, with a slight decrease in the top layers, suggesting a slight decline in their concentrations due to restrictions in their usage in the last 15 years. ❖ On the contrary, PBDEs were showing an increase in their concentrations in the top layers. Concentrations of tri- and tetra-CB congeners were low, while the predominant homologues were the penta- to hepta-CBs.	❖ Sediment cores (~50 cm) were taken from only two locations situated in the Scheldt River, which may not provide the actual status of the overall pollution of the river. ❖ The study was conducted in specific locations with a single period, limiting its ability to capture seasonal or broader variations in PCB concentrations.
He et al. (2006)	❖ PCBs associated with the sediments, measured as the summed responses of Aroclor 1242, 1248, 1254, and 1260 were found to be in the range of non-detectable to 5.98 μg/kg. ❖ In most of the samples, PCB concentrations occurred in the order: TetraCB > TriCB > PentaCB. ❖ It can be seen that the surface sediments in the Yellow River had been only slightly contaminated by PCBs and there were no obvious correlations of either PNBs or PCB concentrations to either TOC or the grain size of sediment.	❖ No obvious correlation was observed between the pollutant concentrations and either the TOC or the grain size of the sediments. ❖ The study was conducted in specific locations with a single period, limiting its ability to capture seasonal or broader variations in PCB concentrations

Xu et al. (2019)	❖ Dredging may not be necessary for PCB remediation if PCBs in sediments are dechlorinated by microorganisms. ❖ In the sediment microcosms, sulfate slightly reduced PCB dechlorination; however, adding fatty acids significantly boosted dechlorination in the Grasse sediment.	❖ The dechlorination preferences differed between the sediments of the Grasse and Hudson rivers, most likely as a result of differences in their geochemical properties. ❖ The geochemistry of the sediment affected how well fatty acid supplementation stimulated PCB dechlorination.
Babut et al. (2019)	❖ The Saigon River bed sediments show minor organic pollutant contamination, likely from tidal effects and urban runoff during the monsoon season. ❖ The contamination transfer pattern raises concerns for areas like the Can Gio mangrove, impacting important ecosystem services downstream.	❖ Prior research on PFAS and PBDEs pollution in HCMC waterways is lacking. ❖ The Saigon River and a few nearby canals were the only areas investigated, providing limited spatial coverage.
Urbanaik et al. (2020)	❖ River sediment is a suitable ingredient for a growing medium for plants. ❖ PCBs in the sediment should be taken into consideration as they may cause ecological harm to the soil and plants. ❖ It was discovered that the risk associated with PCBs could be effectively reduced by thermal processing and further phyto-remediation using zucchini.	❖ The long-term effects of sediment use in growth substrates were not fully explored. ❖ Sediment composition can vary seasonally and geographically, affecting results. ❖ The study did not investigate broader ecological impacts on soil and ecosystems. ❖ Other contaminants or synergistic effects beyond PCBs were not fully examined
Qiu et al. (2020)	❖ Organohalide-respiring bacteria found in contaminated urban river sediments have the ability to dechlorinate hazardous and PCBs through different pathways. ❖ The organohalide-respiring bacteria use bifunctional reductive dehalogenases to dechlorinate both PCBs and tetrachloroethene.	❖ The research focused primarily on mixed cultures, lacking evidence from purified enzymes, which limits the specificity of conclusions about bifunctional reductive dehalogenases. The study did not extensively explore the long-term stability or ecological impacts of enriched OHRB communities in different environmental conditions.
Lu et al. (2021)	❖ PCBs and PBDEs are present in the surface sediments of China's urban rivers that are heavily polluted, the concentrations of PBDEs are significantly higher than those of PCBs. ❖ The most common PCB and PBDEs forms in the sediments are tetra-/di-CBs and deca-BDE, respectively.	❖ This is an initial or exploratory study, providing the first insight into the contamination, conversion, and ecological risk of PCBs and PBDEs in polluted urban rivers in China. ❖ Uncertainties exist regarding several parts of the bioconversion processes, most notably the role played by unidentified Dehalococcoidia.

Chowdhury et al. (2022)	❖ PCB 180 was the most conspicuous in sediments during both pre and post-monsoon seasons. The mean concentration of ΣPCBs in pre-monsoon (69.33 ng/g dw) was higher than in post-monsoon (6.42 ng/g dw). ❖ Sedimentary PCB levels in developed countries (China, England, France, Italy, and South Africa) were mostly comparable to or higher than those in this study. In contrast, PCB levels in river sediments from developing countries (Egypt, Vietnam, Romania, and Mexico) were generally comparable to or lower than the present study.	❖ Since this is the first investigation on PCB contamination in the sediments of the Turag River, Bangladesh does not yet have any baseline data for comparison. ❖ Any methodological restrictions or limitations that the authors encountered are not covered in the paper. ❖ The study makes no recommendations for future research directions or enhancements.
Iwegbue et al. (2022)	❖ Low-chlorinated PCBs were more frequently found in the Niger Delta's river sediments, where PCB concentrations varied from 976 to 6340 ng/g dw. ❖ Paints, pigments and Aroclor mixes are likely the sources of the PCB pollution. ❖ PCB pollution poses a high risk to the ecosystem, according to the risk assessment.	❖ The study was conducted in specific locations within three rivers during a single period (March 2019), limiting its ability to capture seasonal or broader variations in PCB concentrations. ❖ Only surface sediments (0-5 cm depth) were analyzed, missing potential contamination in deeper layers. The composite sampling method might not fully represent PCB heterogeneity across the river systems. ❖ The focus on 28 specific PCB congeners, out of 209 possible, may overlook other significant congeners.
Rimayi et al. (2022)	❖ PCB 77 and PCB 126 had the highest detection rates. ❖ For PCB 126, PBB 10, and PBB 49, the highest measured bioavailable concentrations were found. ❖ Air samples had the greatest toxic equivalency quotients (TEQs), which were followed by sediment samples and water samples.	❖ Low detection rates for bioavailable PBBs, with less than 3 detections above the LOQ for most sites. ❖ Relatively homogenous dispersion of TEQs in the Hartbeespoort Dam, with insignificant differences between sites

5.2. Freely Dissolved Polychlorinated Bi Phenyls (FDPCBs) in RSPA

Freely dissolved polychlorinated biphenyls (FDPCBs) refer to the fraction of PCBs that are not bound to particulate matter or organic matter in a given medium, such as water and are instead dissolved in the aqueous phase. FDPCBs represent the PCBs that are not adsorbed onto

suspended particles or dissolved organic matter in the water. This fraction is important because it is the most bioavailable form of PCBs, meaning it can more easily enter and accumulate in living organisms, causing a greater risk of toxicity to aquatic life and potentially to humans who consume contaminated water or organisms.

5.2.1. Measurement and Analysis of FDPCBs in River Water and Sediment Samples

Passive samplers like polyethylene devices (PEDs) or semi-permeable membrane devices (SPMDs) are often used to measure freely dissolved PCBs in water. These devices accumulate FDPCBs over time, allowing for the determination of time-weighted average concentrations. After retrieval, FDPCBs are extracted from the passive samplers using organic solvents. The extracts are then analyzed using techniques such as gas chromatography coupled with mass spectrometry (GC-MS) or gas chromatography with electron capture detection (GC-ECD).

Freely dissolved concentrations can also be inferred from equilibrium partitioning models that consider the distribution of PCBs between water, particulate matter, and dissolved organic carbon. Accurate measurement and monitoring of this fraction are crucial for understanding their environmental impact, assessing risks, and implementing effective remediation strategies.

From the Scopus search engine, only two articles were found on FDPCBs (Title- abs-key). Among the two, Needham et al. (2019) collected the sample from the Back River Waste Water Treatment Plant (BRWWTP) and Little Patuxent Water Reclamation Plant (LPWRP) and Liu et al. (2016) collected the sample from Lake sediment. Not any study had been done on river sediment during 2004-2023 assessing FDPCBs.

5.3. Pesticide Concentration (PestC) in RSPA

Pesticides are widely used in agriculture and urban areas to improve crop yields and control pests. However, their extensive use has led to significant environmental contamination, particularly in aquatic ecosystems. Rivers, which often receive runoff from agricultural fields and urban areas, act as conduits for pesticide transport. Over time, these chemicals accumulate in river sediments, posing a persistent threat to aquatic life and human health. Many early pesticides were persistent organic pollutants (POPs) that accumulated in the environment and biota, leading to long-term ecological and health issues.

5.3.1. Background and Present Scenario of Pesticide Pollution in River Sediment

Between the 1940s-1950s, the widespread use of synthetic pesticides began post-World War II, with DDT (dichlorodiphenyltrichloroethane) being one of the most prominent. Increased agricultural productivity led to extensive pesticide use to control pests and diseases in crops. The United States banned DDT in 1972, but its use continues in some parts of the world for controlling malaria under specific guidelines of the Stockholm Convention on Persistent Organic Pollutants (POPs).

Modern agriculture uses a wide range of pesticides, including insecticides, herbicides, and fungicides. These include both synthetic chemicals and biological agents. Many countries

have established regulations to control the types and amounts of pesticides used, aiming to minimize environmental impact.

5.3.2. Sources of Pesticide Pollution

***Agricultural Runoff*:** Pesticides applied to crops can wash into nearby water bodies during rain events or irrigation.

***Urban Runoff*:** Pesticides used in urban landscaping and pest control can also contribute to river pollution.

***Industrial Discharges*:** Manufacturing and formulation of pesticides can lead to direct discharges into water bodies.

5.3.3. Rivers Affected by Pesticide Contamination in India

***Ganga*:**
Pesticides Detected: DDT, HCH, Cypermethrin, Endosulfan, Malathion, Chlorpyrifos, Glyphosate, Carbofuran (Behera et al. 2024).

Yamuna:
Pesticides Detected: Chlorpyrifos, Imidacloprid, Endosulfan (Kadiru et al. 2022).

Godavari:
Pesticides Detected: Endosulfan, Chlorpyrifos, Imidacloprid (Giri et al. 2012).

Tapi:
Pesticides Detected: Endosulfan, Chlorpyrifos, Methyl Parathion (Behera et al. 2024).

Sabarmati:
Pesticides Detected: HCH, DDT, endosulfan (Behera et al. 2024).

5.3.4. Bans and Restrictions/Regulatory Framework in India

The Indian government has banned or restricted the use of certain hazardous pesticides, such as Endosulfan and DDT, to reduce their impact on the environment and human health (Juneja and Misra 2011).

The Insecticides Act of 1968 and subsequent amendments regulate the manufacture, sale, and use of pesticides in India. The Central Insecticides Board and Registration Committee (CIBRC) oversee the approval and monitoring of pesticide products.

5.3.5. Analysis According to the Source of Articles and Methods Adopted on PestC

From the graphical representation of Fig. 5.8. the contribution of various sources in the field of river sediment pollution by PCBs has been clearly reflected. *Science of the Total Environment* highest (45%) among all the other sources. The contribution of *Water Research, Environmental Monitoring and Assessment, Chemosphere, Environmental Pollution and Journal of Hazardous Materials* has very little in this study area.

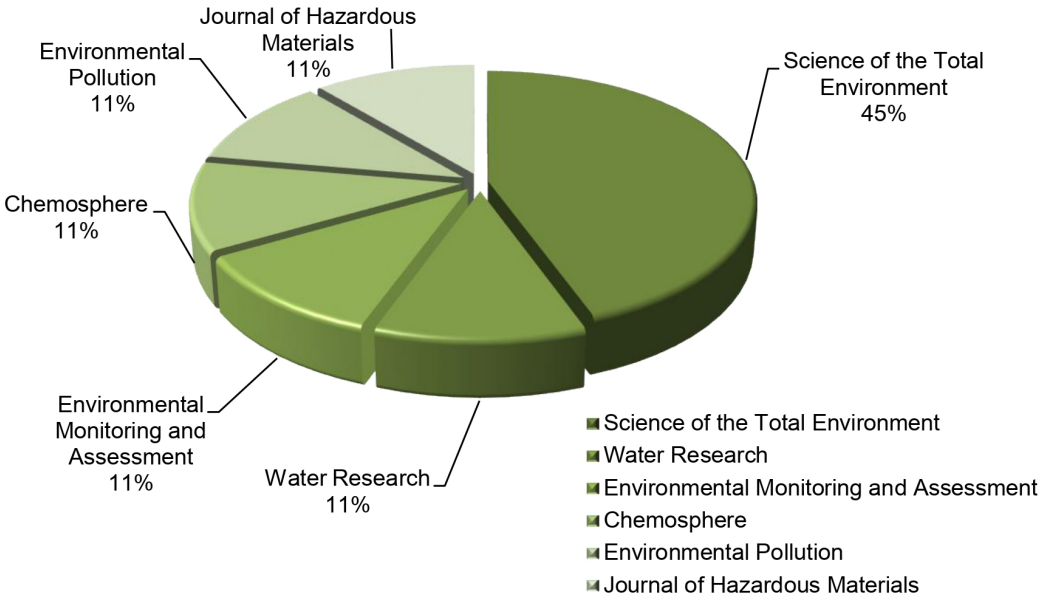


Fig. 5.8. Visual representation in terms of the contribution of article source, for evaluating PestC on RSPA during the time span of 2004-2023.

Out of 22 articles, only nine match our study criteria. The qualitative investigation reveals that the authors (Arisekar et al. 2021; Cui et al. 2020; Rasmussen et al. 2015; Devault et al. 2009) largely used the Gas Chromatograph-Mass Spectrometric (GC-MS) method, about 56% of all the other measurement techniques. Moreover, several authors (do Amaral et al. 2020; Ccanccapa et al. 2016) employed liquid chromatography tandem mass spectrometry (LC-MS/MS) Techniques that are hardly addressed in other journals (Etchegoyen et al. 2017) was Gas chromatography-micro-electron capture detector(GC-µECD). Figure 5.9 shows a graphical view of the frequency of methods.

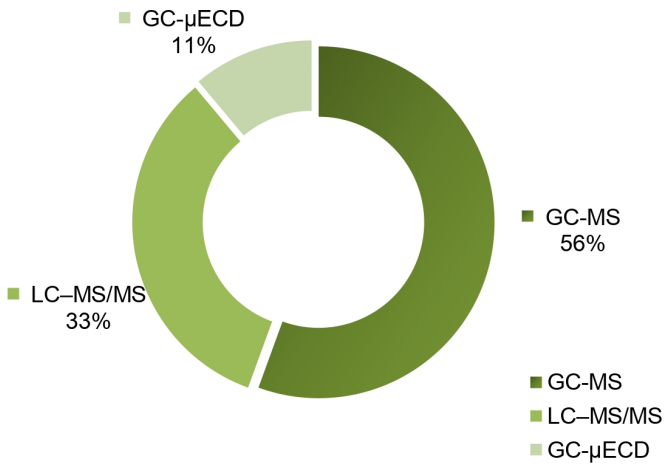


Fig. 5.9. Visual representation of methods adopted for evaluation of PestC on RSPA during the time span of 2004-2023.

5.3.6. Different Methods adopted for PestC evaluation in RSPA.

Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS)

LC-MS/MS stands for Liquid Chromatography-Tandem Mass Spectrometry, a powerful analytical technique used to identify and quantify compounds in complex mixtures. The working principle is similar to GC-MS/MS with some differences. The choice between them depends on the nature of the compounds being analyzed and the specific requirements of the analysis.

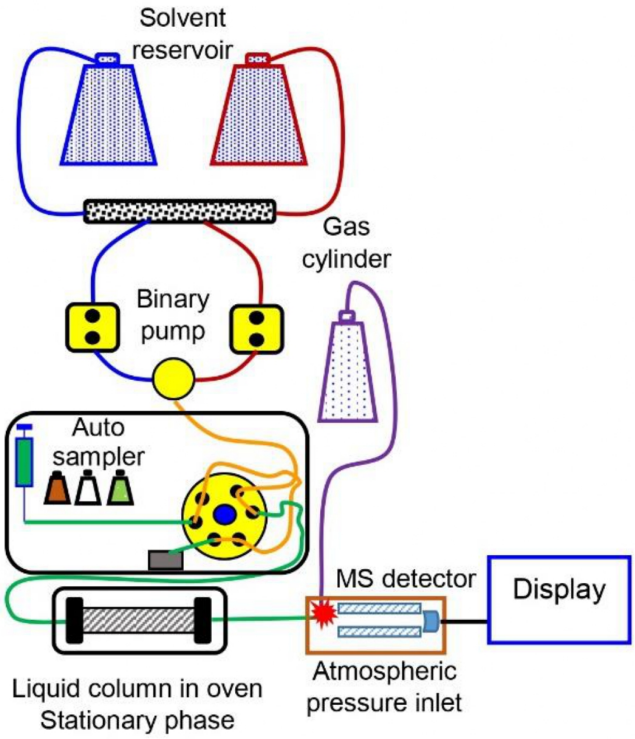


Fig. 5.10. Schematic Diagram of LC-MS/MS.

LC-MS/MS differs from GC-MS/MS in the following ways:

Principle and Methodology: Samples are vaporized and introduced into a gas chromatograph and use a gas (often helium or nitrogen) as the mobile phase and a capillary column as the stationary phase in the GC-MS/MS method. Whether in the LC-MS/MS method Samples are introduced in liquid form and use a liquid mobile phase and a column packed with stationary phase particles.

- GC-MS/MS employs common ionization methods including Electron Ionization (EI) and Chemical Ionization (CI). On the other hand, LC-MS/MS uses Common ionization methods including Electrospray Ionization (ESI) and Atmospheric Pressure Chemical Ionization (APCI).
- GC-MS/MS is suitable for analyzing volatile and semi-volatile organic compounds.LC-MS/MS is suitable for a wide range of non-volatile, polar, and thermally labile compounds.

- GC-MS/MS is typically used for analyzing pollutants like pesticides, herbicides, and volatile organic compounds (VOCs). LC-MS/MS is often used for analyzing pharmaceuticals, personal care products, and other polar contaminants in water and soil.

Some Advantages and Limitations of LC-MS/MS over GC-MS/MS

- LC-MS/MS is suitable for non-volatile, polar, and thermally labile compounds.
- It has more complex sample preparation compared to GC-MS/MS and also often requires more expensive instrumentation and maintenance.

The main findings and limitations of PestC have been included in Table 5.3.

Table 5.3. Main findings and limitations of literatures on PestC

Auth-ors	Main Findings	Limitations
Rasmussen et al. (2015)	❖ Legacy pesticides can significantly contribute to the toxic exposure of stream biota, particularly macroinvertebrate communities, through sediment exposure.	❖ Neglecting legacy pesticides in stream monitoring programs may lead to underestimation of sediment toxicity. ❖ Future strategies should focus on quantifying the toxicity of sediments with legacy pesticides and benchmarking against extensive pesticide screening programs
Cui et al. (2020)	❖ Pesticide concentrations in water, sediments, and soils are influenced by seasonal fluctuations. ❖ Local application is a key cause of current use pesticides, and sediment serves as a secondary source of Historical Use Pesticide emissions.	❖ Interpretation complexity. ❖ Need for further investment.
Arisekar et al. (2021)	❖ Pesticide concentrations in the Thamirabarani River varied with the water, sediments, and fish, but they were often below ecologically safe thresholds. ❖ Low-to-medium toxicity to aquatic creatures in the river basin was suggested by the risk assessment.	❖ The study had insufficient pesticide detection, the existence of risks to human health, and the need for more effective pollution control measures.

5.4. Particulate Organic Matter (POM) in RSPA

5.4.1. Overview of pollution by POM in River Sediment

Particulate Organic Matter (POM) refers to organic particles suspended or settled in water bodies, originating from both natural sources (e.g., decaying plant material) and human activities (e.g., sewage discharge, agricultural runoff). POM pollution became noticeable with

the rise of industrialization and urbanization, where untreated or partially treated organic waste from factories, agriculture, and domestic sources began contaminating rivers. Increased use of synthetic fertilizers and pesticides in agriculture also contributed to higher organic loadings in water bodies.

POM is a complex mixture of organic chemicals, primarily composed of *carbon* compounds such as carbohydrates, lignin, lipids, proteins, and humic substances. It also contains *nitrogen*, *phosphorus*, *sulfur compounds*, and *various trace elements*. The specific chemical composition of POM varies depending on its sources and environmental conditions.

5.4.2. Effects of Pollution by POM in rivers

***Oxygen Depletion*:** POM decomposes in water, consuming dissolved oxygen, which can lead to hypoxia (low oxygen levels) or even anoxic conditions, harming aquatic life.

***Eutrophication*:** Excessive POM contributes to nutrient enrichment, promoting algal blooms that disrupt ecosystems, reduce water quality, and cause fish kills.

***Habitat Degradation*:** POM can settle and accumulate in riverbeds, altering habitats, smothering benthic organisms, and affecting the overall health of the aquatic ecosystem.

***Water Quality*:** High levels of POM can increase water turbidity, reducing light penetration and affecting photosynthesis in aquatic plants, further degrading water quality.

***Human Health*:** Contaminated water can affect drinking water supplies and recreational water bodies, posing health risks to humans.

5.4.3. Analytical Techniques for analyzing POM Compositions

***Microscopy*:** Identifies and quantifies different types of organic particles based on their size and morphology.

***Elemental Analysis*:** Measures the carbon, nitrogen, and other elemental composition of POM.

***Spectroscopy*:** Techniques such as NMR (nuclear magnetic resonance) and FTIR (Fourier-transform infrared spectroscopy) provide detailed information on the chemical structure of organic compounds within POM.

***Stable Isotope Ratio Analysis*:** Helps trace the origins and transformation processes of organic matter by analyzing the ratios of stable isotopes. Carbon has two stable isotopes, ^{12}C and ^{13}C. The ratio of these isotopes ($\delta^{13}C$) can provide insights into the sources of POM, similarly Nitrogen has two stable isotopes: ^{14}N and ^{15}N. The ratio of these isotopes ($\delta^{15}N$) can indicate the trophic level and sources of nitrogen in the POM. Carbon and nitrogen stable isotope ratio analyses are primarily used to trace the sources and processes affecting POM, rather than directly quantifying its concentration.

5.4.4. Analysis According to the Source of Articles and Methods Adopted on POM

Very few numbers of literatures are found evaluating POM from river sediment. Among them, 75% of literatures is from *Science of the Total Environment* and the rest 25% is from *Environmental Pollution*. The graphical representation of the same is given in Fig. 5.11.

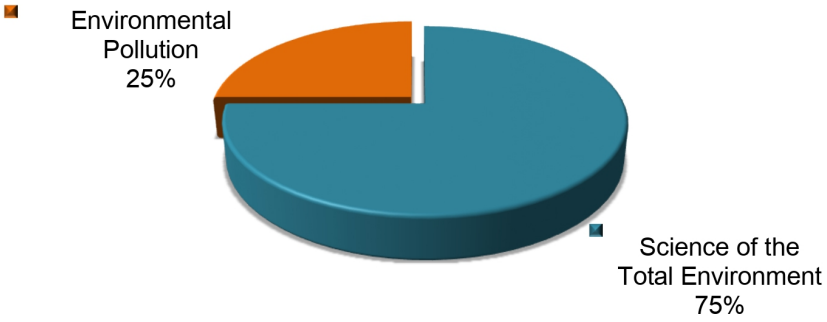


Fig. 5.11. Visual representation in terms of the contribution of literature sources, for evaluating POM on assessing river sediment pollution during the time span of 2004-2023.

The qualitative analysis Fig. 5.12 represents the methods adopted to assess POM concentration during the time span of 2004-2023. It is observed that two methods have been used with the same frequency in the literatures. Those are (i) Loss on ignition (LOI) and (ii) by multiplying POC content with "1.72". The multiplying factor "1.72" is often referred to as the "***van Bemmelen***" factor (Naulier et al. 2017; Swinnen et al. 2020). It is used to convert Particulate Organic Carbon (POC) to Particulate Organic Matter (POM).

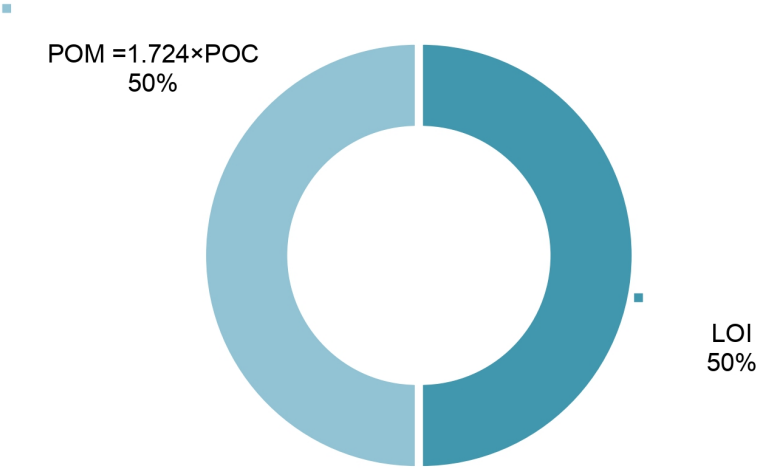


Fig. 5.12. Visual representation of methods adopted for evaluation of POM on RSPA during the time span of 2004-2023.

5.4.5. Different Methods adopted for POM evaluation in RSPA

Loss on ignition (LOI)

The Loss on Ignition (LOI) method is a common procedure used to estimate the amount of particulate organic matter in a sample. This method involves heating a sample to a high temperature (at 500-550°C for 4 hours) to burn off the organic matter, leaving behind only inorganic material. The loss in mass after ignition corresponds to the amount of organic matter. The amount of POM is calculated using the following formula (Eq. 5.1):

$$\text{POM}\ (\%\ \text{dry weight}) = \left(\frac{W_1 - W_2}{W_1}\right) \times 100 \tag{5.1}$$

where, W_1 = Mass of the dried sample before ignition (g) and W_2 = Mass of the sample after ignition (g).

POM by multiplying van Bemmelen factor

The van Bemmelen factor of 1.724 (Brady and Weil 2008) is widely referenced in soil science and environmental studies for estimating the organic matter content based on organic carbon given in Eq. 5.2.

$$\text{POM} = \text{POC} \times 1.724 \tag{5.2}$$

This is a conversion factor used to estimate the amount of organic matter in soils from the measured organic carbon content. It is based on the assumption that organic matter contains about 58% carbon, hence the factor 1.724 (which is approximately 100/58). The main findings and limitations of POM are highlighted in Table 5.4.

Table 5.4. Main findings and limitations of literatures on POM.

Auth-ors	Main Findings	Limitations
Fernandes et al. (2016)	❖ Zn was the most prevalent trace element in the fine sediment fraction (FSS), followed by Cr, Cu, Ni, Co, Sc and Cd. ❖ Trace element concentrations were higher during the dry season, except for Sc and Co, with POM exhibiting a similar pattern.	❖ The study is confined to a single watershed in São Paulo, limiting the generalizability of the findings to other regions or river basins. ❖ The study period covers only one year (July 2009 to May 2010), which may not capture long-term trends.

Casila et al. (2019)	❖ The nutrients and POM characteristics of the Sumida and Shakujii Rivers differ significantly. ❖ The Shakujii River was impacted by freshwater inflows from combined sewer systems, conversely, the POM and nutrient levels in the Sumida River are influenced by tidal processes and inputs from tributary rivers. ❖ During the flood phase of the spring tide, suspended sediments (SS) are carried from the Sumida River to the Shakujii River.	❖ The study was limited to a specific geographic region (Tokyo, Japan) and may not be generalizable to other urban estuaries. ❖ The short duration of the measurements (13 hours) may limit the ability to capture the full range of seasonal or tidal variations in the estuaries.
da Conceição et al. (2020)	❖ Elemental and isotopic analyses of carbon (C) and nitrogen (N), along with the C/N ratio, indicated that the anthropogenic origin of POM in the sediment core was mainly due to domestic sewage.	❖ The study uses a single sediment core for analysis, which may not represent the entire river system or account for spatial variability within the riverbed sediments. ❖ The study is limited to a specific geographical area (Piracicaba River) and may not be generalizable to other urban estuaries.

5.5. Total Organic Carbon (TOC) in RSPA

5.5.1. Overview of TOC Pollution in River Sediment

Total Organic Carbon (TOC) pollution in river sediments is a significant environmental concern as it reflects the amount of organic pollution in aquatic systems. Major rivers in India, including the Ganga, Yamuna, Godavari, Krishna, Cauvery and Sabarmati are affected by TOC contamination. Managing TOC levels is essential to maintaining water quality, protecting aquatic life, and ensuring the ecological balance of riverine environments.

TOC pollution in river sediments refers to the accumulation of organic carbon compounds in the sediment layer of rivers. It comes from natural sources like decaying vegetation, aquatic life, and soil erosion, as well as anthropogenic sources such as urban runoff, industrial discharges, agricultural runoff, and wastewater treatment plant effluents. TOC is a key indicator of the amount of organic material present in the environment, and its levels in sediments can provide insights into the health of aquatic ecosystems, pollution sources, and the overall water quality.

5.5.2. Impact of TOC Pollution in River Sediments

***Eutrophication*:** High levels of TOC can lead to excessive nutrient loading, which causes algal blooms. When these algae die and decompose, they consume oxygen, leading to hypoxic (low oxygen) conditions, which can harm aquatic life.

***Oxygen Depletion*:** The decomposition of organic matter in sediments consumes dissolved oxygen, potentially leading to anoxic (completely devoid of oxygen) conditions, making it difficult for aquatic organisms to survive.

***Biodiversity Loss*:** An increase in TOC and associated pollutants can degrade habitat quality, leading to a reduction in species diversity and abundance.

***Sediment Quality*:** Elevated TOC levels can alter the physical and chemical properties of sediments, affecting processes such as sediment stability, nutrient cycling, and contaminant retention.

5.5.3. Analysis According to the Source of Articles and Methods Adopted on TOC

From the graphical representation of Fig. 5.13, the contribution of various sources in the field of river sediment pollution by TOC has been clearly reflected. The contribution of literature source *Water (Switzerland)* and *Journal of Environmental Quality* is maximum (25% each) among all the other sources.

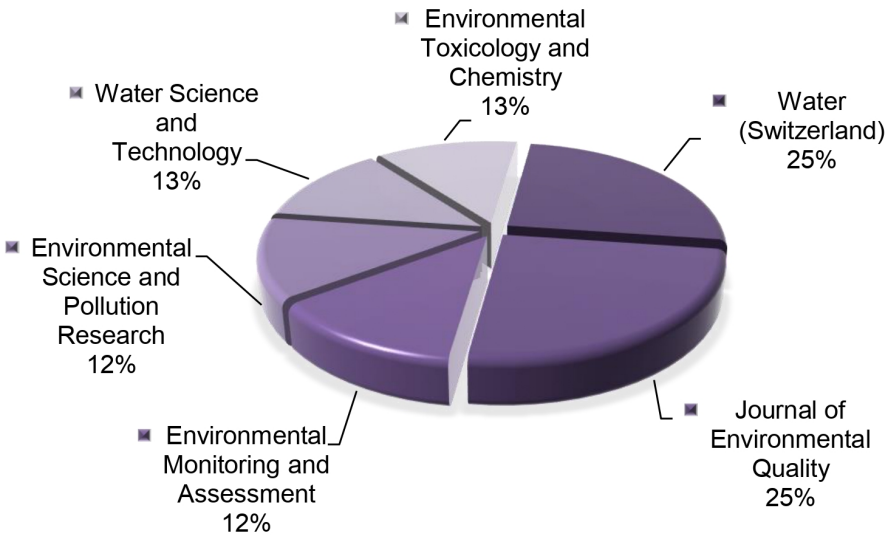


Fig. 5.13. Visual representation in terms of the contribution of literature sources, for evaluating TOC on assessing river sediment pollution during the time span of 2004-2023.

The qualitative analysis illustrated in Fig. 5.14 represents the methods adopted to assess TOC concentration during the time span of 2004-2023. It was observed that three methods/instruments had been used, TOC analyser, Elemental analyser and Method 3090 with frequencies of 37.5%, 37.5% and 25% respectively. Both the TOC analyser (Ozaki et al. 2005;

Fang and Wang 2021) and Elemental analyser (Jia et al. 2017; Khabouchi et al. 2020) work on the same principle mentioned in Method 9060 (USEPA SW-846) (Ouyang et al. 2006).

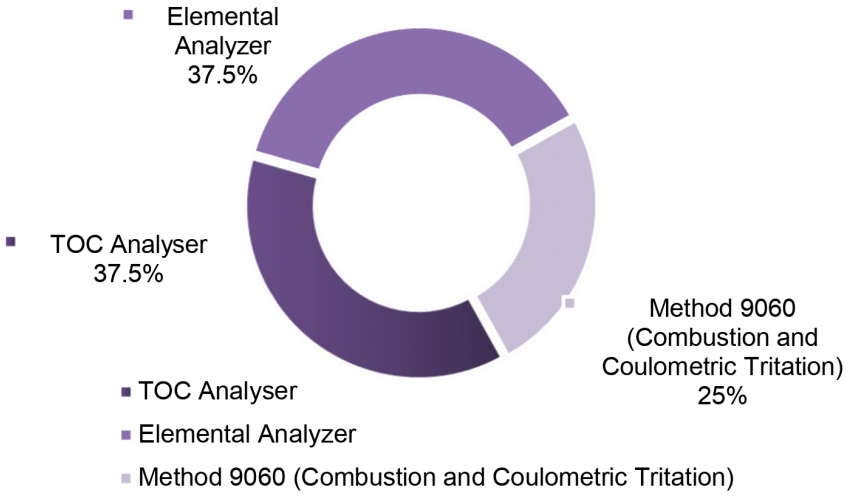


Fig. 5.14. Visual representation of methods adopted for evaluation of TOC on RSPA during the time span of 2004-2023.

5.5.4. Different Methods Adopted for TOC Evaluation in RSPA

"Method 9060" by Combustion and Coulometric Titration

***Sample Preparation*:** The sediment samples were first dried at 70˚C and ground into a fine powder. They were then treated with 10% hydrochloric acid (HCl). Once the effervescing[1] (bubbling or gas release) subsided, additional HCl was introduced. This process of gradually adding acid continued until no effervescing occurred upon the addition of another aliquot[2]. After the acid treatment, the sample was dried again at 70˚C and allowed to cool in a desiccator. A 5- to 30-mg aliquot of the dry, ground sediment was then weighed to the nearest milligram and placed into a carbon-free crucible[3].

Notes:

[1]*Effervescing* refers to the process of bubbling, fizzing, or releasing gas bubbles, typically when a liquid is undergoing a chemical reaction.

[2]An *aliquot* is a precise portion of a sample or solution taken for analysis or experimentation.

[3]A *crucible* is a container or vessel that can withstand extremely high temperatures and is used in various industries, laboratories, and manufacturing processes to melt, burn, or subject materials to high heat.

***Analysis of sample*:** Total organic carbon was measured by combusting the material in a high-temperature furnace within an oxygen-rich atmosphere, converting it to carbon dioxide (CO_2). The combustion gases were then passed through a water vapor filter and subsequently through two reaction filters. The first filter, containing magnesium perchlorate, removed any residual water vapor. The second filter, containing acid dichromate on Silocel and manganese dioxide, absorbed sulfur oxides and oxidized NO_x products, preventing interference in the analysis. Finally, the gases were directed to a coulometer, where the CO_2 was measured using coulometric titration.

TOC Analyser

A TOC analyser is a specialized instrument used to measure the amount of organic carbon in a liquid or solid sample. The TOC analyser typically works by oxidizing the organic carbon in the sample to carbon dioxide (CO_2) and then measuring the CO_2 produced. The instrument basically works on the same working principle as "Method 9060".

***Working Principle*:** The sample (sediment) is typically prepared (e.g., dried, ground) and then introduced either as a slurry or directly into the analyser after acid treatment. If the sample contains inorganic carbon (e.g., carbonates), it may interfere with the measurement of organic carbon. In such cases, the sample is acidified (generally with HCL) to convert inorganic carbon to CO_2, which is then purged from the sample using a carrier gas like nitrogen

The remaining sample, containing organic carbon, is oxidized to convert the organic carbon into CO_2. To do this, the sample is combusted at high temperatures (680-1000°C) in the presence of a catalyst, typically platinum, to oxidize organic carbon to CO_2.

The CO_2 generated from the oxidation of organic carbon is carried by a stream of carrier gas (e.g., air, oxygen, or nitrogen) to a CO_2 detector. The TOC analyser calculates the concentration of TOC in the sample based on the amount of CO_2 detected and the volume or mass of the original sample.

Elemental Analyser

Both types of analysers (TOC and Elemental) use combustion, the TOC analyser focuses on measuring only the organic carbon, whereas the elemental analyser provides a comprehensive assessment of multiple elements in the sample. It measures multiple elements in a sample, including carbon, hydrogen, nitrogen, sulfur and sometimes oxygen.

***Working Principles*:** The sample is combusted at high temperatures (900-1100˚C) in an oxygen-rich environment to convert all elements into their respective gaseous forms (C ~ CO_2, H ~ H_2O, N ~ NO_x, S ~ SO_2). The gases produced during combustion are then separated using gas chromatography or by passing them through a series of traps and columns to remove interferences. The separated gases are then detected by various detectors, depending on the element. CO_2 is typically detected using a thermal conductivity detector (TCD) or non-dispersive infrared (NDIR) detector.

The main findings and limitations of TOC are included in Table 5.5.

Table 5.5. Main Findings and Limitations literatures on TOC

Auth-ors	Main Findings	Limitations
Jia et al. (2017)	❖ Nutrient data showed regional variations, with TOC levels rising from 1.42% at the bottom to 5.97% at the surface in the lacustrine zone. ❖ TN and TP levels increased from the riverine to the lacustrine zones,	❖ The study relied on periodic sampling, which may not reflect short-term fluctuations in nutrient levels that could result from episodic events like heavy rainfall or drought.

	indicating nutrient accumulation in the central reservoir. ❖ Algae blooms were rare due to the depth of the reservoir depth and environmental policies, high TOC flux and nutrient availability suggested a continued risk of eutrophication.	❖ The nutrient inputs were measured at a limited number of locations.
Khabouchi et al. (2020)	❖ The fraction of saturated hydrocarbons extracted from the sediments of Oued Meliane included a majority of organic compounds of a biogenic nature with a small oil input. ❖ The main sources of contamination were discharges from the industrial area, and agricultural activities in the Smenja location near Fahes city, in addition to the effects of the Bir Mcherga dam.	❖ Samples collected at one point in time might not represent the fluctuations in pollution levels throughout the year due to seasonal changes or episodic pollution events. ❖ The number and distribution of sampling sites may not fully capture the spatial variability of organic pollutants.
Fang and Wang (2021)	❖ Total phosphorus (TP) in the sediments was predominantly composed of P_{CDB} (ferric iron-bound P), accounting for an average of 58% of the TP. ❖ The sedimentary TP concentrations exhibited a positive correlation with TOC content and a negative correlation with grain size, suggesting that TOC and grain size are crucial factors to determine the distribution of phosphorus in Danshuei River Estuary sediments.	❖ The study is limited to the DRE in northern Taiwan. Its findings may not be directly applicable to other estuaries with different conditions or anthropogenic impacts. ❖ Study represents a snapshot in time and does not account for seasonal or long-term variations in geochemical species distributions or anthropogenic influences.

5.6. Total Organic Nitrogen (TON) in RSPA

5.6.1. Overview of TON Pollution in River Sediment

Total Organic Nitrogen (TON) pollution in river sediment refers to the presence and accumulation of organic nitrogen compounds within the sediment layer of a river. Organic nitrogen is a component of organic matter, which includes plant material, animal residues, microbial biomass, and other organic compounds. Fertilizers, manure, and crop residues from agricultural fields often contain high levels of nitrogen. These can be washed into rivers during rainfall, contributing to elevated TON levels in the sediment. Also, certain industries release nitrogen-rich organic waste into water bodies, which can settle into the river sediment.

5.6.2. Environmental Impacts of TON Pollution

***Eutrophication*:** High levels of TON can lead to eutrophication, where excessive nutrient inputs stimulate algal blooms. When these algae die and decompose, they can deplete oxygen in the water, leading to hypoxic conditions that harm aquatic life.

***Oxygen Depletion*:** The decomposition of organic matter in sediments consumes oxygen, potentially creating anoxic (oxygen-free) zones that can be detrimental to benthic organisms (organisms living in or on the riverbed).

***Alteration of Sediment Chemistry*:** Elevated TON can change the chemical composition of the sediment, affecting nutrient cycling, sediment stability, and the overall health of the benthic environment.

***Release of Toxic Compounds*:** Under anoxic conditions, the breakdown of organic nitrogen in sediment can release harmful compounds, such as ammonia, which is toxic to aquatic life.

5.6.3. Analysis According to the Source of Articles and Methods Adopted

From the graphical representation of Fig. 5.15, the contribution of various sources on RSPA by TON has been reflected. The contribution of literature sources *Water Research*, *Applied Geochemistry*, *Global and Planetary Change* and *Geomorphology* are commendable.

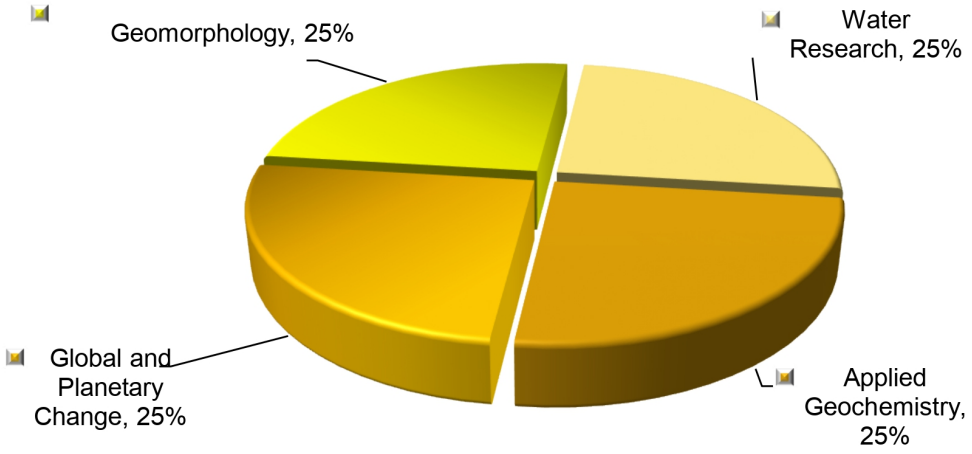


Fig. 5.15. Visual representation in terms of the contribution of literature sources, for evaluating TON on assessing river sediment pollution during the time span of 2004-2023.

The qualitative analysis highlighted in Fig. 5.16 represents the methods adopted to assess TON concentration between 2004 and 2023. It was observed that Elemental analyser (Song et al. 2023, de Morais et al. 2021, and Schulz et al. 2003). Another indirect method was found in Steiger and Gurnell (2003), which measured TON by subtracting the NH_4-N content from TN.

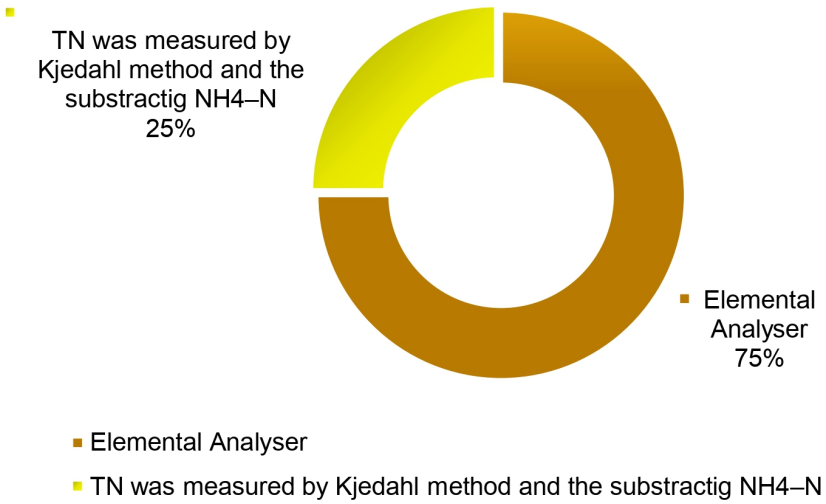


Fig. 5.16. Visual representation of methods adopted for evaluation of TON on RSPA during the period of 2004-2023.

5.6.4. Different Methods Adopted for TON Evaluation in RSPA

Elemental Analyser is already described in 5.5.4. of TOC Segment.

TN was measured by the Kjeldahl method and the subtracting NH_4–N

Total nitrogen (TN) was determined by digestion of a few grams of the samples following the Kjeldahl method, NH_4–N was extracted with 150 ml of 2 mol/l of Potassium chloride (KCl). **NH_4–N** refers to the concentration of nitrogen (N) in the form of ammonium (NH_4^+). The difference between TN and NH_4–N represents an estimate of TON.

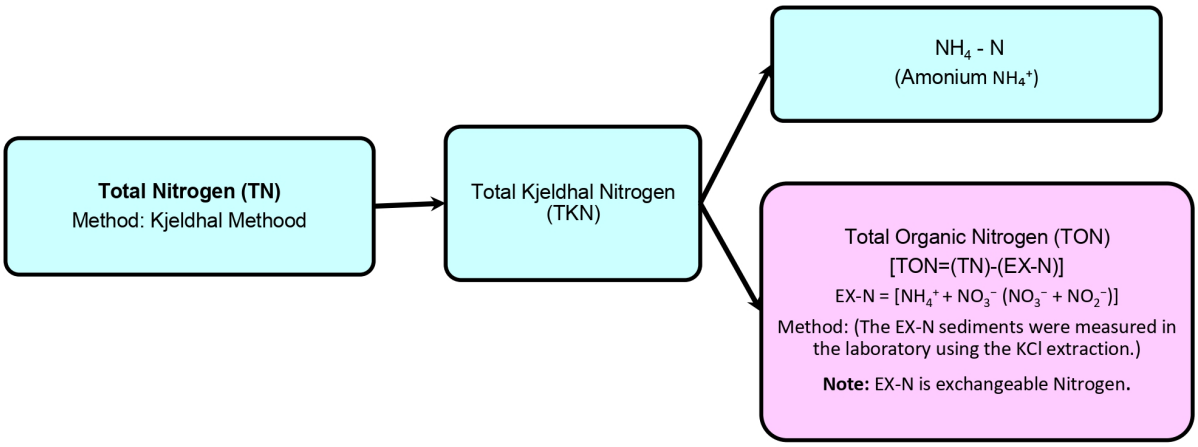


Fig. 5.17. Diagram depicting the steps involved in TON calculation.

The main findings and limitations of TON have been included in Table 5.6.

Table 5.6. Main Findings and Limitations literatures on TON

Authors	Main Findings	Limitations
Schulz et al. (2003)	❖ Macrophytes significantly reduced flow velocities, thereby creating favourable conditions for the settlement of organic seston (SPM). ❖ Sedimentation was influenced by both the speed of the water flow and the availability of seston. ❖ Macrophytes enhanced nutrient retention by promoting the sedimentation of organic seston. ❖ Deposition was the primary process responsible for phosphorus retention in the lower River Spree.	❖ The study was conducted over specific periods (e.g., summer 2001), which may not capture the full variability of sedimentation and nutrient retention processes throughout the year.
de Morais et al. (2021)	❖ Extracted organic matter from sediments (EOMSed) from the Tiete River exhibited the highest average concentrations of non-purgeable organic carbon (NPOC) and total organic nitrogen (TON) and lowest average NPOC/TON molar ratios. ❖ The high degree of eutrophication in the Tiete River indicated a substantial input of simple organic matter with nitrogenous structures.	❖ The findings were specific to the study area and conditions, limiting the generalizability of the results to other regions or different environmental conditions. ❖ The study relied on certain simplifications and assumptions in the modeling process, which may not fully capture the complexity of real-world scenarios.
Song et al. (2023)	❖ Results showed the average annual sedimentary retention of TOC and TON in four reservoirs increased by 16% and 18% after dam construction and rapid eutrophication. ❖ The retention increments accounted for 20.6% of the total flux of TOC into the sea during the same period. ❖ The retention of TOC in reservoirs led to a decrease in their annual flux into the sea by 67.2% in 2016 compared to 1960.	❖ The study acknowledged uncertainty in the model simulations due to assumptions made in the parameterization of physical and biological processes. ❖ Limited availability of high-resolution, long-term observational data

5.7. Total Organic Phosphorus (TOP) in RSPA

5.7.1. Overview of TOP Pollution in River Sediment

Total Organic Phosphorus (TOP) refers to the organic forms of phosphorus bound within organic compounds in river sediments. Unlike inorganic phosphorus, which is commonly found in fertilizers, TOP is associated with organic matter, such as plant residues, animal waste, and microbial biomass.

In river sediments, TOP can accumulate over time, leading to long-term environmental and health impacts. The use of organic fertilizers, manure, and compost can introduce large amounts of organic phosphorus into rivers. This runoff is a primary source of TOP in many agricultural regions. Certain industries, especially those involved in food processing and pulp and paper production, can release organic phosphorus into rivers. Effective monitoring, regulation, and remediation strategies are essential to address this issue and protect both ecosystems and human health. The health risks of TOP in river sediments are substantial and multifaceted, affecting various body systems and posing long-term dangers, particularly for vulnerable populations.

5.7.2. Some Health Risks Associated with TOP Pollution

Chronic exposure can lead to neurodevelopmental disorders in children, cognitive decline, and other neurological issues like headaches, dizziness, and tremors. In children, prenatal and early life exposure to neurotoxic TOP can result in developmental delays, lower IQ, and behavioural problems such as attention deficit hyperactivity disorder (ADHD). Chronic exposure to TOP can lead to liver damage. Pregnant women exposed to TOP may be at higher risk for preterm births, low birth weights, and developmental defects in their children, including congenital disabilities and cognitive impairments.

5.7.3. Methods Adopted for TOP Evaluation in RSPA

Very few studies have been done on river sediment to date. In Avilés et al. (2006), the total phosphorus (TP) concentration measurement process was discussed briefly. To obtain the TP, after the calcinations of a separate sample (1 h, 450˚C), a simple extraction with 3.5 mol /l HCl is performed. For all cases, phosphate was determined in the extracts using a Technicon Autoanalyser AAII (Fernández et al. 1985).

Technicon Autoanalyser AAII

The Technicon Autoanalyser (AAII) is an automated instrument used for chemical analysis, specifically designed to handle large numbers of samples efficiently by performing continuous flow analysis (CFA), where a sample is continuously pumped through a series of tubing, reagents are added, and the chemical reactions are measured. The instrument typically measures concentrations of analytes using colorimetric methods, where the intensity of a color change in the reaction mixture is proportional to the concentration of the target analyte.

The main findings and limitations of TOP have been included in Table 5.7.

Table 5.7. Main findings and limitations of literatures on TOP Literatures.

Authors	Main Findings	Limitations
Avilés et al. (2006)	❖ The study identified that the most abundant form of phosphorus was apatite inorganic phosphorus (AIP), which constituted 68% of the total phosphorus. This was followed by total organic phosphorus (OP), accounting for 29% of the total phosphorus. ❖ Study emphasized that the most significant self-cleansing mechanism for removing phosphorus from the water column was calcite-phosphorus co-precipitation. ❖ Lithology and sewage inputs were found to be less influential in determining phosphorus concentration.	❖ The findings were based on samples collected during specific seasons (early November 2003), which may limit the generalizability of the results across different seasons or hydrological conditions.

5.8. Total Suspended Solid (TSS) in RSPA

5.8.1. Overview of TSS Pollution in River Sediment

Total Suspended Solids (TSS) refers to the portion of solids suspended in water that are not dissolved. These solids include a variety of materials such as silt, decaying plant and animal matter, industrial wastes, and sewage. TSS is a key indicator of water quality and plays a significant role in river sediment pollution.

5.8.2. Sources of TSS Pollution in River

***Natural Sources*:** Erosion of riverbanks, landslides, and the weathering of rocks contribute to the natural sediment load (SL) in rivers.

***Human Activities*:** Agriculture, deforestation, urbanization, construction, and mining can significantly increase the amount of sediment entering rivers. Poor land management practices often lead to increased runoff, which carries more sediment into waterways.

5.8.3. Impact of TSS on Water Quality

***Light Penetration*:** High TSS levels reduce light penetration in the water, affecting photosynthesis in aquatic plants and disrupting the aquatic ecosystem.

***Oxygen Levels*:** Suspended solids can reduce the amount of dissolved oxygen in the water, which is crucial for aquatic life. Sediments can also carry organic matter that decomposes, further depleting oxygen.

***Contaminant Transport*:** TSS can adsorb and transport pollutants like heavy metals, pesticides, and nutrients, spreading contamination through the water system.

5.8.4. Analysis According to the Source of Articles and Methods Adopted

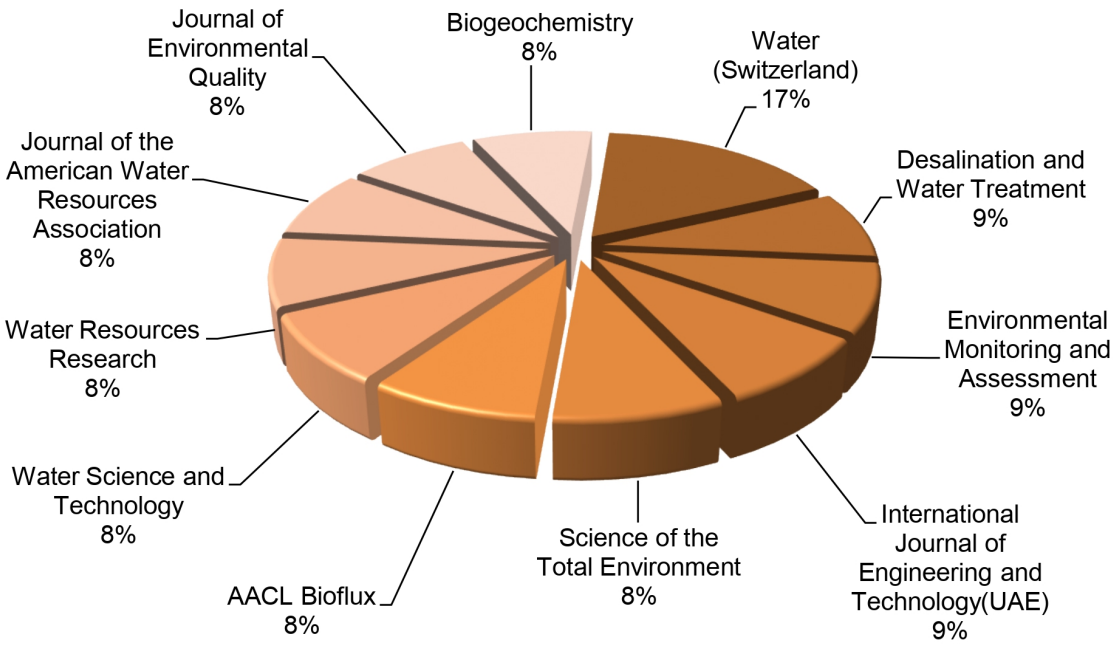


Fig. 5.18. Visual representation in terms of the contribution of literature sources, for evaluating TSS on assessing river sediment pollution between 2004 and 2023.

From the graphical representation of Fig. 5.18, the contribution of various sources in the field of river sediment pollution by TSS has been represented. The contribution of literature source *Water (Switzerland)* was maximum (17%) among all the other sources.

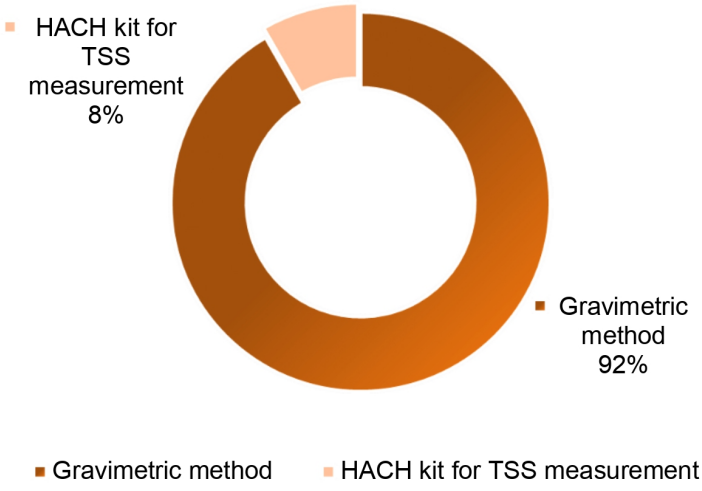


Fig. 5.19. Visual representation of methods adopted for evaluation of TSS on RSPA during the time span of 2004-2023

The qualitative analysis Fig. 5.19 represents the methods adopted to evaluate the TSS concentration in river sediment during the time span of 2004-2023. It is observed that the Gravimetric method was quite popular among the researchers, as it gained 92% of usage frequency for TSS assessment, Jones et al. (2011), Kuhnert et al. (2012), Tuttle-Raycraft et al. (2017) are several authors who adopted this method method in their respective study.

5.8.5. Methods for TSS evaluation in RSPA

Gravimetric method (APHA)

The gravimetric method for measuring Total Suspended Solids (TSS) is a standard procedure outlined by the American Public Health Association (APHA). This method involves filtering a known volume of water through a pre-weighed filter, drying the filter to a constant weight in a drying oven at 103-105°C for at least 1 hour, and then measuring the mass of the retained solids.

The Total Suspended Solids (TSS) concentration is calculated using the following formula (Eq. 5.3):

$$\text{TSS}\ (\text{mg/l}) = \frac{(\text{Weight of dried filter} + \text{Solids}) - (\text{Weight of clean filter})}{\text{Volume of water sample (ml)}} \tag{5.3}$$

HACH Kit

The Hach Kit TSS (Total Suspended Solids) Indicator works by measuring the turbidity of a water sample, which correlates with the concentration of suspended solids. The kit typically uses a photometric method, where a light source passes through the sample, and the intensity of light scattered by the suspended particles is measured by a detector. The higher the turbidity, the higher the TSS concentration. The instrument then converts this turbidity reading into an estimated TSS value based on a calibration curve.

The main findings and limitations of TSS have been included in Table 5.8.

Table 5.8. Main findings and limitations of literatures on TSS

Author	Main Findings	Limitations
Abd Wahab et al. (2018)	❖ The study observed the range of DO (2.11–8.07 mg/L), TSS (0.4–128.2 mg/L) and Suspended Sediment Concentration (SSC) from 0.07 mg/L to 25.6 mg/L. ❖ Water quality analysis showed that TSS and SSC were higher in the dry season but DO were higher in the wet season.	❖ Study was limited to a specific geographic region (Terengganu River Basin). ❖ Study focused on seasonal variations in water quality parameters, but did not explore other potential factors.

Yustika et al. (2019)	❖ The average soil erosion rates in the Sekampung Hulu and Sangharus watersheds were 12.5 Mg/ha/year and 5.6 Mg/ha/year, respectively. ❖ The results indicated that young coffee trees increased soil erosion rates. ❖ The application of Best management practices including conversion to agroforestry coffee, cover crops and contour systems, was effective in reducing soil erosion.	❖ The study focuses on the Sekampung Hulu and Sangharus watersheds. Findings might not be generalizable to other parts of the Amazon Basin or other river systems ❖ Limited historical data on land use and erosion rates posed challenges for accurate long-term assessments.
Marinho et al. (2020)	❖ The total suspended sediment discharge of the Negro River before (3.14 Mt/year) and after (1.43 Mt/year) the Anavilhanas Archipelago indicates a 55% retention of the suspended load due to the low water slope and reduced flow velocity. ❖ The main function of the Anavilhanas Archipelago, from the fluvial standpoint, is to act as a sink for suspended sediments, mainly from the Branco River.	❖ The study focuses on the Anavilhanas Archipelago in the Rio Negro. Findings might not be generalizable to other parts of the Amazon Basin or other river systems. ❖ Data collection was limited to a specific time period, it might not account for seasonal or annual variations in sediment levels.

5.9. Heavy Metals (HevMetC) in RSPA

5.9.1. Overview of HevMetC Pollution in River Sediment

Sediment pollution with heavy metals is a worldwide and is considered to be a serious threat to the aquatic ecosystem because of their toxicity, ubiquitous and persistent nature, non-biodegradability, ability to bio-accumulate in the food chain and subsequent accumulation in aquatic habitats (Zhang et al. 2018). Despite their low solubility, heavy metals will quickly dilute and travel hundreds of kilometers along hydrologic gradients before being absorbed and settling on the bottom sediments (Tam and Wong 2000). Sediments can act as a final sink for heavy metals in the aquatic environment (Guo and Yang 2016). More than 90% of the heavy metal load in the aquatic systems has been found to be associated with suspended particulate matter and sediments (Amin et al. 2009; Zheng et al. 2008). The distribution of heavy metals is influenced by the mineralogical and chemical composition of suspended material, anthropogenic influences, deposition, sorption, enrichment in organisms (Jain et al. 2008) and various physico-chemical characteristics (Singh et al. 2005).

The main reason for this is the increasing amount of metal that is being deposited in the coastal zone from both rivers and nonpoint sources, especially in developing countries (Shulkin et al. 2003).

Common heavy metal pollutants are Cr, Ni, Cu, Zn, Cd, Mn, As (metalloid) and Pb (Table 5.11). These can easily accumulate in the finely grained sediment, remain in water bodies and eventually be carried downstream through the river. Thus sediments act as a major sink of heavy metal pollutants in the river bodies. Therefore, the sediments may serve as a

screening method to detect recent and historical contamination in the surrounding environment, as well as an indication of the pollution levels (Zahra et al. 2014).

5.9.2. Sources of HevMetC Pollution

Heavy Metal Contamination in rivers primarily arises from industrial activities, agricultural runoff, and urbanization. Industries such as mining, smelting, and manufacturing discharge heavy metals like lead (Pb), mercury (Hg), and cadmium (Cd) directly into water bodies. Agricultural practices contribute through the use of fertilizers and pesticides containing heavy metals, which leach into rivers. Urbanization adds to the problem through storm water runoff, which carries pollutants from roads, construction sites, and urban waste. Additionally, wastewater treatment plants and illegal dumping of hazardous waste further exacerbate heavy metal contamination in river systems. Fig.

5.9.3. Impact of Some Key Heavy Metals on Human Health, Aquatic Life, and Environment

Pollution assessment by contamination of heavy metals typically involves testing for several key heavy metals due to their toxicity and prevalence in the environment. Commonly tested metals include lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni), Copper (Cu), Manganese (Mn) and zinc (Zn). Each of these metals has specific harmful effects on human health, aquatic organisms, and the environment.

***Impacts on Human Health*:**

Pb: Lead can cause neurological damage, especially in children, leading to learning disabilities and behavioural problems, kidney damage and reproductive issues in adults.

Hg: Mercury causes neurological and developmental damage, particularly in fetuses and young children. Chronic exposure can lead to cognitive decline, motor dysfunction, and cardiovascular problems.

Cd: Cadmium exposure is linked to kidney damage, bone demineralization (osteoporosis) and an increased risk of cancer. It is also associated with respiratory issues when inhaled.

As: Arsenic is a potent carcinogen and is associated with skin, lung, bladder, and liver cancers. Chronic exposure can also lead to cardiovascular disease, diabetes, and neurological effects.

Cr: Chromium can cause skin irritation, respiratory problems, and lung cancer. Chronic exposure can lead to kidney and liver damage.

Ni: Nickel exposure can cause allergic reactions, skin rashes, and respiratory problems. Long-term exposure may increase the risk of lung and nasal cancers.

Zn: While zinc is an essential nutrient, excessive exposure can lead to gastrointestinal issues, nausea, and immune system impairment. Chronic exposure can cause anemia and pancreas damage.

Cu: Acute copper poisoning can cause gastrointestinal distress, including nausea, vomiting, and diarrhea. Chronic exposure may lead to liver and kidney damage, as well as neurological disorders.

Mn: Manganese is important for bone development and metabolic processes. However, overexposure, particularly through inhalation or contaminated drinking water, can lead to neurological problems, including manganism—a condition similar to Parkinson's disease. High levels of manganese can also affect cognitive functions and motor skills.

Arsenic (As)	Pesticides, fungicides, metal smelters
Cadmium (Cd)	Welding, pesticides, fertilizers, batteries
Chromium (Cr)	Mining, electroplanting, textile, tannery
Copper (Cu)	Electroplanting, pesticides, mining
Lead (Pb)	Paint, pesticides, mining, batteries, automobile
Manganese (Mn)	Welding, fuel addition, ferromanganese production
Mercury (Hg)	Pesticides, batteries, paper industries
Nickel (Ni)	Electroplating, zinc base casting, battery industries
Zinc (Zn)	Refineries, brass manufacture, metal plating

Fig. 5.20. Probable different Sources of Heavy metals.

***Impact of Aquatic Organisms*:** The above mentioned heavy metals are highly toxic to aquatic life, particularly fish and invertebrates. They can affect gill function, reduce growth rates, and impair reproduction. They can also inhibit photosynthesis in aquatic plants and algae, leading to reduced productivity in aquatic ecosystems and disrupting the balance of other essential metals in aquatic organisms.

***Impact on Environment*:** In the environment, heavy metals can accumulate in sediments, affecting benthic organisms and potentially entering the food chain. They can lead to long-term ecological effects, including reduced biodiversity, influence the geochemical cycling of other elements in the environment, affecting water quality and ecosystem stability.

5.9.4. Rivers Affected by HevMetC in India and Sources of Pollution

Several rivers in India are significantly affected by Heavy Metal Contamination (HevMetC) due to industrial discharges, agricultural runoff, and urban pollution. Some of the most affected rivers include:

Ganga River: The **Ganga River** (also known as the Ganges) flows through a total of **five states** in India. These states are Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal. Metal pollution sources are as follows:

- **Kanpur Tanneries (Uttar Pradesh):** Discharge of Cr, Pb and Cd from leather processing and tanning operations (Batabyal 2023).
- **Textile and Dyeing Industries (Varanasi and Kanpur):** Release of heavy metals like Cr and Cd through dyeing processes and chemical treatments (Kumar et al. 2020).
- **Fertilizer Plants (West Bengal and Bihar):** Emission of As and Pb from fertilizer manufacturing and agricultural runoff.
- **Paper Mills (Uttarakhand and West Bengal):** Effluents containing Hg and Pd due to chemical processes used in paper production (Roy and Shamim 2020).
- **Pharmaceutical Industries (Haridwar):** Discharge of various heavy metals, including Hg, during the manufacturing process.

Yamuna River: The **Yamuna River**, a major tributary of the Ganga River, flows through a total of **seven states** in India, these are Uttarakhand, Himachal Pradesh, Haryana, Delhi, Uttar Pradesh, Rajasthan and Madhya Pradesh. Metal pollution sources are as follows:

- **Electroplating Industries (Delhi and Noida):** Cr, Ni, and Cd contamination from electroplating waste (Singh et al. 2020).
- **Thermal Power Plants (Haryana and Uttar Pradesh):** Fly ash and effluents containing Hg, Pd, and Cd from coal combustion.
- **Chemical Manufacturing Units (Panipat and Faridabad):** Discharge of Pd, Cr and other toxic metals during chemical production (Rajan and Nandimandalam 2024)
- **Agricultural Runoff (Haryana and Uttar Pradesh):** Pesticides and fertilizers contributing As, Pd, and Cd to the river.
- **Municipal Sewage (Delhi):** Untreated sewage containing various heavy metals, including Pd and Hg from urban waste.

Godavari River: It flows through Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh and Odisha. Metal pollution sources are as follows:

- **Mining Activities (Maharashtra and Telangana):** Zinc, copper, and lead contamination from mineral extraction and processing.
- **Paper and Pulp Mills (Andhra Pradesh):** Discharge of cadmium, lead, and mercury during pulp bleaching and paper production (Ranthu et al. 2023)
- **Pesticide Manufacturing Units (Maharashtra):** Effluents containing arsenic and lead from the production of agrochemicals.
- **Steel Plants (Chhattisgarh):** Release of chromium, nickel, and cadmium from steel manufacturing processes.
- **Thermal Power Stations (Andhra Pradesh):** Fly ash containing heavy metals like mercury and lead, contaminating nearby water bodies.

Brahmaputra River: Brahmaputra River is one of the major rivers in Asia, it flows through Arunachal Pradesh and Assam. Metal pollution sources are as follows:

- **Oil Refineries (Assam):** Discharge of Pd and Hg from refining processes (Shorna et el. 2021).
- **Coal Mining (Meghalaya):** Acid mine drainage containing As, Pd and Hg from coal mining activities.
- **Tea Estates (Assam):** Runoff containing As and Pd from pesticide use in tea cultivation.
- **Chemical Industries (Assam):** Effluents containing heavy metals like Pd and Cd from chemical manufacturing units.
- **Municipal Waste (Guwahati):** Untreated urban waste contributing heavy metals such as Pd, Hg and As to the river.

Sabarmati River: The Sabarmati River flows primarily through the states of Rajasthan and Gujarat in western India. Metal pollution sources are as follows:

- **Textile Dyeing Units (Ahmedabad):** Cr, Cd and Ni discharge from dyeing processes.
- **Pharmaceutical Industries (Ahmedabad and Gandhinagar):** Release of Hg, Pd and other toxic metals during pharmaceutical production.
- **Chemical Industries (Vatva Industrial Estate):** Discharge of various heavy metals, including Ni, Pd and Cr from chemical manufacturing (Salauddin and Sandesh 2023)
- **Electroplating Units (Ahmedabad):** Effluents containing Cr, Cd and Zn from electroplating operations.
- **Fertilizer Plants (Vadodara):** Release of As and Cd from fertilizer production processes.

Mahanadi River: The **Mahanadi River** is one of the major rivers in eastern India, flowing through the states of Chhattisgarh and Odisha. Metal pollution sources are as follows:

- **Steel Plants (Rourkela, Odisha):** Cr, Ni and Cd contamination from steel production and related processes (Samal et al. 2023).
- **Aluminum Smelters (Sambalpur and Angul, Odisha):** Discharge of Pd, Hg and Cd from aluminium smelting operations.
- **Coal Mining (Talcher, Odisha):** Acid mine drainage and runoff containing Hg, Pd and As from coal mining activities.
- **Thermal Power Plants (Odisha):** Emissions of Hg, Pd and Cd from coal combustion and fly ash disposal (Sahu et al. 2023).
- **Chemical Fertilizer Units (Paradeep, Odisha):** Effluents containing As, Pd and Cd from the production of chemical fertilizers.

5.9.5. Analysis According to the Source of Articles and Methods Adopted

From the graphical representation of Fig. 5.21, the contribution of various sources in the field of river sediment pollution by HevMetC has been clearly reflected. The contribution of literature source *Environmental Monitoring and Assessment* highest (29%) among all the other

sources. *Environmental Earth Sciences* (18%) and *Marine Pollution Bulletin* (11%) also notably contributed on the HevMetC assessment.

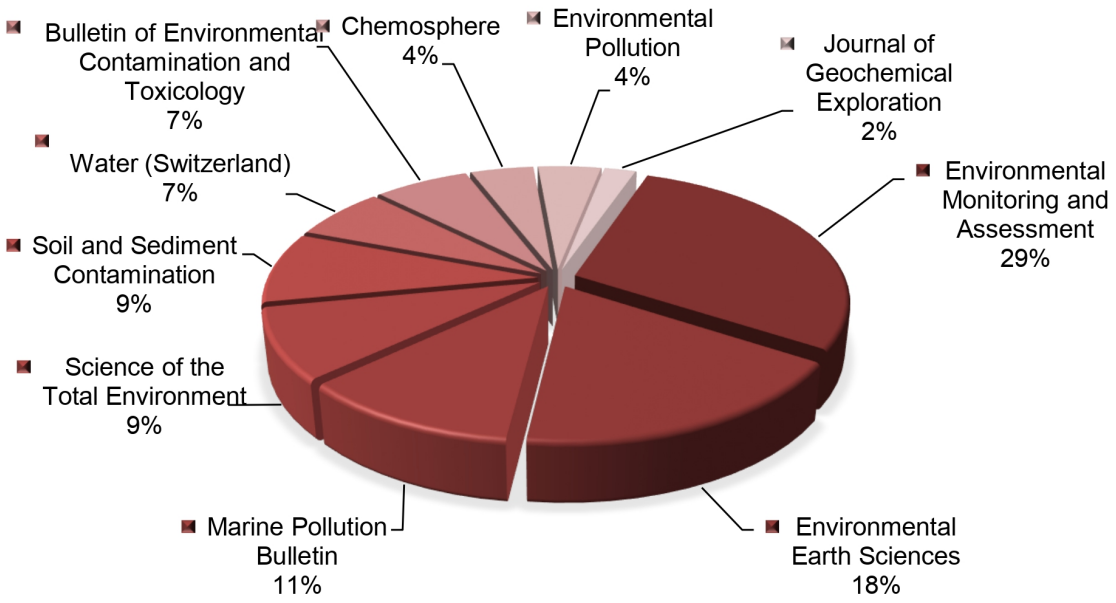


Fig. 5.21. Visual representation in terms of the contribution of literature sources, for evaluating HevMetC on assessing river sediment pollution during the period of 2004-2023.

The qualitative analysis Fig. 5.22, represents the various methods according to their frequency of usage in different articles during the time span of 2004-2023. AAS was found to be the most popular method (37%) for the evaluation of HevMetC on river sediment pollution by the authors (Taghinia Hejabi et al. 2011; Köse et al. 2020). ICP-MS (Tepe et al. 2022; Fan et al. 2021; Salati et al. 2010) and ICP-AES (Yang et al. 2020; Sun et al. 2019; Zheng et al. 2008) achieved the acceptability of 22% and 13% respectively.

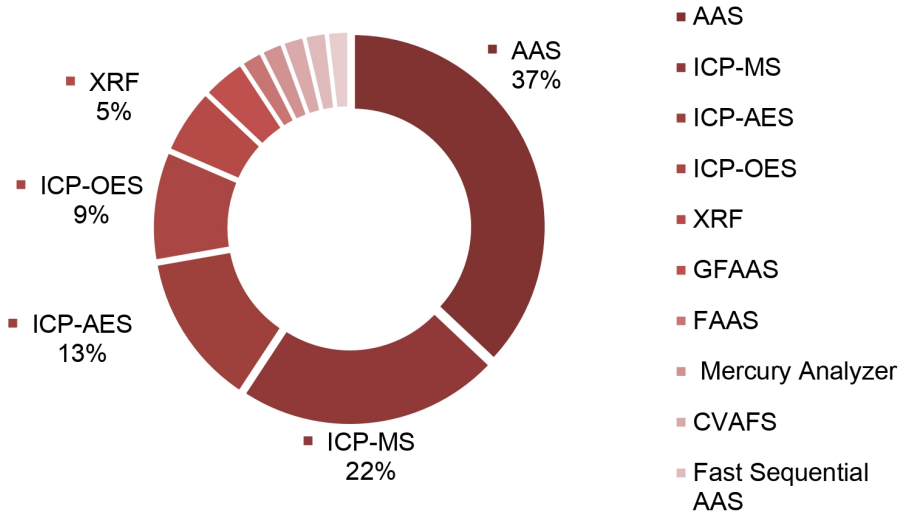


Fig. 5.22. Visual representation of methods adopted for evaluation of HeMetC on RSPA during the time span of 2004-2023.

The measurement methods of HevMetC are given in Table 5.9.

Table 5.9. HevMetC measurement methods adopted in the literatures.

Abbreviation	Method Name
AAS	Atomic Absorption Spectrometer
ICP-MS	Inductively Coupled Plasma -Mass Spectrometry
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
XRF	X-Ray Fluorescence
GFAAS	Graphite Furnace Atomic Absorption Spectrometry
FAAS	Flame Atomic Absorption Spectrometry
CVAFS	Cold Vapour Atmospheric Fluorescence spectrometry
AFS	Atomic Fluorescence Spectroscopy
Hg-Analyser	Mercury analyser

5.9.6. Methods for HevMetC evaluation in RSPA

Atomic absorption spectrometry (AAS)

Atomic absorption spectrometry (AAS) is based on the principle that free atoms in the gaseous state can absorb light at specific wavelengths (Fig. 5.23). Each element has a unique set of wavelengths that correspond to the energy transitions of its electrons, which allows for the identification and quantification of elements in a sample.

Working principle: The sample to be analyzed is typically introduced into the atomization device in either a liquid or solid form. For liquid samples, a nebulizer converts the sample into an aerosol or tiny droplets, which are then transported into a flame or graphite furnace where the atoms are vaporized into gaseous molecules and forms of free atoms. In flame atomic absorption spectrometry (FAAS), the sample aerosol is introduced into a flame where thermal energy creates the necessary conditions for atomization. In electrothermal atomic absorption spectrometry (ETAAS), a graphite furnace is used to achieve higher sensitivity by allowing for the controlled heating and vaporization of the sample.

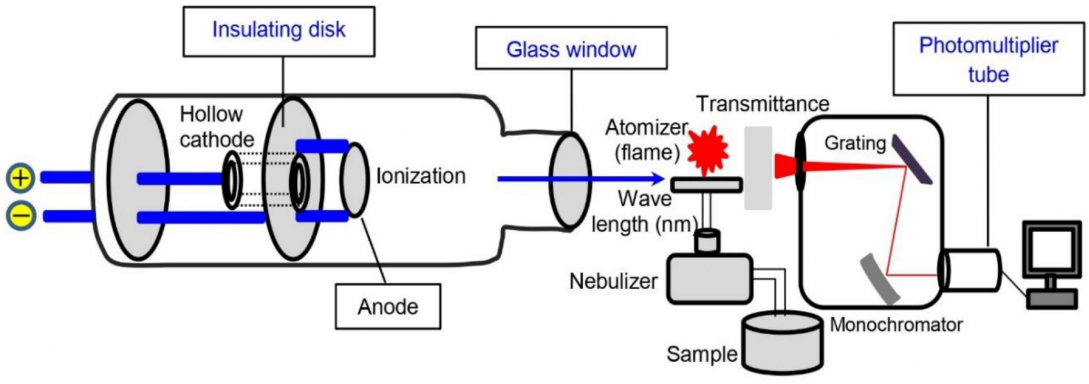


Fig. 5.23. Schematic diagram of an Atomic absorption spectrometry.

A light source, typically a hollow cathode lamp, emits light at the characteristic wavelengths of the element. When this light passes through the atomized sample, specific wavelengths are absorbed by the free atoms, corresponding to their electronic transitions. The light transmitted through the atomic vapour passes through a monochromator and is then monitored using a detector, often a photomultiplier tube (PMT). As the concentration of the element in the sample increases, more light is absorbed by the atoms, resulting in less light reaching the detector, so the intensity of the light reaching the detector is inversely proportional to the concentration of the atoms in the sample. By measuring the decrease in light intensity, quantitative information about the sample can be derived.

Wavelengths of some metallic elements have been listed below (Mathivanan et al. 2014):

Sodium (Na): ~589 nm
Cadmium (Cd): ~228.8 nm
Lead (Pb): ~217.0 nm
Zinc (Zn): ~213.9 nm
Copper (Cu): ~324.8 nm
Iron (Fe): ~248.3 nm
Manganese (Mn): ~279.5 nm
Chromium (Cr): ~357.9 nm
Nickel (Ni): ~232.0 nm
Mercury (Hg): ~253.7 nm

Flame Atomic Absorption Spectrometry (FAAS): The sample is atomized in a flame, typically a mixture of air and acetylene or nitrous oxide and acetylene. Commonly used for the analysis of metals in liquid samples and requires a relatively larger sample volume.

Graphite Furnace Atomic Absorption Spectrometry (GFAAS): The sample is atomized in a graphite tube (furnace), which is electrically heated to very high temperatures. Used for trace element analysis where higher sensitivity is required. Requires a much smaller sample volume compared to FAAS.

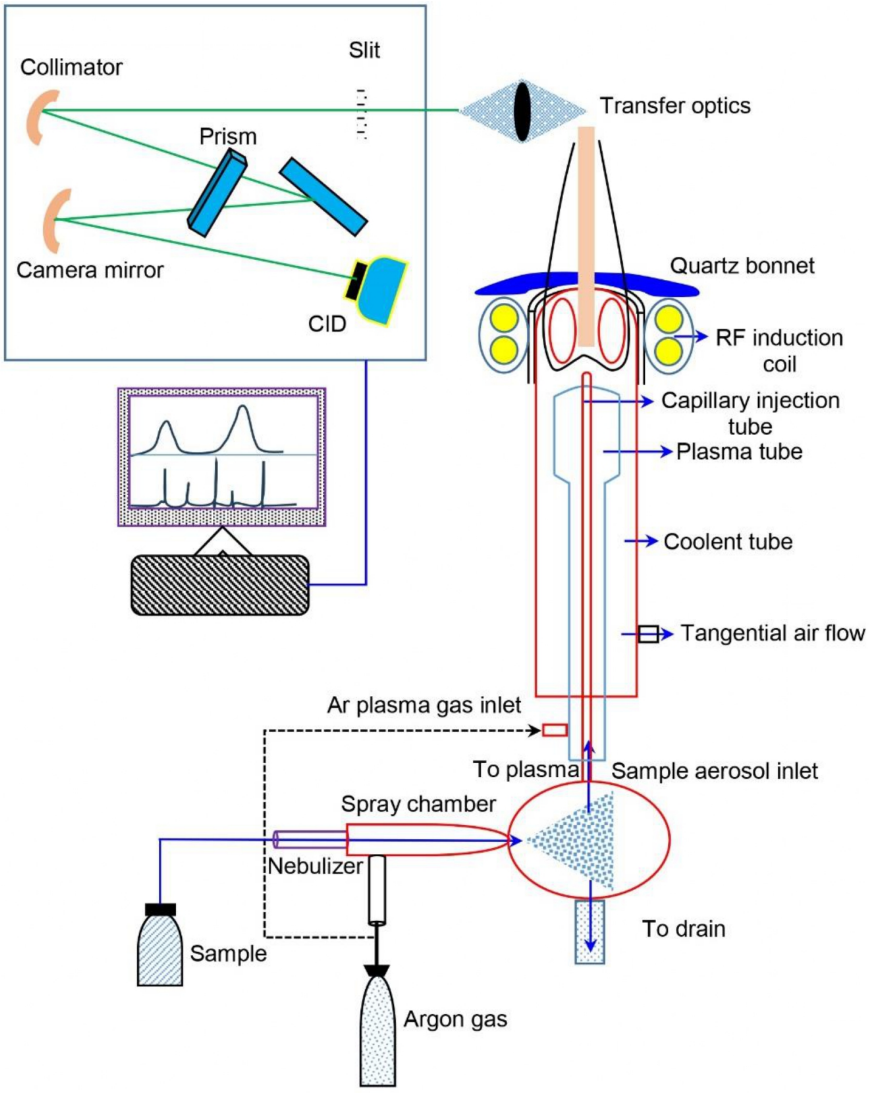
Fast Sequential AAS: An advanced version of traditional AAS that allows for the rapid analysis of multiple elements within a single sample. Unlike conventional AAS, where each element is analyzed separately by changing the lamp or the monochromator settings, Fast Sequential AAS can switch between different wavelengths rapidly. This allows for the simultaneous analysis of multiple elements in a single run.

Inductively Coupled Plasma (ICP)

Inductively Coupled Plasma (ICP) is a highly sensitive and versatile analytical technique used for detecting and quantifying elements in various types of samples (Fig. 5.24).

***Working Principle*:** ICP uses a high-temperature plasma (typically around 10,000 K) as the excitation source, which is generated by passing an inert gas, usually argon, through an electromagnetic field created by a radio frequency (RF) coil. The sample, usually in liquid form, is introduced into the plasma as an aerosol. The high energy of the plasma causes the sample to atomize and ionize. The excited atoms and ions emit light at characteristic wavelengths as they return to their ground state.

The emitted light is measured by a spectrometer, which separates the light into its component wavelengths. The intensity of the light at each wavelength is proportional to the concentration of the corresponding element in the sample.



5.24. Schematic diagram of an Inductively Coupled Plasma.

***Types of ICP Techniques*:**

ICP-MS (Mass Spectrometry): In ICP-MS, the sample is ionized by the plasma, and the resulting ions are introduced into a mass spectrometer. The mass spectrometer separates these ions based on their mass-to-charge ratio. This method offers extremely high sensitivity, capable of detecting elements at parts per trillion (ppt) levels. Used for trace element analysis, isotopic studies, and in fields requiring ultra-trace detection.

ICP-AES (Atomic Emission Spectroscopy/spectrometry) and ICP-OES (Optical Emission Spectroscopy/spectrometry):

ICP-AES and **ICP-OES** are essentially the same technique, and the terms are often used interchangeably. The term "Atomic Emission Spectroscopy" (AES) emphasizes that the technique is based on the emission of light from excited atoms (Fig. 5.25).

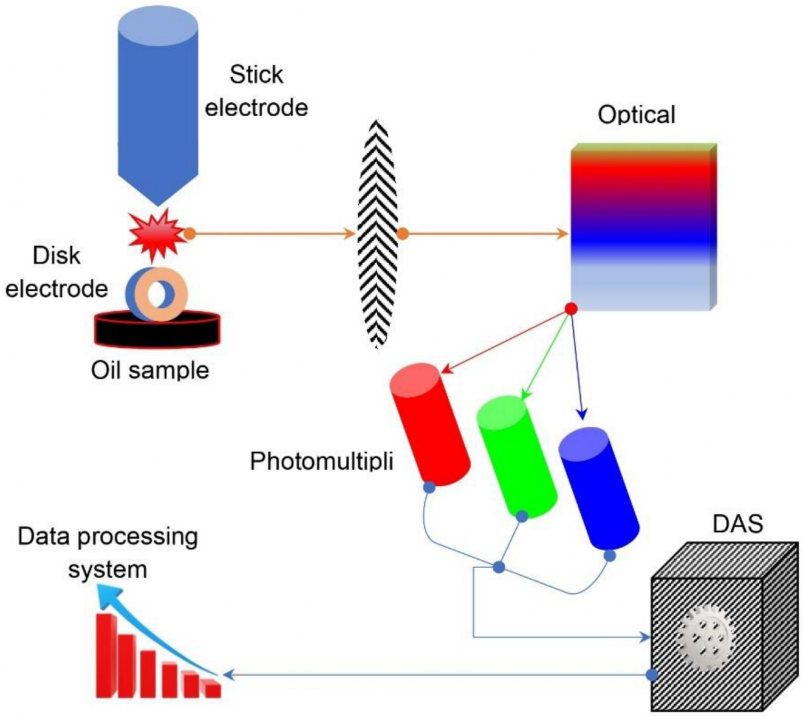


Fig. 5.25. Schematic diagram of an Atomic Emission Spectrometer.

It is an older term that was more commonly used in the earlier days of the technology. It highlights the atomic nature of the emission process, where the excited atoms return to their ground state and emit photons at specific wavelengths.

The term "Optical Emission Spectroscopy" (OES) emphasizes the optical detection aspect of the technique, focusing on the measurement of light across the spectrum. "ICP-OES" is the more commonly used term today, reflecting the broader use of optical methods for detecting and measuring emitted light. It encompasses the entire process of detecting and analyzing the emitted light using optical methods, which may include not just atomic emission but also molecular emissions in some cases.

While ICP-MS is more sensitive and capable of detecting elements at lower concentrations, ICP-AES/ICP-OES are generally more cost-effective and faster for multi-element analysis.

X-ray Fluorescence (XRF)

X-ray Fluorescence (XRF) is a non-destructive analytical technique used to determine the elemental composition of materials (Fig. 5.26).

Working Principle: The sample is irradiated with high-energy X-rays, typically generated by an X-ray tube or a radioactive source. These X-rays have enough energy to eject inner-shell electrons from the atoms in the sample.

When an inner-shell electron is ejected, a vacancy is created. To fill this vacancy, an electron from a higher energy level drops down, and the difference in energy is released as an X-ray photon. This emitted X-ray has a characteristic energy (or wavelength) specific to the element from which it originated. The emitted X-ray photons (fluorescence) are detected by a spectrometer, which measures their energy and intensity.

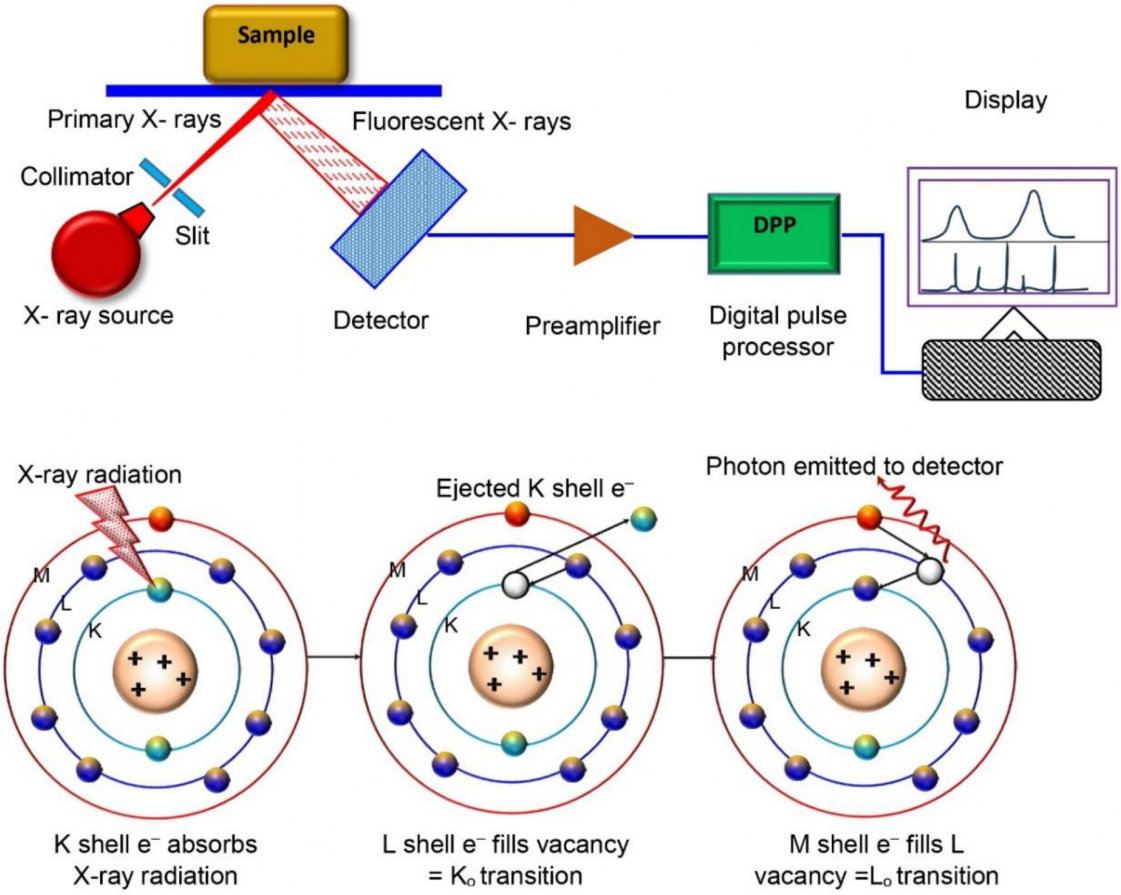


Fig. 5.26. Schematic diagram of a basic XRF analyser depicting K, L, and M electron energy levels of an atom.

Atomic Fluorescence Spectroscopy (AFS)

Atomic Fluorescence Spectroscopy (AFS) is an analytical technique used to detect and quantify elements in a sample by measuring the fluorescence emitted by atoms that have been excited by a light source (Fig. 5.27).

***Working Principle*:** The sample is first atomized, usually in a flame or graphite furnace, converting the sample into free atoms. These atoms are then exposed to a specific wavelength of light, typically from a laser or a lamp. The light excites the atoms, raising their electrons to higher energy levels. As the excited electrons return to their ground state, they emit light (fluorescence) at a characteristic wavelength. The emitted fluorescence is measured by a detector, typically placed at a 90-degree angle to the incident light to minimize interference

from the excitation light. The intensity of the fluorescence is proportional to the concentration of the element in the sample. This information is used to quantify the element.

AFS is especially useful for elements that form volatile compounds, such as mercury, arsenic, selenium, and antimony. Its high sensitivity and specificity make it a valuable tool in environmental and toxicological studies.

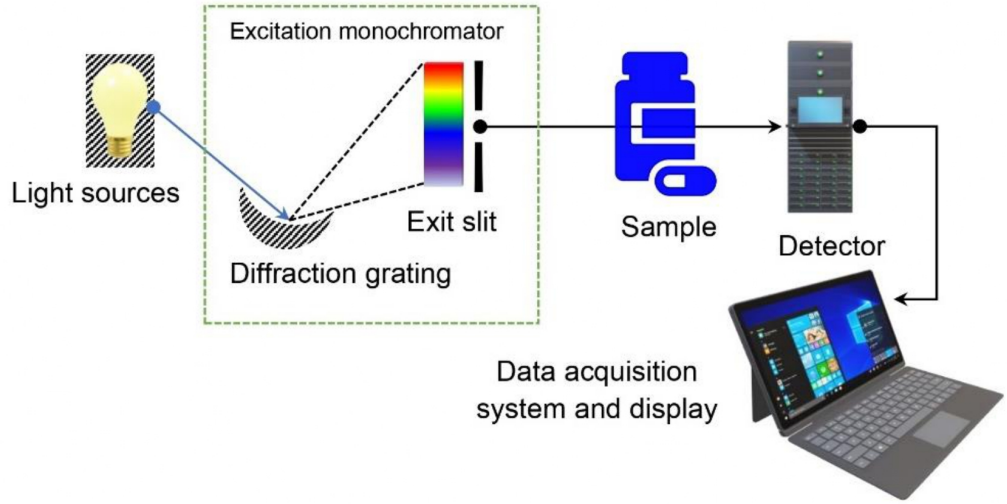


Fig. 5.27. Schematic diagram of a basic AFS analyser.

Cold Vapour Atomic Fluorescence Spectroscopy (CVAFS)

Cold Vapour Atomic Fluorescence Spectroscopy (CVAFS) is a specialized version of Atomic Fluorescence Spectroscopy (AFS) used specifically for the ultra-sensitive detection and quantification of mercury (Hg).

***Working Principle*:** The sample, usually in liquid form, is first treated with a reducing agent, such as stannous chloride ($SnCl_2$) or sodium borohydride ($NaBH_4$), which converts mercury ions (Hg^{2+}) into elemental mercury (Hg^0). The elemental mercury is then released as a vapour. This process occurs at room temperature (hence the term "cold vapour"), and the mercury vapour is carried by an inert gas, such as argon, into the fluorescence cell. In the fluorescence cell, the mercury vapour is exposed to ultraviolet (UV) light at a wavelength specific to mercury (usually 253.7 nm). The mercury atoms absorb this light, which excites their electrons, as the excited electrons return to their ground state, they emit light (fluorescence) at the same wavelength. The emitted fluorescence is detected by a sensitive photomultiplier tube (PMT) or another detector. The intensity of the fluorescence is directly proportional to the concentration of mercury in the sample.

Mercury Analyser

“Mercury analyser” is a broader term that refers to any instrument designed to measure mercury concentration in a sample. Mercury analyser can use different techniques, including CVAFS, Cold Vapour Atomic Absorption Spectroscopy (CVAAS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), or other methods.

The main findings and limitations of HevMetC are addressed in Table 5.10 and lists of different metals and their frequency of assessment in different literatures on RSPA indicated by different colours are shown in Table 5.11.

Table. 5.10. Main findings and limitations of literatures on HevMetC.

Auth -ors	Main Findings	Limitations
Wang et al. (2010)	❖ The aquatic ecosystem has not been significantly contaminated by Cu, Pb, Zn, and Cd, with metal levels in fish muscles all falling under the threshold values set by the National Standards Management Department. ❖ Organs sensitive to heavy metal accumulation could be useful in developing bioindicators for monitoring these metals.	❖ Study focused on a limited number of heavy metals (Cu, Pb, Zn, and Cd) and did not consider other potentially harmful contaminants. ❖ A long-term investigation was required to identify which fish species or tissues could serve as bioindicators for monitoring aquatic contamination.
Aktar et al. (2011)	❖ The accumulation order of these heavy metals was Cu > Zn > Cd > Cr > Pb for sediment. ❖ The pattern of accumulation suggested that deposition was highest for Zn and lowest for Cd in the muscles of both fish species. ❖ Heavy metal contamination in fish could be attributed to the indiscriminate discharge of polluted and untreated sewage sludge into the river.	❖ The study primarily focuses on specific heavy metals (Cu, Cr, Cd, Pb, Zn) and certain fish species. This selective focus might overlook the presence and impact of other potentially harmful metals or species-specific differences in metal accumulation .
Saeedi et al. (2011)	❖ Results indicated that adsorption increased with rising metal concentrations. The adsorption capacity of the sediments for heavy metals followed the order: Pb > Cu > Zn > Cd > Ni > Cr. ❖ The release of Cr and Ni appears to pose the greatest bioecological risk. ❖ The study demonstrated that heavy metal adsorption is primarily related to the organic matter load in the Jajrood River sediments. ❖ All metals, except Cu, showed a strong correlation with the sediment organic matter (SOM) content.	❖ The study uses sediment samples from specific sites along the Jajrood River, which may limit the generalizability of the results to other regions or water bodies with different geological and environmental conditions**.**

Sedláček et al. (2013)	❖ The concentrations of heavy metals (Pb, Cr, Zn, and Ni) tended to decrease in the uppermost layers of the sediment, indicating improved environmental conditions and a decline in the heavy metal industry post-1989. ❖ Phosphorus and sulfur contents increased significantly in the upper layers of the sediment, especially between the 1960s and 1970s, linked to the growing use of detergents and agricultural fertilizers. ❖ Unlike heavy metals, the nutrients have not decreased in recent years, contributing to ongoing problems with water eutrophication and algal growth.	❖ The environmental sampling protocol was not applied in a technical sense, which might affect the precision of the contamination history. ❖ While the study used several proxies for vertical changes in sediments, the results were not recalculated via calibration to absolute elemental concentrations, which could limit the accuracy of the findings.
Li et al. (2020)	❖ The average heavy metal concentrations in the Koshi River (KR) sediments are comparable to the natural background values and are lower than the sediment guidelines. ❖ Principal component analysis revealed that Cr, Co, Ni and Zn were primarily from the parent rock and that Cu, Cd and Pb were derived from both natural and anthropogenic sources.	❖ Study was conducted over a short period (November 2017), which may not capture long-term variations in contaminant levels or ecological impacts. ❖ It covered Nepal and China, but omitted the Indian portion of the river, potentially skewing the assessment of the Kosi River's overall characteristics.
Tepe et al. (2022)	❖ Average concentrations of heavy metals in sediments were measured in mg/kg, following this order: Fe > Al > Mn > Pb > Zn > Cu > Co > Cr > Ni > Cd > As. ❖ The highest concentrations were found for Fe, Al, and Mn, while the lowest concentration was for As. ❖ Except for Pb, all metal concentrations were within the sediment quality guideline (SQG) limits. ❖ Cd exhibited moderate enrichment in the EF index, while Pb showed significant enrichment.	❖ The study focused on three sampling points through the Turnasuyu Stream basin which may not fully represent the variations of other parts of the river.

Xue et al. (2022)	❖ The oxidation-reduction environment during the water sediment regulation (WSR) process at the Xiaolangdi reservoir significantly affected dissolved concentrations of Cu, Cd, Pb, Cr, and As but Ni remained mostly unaffected. ❖ At the Lijin station, the dissolved heavy metal content initially increased and then decreased in the first stage due to the release of heavy metals from resuspended sediments. In the second stage, the heavy metal content gradually decreased as they adsorbed onto fine particles discharged from the reservoir. ❖ The WSR process had a substantial short-term impact on dissolved heavy metal transport.	❖ Study focused on a specific period (WSRS in 2019) and two stations (Xiaolangdi and Lijin), which may not fully represent the variations across different years and other parts of the river. ❖ Previous studies did not include observations in the middle reaches of the river, leading to gaps in understanding the changes in heavy metal fluxes from the middle reaches to the estuary during WSRS.

Table 5.11. Lists of different metals and their frequency of assessment in different literatures on RSPA indicated by different colours.

Authors	Cr	Mn	Co	Ni	Cu	Cd	Zn	Ca	Mg	Fe	K	Na	Pb	Li	As	Hg	Al	Ti	V	Mo
Ali et al. (2023)																				
Xue et al. (2022)																				
Tepe et al. (2022)																				
Wang et al. (2021)																				
Fan et al. (2021)																				
de Filho et al. (2021)																				
Loureiro et al. (2021)																				
Bissassa et al. (2021)																				
Köse et al. (2020)																				
Yang et al. (2020)																				
Arisekar et al. (2020)																				
Jasmin et al. (2020)																				
Li et al. (2020)																				
dos Santos et al. (2019)																				
Oremo et al. (2019)																				
Liu et al. (2019)																				
Sun et al. (2019)																				
Dirbaba (2018)																				

Authors	Cr	Mn	Co	Ni	Cu	Cd	Zn	Ca	Mg	Fe	K	Na	Pb	Li	As	Hg	Al	Ti	V	Mo
Vu et al. (2018)																				
Zhao et al. (2018)																				
Bailon et al. (2018)																				
He et al. (2016)																				
Sharifi et al. (2016)																				
Khan et al. (2016)																				
Wu et al. (2016)																				
Bere et al. (2016)																				
Ding et al. (2015)																				
Niu et al. (2015)																				
Mulk et al. (2015)																				
Bo et al. (2015)																				
Chen et al. (2014)																				
Zahra et al. (2014)																				
Mathivanan et al. (2014)																				
Sedlacek et al. (2013)																				
Hejabi et al. (2013)																				

Authors	Cr	Mn	Co	Ni	Cu	Cd	Zn	Ca	Mg	Fe	K	Na	Pb	Li	As	Hg	Al	Ti	V	Mo
Keskin (2012)																				
Huong et al. (2012)																				
Taghinia Hejabi et al. (2011)																				
Saeedi et al. (2011)																				
Aktar et al. (2011)																				
Salati et al. (2010)																				
Wang et al. (2010)																				
Kim et al. (2010)																				
Liu et al. (2009)																				
Zheng et al. (2008)																				

5.10. Ecotoxicity Test in RSPA

According to the European Water Framework Directive (WFD), the assessment of surface water status is based on ecological and chemical status that is not always in coherence. In these situations, ecotoxicity tests could help to obtain a better characterization of the ecosystems (Roig et al. 2015).

5.10.1. Overview of Pollution by Ecotoxicity in River Sediment

Ecotoxicity of river sediment refers to the harmful effects of contaminants in sediment on aquatic organisms and ecosystems. These sediments can accumulate pollutants such as heavy metals, pesticides, and organic compounds. Following are some adverse effects of ecotoxicity of river sediment.

- Toxic substances in sediments can accumulate in the tissues of benthic organisms, which may then transfer up the food chain, affecting fish, birds, and even humans.
- Contaminated sediments also lead to decreased diversity and abundance of aquatic life, as sensitive species are unable to survive in toxic environments.
- Direct exposure to toxic sediments can cause mortality, reproductive issues, and physiological stress in aquatic organisms.
- Contaminated sediments can disrupt the natural functions of river ecosystems, including nutrient cycling and sediment transport, which can have long-term impacts on water quality and ecosystem health.
- Pollutants in river sediments can pose risks to human health, particularly if they contaminate drinking water sources or are ingested through the consumption of contaminated fish and other aquatic organisms.

Assessing the ecotoxicity of river sediments often involves toxicity testing with model organisms, chemical analysis of contaminants, and ecological risk assessments to understand the potential impacts on the environment.

5.10.2. Rivers Affected by Ecotoxicity Contamination in India

Ganga River: The Ganga is one of the most polluted rivers in India. Sediments in sections of the Ganga contain high levels of heavy metals and organic pollutants, impacting aquatic life and human health (Verma and Pandey 2019).

Yamuna River: The Yamuna, especially in its Delhi stretch, is heavily contaminated with industrial effluents, sewage, and agricultural runoff, leading to toxic sediments (Parween et al. 2021).

Godavari and Krishna Rivers: These rivers face contamination from industrial discharges, especially in Andhra Pradesh and Telangana, leading to ecotoxicity in sediments.

Sabarmati River: In Gujarat, the Sabarmati River suffers from severe pollution due to industrial activities, with sediments showing high levels of toxic metals and chemicals (Patel et al. 2020).

5.10.3. Mitigation and Regulation in India for EcoT.

Microtox test results are usually expressed as EC50 (the concentration of the sample that causes a 50% reduction in the luminescence of *Vibrio fischeri*) or IC50 (inhibition concentration).
EC50 values are typically reported in mg/L or as a percentage concentration of the original sample.
The regulatory limits are-

Very Toxic: EC50 < 1 mg/L
Toxic: EC50 between 1 and 10 mg/L
Harmful: EC50 between 10 and 100 mg/L
Non-Toxic: EC50 > 100 mg/L

5.10.4. Analysis According to the Source of Articles and Methods Adopted

From the graphical representation of Fig. 5.27, the contribution of various sources in the field of river sediment pollution by PCBs has been clearly reflected. *Science of the Total Environment* and *Environmental Science and Pollution Research* both contribute the highest (25%) among all the other sources. *Chemosphere, Chemistry and Ecology, Environmental Chemistry and Ecotoxicology* are the other sources having significant contributions.

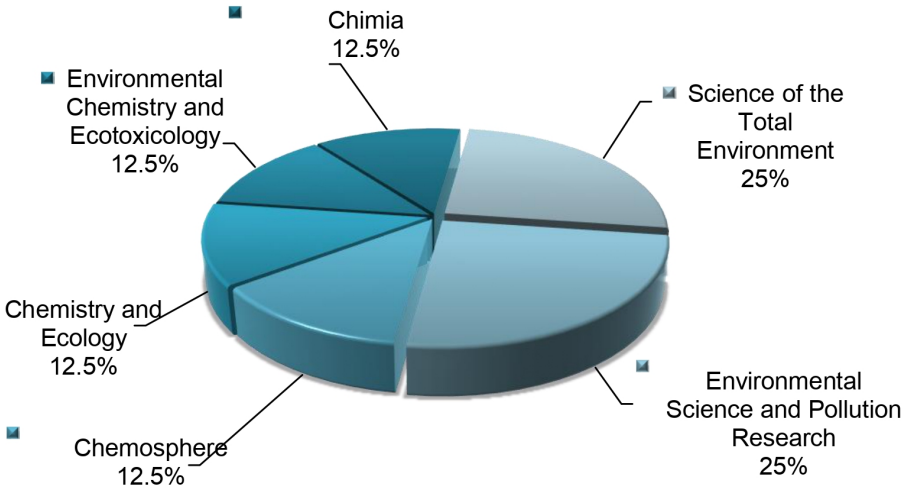


Fig. 5.28. Visual representation in terms of the contribution of literature sources, for evaluating EcoT on assessing river sediment pollution during the time span of 2004-2023.

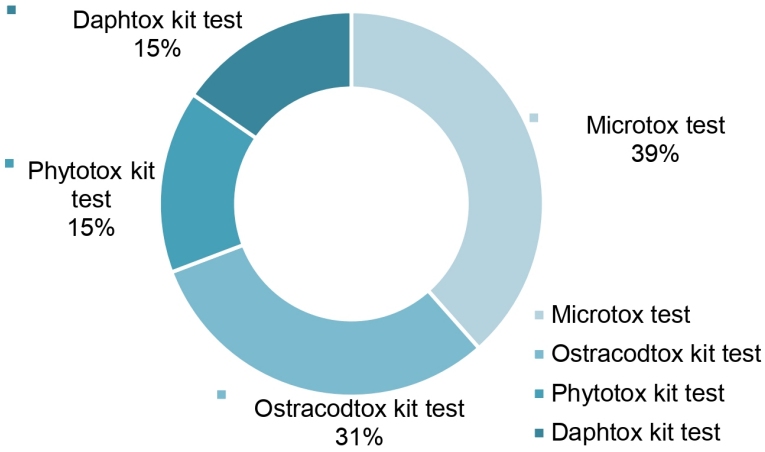


Fig. 5.29. Visual representation of methods adopted for evaluation of EcoT on RSPA during the time span of 2004-2023.

The qualitative analysis Fig. 5.28, represents the various methods according to their frequency of usage in different articles during the time span of 2004-2023. The Mictrotox test (Sahli et al. 2021; Urbaniak et al. 2020) and Ostracodtox Kit test (Mata et al. 2020) are used more frequently with 39% and 31% of the literatures respectively, for the ecotoxicity evaluation. Other test kits used for the evaluation of EcoT are the Phytotox kit test (15%) and the Daphtox kit test (15%).

5.10.5. Methods for Ecotoxicity Evaluation in RSPA

Microtox Analyser

The Microtox test **(**ISO 11348-1:2007) is a widely used bioassay that measures the toxicity of environmental samples, including water, sediments, and soil, by using bioluminescent bacteria. The test is based on the principle that the light emission from these bacteria is inhibited when they are exposed to toxic substances.

***Key Features*:** The test uses the marine bacterium *Vibrio fischeri*, which naturally emits light as a part of its metabolic process. The bacteria are exposed to prepared samples for a specific period, usually ranging from a few minutes to an hour. The amount of light emitted by the bacteria is measured before and after exposure to the sample using a luminometer. The reduction in light emission is directly related to the toxicity of the sample. A greater reduction indicates higher toxicity. Microtox test results are usually expressed as EC50 (the concentration of the sample that causes a 50% reduction in the luminescence of *Vibrio fischeri*) or IC50 (inhibition concentration).

The M500 Analyser (Baran et al. 2023; Roig et al. 2015) is an advanced version of the Microtox Analyser used for conducting the Microtox test, which assesses the toxicity of

environmental samples using bioluminescent bacteria (*Vibrio fischeri*). It is designed to provide precise, reliable, and rapid toxicity measurements in various samples, such as water, soil, and sediments.

Ostracodtox Kit test

The Ostracodtox Kit is an ecotoxicity test that uses ostracods, small crustaceans commonly known as seed shrimp, to assess the toxicity of environmental samples, including sediments, water, and soil. The test is particularly useful for evaluating the impact of pollutants on aquatic ecosystems.

***Key Features*:** The test uses *Heterocypris incongruens* (Devarajan et al. 2015), a species of ostracod that is sensitive to various pollutants. These organisms are ideal for toxicity testing due to their small size, ease of cultivation, and sensitivity to a wide range of toxicants. The test involves preparing a sample, which may include water, sediment, or soil. The sample is then placed in contact with the ostracods. Ostracods are exposed to the sample for a specified period, usually between 48 and 96 hours, depending on the test protocol. After the exposure period, the test measures two key endpoints:

Mortality: The number of ostracods that survive the exposure.
Growth Inhibition: The extent to which the sample inhibits the growth of ostracods, often measured by changes in body length.

Phytotox kit test

The **Phytotoxkit Test** (Baran et al. 2023; Urbaniak et al. 2020) is an ecotoxicological assay that evaluates the toxicity of environmental samples, such as soil, sediment, and water, using higher plants (angiosperms). This test is designed to assess the potential harmful effects of pollutants on plant growth, providing valuable information on the ecological impact of contaminated environments.

***Key Features*:** The Phytotoxkit typically uses seeds of selected plant species that are sensitive to a wide range of toxicants. Commonly used species include *Sorghum saccharatum* (Sorghum), *Lepidium sativum* (Garden cress) (Baran et al. 2023), *Sinapis alba* (White mustard).

The test involves placing seeds of the selected plant species on a layer of the test sample (soil, sediment, or water) in a transparent test plate. The test plates are incubated for a specific period, usually 3 days, under controlled environmental conditions (e.g., temperature, light). After the incubation period, the test evaluates two key endpoints:

Seed Germination: The number of seeds that successfully germinate.
Root Growth: The length of the roots of the germinated seeds, which is a sensitive indicator of toxic effects

Daphtox kit test

The Daphtoxkit Test is an ecotoxicological assay that assesses the toxicity of water, sediments, and other environmental samples using freshwater crustaceans called daphnids, commonly known as water fleas.

***Key Features*:** The Daphtoxkit typically uses *Daphnia magna* (Roig et al. 2015), a widely recognized species in ecotoxicology due to its sensitivity to a broad range of contaminants and its ecological relevance in freshwater environments. The test begins with the reactivation of dormant eggs of *Daphnia magna* in a culture medium. After a short incubation period, the eggs hatch into active daphnids. The hatched daphnids are then exposed to different concentrations of the environmental sample (e.g., water, sediment extract) in multi-well test plates for a specific duration, typically 24 to 48 hours. The test measures the immobilization or mortality of the daphnids as the primary endpoint. The number of immobile or dead daphnids is recorded, and the percentage of affected organisms is calculated. The main findings and limitations of EcoT are detailed in Table 5.12.

Table 5.12. Main findings and limitation of literatures on EcoT.

Author	Main Findings	Limitations
Devarajan et al. (2015)	❖ Whole sediment bioassays had shown more toxicity than pore water tests. ❖ Among the different organisms used, *P. subcapitata* and *C. riparius* were the most sensitive in pore water and whole sediment, respectively. ❖ When chemical stressors negatively impact ecosystem functioning, an ecotoxicological approach using proper bioassays in pore water and sediment can accurately detect these changes.	❖ Study was conducted over a short period (September 2013), which may not capture long-term variations in contaminant levels or ecological impacts. ❖ The research focused on a specific area (CRB), which may limit the applicability of the results to other regions with different environmental contexts or sources of pollution.
Roig et al. (2015)	❖ Metal concentrations in Cauvery River Basin (CRB) sediments were lower than those in hospital outlet pipes (HOP), but both exceeded Sediment Quality Guidelines (SQGs) and the Probable Effect Concentration (PEC) for aquatic life. ❖ Ecotoxicity tests with ostracods showed mortality rates of 22–100% in HOP sediments and 18–87% in CRB sediments.	❖ Study focused on Ebro River watershed which may limit the applicability of the findings to other regions with different environmental conditions or sources of contamination. ❖ Study was conducted over a limited time period (summer of 2013), which may not capture the full range of environmental conditions or long-term trends.

Baran et al. (2023)	❖ Among the individual geochemical indices, enrichment factor (EF) turned out to be the most useful, whereas toxic risk index (TRI) (ΣTRI) was found to be the most important ecological index. ❖ Study concluded that Cd, Zn, and Pb taken altogether have the greatest impact on the level of sediment contamination and pose the greatest potential ecological and health risks to organisms.	❖ The study focused only on the dam reservoir, which may limit the applicability of the findings to the whole river conditions or sources of contamination. ❖ The study was conducted over a limited time period, which may not capture the full range of environmental conditions or long-term trends.
How et al. (2023)	❖ The river sediment was found with high heavy metal concentrations, especially highly bioavailable Cu, Ni, and Zn can be restored using microbial bioleaching with simple settings. ❖ Acidophilic sulfur-oxidizing *Acidicaldus sp*. SV5 effectively bioleached Cu, Ni, and Zn from the contaminated sediment. ❖ *Caenorhabditis elegans* ecotoxicity testing could be used as a screening tool in combination with chemical-based and bioavailability-relevant ecological safety assessment of sediment samples for better decision making.	❖ Study focused on *Acidicaldus sp.* SV5 for bioleaching, limits the exploration of other effective microbial species. ❖ The study focuses on a specific river with high Cu, Ni, and Zn concentrations limits its generalizability to other environments or heavy metals like Pb, Hg, and Cd. ❖ Bioleaching, although an eco-friendly method, often suffers from slow reaction times, which can limit its effectiveness in practical applications.

5.11. Year wise Qualitative Analysis

The present study includes 20 years of literatures which spans from 2004-2023. The qualitative analysis for 5 years has been included in the following sections.

5.11.1. Year 2004-2008

In the time span of 2004-2008, the quantity of published literature on RSPA was very few. Figure 5.30(a) shows the yearly variation of published literatures. The research work tends to decrease from 2005 onwards.

During this period **GC-MS** (Eljarrat et al. 2005; Hong et al. 2008) and **GC-ECD** (Ko et al. 2004; Covaci et al. 2005; Hong et al. 2008) were noticed as preferable to the researchers for evaluating PCBs contamination and for assessing HevMetC contamination in river sediment **ICP-AES** and **AAS** was a good choice then (Zheng et al. 2008). Researchers additionally also measured

the concentration of organochlorine pesticides (OCPs) and polycyclic aromatic hydrocarbons (PAHs) which are known to be environmental pollutants and are often found in substances like coal, tar, and oil. The TOP was evaluated only during 2004-2008 by Technicon Autoanalyser AAII.

No such research work was found on FDPCBs, PestC, POM, TON and EcoT quantification.

5.11.2. Year 2009-2013

In the period of 2009-2013, the quantity of published literature on RSPA was again found to be very few. Figure 5.30(b) shows the yearly variation of published literatures between this time span. The number of research work shows a little increase at the end of 2013.

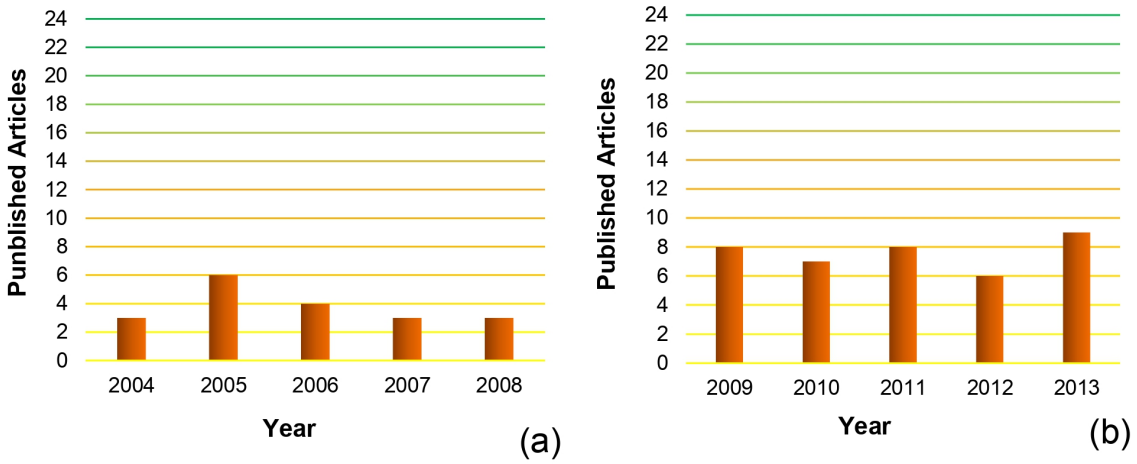


Fig. 5.30. Yearly distribution of published literatures represented in the ordinates for the periods **(a)** 2004 to 2008 and **(b)** 2009 to 2013.

Though X-ray Fluorescence (**XRF**) intruded in the 1950s, during 2009-2013 this method was first seen to be used by the researchers (Sedláček et al. 2013) to measure PCBs concentration. The **AAS** method was seen to be very popular among the researchers, it was then adopted by Aktar et al. (2011), Taghinia Hejabi et al. (2011); Wu et al. (2012), to evaluate HevMetC along with some other contaminants like OCPs, PAHs, PCDDs during this duration. For the evaluation of PCBs, **HRGC-HRMS** was then quite popular and was noticed to be frequently used by several researchers (Kim et al. 2009; Oshita et al. 2010; Yu et al. 2013). TSS and PestC were also examined by employing the gravimetric method and GC-MS.

No research was done on evaluating the contamination by POM, TOC, TON, TOP and EcoT on RSPA.

5.11.3. Year 2014-2018

In the time span of 2014-2018, very little increment of work on RSPA was noticed, but the research work tended to reduce from 2016 (refer to Fig. 5.31a). The use of HRGC-HRMS for PCBs assessment, which has seen increased popularity from 2009 to 2013, declined during the period from 2014 to 2018 and GC-MS (Baqar et al. 2017; Adeyinka et al. 2018) took that place. HevMetC was evaluated by the AAS method (Ding et al. 2015; Bere et al. 2016). Concerns arose regarding PestC, TSS, POM, and TOC, which were assessed using GC-MS, gravimetric method, the *van Bemmelen* factor (1.72) to convert POC to POM, and a Euro Vector elemental analyser, respectively. Ecotoxicity from sediment contamination on benthic organisms, such as *Vibrio fischeri*, *Daphnia magna*, and various crustaceans, was tested using Microtox, Daphtoxkit, and Ostracodtox, (Roig et al. 2015) respectively. No such work on FDPCBs, TON and TOP was done.

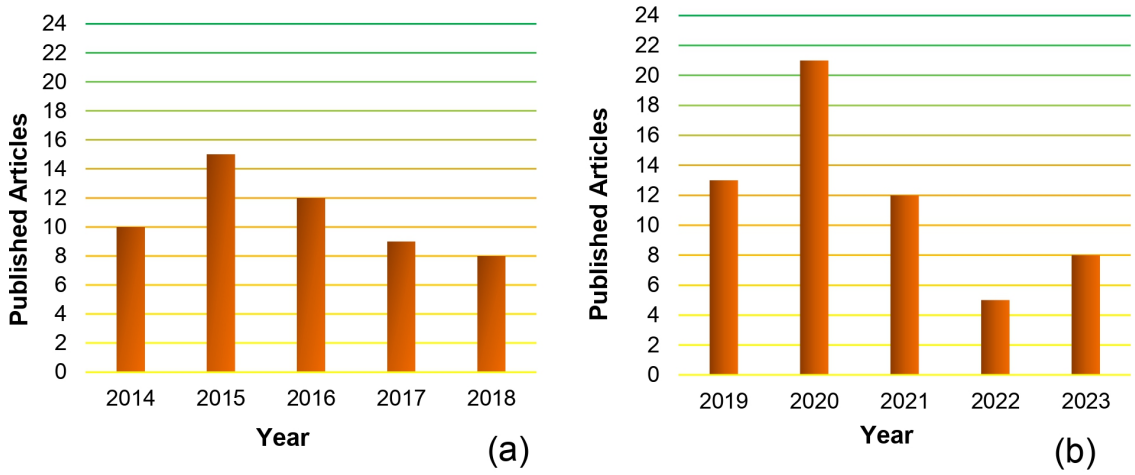


Fig. 5.31. Yearly distribution of published literatures represented in the ordinates for the periods **(a)** 2014 to 2018 and **(b)** 2019 to 2023.

5.11.4. Year 2019-2023

Between the years 2019-2023, the quantity of published literature on RSPA was fairly good compared to previous years. Figure 5.31(b) shows the yearly variation of published literatures regarding this time span. The research work increased to a huge number in the year 2020, which may be the reason behind this reasonable increase of research work due to the pandemic situation, but this was not consistent. From 2021 the graph shows a huge decrease in work on RSPA.

GC-MS (Iwegbue et al. 2020; Lu et al. 2021H) and ICP-MS (Arisekar et al. 2020; Xue et al. 2022) were adopted by the researchers for evaluating PCBs and HevMetC respectively with a majority. POM, TOC, TSS and TON were assessed by LOI, Horbia Carbon analyser (Fang and Wang 2021), gravimetric method and elemental analyser respectively. Microtox Kit (Sahli et al. 2021; Baran et al. 2023) had been used significantly to assess the ecotoxicity. TOP remains unassessed.

Chapter 6

Conclusions and Recommendations

6.1. Conclusions

- The most influential subject area that has made high contributions in their respective fields is **Environmental Science** (Fig. 4.2).
- The most influential literature sources that had made highly impactful contributions in their respective fields are **Environmental Science and Technology** and **Science of the Total Environment** (Table 4.1a).
- The most productive literature sources, which made highly impactful contributions in their respective fields are **Science of the Total Environment**, **Chemosphere** and **Environmental Monitoring and Assessment** (Table 4.1a).
- The most frequently used keywords in the field of River Sediment Pollution Assessment (**RSPA**) where at least any of the10 selected parameters were used are **Sediment** (53), Polychlorinated Biphenyls (**PCBs**) (34), **Heavy Metals** (28), **Risk Assessment** (10), Poly Brominated Diphenyl Ethers (**PBDEs**) (9) and polychlorinated dibenzofurans (**PCDD/Fs)** (9).
- Some of the least occurred keywords in the field of RSPA are Total Suspended Solids (**TSS**), **Sedimentation**, **Sediment Quality**, persistent organic pollutants (**POPs)**, and **Pollution Assessment** (Table 4.2).
- Countries actively contributing to the research domain of RSPA are Spain from the aspect of impactful contribution and China, Spain, United States from the aspect of productive contribution (Table 4.3a).
- The most productive researchers are **Lu Q.** and **Zhang Q.** (Table 4.4a).
- The most influential researchers are Eljarrat et al. (2005), Barhoumi et al. (2019), Zheng et al. (2008), and Zhang et al. (2004) (Table 4.5).
- The article received the highest number of citations and discussed the key research areas associated with, this influential article is Zhang et al. (2004).
- The most studied emerging contaminants are PCBs and Heavy Metal Concentration (HevMetC), and significant methodologies adopted by the authors to evaluate the contaminants in the RSPA were Gas Chromatography Mass Spectrometry (GC-MS) and Atomic Absorption Spectrometry (AAS), respectively.

- The least studied contaminants are Total Organic Phosphorus (TOP), Total Organic Nitrogen (TON) and Ecotoxicity Test (EcoT) in RSPA.
- A brief idea about the objectives, study region, methodology adopted and main findings of published articles (Appendix III).

6.2. Limitations of this Review Study

The limitations of this study are given below

- It was left beyond the scope of this study how pollutants within their permissible and acceptable concentrations affect river sediments. It overlooked the potential effects these pollutants can have on sediment quality and composition, despite meeting regulatory standards.
- Limitations of the studies stem from their focus on evaluating only specific emerging pollutants based on selected keywords, leaving out other potential contaminants that were not included in the scope of this research.
- A regionally specific study could provide a more accurate representation of pollutant loads within major river catchments, making it more effective for environmental impact assessment.
- This study does not explore the pathway of pollution as it moves from river sediments into the water, subsequently entering aquatic life, and eventually impacting humans.
- It does not evaluate the remediation technologies, with in-situ methods often favored for their cost-effectiveness and time-saving advantages over ex-situ methods.

6.3. Future Scopes

To address the limitations identified in this study, future research should focus on several key areas.

- Future research should focus on several key areas. Firstly, a detailed investigation into the effects of pollutants based on their permissible and acceptable concentration levels in river sediments is needed. This will provide a more accurate understanding of the impact of various contaminants.
- Future studies should expand the scope to include emerging pollutants not covered by the current research, especially those beyond the selected keywords, to ensure a comprehensive assessment of all potential environmental risks.
- Region-specific studies are also crucial for a more precise evaluation of pollutant loads in major river catchments, as local environmental conditions can significantly influence pollutant dynamics.

- Furthermore, research should explore the entire pathway of pollution, from river sediments to water, aquatic life, and ultimately to humans, assessing the effects on human health. This will help provide a holistic view of the environmental and health risks posed by contaminated sediments.
- Lastly, future studies should evaluate various remediation technologies in greater detail, comparing the efficiency of in-situ and ex-situ methods. A thorough analysis of the cost-effectiveness, time efficiency, and environmental impact of these technologies will offer valuable insights for improving sediment management strategies and mitigating pollution in urban river systems.

Recommendations are made to improve sediment management and reduce river sediment pollution load, aiming for more sustainable practices in river systems.

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Appendix I

Sl No.	Source Title	Number of articles
1	Ecotoxicology And Environmental Safety	3
2	Environmental Earth Sciences	2
3	Environmental Research	2
4	Fresenius Environmental Bulletin	2
5	Journal Of Soils And Sediments	2
6	Water Quality Research Journal Of Canada	2
7	Water Research	2
8	Applied Geochemistry	1
9	Applied Sciences Switzerland	1
10	Archives Of Environmental Contamination And Toxicology	1
11	Bioremediation Journal	1
12	Canadian Water Resources Journal	1
13	Chemistry And Ecology	1
14	Chinese Journal Of Geochemistry	1
15	Desalination And Water Treatment	1
16	Ecological Applications	1
17	Ecological Safety Of Coastal And Shelf Zones Of Sea	1
18	Environmental Geochemistry And Health	1
19	Environmental Sciences Europe	1
20	Environmental Technology	1
21	Food Chemistry	1
22	Frontiers Of Earth Science	1
23	Human And Ecological Risk Assessment	1
24	Hydrological Processes	1
25	Hydrology Research	1
26	International Biodeterioration And Biodegradation	1
27	International Journal Of Environmental Research And Public Health	1
28	International Journal Of Environmental Science And Technology	1
29	International Journal Of Environmental Studies	1
30	International Journal Of Phytoremediation	1
31	Journal Of Aquatic Food Product Technology	1
32	Journal Of Chemical Technology And Biotechnology	1
33	Journal Of Cleaner Production	1
34	Journal Of Environmental Economics And Management	1
35	Journal Of Environmental Engineering United States	1
36	Journal Of Geochemical Exploration	1
37	Journal Of Separation Science	1
38	Polish Journal Of Environmental Studies	1
39	Regional Studies In Marine Science	1
40	Soil And Sediment Contamination	1
41	The scientific world journal	1
42	Toxicological And Environmental Chemistry	1
43	Toxicology And Industrial Health	1
44	Water Air And Soil Pollution	1
45	Water Environment Research	1
46	Water Science And Technology	1
47	Water Science And Technology Water Supply	1
	TOTAL	55

Appendix II

Table S1. Detailed exclusion criteria of the parameter PCBs.

Authors	Exclusion reasons
Capozzi et al. (2023)	Only fish sample was measured. **Sediment sample was not directly collected and measured**. The concentration of PCB at the selected study site was generated by using two methods of correlations, they are-(i) PMF-generated factors and (ii) EBK.
Yu et al. (2023)	Sediment sample was collected from the **YRE** marginal to the East China Sea, Bohai Sea and Yellow Sea. (YRE was affected by several mining activities (Guo and Deng 2022).
Wang et al. (2023)	Water and sediment from the middle reach of the **Yangtze River** (Wuhan, China) were studied. (YRE was affected by several mining activities (Guo and Deng 2022).
Dron et al. (2022)	The concentrations of 31 PCB congeners and 15 banned pesticides or metabolites were measured in 5 tissues of 68 **striped dolphins** stranded in the Northwestern Mediterranean coast in 2010–16
Long et al. (2022)	Surface and suspended sediments were collected from **nearshore stations** on the Canadian side of Lake Ontario and the St. Lawrence River.
Rao et al. (2022)	48 farming **crabs** in the lower reaches of the **Yangtze River** were monitored. They do not analyse the sediment samples (YRE was affected by several Mining activities, Guo and Deng 2022)
Urbaniak et al. (2022)	PCB concentration was not measured directly. The objective was to examine the occurrence of the functional PCB-degradation genes in the growth substrate, which was Hudson River sediment (in **bacteria** of HRS).
Diedrich et al. (2022)	Sites were selected near current and former dam impoundments, extending from the river mouth at Grand **Traverse Bay, Lake Michigan,** to the upper reach of the restored river at Brown Bridge. While other locations like **streets and lakes** were also analyzed, they are not the focus of this study.
Silva et al. (2022)	Sample was taken from **Green Bay**, a sub-basin of **Lake Michigan** at the mouth of the Fox River.
Vauclin et al. (2021)	Secondary channels, such as **oxbow lakes and backwater areas**, were selected as they represented stable water environments.
Gong et al. (2021)	**Lake** sediment sample has been examined.
Duarte-Restrepo et al. (2021)	Sample collected from marine sediment of **Cartagena Bay** which is an estuarine system located in the Caribbean Sea.
Vauclin et al. (2021)	The sediment core was collected from the **floodplain and secondary tributaries, not from the main river channel**, which is not the focus of this study.
Pandelova et al. (2021)	These sampling areas were adjacent to the flowing water but **not directly in the main river channel**. The samples were collected from a container placed near the rivers, where sediments would deposit over time.
Aziza et al. (2021)	Soil samples were collected from a **floodplain area (not from the river)** after the flood water had receded completely into the river channel.
Lundin et al. (2021)	Sample was **Chinook salmon fish**.
Chen et al. (2021)	**Pearl River delta which is marginal to sea**.
Tang et al. (2020)	The Pearl River estuary is on the **connecting sites of the South China Sea**.
dos Santos et al. (2020)	Study area is located at the western **South Atlantic upper continental margin**.
Pinheiro et al. (2020)	Brown bullhead **fish tissue** has been used as a sample.
Hoffman et al. (2020)	Sample was **demersal fish** of the coastal river to assess tumor prevalence.
Lo et al. (2019)	Sample was **sedimentary microplastic**.
Mo et al. (2019)	Sample was taken from **coastal surface sediments** around Hainan Island in South China.
Falk et al. (2019)	The sediment sample was **not measured directly** from the study area, it was calculated using inverse distance weighted (IDW) interpolation from the previous dataset concentrations.

Zhao et al. (2019)	Study area was the **Yangtze River estuary, inner shelf of East China Sea**. (YRE was affected by several mining activities (Guo and Deng 2022)
Metelkova et al. (2019)	The samples were collected in different types of areas: **offshore waters, coastal and fairway zones, and suburban and urban places**.
Reyna et al. (2019)	The sample was Asian **clam,** *Corbicula largillierti* from Suquía River basin flows across the central region of Córdoba Province, Argentina. Sediment sample was not evaluated.
Windsor et al. (2019)	Sample is associated with large scale industries such as **coal mining** and coal gasification.
Rodenburg et al. (2019)	Sample was **Clams** (*Corbicula fluminea*). Sediment sample was not evaluated.
Fernandez et al. (2019)	Sample is from **bay Santander** (spain).
Govaerts et al. (2018)	**Copper mine** near the study site.
Adams et al. (2018)	Sample was **Lake sediment** (Baikal Lake).
Chen et al. (2018)	Study area has a connection with the **sea, island and bay**.
Ali et al. (2018)	Azad Jammu and Kashmir (AJK) region was selected for water sampling. **Dedicated sediment sample collection was not mentioned**.
Custer et al. (2018)	**Tree swallow (bird) eggs and nestlings** were collected from 16 sites across the Great Lakes. Sediment sample was not evaluated.
Pintado-Herrera et al. (2017)	Surface sediment samples were collected from the **PRE region and the adjacent northern South China Sea**.
Meng et al. (2017)	Study area **along Bohai and Yellow Seas.**
Huo et al. (2017)	Study area was a shallow freshwater **lake** in eastern China.
Wu et al. (2017)	Colonization effect of organic compounds on **polymer/plastic in marine environment**.
Rodenburg et al. (2017)	**Sediment sample was not collected** or tested in this work. An analysis was done on previous work data (CARP-2007) by PMF.
Chen et al. (2017)	Study area was **Yangtze River estuary**, marginal to East China Sea and Yellow Sea. (YRE was affected by several mining activities (Guo and Deng 2022).
Kraus et al. (2017)	**Riparian spiders** and surface sediment have been used as samples and the discussion focused on the riparian spider.
Guo et al. (2017)	Study area was **Lake Michigan**.
Praipipat et al. (2017)	Study was done to apportion the major sources of PCBs by PMF from a previous study (1999-2011), where **air samples** have been used.
Trevisan et al. (2017)	Sample was mangrove **Oysters** (*Crassostrea brasiliana*) exposed to seawater from Balneário Camboriú, an important tourist destination in Brazil that is affected by urban sewage.
Lee et al. (2017)	Surface sediment samples were collected around and in the barrier islands **marginal to East Sea.**
Malina et al. (2017)	**Sample directly not measured** but analysed by a "model emaluator" from previously measured data.
Shipley et al. (2017)	Historical data review and source analysis was done by collecting data from several agencies. Concentration was **not measured in this study**.
Hall et al. (2017)	**Creek** sample was assessed.
Liu et al. (2016)	Study area was **Lower Great Lakes**.
Montuori et al. (2016)	Study area was Tiber river estuary, **marginal to the Tyrrhenian Sea.**
Combi et al. (2016)	**Sea sediment** was analysed.
Zhao et al. (2016)	Study area was a reclaimed **wetland** in the Pearl River estuary.
Li et al. (2016)	Yellow River Delta, is a **wetland adjacent to Yellow River and Bohai Bay.**
Wu et al. (2016)	Sediment sample was collected from the **strait and river to the marginal sea area.**
Nizzetto et al. (2016)	INCA (Integrated Catchment models) was introduced in this study. The INCA is not an analytical method for measuring PCBs directly. **PCBs concentration was not measured by any analytical method**.
Josefsson et al. (2016)	**Only water sample** was measured and the study area was also adjacent to the Baltic Sea.

Dungen et al. (2016)	**Human blood sample** was examined.
Evans et al. (2016)	**Lake** sample was studied.
Martinez et al. (2016)	Sample was collected from the **backwater area** of the Upper Mississippi River and from **Oxbow Lake.**
Field et al. (2016)	Sample **directly not measured** but analysed by a "model emaluator" from previously measured data.
Qiu et al. (2016)	**Bacteria** was collected from river sediment to analyse the degradation of PCB No. 209 which was purchased from the industry.
Sakai et al. (2016)	Sample was **surface water** not sediment.
Duffy et al. (2016)	Toxicity tests have been done on *Chironomus dilutus* (one type of fly) collected from sediment but not directly on sediment.
Yuan et al. (2015)	Study area near **Liaodong Bay** (also Bohai Sea).
Lai et al. (2015)	Study area was the Pearl River Delta which is **marginal** to the **South China Sea.**
Lu et al. (2015)	Study area was **Lake.**
Eqani et al. (2015)	Water and fish samples were tested. **No analysis was found for the Sediment sample** in this study. DL-PCBs data for sediments from the Chenab River had been collected from the previous study by Eqani et al. (2012b).
Cheng et al. (2015)	Surface sediments were collected from the open **Indian Ocean.**
Lu et al. (2015)	A model evaluation was done by " Fugacity level III modeling", with data collected from the UK Soil and Herbage Pollutant Survey (UKSHS) Report and a previous monitoring study on PCB pollution, **direct sediment sample was not measured**.
Solaunet al. (2015)	Superficial sediment data from the LQM (Borja et al., 2004) corresponding to the period 2002–2011 were included in the present study to establish the correlation between mussel data, but it was **not directly measured** in the present study.
Li et al. (2014)	Study area was the Pearl River estuary, **marginal to the South China Sea.**
Khairy et al. (2014)	Various Blue **crab species and homogenized fish tissues** were used as samples.
Zhang et al.(2014)	Surface sediment samples were collected from the Yangtze River delta (YRE was affected by several mining activities (Guo and Deng 2022).
Hosoda et al. (2014)	Plastic resin pellets were collected from Ghanaian beaches (9 sites) and sediment sample was collected (2 sites) from the **Lake and lagoon** area.
Zhang et al. (2014)	Sediment sample collected from **Qinzhou Bay, Beibu Gulf**.
Men et al. (2014)	Study area was the Daliao River **estuary of Liaodong Bay, Bohai Sea**.
Morselli et al. (2014)	EcoDynA, a fugacity-based model developed to investigate the fate of organic chemicals in a dynamic organism–water–sediment system**. Direct measurement of PCB concentration was not done**.
Conka et al. (2014)	**Copper production**, and scrap copper processing industries near the study site.
Waszak et al. (2014)	The study area was at the Vistula River and the Duoro River estuaries **marginal to the southern Baltic Sea and Portuguese coast of the Atlantic Ocean**.
Charrasse et al. (2014)	Sample was collected from five heavily contaminated dredged sediment areas which are **mainly marine harbours, rivers, canals and highway sedimentation tanks**.
Undeman et al. (2014)	Assessment was done on **Baltic sea**.
Duan et al. (2013)	**East China Sea** sediment was assessed.
Combi et al. (2013)	Study site was **Guaratuba Bay**, SW Atlantic.
Duan et al. (2013)	Study was carried out in the sediments of the **Yellow Sea**.
Saba et al. (2013)	Sample was examined from **Newmark Bay**.
Grilo et al. (2013)	The study area was a **lagoon** which is connected to the sea.
Ozyurek et al. (2013)	**Creek** sediment sample was examined.
Zhao et al. (2013)	Sediment sample (28 sample sites) was collected from the Three Gorges Dam, which is in the Yangtze River (YRE was affected by several mining activities (Guo and Deng 2022).
Stapanian et al. (2013)	Sample was collected from Burbot (**fish species**) from **Lake Erie**.
Custer et al. (2013)	Study sites were along **bay and lake** sides and the sample was **eggs of tree shallow bird**.
Yang et al. (2012)	Sediment samples were collected from a special **marginal area in the East China Sea**.

Rodenburg et al. (2012)	PCB concentration measurement was done on samples from **WWTP** in the New York Metropolitan Area, not from the river.
Kucuksezgin et al. (2012)	Study locations are near various **bays and also marginal to the Aegean Sea.**
Wang et al. (2012)	Sediment sample was collected from a highly eutrophicated **Lake**.
Pazi et al. (2012)	Candarli **Gulf, which is also marginal to the Aegean Sea.**
Zheng et al. (2011)	Study area was **Bohai Bay.**
Rodenburg et al. (2011)	Identification of the source of PCB contamination was evaluated by collecting data from CARP by the PMF method. PCB concentration in the **sediment sample was not measured directly**.
Wang et al. (2011)	Study area was the Pearl River Delta, mostly nearest to different **bays and sea regions**.
Sanctorum et al. (2011)	**Coal mining** near the study sites.
Zhao et al. (2011)	Sediment samples were collected from the **mouth of the Daliao River at the open sea.**
Vigano et al. (2011)	**Fish sample** was examined.
Palmer et al. (2011)	**Water samples** were collected at seven Public Water Systems along the Hudson River. **No sediment sample was analysed.**
Langston et al. (2010)	A **review study**, to draw together a range of published and unpublished data concerning contaminants in sediment and biota in the Severn Estuary. **Sediment sample was not analysed.**
Yang et al. (2009)	Surface sediment (27 samples) was collected from the Wuhan reach of the Yangtze River. (YRE was affected by several mining activities (Guo and Deng 2022)
Urban et al. (2009)	**Fish sample** was studied fish from the Lower Passaic River, New Jersey.
Madenjian et al. (2009)	**Fish sample** was analysed from **Saginaw Bay**.
Jofra et al. (2008)	Sample was **leopard frog**.
Foster et al. (2008)	Study area was the Mid-Atlantic **coastal river basin** (USA).
GÃ³mez-GutiÃ©rrez et al. (2007)	**Mediterranean sea** sediments were evaluated.
Pan et al. (2007)	Study area was **Qingdao coastal sea**.
Zhang et al. (2007)	**Yellow sea** surface sediment was evaluated.
Johnson et al. (2007)	Sample was juvenile chinook **salmon fish.**
Hu et al. (2007)	Study area was the **creek**.
Chuiko et al. (2007)	Sample was **fish's liver**.
Li et al. (2007)	Study area was **the creek**.
Kajiwara et al. (2007)	The sample was collected nationwide in Japan, which includes **different rivers, lakes and pond samples.**
Marvin et al. (2006)	Distribution of HBCD in Detroit River suspended sediments was evaluated and compared with **previous study data on PCBs**.
Koh et al. (2006)	Sample was collected from **Yeongil Bay,** Korea.
Katsoyiannis et al. (2006)	Study was done after **an accidental fire in one of the power plants** during which losses of an amount of Aroclor 1232 were recorded.
Song et al. (2006)	Concentration of PCBs was **not measured in the present study.**
Dimou et al. (2006)	Sample was collected from **Newark Bay Estuary.**
Mcmaster et al. (2006)	Contaminants from specific sources including **pulp mill effluents**, atmospheric **transport of mercury and the Alberta oil sands operations were assessed**.
Heidtke et al. (2006)	Summarization of an international workshop held to address monitoring, modeling, and management of PCBs within the **Detroit River-Western Lake Erie** by a group of technical experts.
Custer et al. (2006)	Pollution analysis was done on Barn **Swallows eggs and nestlings.**
Secco et al. (2005)	Study area was the **Lagoon** of Venice.
Hartmann et al. (2005)	Sample was collected from **Narragansett Bay.**

Table S2. Detailed exclusion criteria of the parameter FDPCBs.

Authors	Exclusion reasons
Needham et al.(2019)	Sample (bio solids) was collected from the Back River **Waste Water Treatment Plant** (BRWWTP) and Little Patuxent Water Reclamation Plant (LPWRP).
Liu et al.(2016)	**Lake** sample (water and air) was examined.

Table S3. Detailed exclusion criteria of the parameter PestC.

Authors	Exclusion reasons
Loughlin et al. (2022)	Sample was collected from the Carnaval **Creek** basin.
Postigo et al. (2021)	Surface water and groundwater were collected for analysis, **no sediment sample was tested.**
Cryder et al. (2021)	Study was carried out from a sample of **Wetland ponds**.
Chandler et al. (2021)	Soil sampling was performed from the Mahantango **Creek** watershed.
Wang et al. (2020)	Sediment samples were collected from the **estuarine-inner shelf areas of the East China Sea**.
Salerno et al. (2018)	Freshwater mussels were collected from Maitland River and toxicity tests by selected pesticide/insecticides were done. Water sample was also analysed but **sediment sample was not evaluated.**
Anderson et al. (2014)	Santa Maria **River estuary and Orcutt Creek** sample were evaluated.
Masia et al. (2013)	Sediment samples were taken from **irrigation channels and marshes**, not from rivers.
Ensminger et al. (2013)	Study areas were the Bay Area, **Creek and Salt Creek watersheds**. No river sediment was collected and analysed.
Lizotte et al. (2012)	Only water samples were collected, a **sediment sample was not collected.**
Zhang et al. (2008)	Direct pesticide concentration **measurement on sediment samples was not done**.
Dierksmeier et al. (2002)	**Rice drainage channel** sediment was analysed, but no river sediment was examined.

Table S4. Detailed exclusion criteria of the parameter POM.

Authors	Exclusion reasons
Fabre et al. (2023)	**Partially insufficient data.** Only Water samples containing suspended sediments were used to measure both dissolved organic carbon (DOC) and particulate organic carbon (POC). POM was not evaluated.
Jiang et al. (2023)	**Partially insufficient data.** Nitrous oxide (N2O) emissions from riverine water were evaluated**.** POM was not evaluated.
Xie et al. (2023)	**Partially insufficient data.** Sample was fish, shrimp and Shellfish. No sediment sample was analysed and POM was not evaluated.
Gong et al. (2023)	Surface water and SPM samples (approximately 0–50 cm below the air-water surface) were collected for evaluation. **Sediment sample was not examined**. Also, POM concentration was not evaluated (POC, DOC measured).
He et al. (2022)	**Partially insufficient data.** In this study, a part of Colloidal Uranium (U) in river water/sediment identified as a nano-colloidal (0.1 μm–3 kDa) particle, which is mainly composed of POM was analysed, but not by measuring the POM.
Mundo et al. (2022)	**Bay sample** was studied.
Zhang et al. (2022)	**Sediment sample was not evaluated**. RPOM was measured using the Regional Ocean Modeling System (ROMS) from collected water samples.

Tan et al. (2022)	Study area was the **Yangtze River Estuary, at the East China Sea and Jiulong River Estuary, marginal to the South China Sea.**
Li et al. (2022)	Study area was the Pearl River estuary, in the **South China Sea.**
Bodereau et al. (2022)	**Partially insufficient data.** Only SPM from water samples were collected at the outlet of the Rhone River, **sediment samples were not analysed**. POC and particulate organic radiocarbon signatures (Δ14C-POC) were evaluated, but POM was not evaluated.
Xu et al. (2021)	**Partially insufficient data**. Not relevant for POM evaluation.
Miranda et al. (2021)	Sample was collected along **Bulimba Creek**.
Upadhayay et al. (2021)	Water samples containing suspended sediment were assessed. **No sediment sample was tested**.
Pruski et al. (2021)	The study area was located 2.5 km from the Rhone River mouth in the pro-delta area, **near the Mediterranean Sea.**
Yu and Gan (2021)	The Pearl River Estuary (PRE) and its adjacent **shelf waters off the northern South China Sea**. The mitigation of eutrophication and hypoxia through oyster aquaculture was studied. **Sediment sample was not collected for evaluation**.
Li et al. (2020)	**Partially insufficient data.** POC was evaluated not POM.
Derrien et al. (2019)	Sediments composed of soil and algae POM sources were incubated under different conditions. **No river sediment sample was analysed.**
Xuan et al. (2019)	**Partially insufficient data.** TN, TOC, C and N stable isotopes ($\delta^{15}N$ and $\delta^{13}C$) and radioactive Isotopes (^{210}Pb and ^{226}Ra) were measured.
Chakraborty et al. (2019)	**Partially insufficient data.** DOM was evaluated from the collected sediment sample, but POM was not assessed.
Adhikari et al. (2019)	The study area was the northern **Gulf of Mexico (GOM).**
Rocha et al. (2019)	**Partially insufficient data.** POM from the sediment sample was not evaluated.
Brown et al. (2019)	Water samples were collected from Upper North Grain a well-studied U.K. **peatland catchment** in the Peak District National Park.
Li et al. (2019)	Sediment samples were collected from several mangrove habitats classified as atypical **semi-enclosed sea entrance sites throughout the Maowei Sea** in southern China.
Bainbridge et al. (2018)	Marine ecosystem was evaluated on the **Great Barrier Reef** (GBR). **No river sediment was studied.**
Masson et al. (2018)	**Partially insufficient data.** SPM was collected and evaluated, no sediment sample was examined. POC was measured only in the collected SPM sample.
Derrien et al. (2018)	**Partially insufficient data.** Source tracing tools of stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) and fluorescence spectroscopy were used to estimate the relative source contributions to sediment organic matter (SeOM). Concentration of POM was not evaluated.
Worrall et al. (2018)	The study used data from the Harmonised Monitoring Scheme (HMS - Bellamy and Wilkinson, 2001). **Sample collection and measurement were not done directly**.
Yu and Zhang (2017)	The study area was a **semi-enclosed area of the Bohai Sea.**
Naulier et al. (2017)	The study area had an impact on **Nuclear power plant accidents/Radionuclides.**
Morita et al. (2017)	Study was done at tidal flat sampling sites in **Okinawa Island marginal to the North Pacific Ocean**.
Bunte et al. (2016)	Study areas were Little Granite **Creek** and East St. Louis **Creek**.
Yang et al. (2016)	**Partially insufficient data.** Particulate Organic Carbon (POC) concentration data from U.S. Geological Survey (USGS) gauge stations were obtained.
He et al. (2016)	**Partially insufficient data**. Alkaline-Extractable Organic Matter (AEOM) was obtained from the solid sediments as a representative POM. Specifically, the measurement of POM concentration in the sample was not done.
Kim et al. (2016)	A replicated **paddy microcosm** system was analysed, the river was not the concern.
Bonifacio et al. (2014)	**Partially insufficient data.** OC, TN, and C/N ratios were evaluated. POM concentration evaluation was not done.
Worrall et al. (2014)	The study used sediment flux data from previous studies and was also not relevant for the measurement of POM.

Duan et al. (2014)	**Partially insufficient data** as part of organic matter ($\delta^{13}C$, $\delta^{15}N$, C/N ratio) was evaluated.
Undeman et al. (2014)	Sediment sample was analysed from the **Baltic Sea.**
Fox et al. (2014)	The study site was the South Elkhorn **Creek.**
Diem et al. (2013)	**River bank sediment** was examined.
Tesi et al. (2013)	**Partially insufficient data.** POC, PN, Carbon and nitrogen isotopic compositions of POM ($\delta^{13}C$ and $\delta^{15}N$ values) were evaluated from the water sample. POM concentration evaluation from sediment samples was not done.
Osburn et al. (2012)	Only surface water samples were analysed, **No sediment sample was collected** from the river bed and POM concentration measurement was not done.
Piscart et al. (2011)	**Partially insufficient data.** POM concentration measurement was not done.
Littler et al. (2010)	The two study sites were a back-reef sedimentary **lagoon**.
Dang et al. (2010)	Sample was collected from the **creek**.
Maia et al. (2009)	Only surface water samples were analysed, **No sediment sample was collected** from the river bed and POM concentration measurement was not done.
Goñi et al. (2009)	Sediment sample was collected from Winyah **Bay**.
Liu et al.(2007)	**Partially insufficient data.** POC, PN, Carbon and nitrogen isotopic compositions of POM ($\delta^{13}C$ and $\delta^{15}N$ values) and C/N ratios were evaluated from SPM, which was obtained by filtering collected sample water. **POM concentration evaluation from sediment samples was not done.**
Hunken et al.(2007)	Sand bed streams were examined, **and no sediment sample was collected** from the river bed and evaluated for POM concentration.
Bănaru et al. (2007)	The study area was located on the **Black Sea coast**.
Wharton et al.(2006)	The paper focuses on the modification of flow velocities and the trapping of fine sediment (particles <2 mm in diameter) which include fine particulate organic matter (FPOM) by in-stream macrophytes. **POM concentration evaluation in sediment was not done.**
Goni et al. (2006)	Study area was a **gulf** (a deep inlet to sea)

Table S5. Detailed exclusion criteria of the parameter TOC.

Authors	**Exclusion reasons**
Tao et al. (2023)	**Bay Sample** was analysed.
Krickov et al. (2023)	Surface water samples and SPM from collected water were analysed. **Sediment sample from the river was not evaluated**.
Guan (2022)	Study area was the Yellow River **wetland.**
Vandekerkhove et al. (2021)	Glacial lake outburst floods in fjord sediments were analysed, which was an accidental incident, also sediment cores were retrieved from the Martinez **Channel**, and river sediment was not analysed.
Fuller et al. (2021)	Study area was **Lagoon.**
Wang et al. (2020)	Surface sediments in the Yellow River Delta **wetland** were investigated.
Xue et al. (2019)	**Sediment sample from the river was not collected** for evaluation in the present study, only Urban and background soil was investigated.
Zhang et al. (2018)	Sample was evaluated from **Wetland**.
Magni et al. (2017)	Sample was evaluated from **Lagoon.**
Wang et al. (2017)	Sample was evaluated from **Wetland**.
Yang et al. (2016)	The Hsin-Sheng (a plain terrain) was drilled 1 km north of the Jishuei River and 15 km from the west coast of Taiwan. **River sediment was not evaluated**.
Li et al. (2016)	Sampling was done from Changjiang Estuary, **China marginal to the Yellow Sea and the East China Sea.**
Bernot et al. (2016)	Study samples were collected from a watershed **not directly from the river.**
Murat et al. (2016)	Study region was the **English Channel, not any river.**
Lou et al. (2016)	Sample was evaluated from **Wetland**.

Chakraborty and Babu (2015)	How the concentration of TOC was measured, was not mentioned.
Shi et al. (2014)	Surface sediment samples were collected along the Yangtze Estuary and its nearby coastal areas of the East China Sea.
Nie et al. (2013)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, Guo and Deng 2022)
Kang et al. (2013)	Study area was **Bay**.
Tomiyasu et al. (2013)	Study area was affected by small-scale **gold mining.**
Zhao et al. (2011)	Study area was Daliao River **Estuary, marginal to the Bohai Sea**.
Ni et al. (2008)	Study area was the Pearl River Delta, **marginal to the South China Sea**.
Zou et al. (2007)	Sample was composite surface soil, collected from various kinds of vegetable growing land, **not from the river**.
Gustin et al. (2006)	**Wetland** sample was evaluated.
Calace et al. (2006)	Mediterranean **sea sample** was analysed.
Wan et al. (2005)	TOC concentration of the collected sample from the Haihe River basin was not measured.
Huang et al. (2005)	**Lake sediment** sample was evaluated.
Yang et al. (2005)	Sediments collected from the **East China Sea** were studied.
Rodziewicz et al. (2004)	TOC was not measured for the sample collected.
Piotrowski (2004)	Sediment sample was collected from Roztoka Odrzańska, **a bay** of the Szczecin Lagoon. (Wikipedia-aug 24)

Table S6. Detailed exclusion criteria of the parameter TON.

Authors	**Exclusion reasons**
Peng et al. (2023)	**Wetlant** sample was evaluated.
Downey et al. (2023)	**Cave sediment** sample was analysed. No river sediment was analysed.
Qi et al. (2023)	Samples were collected in the **Taiwan Strait** (TWS) and the **South China Sea** (SCS).
Shen et al. (2022)	**Groundwater** was evaluated, instead of river sediment.
Lv et al. (2022)	Study area was **Xiangxi Bay**.
Li et al. (2021)	**Partially insufficient data.** Total Nitrogen (TN) was evaluated.
Sun et al. (2021)	Quaternary sediments from **aquifers and aquitards (Groundwater)** of Jianghan Plain (JHP), China were evaluated.
Wu et al. (2013)	**Lake Wuliangsu** of the Yellow River Basin (north China) was the study area.
Xia et al. (2008)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004; Song et al. 2010; Wang et al. 2011; Guo and Deng 2022)

Table S7. Detailed exclusion criteria of the parameter TOP.

Authors	**Exclusion reasons**
Yuan et al. (2015)	Sediment cores were taken from a riverine **wetland** located in the Huaihe River valley.

Table S8. Detailed exclusion criteria of the parameter TSS.

Authors	**Exclusion reasons**
Basu et al. (2023)	Study location is within Hudson Bay and Remote sensing (MODIS) method was adopted for TSS quantification. **Not any type of sample was collected and measured.**

Yao et al. (2022)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, Guo and Deng 2022)
Jiang et al. (2021)	**Lake sample** was studied.
Seo et al. (2020)	Image taken by Geostationary Ocean Color Satelite (GOCS) system TSS was analysed. **Not any type of sample was collected and measured.**
Zhou et al. (2018)	Study was done on an **artificial river channel**.
Hou et al. (2017)	A remote sensing algorithm was developed to estimate the concentrations of TSS in large lakes and reservoirs by surface reflectance of the Moderate Resolution Imaging Spectroradiometer (MODIS). **Not any type of sample was collected and measured.**
Li et al. (2017)	Study area was the **coastal bay**.
Ayana et al. (2015)	**Lake sample** was evaluated.
Mbonimpa et al. (2014)	TSS was **not directly measured by collecting the sample**, the data was obtained for analysis from the United States Geological Survey (USGS).
Rossi et al. (2013)	The methodology for TSS emission involved using a stochastic model to predict TSS concentrations from **combined sewer overflows** (CSOs) and stormwater in **separate sewer systems**.
McCarthy et al. (2012)	**Stormwater runoff** was analysed from five urbanized catchments in North Carolina, USA. **Not any sample from the river was analysed**.
Miller et al. (2011)	Sample was not collected directly from river. Study concentrated on **agricultural watershed** and urban watershed.
Chen et al. (2011)	Study area was Apalachicola **Bay**.
Kadlec et al. (2011)	Study site was **wetlands**.
Kadlec et al. (2010)	Wetland treatment was analysed. Study region was a **wetland**.
Brock et al. (2008)	Samples were collected generally from various **lakes.**
Chavan et al. (2008)	Experimental wetland mesocosms were the sampling sites, which were constructed near the **confluence of Steamboat Creek** and the Truckee River at the Truckee Meadows Water Reclamation Facility.
Houser et al. (2006)	Study was done on different tributaries of various **creeks**.
Brett et al. (2005)	17 streams (**creek**) located in the **Lake Washington and Lake Sammamish watershed** of the Seattle region of Washington State, USA were examined. Only water samples were analysed.
Dodds et al. (2004)	**Direct sampling and measurements were not done**, TSS data was obtained from the United States Geological Survey – USGS.
Audry et al. (2004)	Cronic Cd pollution due to mining and industrial development in the late nineteenth century. The study site has a **mining** effect.

Table S9. Detailed exclusion criteria of the parameter HevMetC.

Authors	Exclusion reasons
Fan et al. (2023)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, and Guo and Deng 2022)
Eschenfelder et al. (2023)	A case study of the **Clyde drainage basin (no river sediment had been the sample)** was used to quantify excess heavy metal concentrations in the region through conservative mixing models. The study area, Upper Clyde region had been home to **intensive mining** for the last several centuries.
Wang et al. (2022)	Sample was examined from Central Yangtze **Lakes**, China.
Guo and Deng (2022)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, was Guo and Deng 2022)
Leet al. (2022)	Surface **seawater** and wastewater from the Red River **coastal aquaculture zone** were analysed.
Zhang et al. (2022)	Study area was **the Pearl River Estuary, marginal to the South China Sea.**
Chen et al. (2022)	Sediment and water samples of Shanghai Port were analysed, Shanghai Port (with a deep seaport and a river port) is located at the intersection of the Yangtze River and the East Sea and samples were collected **marginal to the East Sea.**
Zhao et al. (2021)	Samples were collected from freshwater **wetlands**, brackish **wetlands** and **salt marshes** located in the nature reserve of the YRE.

Wanjeri et al. (2021)	Study site was Sabaki River **estuary** (Kenya, Indian Ocean).
Li et al. (2021)	**Lake** water sample was analysed.
Chalov et al. (2020)	Stusy region contains copper-molybdenum **mining** in areas like Erdenet, Mongolia.
Aramendía et al. (2020)	Study area was the Guadalquivir estuary (southwestern Spain) in a **marine disposal area**.
Sedláček et al. (2020)	Sediment sample was collected from **Coal-Mining**-Impacted Oxbow **Lake**.
Ye et al. (2020)	The study area was Pearl River Estuary **marginal to the South China Sea.**
Luo et al. (2020)	**Acid mine** drainage affected region in South China was studied.
Zhuang et al. (2020)	The study was carried out at 6 typical **intertidal zones** in northern China. Intertidal zones are located at the **interface between the ocean and land.**
Kontas and Bostanci (2020)	The study area was the lower Melet River. **Mining activities** are carried out in this region and these activities constitute a resource in terms of copper, lead and zinc elements.
Fan et al. (2020)	The assessment was done at the **Yangtze River Estuary of the East China Sea.**
Szabó et al. (2020)	Soil samples were collected from 14 swales and 14 point bars next to the Nagy-Morotva-Lake.
Xiong et al. (2020)	Crayfish and sediment samples were collected and analysed from **uncultivated and cultivated ponds** in the middle reach of the Yangtze River.
Shojaeezadeh et al. (2020)	A case study was done at **Fountain Creek Watershed.**
Nkinda et al. (2020)	The study region was at the Mara River basin in Tanzania, which is part of a larger Lake Victoria basin that has been highly influenced by large-scale **gold mining activities** in the region.
Li R et al. (2020)	Samples were collected from major urban mainstream sections in the middle and lower reaches of the Changjiang River (also known as the Yangtze River), which was affected by **Mining** and industrial emissions.
Dukes et al. (2020)	Surface water and sediment samples were collected from **creeks** which feed into Lake Greenwood and from sites located on Lake Greenwood.
Chen et al. (2020)	The sample was collected from the subaqueous delta near the margin of the current lobe of the Yellow River Delta, **not from the river**.
Liang et al. (2019)	Study region was at Zhejiang **nearshore area,** East China Sea.
Cmelík et al. (2019)	Sampling sites were the Bílina River basin, including places where industrial polluters (chemical factories, **brown coal mines**) are located on the river.
Zhang et al. (2018)	Sediment samples were collected from the Zijiang River, which was affected by **antimony mining and smelting factories** in the downstream.
Liu et al. (2018)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, and Guo and Deng 2022)
Hahn et al. (2018)	The sample was not collected directly from the river.
Bawa-Allah et al. (2018)	Lagos **Lagoon** of Nigeria was studied.
Ghazanfari Shabankareh et al. (2018)	Study area was at a stretch of Musa **Creek beaches**.
Huang et al. (2018)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, and Guo and Deng 2022)
Duivenvoorden et al. (2017)	The study region was the **Marlborough Creek system**, a series of pools intervened by riffles extending along the creek. Also, a chrysoprase **mine** operates in the catchment of Develin Creek, one of Marlborough Creek's main tributaries.
Bi et al. (2017)	Surface sediment of typical **estuaries that empty into the sea** in eastern China was studied (Liaohe River Estuary, Yellow River Estuary, Yangtze River Estuary, Minjiang River Estuary, and Pearl River Estuary).
Liao et al. (2017)	The study site was Maba River, South China has been affected by the smelting and **mining industry** since 2000.
Li et al. (2017)	Study site was an **antimony mine area** in central China.
Han et al. (2017)	The study site was the Yangtze River Estuary, **at the coastal outfall of the Yangtze River to the East China Sea.**

Sun et al. (2017)	The experimental plot was laid in the middle marsh at the intertidal zone of the Yellow River estuary, **no sediment sample was examined from the river.**
Wang et al. (2017)	Sample was collected from the **shallow Sea Wetland** of Liaodong Bay.
Akin et al. (2017)	**Gokcekaya Dam Lake** on Sakarya River was the study region.
Feng et al. (2017)	The study samples were collected from Mulberry fish pond, mangrove exhibition park, mangrove research base and non-restored mangrove along the river bank. **Sample directly from the river was not evaluated.**
Mna et al. (2017)	Sediment cores from **Bizerte Lagoon** were assessed.
Kim et al. (2017)	The study was done on stream samples (not on river), located near the **Yeonhwa II mine** in South Korea.
Lu et al. (2017)	Surface sediments of the **South Yellow Sea** and the northern part of the **East China Sea** were evaluated.
Kerr et al. (2017)	As per best of our knowledge, the sediment sample may not have been tested, **only the water sample was analyzed.**
Deng et al. (2016)	The study area was a **shallow lake**.
Kuang et al. (2016)	Sample was collected from the **junction of the Yangtze River and the Bohai Sea.**
Banerjee et al. (2016)	Jamshedpur stretch of Subarnarekha river, which has an effect on **mining activities**.
Guan et al. (2016)	Ningxia-Inner Mongolian reaches of the Yellow River (NIMYR) have an impact on the **mining** industry.
Liu et al. (2016)	SPM, water and sediment core were sampled from Namfei River which flows at the **confluence of the bay area of Lake Chaohu.**
Tao et al. (2016)	The study area was the Xiangjiang River, which has an impact on the Shuikoushan **Mining** Bureau.
Guo and Yang (2016)	Study was done on **the inner shelf of the East China Sea.**
Lin et al. (2016)	Study was done at **seagrass sites** along the Yellow River Estuary, marginal to the Bohai Sea.
Arslan et al. (2015)	Gumuskoy **Silver Mine**,Turkey was the study region.
Hu et al. (2015)	The study sites belong to **offshore areas** of the Changjiang River, marginal to the Yellow Sea and East China Sea.
Zhao et al. (2015)	The study was done on Hainan island, which was affected by **several mining plants**.
Ferati et al. (2015)	**zinc mine** plant was near the study site
Syakti et al. (2015)	Sediments of Segara Anakan **Lagoon** were evaluated.
Xiao et al. (2015)	Study region was at riparian and ditch **wetlands**.
Zhang et al. (2015)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, and Guo and Deng 2022)
Wang et al. (2014)	Sample was collected from the Yangtze River and its tributary. Yangtze River has an impact of several **mining industries**.
Kalender et al. (2013)	The study area has been affected by **mining activity** since BC.
Guo et al. (2013)	The study region has effects of **gold mine and copper mine.**
Lin et al. (2013)	The sample was collected from sea and harbor areas which were **marginal to the sea**.
Dalai et al. (2013)	The study area was Tuul River, which was affected by **gold mining.**
Djordjevic et al. (2012)	The study site was Korbevacka River of Serbia, the river is a main recipient of all kinds of pollutants from the **Pb−Zn mine "Grot."**
Kirschbaum et al. (2012)	The Study area was Yacoraite River drainage basin, Aguilar underground **mine (Pb–Ag–Zn)** is located in the upper reaches of the river basin.
Petronio et al. (2012)	The study area was Mar Piccolo, which is an inner **semi-enclosed basin with lagoon features**.
Cui et al. (2011)	Newly formed **Wetland** of the Yellow River Delta.
Sun et al. (2011)	Effect of ore **mining** activities in the study region.
Yi et al. (2011)	The study site **Yangtze River** was exposed to **contamination from mining** and other industrial activities (Feng et al. 2004, Song et al. 2010, Wang et al. 2011, and Guo and Deng 2022)
Augustinus et al. (2010)	The study region Macquarie Harbour in southwest Tasmania, Australia, has been affected severely by the establishment of **mines**.

Deng et al. (2010)	Sample was collected from **Bay**.
Balkis et al. (2010)	Sample was collected from **Bay**.
Xiao et al. (2010)	The study site was the middle stream zone of the Le An River, which was highly impacted by two of the largest Dexing **Copper Mine** and Yinshan **Lead-zinc Mine**.
Mdegela et al. (2009)	Illegal small-scale **gold mining** and associated use of mercury taking place in the Mindu area.
Moberly et al. (2009)	The study site of the Coeur d'Alene River in northern Idaho has been impacted by decades of **mining operations**.
Frankowski et al. (2009)	Samples of sedimentary rocks to be studied were collected from the **Warta River valley** of Poland, not from the river directly.
Zorer et al. (2009)	Basalt lavas discharging from **Tendürek Volcano** were near the study site.

Table S10. Detailed exclusion criteria of the parameter EcoT.

Authors	**Exclusion reasons**
Méndez-Fernándezet al. (2019)	Study site has impact of **mining**.
Roberta et al. (2014)	**Lake** sample was evaluated.
Shoji et al. (2014)	Literature could not retrieved.
Lambert et al. (2013)	Impact of natural rubber latex (NRL) condom degradation products on sediment-dwelling organisms was assessed, which was **not relevant** to our study.
Spencer et al. (2006)	The study was conducted in the lime-house basin which is a **canal basin** connected to the river Thames, rather than directly in the river itself.

Appendix III

Table S11. Detailed inclusion criteria of the parameter PCBs.

Authors	Objectives	Location	Study site	Nearby industries/reason	Method for measuring target parameter -PCBs	Extra Parameter	Method	Key Finding
Iwegbue et al. (2022)	The characteristic concentrations of 28 PCB congeners, their spatial distributions, sources, and associated risks to the ecosystem were investigated in sediments of some rivers in the Niger Delta of Nigeria.	Nigeria	The Afiesere River, Edor River and Okpare River.	Glass industry and power plant	GC-MSD-SIM OR GC-MS	PH, EC, TOC	Standard Methods	The concentrations of PCBs in these river sediments were relatively higher than those reported in sediments from many parts of the world which signifies poor regulation and enforcement, continuous emissions from old electrical equipment, and improper management and disposal of PCB-containing wastes in Nigeria.
Chowdhury et al. (2022)	Assessment of Polychlorinated biphenyls (PCBs) in sediments of Turag River, Dhaka, Bangladesh	Bangladesh	Turag river	Garments, textile, pharmaceuticals, chemicals, pesticides, jute, metal industries tobacco, ink, pulp and paper mills, food processing, tanneries, etc.	Gas chromatograph-electron captured detector(GC-ECD)			PCB 180 was found to dominate in sediment samples in both pre- and post-monsoon seasons, with higher ΣPCBs concentrations in pre-monsoon. PCBs levels in developed countries (China, England, France, Italy, and South Africa) were generally similar or higher, while those in developing countries (Egypt, Vietnam, Romania and Mexico) were comparable or lower than in this study.
Rimayi et al. (2022)	Assessmnt of bioavailable polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), dioxin-like PCBs (dl-PCBs), and polybrominated biphenyls (PBBs) on ambient air, water, and sediment in the Hartbeespoort Dam area in South Africa.	South Africa	Dam wall, Crocodile River, Magalies River, and Harbour sites of the Hartbeespoort Dam.	Crocodile River site, lies downstream of Johannesburg, the most industrialised city in Africa.	GC × GC-TOF	PCDDs, PCDFs, dl-PCBs, PBBs	GC × GC-TOF	The highest quantified bioavailable concentrations were for PCB 126, PBB 10, and PBB 49. Air samples had the greatest toxic equivalency quotients (TEQs), which were followed by sediment samples and water samples.

Lu et al. (2021)	Risk assessment to estimate the potential ecological risk of PCBs and PBDEs in nationwide polluted urban river sediment.	China	173 nationwide black-odorous urban rivers.		GC-MS-EI-SIM	PBDEs	GC-MS-ECNI-SIM	Surface sediments of polluted urban rivers in China were contaminated with PCBs and PBDEs, with PBDE levels being much higher than PCB levels. The average concentrations of PCBs and PBDEs in sediment samples reached 10.73 and 401.1 ng/g dw respectively.
Qiu et al. (2020)	To clarify how OHRB-mediated PCB and PCE dechlorination are related and to determine which scenario the PCB/PCE-dechlorinating OHRB used.	China	174 nationwide black-odorous urban rivers.		GC-ECD			Organohalide-respiring bacteria were found in contaminated urban river sediments, which had the ability to dechlorinate hazardous and persistent polychlorinated biphenyls (PCBs) through different pathways.
Choo et al. (2020)	To find out the relative distributions and contamination patterns of seven groups of legacy (PBDEs, PCBs, OCPs, HBCDs, and PFASs) and emerging (PCNs and SCCPs)	South Korea	Three major rivers in south korea,namely the Nakdong, Namhan and Yeongsan.		GC-HRMS	PBDEs, OCPs, HBCDs, PFASs	GC-HRMS and LC-MS/MS	SCCPs (short-chain chlorinated paraffins) were the most widely distributed among all targeted POPs in river sediment and crucian carp, while PFASs (perfluoroalkyl substances) were more commonly found in river water. The dispersion patterns of legacy POPs seemed to be influenced by their physicochemical properties, but new POPs exhibited remarkably distinct distribution patterns across all media.
Iweghue et al. (2020)	To determine the concentrations, spatial distribution patterns, sources and risks of PCBs in sediments from water bodies around oil production facilities in the Escravos River Basin.	Nigeria	The Escravos river basin.	Crude oil production facility which has an oil terminal pump.	GC/MS	TOC	Walkley and Black wet oxidation method	The median concentration of Σ28 PCB in sediments was 2300 ng/g. PCB levels were higher near oil production facilities than in residential or dockyard areas. Lower chlorinated PCBs were more prevalent than higher chlorinated ones. Risk assessments indicated very high potential risks for both organisms and humans.
Irerhievwie et al. (2020)	The objective of this study was to evaluate the spatial distribution and likely risks to both organisms and humans arising from exposure to PCBs in sediments from the Niger, Ase and Forcados rivers.	Nigeria	Niger delta region comprising three river namely Niger, Ase and Forcados.		GC-MSD	PH, Electrical conductivity, Total organic carbon content	Standard Methods	According to the study, the sediments of the Niger River had greater PCB contents than the Ase and Forcados Rivers. In sediment, the PCB concentration of these rivers showed that low chlorinated PCB congeners predominate and are within the worldwide concentration range.

Chitsaz et al. (2020)	To analyze the PCB data from these methods 1668 sediment samples via Positive Matrix Factorization (PMF) and to identify the Sources of PCBs in the Upper Hudson River sediment post-dredging.	New york-U.S. A	Upper Hudson River	2 General Electric Plant (capacitor manufacture)	HRMS			The dechlorination factors indicated that ortho-position chlorines were removed in the sediment, potentially leading to the total dechlorination of PCBs to biphenyl in theory. Only one component, representing 1.7% of the PCB mass, was attributed to sources other than the GE (General Electric) plant, such as urban areas and tributaries. This suggested that minimal recontamination may have occurred after dredging.
Urbaniak et al.(2020)	To utilize PCB-contaminated river sediments and offer an alternative, integrated approach to technologies used so far alone.	USA	Upstream of Hudson River near Water for located above the Mohawk River tributary and above Champlain Canal lock-1.		GC(SIM mode)			River sediment was considered a suitable ingredient for a growing medium for plants. However, PCBs in the sediment posed potential ecological harm to the soil and plants. It was found that the risk associated with PCBs could be effectively reduced through thermal processing followed by phytoremediation using zucchini.
Belháčová-Minaříková et al.	Application of equilibrium passive sampling to profile pore water and accessible concentrations of hydrophobic organic contaminants	Europe (Germany to Romania)	9 locations along the Danube River	Affected by agricultural,industrial and urban effluents and navigation.	GC-MS/MS			Total concentrations of HOCs (PCBs, PAHs, and OCPs) in sediments were poor indicators of bioavailability, but multi-ratio equilibrium passive sampling (EPS) effectively addressed this issue by measuring pore water ($C_{W:0}$) and accessible ($C_{AS:0}$) concentrations. The study highlighted the utility of EPS in accurately measuring bioavailable HOCs and enabling effective environmental risk assessments.
Ndunda et al. (2020)	Spatial and temporal trends of polychlorinated biphenyls in water and sediment to provide information towards proper management of aquatic systems in Kenya.	Kenya	Three sites along Nairobi River to cover upstream, midstream, and downstream	Light industries, garages, and car wash activities	GC-ECD			Nairobi River recorded high levels of PCBs compared with what had been reported in the past along the Kenyan coast and Lake Victoria. High levels of PCBs were found downstream, which was indicative of the fact that human activities that increased down the river were contributing factors to PCB load.
Khairy et al. (2020)	Estimate freely dissolved concentrations of PCDD/Fs and PCBs in pore-water and the overlying water using the multisampling system.	USA	Lower Passaic River		GC-MS/MS			In situ pore-water passive samplers were found to be better predictors of lipid-based concentrations in freshwater benthic organisms compared to sediments, outperforming the common equilibrium partitioning theory. There were no significant spatial differences in PCBs and PCDD/Fs concentrations in river water, indicating river water was more useful for establishing temporal trends rather than spatial trends.

Barhoumi et al. (2019)	To Investigate the occurrence, spatial distribution, potential sources and ecotoxicological risk of a large variety of trace metals, PAHs and POPs in surface sediments.	Romania	Someşu Mic River, located in Northwest Romania.		GC-MS	Trace metals, OCPs	AAS, GC-ECD	The total PCB concentrations ranged from 2.7 to 252.7 ng/g dw, with distinct contamination signatures for tri- to tetra-chlorinated PCBs, indicative of pollution from Aroclor-1016 and -1254 technical mixtures. Sediment Quality Guidelines (SQGs), along with the mean effect range-median quotient (m-ERM-Q) and toxic equivalent factor (TEF), indicated that the highest ecological risks occurred for PCBs and DDTs.
Wang et al. (2019)	Occurrence, sources and ecotoxicological risks of polychlorinated biphenyls (PCBs)	China	Pearl river delta		GC-μECD			Light PCBs (i.e. tetra-, tri-, and penta-PCBs) accounted for a higher proportion at all sampling sites. PCBs were largely accumulated in surface sediments, showing a decrease with depth along sediment cores
Zanardi-Lamardo et al. (2019)	To evaluate the Distribution and sources of organic contaminants in surface sediments of the Hooghly River estuary and Sundarban mangrove.	India	Hooghly river estuary and Sundarban mangrove.		GC-MS	PAHs, DDT	GC-MS	Concentrations of Σ182PCB ranged from not detected (nd) to 13.5 ng/g dw. Study revealed that the concentration of the majority of the PCB congeners was below the detection limit, while an overall relative abundance of DDT and PAH concentrations was found at all sampling stations. Diagnostic ratios suggested that major sources of PAHs are combustion processes. Heavier PCB congeners suggest local sources and short-range transport of such chemicals.
Babut et al. (2019)	To provide an up-to-date diagnosis of the contamination of Saigon River sediments by a range of historical and emerging chemicals.	Vietnam	Saigon River in Ho-chi-minh city.	30,000 small industrial production units and more than 800 large-scale factories.	GC-MS/MS	PAHs, PBDEs and PFASs	GC-MS/MS and LC-MS/MS	Bed sediments of the Saigon River were weakly contaminated by a range of organic pollutants, likely due to the strong tidal influence in the river and the runoff of contaminants from urban surfaces during the monsoon season.
Xu et al. (2019)	This study documents the effects of sulfate on PCB dechlorination rate, extent, pathway, preferences and dechlorinating-related microorganisms and the influence of fatty acids on PCB dechlorination in sulfate-amended sediment microcosms.	USA	Hudson River and from the Grasse River.		GC-μECD			Dredging was not deemed necessary for PCB remediation if PCBs in sediments were dechlorinated by microorganisms. In the sediment microcosms, sulfate slightly reduced PCB dechlorination; however, the addition of fatty acids significantly boosted dechlorination in the Grasse sediment.
Urbaniak et al.	To evaluate the influence of the river sediment on PCB content and phytotoxicity of soil–sediment mixtures were measured using Phytotoxkit and by growing cucumber and zucchini.	USA	Upper Hudson River.		GC-MSD-SIM			Zucchini was found to be more resistant than cucumber to sediment amendment of soil. Moreover, zucchini planted samples showed higher, however statistically unconfirmed, reduction of the total PCBs than cucumber and unplanted samples

Adeyinka et al. (2018)	To investigate the presence and concentration of selected PCBs: PCB 28, PCB 77, PCB 101, PCB 52, PCB 153, PCB 105, PCB 138, and PCB 180 in soil, sediment, and surface water samples of the Msunduzi River during winter and spring seasons.	South Africa	Msunduzi River	Highly industrialized areas as well as rural and agricultural areas.	GC-MS			Surface water had lower PCB concentrations than sediment, with higher total PCB levels in winter than in spring. Among all sampling sites, Du Toit had the highest PCB levels, while the lowest was observed after chlorination at the Darvill wastewater treatment plant.
Su et al. (2018)	To thoroughly study the composition and distribution of PCBs in bottom sediments from the Yellow River of Henan section. In addition, the current contamination situation with selected PCBs and the effects of seasonal variation and the characteristics of the environment on the distribution of these compounds.	China	Main stream and the tributaries of the Yellow River in Henan section.	Two major hydraulic projects in Yellow River, Sanmenxia Reservoir and Xiaolangdi Reservoir.	GC-MS/MS	TOC	Elemental Analyser	Compared to other aquatic environments in China, PCB levels in the studied area were relatively low. PCBs in surface sediments likely originated from local input or atmospheric deposition. Based on sediment quality guidelines (SQG), the risks posed by PCBs in the sediments were considered negligible.
Sevin et al. (2018)	The aim of this study was to determine selected POPs including polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and organochlorine pesticides (OCPs) from water and sediment samples collected from 12 stations in Ankara River for 12 months.	Turkey	12 stations in Ankara River.	.	GC-MS	POP, PBDEs, OCP	GC-MS	Among tested POPs in water p,p'-DDE was the most detected contaminant in water samples. Concentrations of POPs in general were much higher in sediment samples compared to water. No PCB residues were detected in water samples. However, PCB 101 was the most common contaminant in sediment. No differences between urban and rural regions were observed.
Kilunga et al. (2017)	To discuss the occurrence and spatial distribution of toxic metals, POPs and PAHs in sediments from three of the main rivers draining the capital city of Kinshasa. In addition, the degree of sediment pollution by heavy metals was evaluated using geo-accumulation index (Igeo) and enrichment factor (EF) calculation.	Democratic Republic of the Congo (DRC)	Three rivers named Makelele, Kalamu and Nsanga draining the capital city of Kinshasa.		GC-MS/MS	PAHs, PBDEs; HM; TC,TN; TP	GC-MS/MS; ICP-MS; Elemental analyser; Spectrometer	Results showed that Cu, Zn, Cd, and Pb were the predominant toxic heavy metals found in most sediments, with contamination levels higher than in other Congo River basins. The Makelele River was the most contaminated among the rivers investigated. The findings indicated significant pollution risks to human health and the aquatic environment.
Anim et al. (2017)	To quantify the amounts of polychlorinated biphenyls (PCBs) and brominated flame retardants (BFRs) in the Brisbane River estuary's sediments.	Australia	Brisbane River.		GC-MS/MS	TOC; BDE; HBCD	Walkley-Black; GC-NCI/MS; HPLC-MS/MS	The findings of the study showed that the target compounds were regularly detected but at relatively low levels compared to similar studies elsewhere, with the contaminants fairly evenly distributed along the river.

Baqar et al. (2017)	To assess the occurrence, ecological risk and spatial-temporal variations of PCBs in the water and surface sediments.	Pakistan	The River Ravi and its three tributaries in Pakistan.		GC-MS			Among the studied PCB congeners, PCB-114 was the most prominent in sediments during both seasons. PCB-37 and PCB-66 were the most dominant congeners during the pre-monsoon and post-monsoon seasons, respectively. The Nullah Deg was identified as the most contaminated tributary of the River Ravi due to industrial and urban wastewater. The ecological risk assessment revealed a significant potential ecological risk during the pre-monsoon season and a moderate risk during the post-monsoon season.
Lu et al. (2017)	To analyse to what extent, the freshwater of river Thames bed sediments are contaminated with HCB, 7 PCBs and 6 PBDEs; to assess whether this contamination can be linked to local sewage effluent discharge and to examine whether POPs contamination can be correlated to the depth of the sediment sample.	England (UK)	Seven sites in the River Thames and its tributaries.		GC-MS (EI-SIM)	POP	GC-MS (EI-SIM)	The highest sediment concentrations of POPs were found in the urbanized tributaries, The Cut and Littlemore Brook. Generally, chemical concentrations were higher in sediment samples from downstream of the sewage treatment works (STW) compared to upstream. Significant variation in PCB, BDE, and HCB concentrations was observed with depth in sediment samples from Littlemore Brook Upstream, with higher levels in the second layer compared to other layers.
Rimayi et al. (2017)	The aim of this study was to characterise the contaminating technical PCB mixtures and pyrogenic/petrogenic PAHs in sediment.	South Africa	The study area consisted of the Jukskei River and Klip River.	Heavy industrial activity nearby.	GC-MS	PAH, alkyl PAH and TOC	GC-MS and Walkley-Black method	The Jukskei and Klip River sediments showed trends of contamination by relatively unweathered Aroclors in all sites except the lowly contaminated sites of Buccleuch and Henley. PCBs 138, 153 and 180 were the most abundant PCBs in the majority of the sites studied. Henley site in the Klip River recorded the lowest ΣPCB and ΣPAH concentrations.
Wang et al. (2016)	To comprehensively investigate PBDEs, PCBs and PCDD/Fs in the whole basins of seven rivers.	China	Seven major river basins around China.		HRGC/HRMS	PBDEs and PCDD/Fs	HRGC/HRMS and GC/LRMS	The spatial analysis identified a decreasing trend of POPs levels from south to north of China. The contamination in the Pearl River Basin was more serious compared to the other river basins, followed by the Yangtze River Basin. The congener profiles demonstrated an evident influence of the industry and commerce development on the POPs distribution.
Cui et al. (2016)	To evaluate spatial-temporal variation, possible source and ecological risk of PCBs in sediments from Songhua River.	China	Songhua River	Different industrial development.	GC–NICIMS	TOC,	TOC Analyzer	The temporal trend showed that total PCBs in the sediment have decreased since 2008. The main sources of PCBs in the sediment were point source pollution, discharge of historical usage and industrial sewage. A risk assessment indicated that most of the sampling sites had low potential ecological risk.

Lu et al. (2016)	To link hydro-biogeochemical cycles to PCB dynamics, specifically between landscapes and riverscapes, to better understand the impact of short-term weather variations on PCB mobilisation and transport in the catchment and also identify sensitive parameters in the modeling exercise.	UK	River Thames		GC-MS			The study was a follow-up to a previous study where a Level III fugacity model was used to simulate PCB behaviour in the Thames. The INCA-Contaminants model effectively predicted PCB dynamics, including sharp increases in upper sediment concentrations following extreme flooding events. It identified catchment soils as the primary source of PCBs, with river sediments acting as significant reservoirs and secondary sources of PCBs.
Brito et al. (2015)	To assess the impact of hydrocarbons, PCBs and heavy metals on bacterial communities in Lerma River	Mexico	Confluence of the Laja River with the Lerma River.	Thermoelectric Power Plant, Petrochemical Oil Refinery.	GC-ECD	PAHs, Metal concentration	GC/MS, AAS	The industrial and urban discharges of Salamanca city into the Lerma River are poorly treated and also reveal the lack of local environmental policies to protect the river water, directly affecting both the fauna and flora, in addition to human health
Peverly et al. (2015)	To measure the concentrations of several POPs in sediment from the Chicago Sanitary and Ship Canal (CSSC) with the goal of determining if the city, the Stickney water reclamation plant, the Cal-Sag Channel, or some other human-related activity was a source of these compounds.	Chicago (USA)	Chicago River at Lake Michigan.		GC-MS/MS	PAHs, OPE	GC-MS/MS	The geometric mean concentrations of 16 PAHs ranged from 11,000 to 420,000 ng/g dw, with the highest levels at both ends of the canal. Total PCB concentrations had a geometric mean of 1,400 ± 500 ng/g dw. ANOVA (Analysis of Variance) results suggested that downtown Chicago was likely a PAH source, the Cal-Sag Channel a PCB source, and neither the WWTP nor the Cal-Sag Channel significant sources of brominated flame retardants or OPEs
Lv et al. (2015)	To assess spatial and seasonal variations of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in the sediment.	China	Along the mainstream of Liaohe River.		GC/MS(EI-SIM)	PBDEs	GC/MS (EI-SIM)	PBDEs in Liaohe River were at a relatively low level, dominated by BDE 209, while PCBs were at a relatively high level, with tri- and tetra- PCBs as dominated congeners.
Schafer et al. (2015)	Application of equilibrium sampling to determine the bioavailability of HOCs in sediments and correlated the data with PCB concentrations in bream derived from an independent monitoring program.	Germany	Ten locations along the River Elbe.		GC-MS/MS			The close correlation between contamination of sediments and PCB bioaccumulation in fish demonstrates the major impact of sediments on PCB bioaccumulation. As per the study, Equilibrium sampling can help to understand the bioaccumulation of sediment-associated HOCs in this fish species and potentially in other benthic organisms.

Kanzari et al. (2015)	To know the distribution of organic pollutants in the sediment along the Durance River and the Berre lagoon and also to identify the different sources of hydrocarbons and evaluate ecotoxicological risk.	France	Durance River (15 stations) and Berre Lagoon (two stations)	30 sewage treatment plants, several industries around like steel and iron industries, refineries, heavy traffic of trucks and cars, oil industry.	GC-MS	Hydrocarbones. Pesticides	GC-MS	The study sites were contaminated by a variety of organochlorine and organo-phosphorous pesticides, but the content of total PAHs and total PCBs in studied samples are lower, than those found in many other aquatic systems and significantly less than current sediment quality criteria (ERL and ERM).
Gakuba et al. (2015)	To determine the occurrence, concentrations and significance of eight selected PCBs in water, pore water and sediment samples collected from 15 different sites along the Umgeni River.	South Africa	Umgeni River	River is affected by dumping of domestic waste from informal settlements, seepage of industrial wastes, use of agricultural pesticides etc.	GC-MSD (SIM)			All the eight selected PCB congeners were found in all 15 sites investigated and in all matrices. The concentrations of PCBs increased clearly at the sites of the Wastewater Treatment Works. The PCB levels were higher in sediment than in water and pore water. PCB 180 is the most abundant PCB in water, pore water and sediment samples.
Toan et al. (2015)	To assess the levels and distribution of PCBs in the surficial sediments from the Cauvery River and in the agricultural soil of the KieuKy area.	Vietnam	Ten sediment samples along the CauBay River and ten soil samples in KieuKy area were collected.		GC-MS	TOC	TOC Analyzer	Levels of PCBs in the sediment of the CauBay River are lower than those in the Kim Nguu River but higher than in the TamGiang – CauHai lagoon TOC may have an impact on the PCB accumulation in sediment. From the upstream to downstream, total PCB concentration has a decreasing trend. Heavily chlorinated PCBs are more accumulative in the sediment, whereas lightly chlorinated PCBs are degraded and volatilized faster than the other PCBs
Huang et al. (2015)	To determine the extent of heavy metals and PCB pollution and establish a historical trend of such pollution in the Lianhua Mountain reservoir of the Pearl River Delta.	China	Lianhua Mountain reservoir, located in the south of Dongguan City and in the Pearl River Delta of China.		GC-MS and GC-ECD	Cr, Cu, Ni, Pb, and Zn	ICP-OES	The results reflect a typical non-point source pollution of PCBs where there is no uniform spatial distribution of pollutant concentrations. The trend of decreasing PCB concentrations with increasing the chlorine atoms in each congener is also evident in this study. Cu, Zn, and Cr were the major pollutants detected in this study area. At prevailing conditions and with reference to the results of this study heavy metals and PCBs concentrations in the study area are expected to have a steady increase for the next decade.

Mwanamoki et al. (2014)	To discuss the occurrence and spatial distribution of metals, POPs and PAHs in sediments of a river-reservoir system (Congo River basin: CRB) and lake-reservoir.	Africa	Congo River basin: CRB		GC-MS/MS	PAHs, POP, Heavy metals(Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Ag, Cd, Sn, Sb, and Pb,) ,TC,TN	ICP-MS, Elemental analyser, spectrophotometer	The Congo River basin was an impacted area of the Congo River in the vicinity of Kinshasa, especially in the site of pool Malebo by Heavy metals, PAHs, POPs. PCBs were found to be present only in the sediments from the site of Mongole. 12 PCB congeners were detected. In the sediments from Chanic, only 5 PCBs (101, 138, 149, 153, and 180) were detected. In both sediments, the most representative congeners were in order 138 > 153 > 180 > 149, hexa and hepta chlorinated. The surface sediments of the Congo River in the vicinity of Kinshasa present important environmental hazards.
Syed et al. (2014)	To assess the status, spatial distribution and possible potential sources of organochlorines in surface sediments of the Ravi River.	Pakistan	Ravi River, a transboundary river between Pakistan and India is an integral part of an Indus system in the Punjab region.	Industrial effluents drain into the river and receives agricultural and municipal waste.	GC-EI-MS(SIM)	OCPs	GC-ECD	OCP levels from the Ravi River were found lower or comparable to other studies from all over the world but were recorded as being higher than those from sediments of the River Chenab, Pakistan. The comparisons of OCPs and PCBs concentrations with the available sediment guidelines indicated severe contamination of DDTs and PCBs and highlighted the potential for adverse biological effects in the area studied, especially near the discharges/drains from the industrial and urban sites.
Mourier et al. (2014)	To evaluate the upstream–downstream distribution and temporal trends of PCB contaminated sediment and to assess the potential effects of major industrial areas and tributaries.	France	Along Rhone River.		HRGC-HRMS	TOC, Radionuclides	high-temperature combustion, low-noise gamma spectrometry	PCB concentrations increased significantly from the upstream to the downstream sites of greater Lyon along the Rhône River, reaching a maximum of 417.1 µg/kg indicating that greater Lyon and some tributaries to the lower Rhône River currently (2013) were the principal sources of PCBs to the river. Reduction in PCB concentrations has slowed since 2000.
Mahmood et al. (2014)	Levels, distribution profile, and risk assessment of polychlorinated biphenyls (PCBs) in water and sediment.	Pakistan	14 sampling sites located across the River Chenab and its two tributaries.		GC-EI-MS			The concentration of ΣPCB in sediments ranged between 0.82 and 60 mg/g. Among congeners, PCB-28 dominated with 18 % of the total PCBs followed by PCB-169 (12 %), PCB-8 (9 %), PCB-37, and PCB-49 (5 %). Dioxin toxicity equivalency (TEQ) was calculated and PCB-126 and PCB-169 showed higher TEQ values compared with the WHO guidelines, and sediment samples were more toxic than the water samples.

Malik et al. (2014)	To assess the pollution status and levels of persistent organo-halogenated contaminants in surface sediments of the Soan River and its feeding tributaries.	Pakistan	Soan River and its tributaries.		GC-MS	PBDEs, OCPs	GC-MS (SIM)	The total concentrations of Σ34PCBs in Soan River ranged from 37.4 to 187 ng g−1. Among analysed PCBs, the most frequently observed congeners were 18-, 44-, 153- and 180-CBs. The trend of the most contributing congeners was as follows: CB-149 > -153 > -18 > -138 > -44. The elevated concentration of PCBs at Soan River possibly resulted from anthropogenic activities like diesel-powered electrical generators for agriculture purposes. The results also indicate that there exist certain potential eco-toxicological risks in the Soan River and feeding tributaries.
Mackenbach et al. (2014)	To assess the impact of remediation on the Ottawa River in Toledo Ohio, USA, a historically contaminated river that underwent extensive remediation via dredging.	USA	18 sites on the Ottawa River.		GC-MS			Post-dredged total PCB concentrations in the Ottawa River sediments ranged from 7.0 to 360.2 mg/g dry-weight organic carbon whereas in pre-dredged conditions the range of total PCBs was 0.8 to 2007.6 mg/g dry-weight organic carbon. Tenax best reflected the changes in exposure of oligochaetes to pre- and post-remediated sediments. With 75% of these data corresponding to the literature-based Tenax model, the Tenax model provides a unique tool for quickly quantifying potential exposure to benthic organisms in the evaluation of remediation.
Miglioranza et al. (2013)	The occurrence and distribution of OCPs, PCBs and PBDEs in several environmental matrices (soil, sediment, suspended particle matter and macrophytes) along the Río Negro basin in relation to land use.	Brazil	Along the Rio Negro basin which is located across the northern region of Argentinean Patagonia.		GC-ECD	OCP, PBDEs	GC-MS, GC-ECD	PCBs (0.8 ng/g) were confined mainly to close areas related to hydroelectric power plants and dams located in the Upper Valley, and also to urban areas. Although there was a decreasing gradient of these pollutant concentrations through the river flow, downstream urban areas enhanced PCB concentrations in the aquatic environment. Pollutant levels in SPM were 1–10 fold higher than bottom sediments, with a similar distribution pattern of pollutants, showing the high OCP, PCB and PBDE loads transported by stream water.

Wetzel et al. (2013)	To identify the spatial distribution and the potential gradients of sediment pollutants in the Elbe estuary and to estimate the spatial distribution of sediment toxicity of organic pollutants, using the TU approach for benthic algae, invertebrates and fish.	Czech Republic	36 stations in the Elbe estuary.		GC	Heavy metals, PeCB, HCB, HCH,OCS,OCN,PAH,OT	ICP-MS, AAS, GC-MSD, GC–MSD/NCI, GC-MS	HM pollution in the Elbe estuary showed the highest concentrations of Zn (mean=392 mg) followed by Cr and Pb, while relatively low values were measured for Cd and Hg. The sum of PCBs (mean=26 μg kg−1). Correlation analysis showed a general decrease in sediment contaminant concentrations from the stations near the port of Hamburg towards the open sea.
Praipipat et al. (2013)	Source apportionment of PCBs in the sediment of the Delaware River.	USA	Delaware river		HRGC-HRMS			PCB congener patterns in the sediment of the Delaware River suggest that the historical production of TiCl4 (Titanium tetrachloride) is the largest source of PCB sediment contamination in this urbanized waterway. This deca PCB signal (PCB-206, 208, 209) shows no sign of degradation and the localized nature of the deca signal suggests that its transport is minimal. Lack of degradation and minimal transport means that the Delaware River will continue to be impacted by this industrial legacy for decades to come. PCB 11 from the use of diarylide pigments is also important and is delivered to the river primarily via the atmosphere.
Beckingham et al. (2013)	To monitor changes in bioavailability and flux of polychlorinated biphenyls (PCBs) following a pilot-scale amendment of activated carbon in Grasse River by the application of passive samplers.	USA(NY)	Sediments in the lower Grasse River.		GC-ECD			Passive sampling can serve as a useful tool for the characterization of bioavailability and diffusive transport potential of HOCs in sediments. Application of adsorptive amendments like Activated Carbon in the field can be related to changes in bioaccumulation in benthic invertebrates.
Li et al. (2013)	To improve the understanding of the overall POP pollution status in the lower reaches of this basin.	China	17 sediment samples from the main rivers and lakes within the lower reaches of the Haihe River basin.		HRGC-HRMS	PCDD, OCP, TOC	HRGC-HRMS, TOC Analyser	The concentrations of 12 dl-PCBs in the 17 sediment samples ranged from 0.0 187 to 50.017 ng/g dw. There was a general tendency for high levels of residual POPs to be found in the lower reaches of the Haihe River Basin where there was a large concentration of chemical production plants. Sites with extremely high contamination levels caused by historical chemical production were likely to result in the bioaccumulation of these POPs with higher levels occurring in the aquatic food chain, posing a potential risk to aquatic life.

Yu et al. (2013)	To investigate and compare the levels of PCBs in all collected samples.	China	The sampling (21) was conducted around a river in north Beijing.	The river is continuously receiving treated effluent from a WWTP.	HRGC-HRMS			The highest concentration of total PCBs was observed in zooplankton (151.1 ng/g lipid weight), and soil-dwelling invertebrates showed higher concentrations than phytophagous insects at the riparian zone. Although a high prevalence of PCB-11 and PCB-28 was found for most aquatic-based samples in this riparian zone, the mid-chlorinated congeners (e.g. PCB-153 and PCB-138) became predominant among chironomids and dragonflies as well as soil-dwelling invertebrates, which might suggest a selective bio driven transfer of different PCB congeners.
Prokes et al. (2012)	To assess the levels and distribution of dissolved hydrophobic organic contaminants (PAH, PCB, OCP, HCB) from their accumulation in silicone rubber passive samplers made from poly-di-methyl-siloxane (PDMS) sheets	Czech Republic	Five sampling sites at Morava River and its tributary Drevnice.		GC-MS	PAH, OCP, HCB	GC-MS	The spatial variability of dissolved POPs in the studied region was relatively small, which indicates that diffusive pollution sources dominate over local point sources. Concentrations of the most volatile PAHs decreased with increasing water temperature. Release of contaminants from polluted suspended particles deposited to the water bodies via dry and wet atmospheric deposition and soil erosion. The calculated concentrations of PAHs in pore water were up to three orders of magnitude higher than those in the water column indicating that sediments can act as a potential pollution source.
Mackenbach et al. (2012)	To create a literature-based model taken from independent studies using 24-h Tenax extraction data paired with both laboratory-exposed and field-collected oligochaete bioaccumulation data and then evaluate the utility and reliability of the newly developed model	USA	Ottawa River in Ohio.		GC-MS			The model accurately estimated the bio-accumulation of PCBs in L. variegatus exposed to a wide range of field sediment concentrations and characteristics. The newly developed model should provide regulatory personnel with an additional option for assessing the bioavailability of PCBs with a wide variety of sediment characteristics.
Zhao et al. (2012)	To assess the current contamination status of polyhalogenated aromatic hydrocarbons (PHAHs) in sediments from the fourteen principal rivers.	China	Selected rivers from Hai River basin.		GC-MS/MS	PBB, PBDEs	GC-MS/MS	PCBs had the highest concentrations in sediment samples collected from River Luan and River Daqing. The most predominant PCB congener in these samples was PCB138, which accounted for about 24% of the sum of the seven indicator PCB congeners (PCB28, 52, 101, 118, 138, 153, and 180) measured in the two rivers. Study indicates that low levels of the selected PHAHs (including concentration of PBB, PBDEs, PCB) were generally observed in sediments collected from these rivers, thus suggesting that, in terms of PHAHs investigated during this study, the sediments from the rivers selected for this study, can be regarded as “relatively clean”.

Lugo-Ibarra et al. (2011)	To assess the temporal changes of PCBs and OCPs in two distinctive modern channels of the Colorado River (CR) delta.	US	Colorado River (CR) delta	Geothermal power plant, agricultural land	GC-ECD	OCPs	GC-ECD	PCB-138 (4.2 ng/g dw) is enriched in HR suggesting its origin in dielectric oils from the geothermal power plant. PCB concentrations in both cores did not exceed international threshold guideline values. The DDTs were the most abundant OCPs in HR, particularly DDE. Consequently, this site is considered significantly impacted.
Ho et al. (2011)	To understand the effect of coplanar PCB concentration on the dechlorinating microbial community and on biodegradation in estuarine sediments.	Taiwan (Republic of China)	Estuary of Er-Jen River.		GC/MS			Study clearly showed that PCB concentration has effects on biodegradation and the succession of dechlorinating microorganisms. In addition, bacteria or phylotypes with the ability to exclusively dechlorinate flanked and unflanked meta chlorine, and bacteria exclusively dechlorinate double flanked, single flanked, and unflanked para chroline had not been reported before.
Hsieh et al. (2011)	To examine the levels and distribution pattern of PCBs in surface sediments in the Donggang River and its tributaries.	Taiwan (Republic of China)	Donggang River Watershed.		GC-MS(ECD)			121 PCB congeners were examined and 98 congeners were detected. Congeners 191, 85, and 26 were the most commonly detected, however, PCB 26, 12+13, and 52 were the most abundant congeners and contributed 11.5, 8.4, and 6.96% to the total PCBs, respectively. The total concentrations of PCBs in the sediment ranged from 25.5–63.5 ng/g dw with a geometric mean ± standard deviation of 4.00 ± 1.73 ng/g dw. The highest concentration was found at the downstream sampling site near the head of the estuary. In general, the average concentrations in the tributary sampling sites were higher than those in the main stem sampling sites. The concentrations were considerably lower than those found in other studies of nearby areas in Taiwan and around the world.

Zhao (2010)	To assess the distribution and ecological risk of PCBs and OCPs in surficial sediments from the Haihe River and Haihe Estuary Area.	China	The confluence of Beiyunhe and Haihe River to the HaiheEstuary Area and from Bohai Bay.		GC-MS-EI-SIM	OCP, DDT, HCB, HCH	GC-ECD	In general, the concentrations of all POPs from the Haihe River were higher than those from the Haihe Estuary Area. Compositional analyses of the POPs indicated that tri-PCBs were dominant in sediment from the Haihe River, while tetra-PCBs and penta-PCBs were identified as being prevalent in the Haihe Estuary Area. The concentrations of ∑PCBs in sediments from the Haihe River and the Haihe Estuary Area ranged from a mean of 99.1 ng/g and a mean of 9.49 ng/ g, respectively. Compared with other areas around the world, the concentrations of POPs in sediments from the Haihe River were higher.
Zhang et al. (2010)	To present the detailed data of spatial distribution and concentration magnitude of PCDD/Fs and PCBs in the surface sediments of the middle and lower reaches of the Liaohe River.	China	Liaohe River mainstream, and one sediment sample was collected from Liu River.		HRGC-HRMS (SIM)	PCDD/Fs	HRGC-HRMS(SIM)	The concentrations of ∑PCBs in the sediment samples ranged between 1.85 ng/g, dw and 1075. 61 ng/g, dw with an average value of 232.87 ng/g, dw. However, the PCB levels in sediments of the middle and lower reaches of the Liaohe River were much higher than those in the Yangtze River Delta. The PCB congeners identified in all surface sediment samples were predominated by tri- to hexa-chlorinated biphenyls. These results suggest that the contamination of PCBs in surface sediments of the Liaohe River should originate from a combination of technical PCB usages and combustion processes. For the PCBs, the major source was identified as the usage of technical PCB products, especially the Chinese No. 1 PCB.
Lakshmanan et al. (2010)	To quantify the PCB ambient concentrations in the various media and understand their spatial distribution in the system.	US(Texas)	The Houston Ship Channel (HSC) system, located in the San Jacinto River (SJR) Basin.	Petrochemical complex, Chemical production, oil refinary	HRGC-HRMS	TOC	Persulfate-Ultraviolet or Heated-Persulfate Oxidation Method	The relatively high water, sediment and tissue PCB concentrations observed in the Houston Ship Channel place it amongst the top contaminated industrial areas worldwide. The PCB concentrations in the dissolved phase were greater than the suspended phase. PCB-209 was detected in the suspended water phase and in sediment (10%) prompting interest in its sources to the Hudson Ship Channel. A significant correlation and transfer of PCBs had been observed. Dioxin-like PCBs contributed significant toxicity to the total equivalent in tissue (33%), while they were insignificant in water (<10%) and sediment (<5%). The PCB concentrations over time showed a significant decrease in suspended water, sediment and tissue, while dissolved water concentrations showed insignificant change.

Oshita et al. (2010)	To evaluate the PCB and water extraction characteristics of DME from contaminated sediment and the recovery and reusability of DME after extraction	Japan	Shorenji River, flowing under Okijima Bridge in Osaka.		HRGC/LRMS	TOC	TOC Analyser	Liquefied DME could be used to simultaneously extract PCBs and water from river sediment. The maximum extraction efficiencies of liquefied DME for PCBs and water were 99% and 97%, respectively. A large number of PCBs and water could be extracted by increasing the extraction time and the liquefied DME/sediment ratio. It also showed that higher chlorinated PCBs can be extracted more easily than lower chlorinated PCBs. The highest value of ∑PCB concentration was measured as 9.4 mg/kg, dw.
Kim et al. (2009)	Survey on OCPs, PCDD/Fs, dioxin-like PCBs and HCB in sediments.	South Korea	Han River.		HRGC-HRMS (SIM)	PCDD/Fs, HCB and OCPs and TOC	HRGC-HRMS(SIM) and GC-MS and CHN analyser	DL-PCBs concentrations from surface sediment samples ranged widely from 41.5 to 4,530 ng/kg. The TEQ concentration of PCBs ranged from 0.0118 to 0.626 ng TEQ/kg. DL-PCBs levels in sediments collected near metropolitan Seoul were higher than those in rural regions such as Bukhan and Namhan river regions. The composition of PCB 118 presented the predominant congener and then followed by PCB 105, 156, and 77 in all sediment samples. The distributions of HCB, DL-PCBs, and PCDD/Fs are significantly correlated with each other. This indicates that these compounds could come from a similar pollution source.
Ren and Li et al. (2009)	To assess the contamination status of PCDD/Fs and PCBs in surface sediments from the East River, and investigate the main sources of PCDD/Fs.	China	East River.		HRGC-HRMS	PCDD/Fs	HRGC-HRMS	PCBs contributed only 2–9% of the total TEQ (PCB + PCDD/F). DL-PCBs concentrations were found to be not high, which was consistent with the previous study on PCBs in the Pearl River Delta. The overall conclusion states that the concentrations of PCDD/Fs and DL-PCBs in sediments from the East River were found to be not very high.

Hui et al. (2009)	To investigate the levels of PCDD/Fs and dl-PCBs and discuss the spatial distributions and potential sources in these two estuaries.	China	Yellow Estuary and Yangtze Estuary in China.	Shengli Oilfield (the second largest oil producing base in (China) and Shanghai (the biggest metropolitan in China).	HRGC-HRMS	PCDD/Fs	HRGC-HRMS	For dl-PCBs, lower chlorinated congeners (CB77, CB118, and CB105) were found to be dominant, while highly chlorinated congeners were substantially lower. Thus, PCBs in two estuaries are possibly derived from the use or production of Chinese technical products of PCB3. The concentration ranges of DL- PCBs and WHO-TEQ were 0.04–139 and 0.11–1.01 pg/g dw respectively in sediment from two estuaries. PCDD/Fs were the major contributor to total TEQ for surface sediments from two estuaries. Although the levels of dioxins in two estuaries are low in comparison with many other aquatic systems.
Ren and Zhou et al. (2009)	To assess the contamination status of PBDD/Fs in surface sediments from the East River, the characteristics and the sources of PBDD/Fs.	China	Along the East River.		HRGC-HRMS	PBDD/Fs	HRGC-HRMS	PCDD/Fs contributed dominantly to the total TEQs of PCDD/Fs, PBDD/Fs and dioxin-like PCBs in most samples. The total concentrations of eight PBDD/Fs in the surface sediments were found to range from 0.32 to 110 (mean 13) pg/g, dw. The concentrations of PBDD/Fs were much lower than those of PCDD/Fs, the TEQ concentrations of PBDD/Fs were only 2%–11% of the total TEQ. Dioxin-like PCBs contributed only 1%– 5% of the total TEQs. It can be concluded that PCDD/Fs contributed dominantly to the total TEQs at most sites in this study.
Carvalho (2009)	To assess the distribution and origin of PCB congeners in the Mekong River delta.	Vietnam	Mekong River delta, from the border of Vietnam with Cambodia to the coast of South China Sea.		GC-ECD			The median concentration of ∑PCB congeners was 0.279 ng/g dw in sediments. In the Mekong River delta, PCB concentrations were generally lower than in other regions of Vietnam and their likely sources have been waste discharges from repair workshops and other facilities in the delta cities. Despite the generally low levels of PCBs in the Mekong Delta, still relatively higher concentrations were measured near the main cities of the delta. It was found that the concentration of PCBs in molluscs is about 24 times higher than concentrations in sediments. PCB 128, 138, 149, and 153 were found to be dominant.

Doong et al. (2008)	To determine the concentrations and possible sources of POPs and trace metals in water and surface sediments from the Gao-ping River.	Taiwan	Along Gao-ping River and its tributary were selected.		GC-ECD	OCPs and 8 metals (Cr, Cd, Pb, Ni, Zn, Cu, As, Hg) and TKN,TP	GC-ECD and ICP-MS and Standard methods (APHA-1995)	High concentrations of heavy metals including Cr, Zn, Ni and Cu ranging from 10.7 to 180 mg/kg, dw were detected in sediments from the Gao-ping River. The total concentrations of OCPs were in the range of 0.47–47.4 ng/g-dw. The polychlorinated biphenyl (PCB) concentrations in sediments from the Gao-ping River ranged between 0.37 and 5.89 ng/g-dw. In summary, trace amounts of POPs in estuarine sediments from the Gao-ping River were detected, showing that there still exists a wide variety of POP residues in the river sediments in Taiwan. The mean value of ∑PCBs was 1.43 ng/g, dw.
Hong et al. (2008)	To demonstrate a new "ozonation technique" that incorporates rapid, successive cycles of pressurization and depressurization, enabling more effective treatment of PCB and PAH contaminated sediments than conventional ozonation would.	US	Passaic River, Waukegan Harbor, St. Louis River, and Wells NERR.		GC/MS	PAHs	GC/MS	Near complete or complete removal of contaminants can be achieved within a shorter ozonation time than possible by conventional bubbling ozonation. Both PAH and PCB contaminants were completely or significantly removed (>95%).
Liu et al. (2007)	To assess the occurrence of PCDD/Fs and PCBs pollution in sediments.	China	Along the Haihe River and Dagu Drainage River.		GC/MS (EI)	PCDD/Fs and TOM	GC/MS (EI) and Loss-on-ignition	The levels of PCDD/Fs and PCBs in Haihe River were lower than the value of safe sediment for samples. The concentrations of PCBs in the sediments from the mainstream of Haihe River and Dagu Drainage River were 0.07– 0.54 pg TEQ/g dw and 21 pg TEQ/g dw respectively. The pollution source of PCBs could not be identified. The correlation between PCDD/Fs or PCBs and total organic matter (TOM) showed that PCDD/Fs or PCBs were independent of TOM.
El-Kady et al. (2007)	To assess PCBs and dioxins, in sediment and fish samples along the River Nile near the industrial areas of Greater Cairo.	Egypt	River Nile in Greater Cairo from three sites namely Helwan, Rod El-Farag, and Shobra El-Khyma		HRGC-MS	PCDDs, PCDFs	HRGC-MS	The most abundant PCB congeners were the indicator PCBs (28, 52, 101, 138, 153, 180) constituting 88.6–90.5% of the total amount of PCBs. PCB congener 28 among the indicator PCBs, PCB-77 among the non–ortho -PCBs and PCB-118 was found to be the most abundant PCB congener of the mono-ortho PCBs. The data of this study revealed that the concentrations of PCBs and dioxin in the aquatic environment in the River Nile, Egypt currently were markedly lower than those reported previously for the River Nile

Wang et al. (2007)	To elucidate the source and distribution of PCBs and OCPs, and to evaluate their contamination in sediments from the Daliaohe River watershed.	China	Daliaohe River Estuary	Subjected to a flood just during the sampling period	GC-MS(SIM)	TOC , OCP	TOC Analyser, GC-ECD	The total concentrations of OCPs varied from 3.06 to 23.24 ng/g. Many OCPs such as γ-HCH, DDT and Heptachlor were found in this survey. The adverse effect of γ- HCH in sediments of the Daliaohe River system was assessed, which was evidence of the recent use of lindane. It possibly came from the runoff of polluted soils and long-scale transportation. Higher concentrations of PCBs were detected in the vicinity of cities and wharf. Total PCB concentrations ranged between 1.88 and 16.88 ng/g. The study showed a moderate level of OCPs and PCB contamination compared to that in other countries.
He et al. (2006)	To evaluate the distribution and concentration of 10 nitroaromatic compounds and polychlorinated biphenyls (PCBs).	China	Mid- and down-stream of the Yellow River.		GC-MS	NBs	GC-ECD	PCBs associated with the sediments, measured as the summed responses of Aroclor 1242, 1248, 1254, and 1260 were found to be in the range of non-detectable to 5.98 μg/kg. In most of the samples, PCB concentrations occurred in the order: TetraCB > TriCB > PentaCB. Levels of ∑NBs in the Yellow River were relatively low in comparison with values reported from other river and marine systems, and PCB levels were comparatively low. It can be seen that the surface sediments in the Yellow River had been only slightly contaminated by PCBs and there were no obvious correlations of either PNBs or PCB concentrations to either TOC or the grain size of sediment.
Hung et al. (2006)	To investigate the sedimentary distribution of PCBs in the Danshui River Estuary and nearby coastal areas, as well as their associations with carbonaceous materials.	Taiwan (Republic of China)	Danshui River and nearby coastal areas.		GC-MS	TOC	Perkin–Elmer analyser	Total PCB concentrations in the sediments showed an average value of 15.8 ng/g. The highest total PCB concentration in surface sediments was located near the discharge point of an ocean outfall pipeline, suggesting that the sewage treatment plant has discharged PCBs in the past. Some specific PCBs (e.g. PCBs 28/31, 43/52, 66, 70, 88/95, 110 and 132/153/ 168) showed more significant correlations with BC than with total organic carbon, suggesting that BC plays a major role in the distribution of some PCBs.

Covaci et al. (2005)	To measure the concentrations of organic pollutants and to evaluate temporal trends in pollution of PCBs, OCPs and PBDEs.	Belgium	Scheldt river, near Antwerp, Belgium		GC-ECD	OCPs and PBDEs	GC-ECD and GC-MS-ECNI(SIM)	This study showed a relative steady state for PCBs and DDTs, with a slight decrease in the top layers, suggesting a slight decline in their concentrations due to restrictions in their usage in the last 15 years. On the contrary, PBDEs were showing an increase in their concentrations in the top layers. Concentrations of tri- and tetra-CB congeners were low, while the predominant homologues were the penta- to hepta-CBs.
Eljarrat et al. (2005)	To determine the content of PBDEs, PCDDs, PCDFs and PCBs.	Spain	Harbours of Almeria and Tarragona, and the mouths of the Beso´ s and Llobregat rivers in Barcelona.		GC/Ion Trap MS	PCDDs, PCDFs	GC/Ion Trap MS	From the 15 sediments analysed, four exceeded the safe value set at 20 pg TEQ/g dw, samples corresponded to the Beso´ s and Tarragona areas, which represented the most industrial area and are affected by sewage sludge discharge respectively. This is the first time that PBDE levels were reported in coastal sediments from Spain, with the highest values observed in samples collected in the mouth of the Llobregat River. The dominant congeners are PCB-77 for non-ortho-PCBs and PCB-118 for mono-ortho-PCBs. Total WHO-TEQ values were calculated for dioxin-like PCBs ranging from 0.2 to 63 pg TEQ /g dw.
Zhang et al. (2004)	To carry out a survey of PAHs, PCBs and OCP in Beijing environments, focusing on the water and sediment phases.	China	Tonghui River		GC-μECD	OCP, PAHs	GC-μECD, GC-MSD(SIM)	The concentrations of the OCPs are below the lower limit of Chinese guidelines for water quality, but some are very close to the critical value. The concentrations of PCBs in sediments varied from 0.78 to 8.47 ng/g, dw. The concentration of these selected organic pollutants in sediment was higher than those in surface water. In sediment, the predominant compounds were PCB28, PCB31 and PCB153, which accounted for 71% of total PCBs in sediment. The study concluded that the PCBs came from the residues from the former application and due to their resistance to degradation in the environment, PCBs could be continuously detected for many years.

Koh et al. (2004)	To measure concentrations of dioxin equivalents by use of the H4IIE-luc cell bioassay and compare them to instrumentally derived dioxin equivalents (TEQs) contributed by PCDD/Fs, coplanar PCBs, and certain PAHs in sediment and water samples.	Korea	Hyeongsan River and one from Yeongil Bay, Korea.		GC-ECD	OCP, PAHs, (PCDDs, PCDFs)	GC-ECD, GC-MSD, HRGC-HRMS	Mass balance analysis comparing instrumentally derived TEQs to bioassay-derived TCDD-EQs suggested that the known contaminant composition associated with the Hyeongsan River sediment samples could account for the dioxin-like potency observed in the H4IIE-luc bioassay. Varying concentrations of PCDDs/DFs, PCBs, and PAHs were detected in sediment and water samples from Hyeongsan River, while PCBs and PAHs contributed relatively small fractions to the overall activity of dioxin-like potency. PCBs were detected in sediments from all six sampling locations with mean concentrations of 61.4 ng/g, dw. Chemical profiles of target analytes in sediment and water samples revealed that there was a gradient of concentrations along the river from upstream to downstream, which suggested that the primary source was a wastewater reservoir adjacent to a sewage treatment plant (STP).
Ko et al. (2004)	To estimate seasonal and annual riverine loads to the Chesapeake Bay.	US	Along the Susquehanna River upstream of the Conowingo Dam.		GC-ECD	PAHs and TOC	GC-MS(SIM) and Elemental analyser	t-PCB and ∑36PAH concentrations in the Susquehanna River surface sediment (36 ±10 ng/g and 3 ± 1 μg/g, respectively) are lower than their particulate phase concentrations in the water column indicating that the suspended particles in the Susquehanna River were the mixture of the sediment resuspension and the other types/sources of particles enriched in organic contaminants. Concentrations of PCBs and PAHs in river particles (ng/g) were twice as great as those in the northern Chesapeake Bay, indicating that the Susquehanna River is an important source of these contaminants in the bay. The total PCB annual loadings from the Susquehanna River to the Chesapeake Bay was 76 kg/year.

Table S12. Detailed inclusion criteria of the parameter PestC.

Authors	Objectives	Location	Study site	Nearby industries/reason	Method of measuring target parameter-PestC	Key Finding
Mohasin et al. (2023)	To evaluate the risk assessment of persistent pesticide pollution by the development of an indicator integrating site-specific characteristics.	India	Lower Ajay River Basin floodplain and the floodplain of the Lower Ganges Basin.	Cultivation of paddy, sugarcane, mustard seeds and potato in nearby areas.	GC-MSD	The mean concentrations of 14 out of the 20 measured organochlorine pesticides (OCPs) were significantly lower in the post-pandemic period compared to the pre-pandemic period. This reduction in pesticide concentrations may suggest a decreased use of OCPs in agricultural practices during the pandemic. Despite this decline, the area was still identified as having the highest Level of Concern, even though the OCP concentrations on their own met general guidelines.
Arisekar et al. (2021)	To evaluate the distribution of pesticides and assess the ecological and human health risks associated with pesticide residue concentration in the Thamirabarani River.	India (Tamil Nadu)	Four main areas of interest around the Thamirabarani river basin.		GC-MS	The calculated daily intakes of endosulfan, aldrin, and endrin were above the Codex Alimentarius Commission- acceptable daily intake guidelines (CAC-2020). However, the concentration of pesticides in sediments was below the Sediment Quality Guidelines (SQG). The average concentration of pesticides in fish (Labeo rohita) was also below the maximum residual limits (MRL) set by the CAC. The human health risk assessment showed that children and adults exposed to pesticides in water and sediments through ingestion and dermal contact could have higher cancer risks than inhalation.
Reiber et al. (2021)	To monitor the effects and recovery of the macroinvertebrate community for more than two years after a catastrophic pesticide spill.	Germany	Holtemme River		GC/MS	All taxa showed strong short-term effects, with the exception of the Tubificidae and Chironomidae. Community-level effects were also discernible, as overall abundance, taxonomic diversity, and biomass all sharply declined. The study found long-term effects on the taxon level for 7 taxa for which abundance showed no recovery compared to one or both reference values. The exact source of the pesticide spill remains unknown.
Cui et al. (2020)	To investigate the occurrence and fate of nine target pesticides in water, sediment and soil within the catchment environment.	Scotland	River Ugie catchment, Scotland.		GC-MS	Concentrations of target pesticides in water, sediments and soils were 4.5–45.6 ng/L, 0.9-4.6 ng/g dw and 1.7–8.0 ng/g dw, respectively. Concentrations of pesticides in water were found to be significantly influenced by season, while concentrations of pesticides in riverine sediments showed significant spatial heterogeneity. Sediment-water exchange showed that the sediment acts as an important secondary emission source, particularly for the historic-use pesticides (HUPs), while current local application and sediment emission are both major driving forces for current-use pesticides (CUPs) in the riverine environment.

do Amaral et al. (2020)	To investigate whether seasonally-varying abiotic factors are more important than pollutants in the regulation of biochemical biomarkers' response of two fish species living in a large reservoir in Southern Brazil.	Brazil	Passo Real reservoir, in a subtropical region of Southern Brazil.	Electric power generation, agriculture and livestock, receives sewage from adjacent households.	LC-MS/MS	The current study has clearly shown the difficulty in checking the effects of pollutants on different fish species' tissues since the responses of biomarkers to pollutants were mixed with normal responses to environmental factors, mainly to seasonality (on a large scale) and temperature (on a small scale). Azoxystrobin, simazine and propoxur were the pesticides that mostly contributed to the variation, whereas metals had a lesser contribution to it.
Etchegoyen et al. (2017)	To determine the occurrence, concentration, and fate of pesticides in surface water and bottom sediments of the principal tributaries and main course of the Paraguay- Paraná River.	South America	22 sites along the Paraguay-Paraná River and tributaries.	Untreated domestic or industrial effluents, untreated domestic or industrial effluents.	GC-μECD	The ranges of total measured pesticide concentrations in water and sediments have been found as 0.004–6.62 μg/l and 0.16–221.3 μg/kg dw, respectively. Endosulfans, cypermethrin, and chlorpyrifos were ubiquitous compounds in both environmental compartments and quantitatively the most relevant. All concentrations detected in water were over the recommended guidelines for the protection of aquatic biota. The partitioning indicated a higher affinity for the sediments. Agricultural activity is the source of pesticide-pollution loads, transported by tributaries that reach the main watercourse and alter the quality of the aquatic ecosystem.
Ccanccapa et al. (2016)	To monitor 50 currently used pesticides in water and sediments of the Júcar and Turia Rivers.	Ukraine	Along Jucar River and the Turia River.		LC–MS/MS	Mean concentrations of pesticides ranged from <LOQ up to 200 ng/L. Chlorpyrifos was the most frequent pesticide whereas imazalil, thiabendazole, tolclofos methyl, ethion and carbofuran were those found at higher concentrations. The temporal variations also indicated a strong relation of pesticide concentrations with hydrology, the higher the river flow, the higher the number and frequency of pesticides but at lower concentrations. At lower river flows higher pesticide concentrations were detected.
Rasmussen et al. (2016)	To analyse the potential impact of pesticides originating from conventional rice production in the hydrological catchment of River San Lázaro, a tributary stream of the River Tempisque in Costa Rica.	Costa Rica	River San Lázaro.	Rice production land.	GC-μECD and GC-MS (SIM)	Pesticide concentrations in water exceeded current safety thresholds, particularly during the rainy season, while sediment-associated pesticide levels surpassed these thresholds in three out of six samples. Notably, the highest predicted pesticide toxicity in sediments was recorded at the Mata Redonda site, indicating that the nature reserve received significant pesticide pollution from upstream areas. These findings suggest that pesticide pollution likely contributed to the deterioration of the ecological status at the sampling sites.
Rasmussen et al. (2015)	To compare the toxicity of legacy pesticides and their metabolites to those of contemporary pesticides in 19 Danish 1st and 2nd order streams situated in agricultural landscapes covering a range of agricultural intensity, local climate and soil types.	Europe	19 Danish 1st and 2nd order streams were sampled.	Agricultural land and forest nearby.	GC-MS	The study suggests that legacy pesticides can be highly significant contributors to the contemporary toxic exposure of stream biota, especially macroinvertebrate communities and that those communities were primarily exposed to legacy pesticides via the sediment. Among the legacy pesticides, the organophosphate chlorpyrifos and organochlorines such as DDT and lindane were the strongest drivers of high SumTU for daphnia, fish and sediment-dwelling invertebrates. The dominant source of legacy pesticides was the upper soil layers of the catchments, originating from past agricultural applications.

Devault et al. (2009)	To understand the effect of reservoir configurations on sediment pesticide fate.	France	Two dams were selected on the River Garonne.	Herbicide-contamination sediment from agricultural land.	GC-MS	The present study shows that the theoretical lifespan (weak remanence in vitro) and the results observed in the sediment are conflicting. Pesticide contamination in the Carbonne reservoir indicates conservation, even accumulation, of herbicide molecules while in the Golfech reservoir transformation processes dominate. The hydromorphological position of the Golfech reservoir, i.e. located at the junction of two rivers with contrasting hydrological regimes and very different oxygenation conditions, leads to accelerated pesticide desorption or degradation.

Table S13. Detailed inclusion criteria of the parameter POM.

Authors	Objectives	Location	Study site	Nearby industries/reason	Method of target parameter-POM	Extra Parameter	Method	Key Finding
Laursen et al. (2023)	To quantify the flocculation and settling dynamics of positively buoyant microplastic (MP) in combination with fine-grained sediment.	Tanzania	Along the Mzimbazi River.	Industrial area e.g., plastic, iron, textile, and food processing industries and several formal and informal dumpsites.	Loss On Ignition (LOI)			The study determined that the settling speeds of microplastics (MP) and fine-grained sediments in estuarine waters were between five and 21 times faster than in freshwater. This effect is due to the increased ionic strength that occurs when particles enter saline water. Consequently, small, positively buoyant high-density polyethylene (HDPE) microplastics from land-based sources, carried by rivers, tend to settle and accumulate in estuarine environments. This process decreases the overall quantity of microplastics entering the wider marine environment.
da Conceicao et al. (2020)	To estimate the historical evolution of pollution levels of trace elements (Cd, Cr, Cu, Ni, Pb, Zn and Sc) and POM in riverbed sediment from the lower course of the Piracicaba River.	Brazil	Lower course of the Piracicaba River, upstream from the Barra Bonita Reservoir.		POM=1.72*POC	(Cd, Cr, Cu, Ni, Pb, Zn and Sc) and (POC, PON, $\delta^{13}C$ and $\delta^{15}N$ isotope)	ICP OES, GC-ANCA	Elemental and isotopic analyses of carbon (C) and nitrogen (N), along with the C/N ratio, indicated that the anthropogenic origin of particulate organic matter (POM) in the sediment core was mainly due to domestic sewage.

Casila et al. (2019)	To analyze the effect of neap-spring hydrodynamics on salt and SS transport, and nutrient variability and determine the unique phenomena occurring in three multi-branched urban estuaries.	Tokyo, Japan.	The estuarine areas of the Arakawa, Sumida and Shakujii Rivers.		Loss On Ignition (LOI)	TN, TP, phosphorus and elevated nitrate (NO_2+ NO_3-N) and Suspended Sediment Concentration (SSC)	Autoanalyzer and Gravimetric method (SSC)	The Sumida and Shakujii Rivers are adjacent yet the nutrient and POM had different natures. The Shakujii River is heavily influenced by freshwater inflows from combined sewer systems, which bring POM, nutrients, and sediments into the river. In contrast, the POM and nutrient levels in the Sumida River are affected by tidal processes and contributions from tributary rivers. During the flood phase of the spring tide, suspended sediments (SS) are transported from the Sumida River to the Shakujii River.
Fernandes et al. (2016)	To assess the advantages of combined analysis of trace elements (Cu, Co, Cr, Zn, Cd, Ni and Sc) with POM in order to identify their natural and anthropogenic sources in a tropical environment.	Brazil.	The Sorocaba River mouth, watershed in the Sao Paulo State.		POM=1.72*POC	(Cu, Co, Cr, Zn, Cd, Ni, Sc) and (POC, PON, isotopes $\partial^{13}C$ and $\partial^{15}N$)	ICP OES, GC-ANCA	Zn was the most abundant trace element in the FSS, followed by Cr, Cu, Ni, Co, Sc and Cd. There was a higher concentration of trace elements during the dry season, except for Sc and Co. The POM showed the same trend. The calculated enrichment factors and geoaccumulation index indicated that most of the trace elements are of geogenic origin, except for Zn, while the source of Zn is related to this domestic sewage.

Table S14. Detailed inclusion criteria of the parameter TOC.

Authors	Objectives	Location	Study site	Nearby industries/reason	Method of target parameter-TOC	Extra Parameter	Method	Key Finding
Fang and Lien (2021)	To evaluate the distribution, speciation transformation and partition of Hg within the DRE by analyzing different Hg species, including the total Hg and methyl Hg in water and sediment samples.	Northern Taiwan	Tidal area of the estuarine system of Danshuei River Estuary (DRE).		TOC Analyser (Horbia Carbon analyzer)	Hg, Fe, Mn	CVAFS (Hg), FAAS (Fe, Mn)	The analyzed results indicated that the DRE is contaminated by Hg, and the evidence of Hg sediment was more significant than that of the dissolved Hg. Most of the sedimentary total Hg concentrations exceeded the biological effects range low value of NOAA guidelines (ERL, Hg 150 ng/g). The sediment total Hg (STHg) concentrations inversely and positively correlated with the grain size and TOC content, respectively, suggesting that sediment Hg distributions were strongly influenced by both parameters.

Fang and Wang (2021)	To study the concentrations and spatial distributions of different fractions of phosphorus by employing the SEDEX method.	Northern Taiwan	Tidal area of the estuarine system of Danshuei River Estuary (DRE).		TOC Analyser (Horbia Carbon analyzer)	P, Fe and Mn		The surface sediments of the Danshuei River Estuary (DRE) were mildly contaminated with phosphorus (P). The total phosphorus (TP) in the sediments is primarily composed of PCDB (ferric iron-bound P), which makes up an average of 58% of the TP. The sedimentary TP concentrations showed a positive correlation with total organic carbon (TOC) content and a negative correlation with grain size, indicating that TOC and grain size are key factors influencing the distribution of phosphorus in the DRE sediments.
Khabouchi et al. (2020)	To identify the origin, type, and distribution of hydrocarbons in the surface sediments of the Oued Meliane.	Tunisia (Africa)	Upstream of Oued Boudhebane watershed, to downstream of the Oued Meliane near Rades.	Industrial, urban, agricultural, metal, and metallurgical	Analytik Jena N/C 2100S (Elemental Analyser)			The results indicated the adherence of Oued Meliane to the pollution of the Tunis Gulf. The fraction of saturated hydrocarbons extracted from the sediments of Oued Meliane included a majority of organic compounds of a biogenic nature with a small oil input. The main sources of contamination were discharges from the industrial area of Zaghouan city, and agricultural activities in the Smenja location near Fahes city, in addition to the effects of the Bir Mcherga dam.
Jia et al. (2017)	To analyze the historical record of sedimentary nutrients and the mechanism of controlling algae blooms.	China	Upstream, estuary, and the central regions of the Xin'an Reservoir.		Euro Vector elemental analyzer	Inorganic carbon (IC), stable isotopes $\delta^{13}C$ and $\delta^{15}N$,	hydrochloric acid titration method (IC), isotope ratio mass spectrometer (δ13C and δ15n)	Nutrient data showed regional variations, with TOC levels rising from 1.42% at the bottom to 5.97% at the surface in the lacustrine zone. TN and TP levels increased from the riverine to the lacustrine zones, indicating nutrient accumulation in the central reservoir. Although algae blooms were rare due to the reservoir's depth and environmental policies, high TOC flux and nutrient availability suggested a continued risk of eutrophication.
Ouyang et al. (2006)	To investigate temporal and spatial distributions of sediment TOC and its relationships to sediment contaminants.	Florida (US)	Cedar and Ortega Rivers		Method 9060 (USEPA SW-846) by using coulometric titration			Significant temporal changes in sediment TOC concentrations were observed over the past century, reflecting variations in the characteristics and magnitude of inputs into the rivers. Meanwhile, high concentrations of contaminants, specifically total polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were detected in Cedar River sediments. However, no correlation was found between TOC and PAHs or PCBs. The study revealed that the southern part of the Ortega River received a higher load of TOC, whereas most hydrocarbons were concentrated in the Cedar River.
Ouyang et al. (2005)	To investigate the characteristics and spatial distribution of pesticide chlordane in sediments from the Cedar and Ortega rivers.	Florida (USA)	Cedar and Ortega rivers		Method 9060 (USEPA SW-846) by using coulometric titration	Chlordane	Kriging Analysis	A plot of total organic carbon (TOC) normalized chlordane concentrations showed that the effects of grain size on sediment chlordane contamination were negligible. The overall study revealed that the Cedar River and the northern end of the Ortega River had total chlordane concentrations above the PEL (4.79 g/kg), value, which could pose a potential risk to aquatic life. In general, higher chlordane concentrations were found in the Cedar River sediments as compared with those in the Ortega River.

Ozaki et al. (2005)	To investigate whether sediment fractions based on grain size distribution have an influence on their dioxin contents, and which fractions are likely to contain higher dioxin contents.	Japan	Kizu and Sumiyoshi Rivers in Osaka		TOC Analyzer	PCDDs/Fs and co-PCBs	HRGC-HRMS	The study found that dioxin toxicity equivalency unit (TEQ) concentrations increased as sediment grain size decreased and were also higher with increasing total organic carbon (TOC), total carbon (TC), ignition loss (IL), and total sulfur and nitrogen in the sediment. Therefore, reporting dioxin levels without accounting for grain size distribution could be misleading, and conventional sedimentation and separation techniques may be ineffective for treating contaminated sediments.
Peng et al.(2005)	To quantify the relationships between diverse sediment characteristics and trace-metal distribution under controlled experimental conditions.	China	12 major rivers in eastern China.		Elemental Analyzer	Cd, Zn, carbonates	AAS(Cd, Zn), Gravimetric method.	The distribution coefficients (Kd) were strongly influenced by the total organic carbon content and Fe-Mn oxide at a pH of 7.0. A quantitative model, utilizing the experimentally determined phase distribution coefficients (Kd)i was employed to examine the impact of various geochemical phases in the sediment on metal distributions. The (Kd)i for total organic carbon (TOC) and Fe-Mn oxide phases showed significant pH dependence. Total organic carbon primarily governed the distribution of Cd, while Fe-Mn oxide exhibited the greatest affinity for Zn.

Table S15. Detailed inclusion criteria of the parameter TON.

Authors	Objectives	Location	Study site	Method of target parameter-TON	Extra Parameter	Method	Key Finding
Song et al.(2023)	To elucidate the effect of eutrophication on the retention process and estimate the overall retention quantity of each biogenic element in all reservoirs of the entire catchment.	China	Sediment cores collected from the Pengshui, Wuqiangxi, Three Gorges, and Danjiangkou reservoirs.	Elemental Analyzer (Vario Macro cube)	TOC	Elemental Analyser (Vario Macro cube)	The results showed that the average annual sedimentary retention of TOC and TON in the four reservoirs increased by 16% and 18% after dam construction and rapid eutrophication. The retention increments accounted for 20.6%, 7.0%, 8.8%, and 12.1% of the total flux of TOC, DIN, DIP, and DSi into the sea during the same period, respectively. The retention of TOC and DSi in reservoirs led to a decrease in their annual flux into the sea by 67.2% and 61.4% in 2016 compared to 1960.

de Morais et al.(2021)	To evaluate the elemental and molecular features of the extractable organic matter (OM) of sediments.	Sao Paolo (Brazil)	Piracicaba River, at the confluence region and from the Tiete River.	Elemental Analyzer	TC	Dry combustion method	Extracted organic matter from sediments (EOMSed) from the Tiete River exhibited the highest average concentrations of non-purgeable organic carbon (NPOC) and total organic nitrogen (TON) and the lowest average NPOC/TON molar ratios. The high degree of eutrophication in the Tiete River indicated a substantial input of simple organic matter with nitrogenous structures. The humic-like component in EOMSed was the most abundant in both rivers.
Schulz et al.(2003)	To evaluate the influence of macrophytes on sedimentation and nutrient retention in the lower River Spree.	Berlin (Germany)		Elemantal Analyser (Vario EL, Elementar)			Macrophytes significantly reduced flow velocities, thereby creating favorable conditions for the settlement of organic seston (SPM). Sedimentation was influenced by both the speed of the water flow and the availability of seston. Macrophytes enhanced nutrient retention by promoting the sedimentation of organic seston. The retention through deposition depended on the species composition of macrophyte stands.
Steiger and Gurnell	To evaluate spatial hydrogeomorphological influences on sediment and nutrient deposition in riparian zones.	France	The study reaches on the Garonne River, seven riparian sites are selected for sediment sampling.	TN was measured by Kjedahl method and the substractig NH_4–N	TOC, TP	Combustion (TOC), Ignition (TP)	Sediment particle size was found coarser in areas with higher sedimentation, while TOC, TON, and total phosphorus (TP) levels rise with increased sediment deposition. Additionally, the concentrations of TOC and TON significantly increased as the percentage of silt and clay in the deposited sediments increased.

Table S16. Detailed inclusion criteria of the parameter TOP.

Authors	Objectives	Location	Study site	Method of target parameter-POM	Extra Parameter	Method	Key Finding
Aviles et al. (2006)	To characterize the phosphorus forms in surface sediments and examine the relationship between phosphorus concentration and other sediment properties.	Southern Spain	The River Guadalfeo	Technicon Autoanalyzer AAII	TC, TN	CHN Autoanalyzer	The study found that apatite inorganic phosphorus (AIP) was the predominant form of phosphorus, making up 68% of the total phosphorus. Total organic phosphorus (OP) followed, contributing 29% of the total. It was highlighted that calcite-phosphorus co-precipitation was the primary self-cleansing mechanism for removing phosphorus from the water column. In contrast, lithology and sewage inputs had a lesser impact on phosphorus concentration.

Table S17. Detailed inclusion criteria of the parameter TSS.

Authors	Objectives	Location	Study site	Method of target parameter-TSS	Extra Parameter	Method	Key Finding
Abd Wahab et al. (2023)	To assess the impacts of land use activities along the Kenyir Lake Basin based on the sedimentation problem	Malaysia	21 sampling stations which are in different rivers in the Kenyir Lake Basin are studied, only **water sample** were analysed.	Gravimetric method			The results indicated that the Besar River sub-catchment had the lowest annual sediment load at 3,833.70 kg/km²/year, while the Kenyir River sub-catchment had the highest at 128,070.86 kg/km²/year. Downstream and midstream regions of the Kenyir Lake Basin exhibited higher sediment loads than upstream areas, with sedimentation driven by anthropogenic activities, hydrological and geomorphological factors, growth and development, and climate change.
Marinho et al. (2020)	The aim of this article is to report data collected at the Anavilhanas Archipelago and lower Negro River, concerning temporal and spatial variability of water and suspended solids flows.	USA	Five sample sections in the lower Negro River between 2016 and 2019	Gravimetric method after filtration through 0.45µm cellulose acetate membrane			The mean TSS concentration of the Negro River upstream and downstream of the Archipelago was 3.28 mg/L and 1.63 mg/L respectively. The total suspended sediment discharge of the Negro River before (3.14 Mt/year) and after (1.43 Mt/year) the Anavilhanas Archipelago indicates a 55% retention of the suspended load due to the low water slope and reduced flow velocity. The main function of the Anavilhanas Archipelago, from the fluvial standpoint, is to act as a sink for suspended sediments, mainly from the Branco River.
Abd wahab et al. (2019)	To prove the sedimentation problem especially the formation of total suspended solids (TSS) and annual sediment load (SL).	Malaysia	29 main sampling stations that are located around the basin representing the length of the Terengganu River.	Gravimetric method			The results showed that the highest average of TSS was 67.2 mg/L (wet season) and 128.2 mg/L (dry season) which are class III. The highest turbidity is 43.57 (wet season) and 21.57 (dry season) which are Class II based on the National Water Quality Standard (NWQS). The contributors to sedimentation problems are from unsustainable land use such as sand mining activities which effectively trap the bed sediments, backflow that carries out high sediments, as well as sedimentation produced due to the river bank erosion. The study suggested that sedimentation management in the Terengganu River Basin is recommended.
Yustika et al. (2019)	To determine the water quality based on annual estimates of TSS concentrations for 2016.	Indonesia	Main streams of the Sekampung Hulu and Sangharus Rivers at two sites each.	Gravimetric method (APHA-1999)			The TSS concentrations in the Sekampung Hulu and Sangharus Rivers ranged from 36–813 mg/L and 16–146 mg/L, respectively and the average soil erosion rates in the Sekampung Hulu and Sangharus watersheds were 12.5 Mg/ha/year and 5.6 Mg/ha/year, respectively. The results indicated that young coffee trees increased soil erosion rates. The application of best management practices (BMPs) including conversion to agroforestry coffee, cover crops and contour systems, was effective in reducing soil erosion in both the Sekampung Hulu and Sangharus watersheds.

Abd wahab et al. (2018)	To assess the spatial and temporal variations of Dissolved Oxygen (DO), TSS and Suspended sediment concentration (SSC) in the Terengganu River.	Malaysia	Water samples were collected from 29 sampling station for Dry season and Wet season along Terengganu River Basin	Gravimetric method	DO, SSC	APHA method and Gravimetric method	The study observed the range of TSS was 0.4 mg/L – 128.2 mg/L. The distribution of land use and land cover activities affected the level of water quality in watersheds. Water quality analysis showed that TSS and SSC were higher in the dry season but DO were higher in the wet season. The increasing suspended solid could lead to an increase in the turbidity and the odours and colour of the water. Law enforcement is expected to be carried out, especially to illegal land use activists around the Terengganu River Basin.
Tuttle-Raycraft et al. (2017)	To examine the effect of TSS concentration on the clearance rates (CR) of newly transformed juvenile mussels and adult mussels and to determine at what level any effect occurs.	Canada	Juvenile and adult mussels along with sediment sample were collected from rivers in Southern Ontario (Thames River, Lyn Creek, Maitland River).	HACH kit for TSS measurement			The results of this study indicated that TSS concentrations have a negative effect on mussel clearance rates (CR), and they have implications for the conservation and management of aquatic ecosystems. Specifically, TSS should be monitored and not exceed high values for long periods in freshwater ecosystems with low turbidity, especially during periods when newly excysted juvenile mussels are present because they are more vulnerable than adults.
Bougdah et al. (2017)	To assess the surface water, sediment and salts budget for the Zit Amba dam and the fluxes into the adjacent coast through the Kebir West River outlet.		Dam of Zit Amba in the Kebir West River catchment.	Gravimetric method	TDS		Zit Amba dam seems to be affected by sediment sinking and is thus subjected to severe and rapid clogging leading to a reduction in flow at the exit of the dam by 36%. The retention rate was 67% of the receiving sediment masses. Annual retention of TDS in the dam is in the order of 100000 tons (50%). It was considered that the water of the basin studied, has low content of TSS, particularly at the mouth of the river.
Pak et al. (2016)	To analyse the characteristics of the hydraulics and water quality of the Baekje Weir reach of the Geum River by EFDC model.	South Korea	The study site is the Baekje Weir reach of the Geum River.	Standard Method 2540B (APHA) - Gravimentric method			The resulting trend of four rainfall events showed that as rainfall increases, the TSS concentration increases as well. For the two larger events, at the upstream of the weir, TSS was observed to decrease or remain constant after the rainfall event depending on the lowering of the open gate. At the downstream, the TSS supply was controlled by the weir during and after the rainfall event resulting in a decline in the TSS concentration.
Kuhnert et al. (2012)	To extend the loads regression estimator (LRE) methodology and demonstrate its application for analyzing a 24-year record of TSS concentrations in the Burdekin River	Australia	Inkerman Bridge, Burdekin River	APHA-2005-Gravimetric method			The results revealed significant variability in loads across different years. Including vegetation cover as a predictor had a notable impact on TSS concentration, with values decreasing by up to 2.1% for each percentage increase in vegetation cover. The findings indicated that managing vegetation cover during dry years can effectively reduce TSS loads from the Burdekin catchment.

Jones et al. (2011)	To develop a surrogate measure for estimating TP and total suspended solid (TSS) concentrations with high frequency.	North America	Little Bear River watershed of northern Utah.	EPA Method 340.2-Gravimetric method			The surrogate relationships between turbidity and TSS at both sites were similar. The differences in the surrogate relationships between turbidity and TP at the upper and lower watershed sites were a result of the predominant form of phosphorus at each site. At both sites, the relationships between turbidity and TP varied between spring snowmelt and base flow conditions. This approach enabled the calculation of high-frequency time series of TP and TSS concentrations previously unavailable using traditional monitoring approaches.
Jones and Schilling (2011)	To develop a method for estimating TP and total suspended solid (TSS) concentrations with high frequency.	Utah (US)	Water quality samples were collected at the two sites - the Little Bear River at Paradise, located in the upper watershed above Hyrum Reservoir and at the Little Bear River at Mendon, located in the lower watershed near the river's terminus at Cutler Reservoir.	Method 340.2 - Gravimetric method	TP, TDP and Trace Elements	EPA Method 200.8 (TP, TDP) and ICP-MS	For TSS, the relationships with turbidity remained consistent across different hydrological conditions. The surrogate relationships between turbidity and TSS were similar at both sites. However, the differences in the surrogate relationships between turbidity and TP at the upper and lower watershed sites were due to the predominant form of phosphorus at each location.
Fulweiler et al. (2005)	To quantify the nitrogen (N) and phosphorus (P) flux to the estuary, by measuring all forms of nitrogen and phosphorus, as well as suspended solids at the mouth of the river.	USA	Water samples were collected at the Stillmanville Dam in Westerly, Rhode Island, where the Pawcatuck is still a free-flowing river not influenced by the tide.	TSS concentration was determined from the average of three dry weights-Gravimetric method	(nitrite, nitrate, ammonium, dissolved inorganic phosphorus); (TDN, TDP).	Lachat Instrument QuikChem; per-sulfate digestion;	In normal river discharge conditions, the N flux would be approximately 26.0×10^6 mol/y or about 20% of the nitrogen inputs to the watershed. Since TSS concentrations increase with discharge, fresh particulate matter may be re-suspended first from the streambed or carried to the river through overland flow. At higher water discharge, eroded sediments low in nutrients may comprise more of the total suspended matter. Study indicated that nitrogen concentrations and annual fluxes can be reliably predicted by river discharge alone. Phosphorus did not exhibit this behavior, and measurements are required to evaluate its flux from the watershed.

Table S18. Detailed inclusion criteria of the parameter HevMetC.

Authors	Objectives	Location	Study site	Nearby industries/ reason	Target Parameter	Method	Extra Parameter	Method	Key Finding
Ali et al. (2023)	To assess heavy metals concentration and its effects on microbial diversity.	Pakistan	At River Swat and River Kabul.		Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn	AAS			The Cd concentration exceeded the Environment Canada standard (0.68 mg/kg) in some samples. Additionally, the Cd concentration also surpassed the NOAA limit (1.2 mg/kg) in some samples. All the samples were found within the permissible limit of USEPA (>6 mg/kg). The comparative analysis of heavy metals in both rivers revealed that heavy metals concentration in River Kabul was higher than in River Swat.
Xue et al. (2022)	To evaluate the impact of water-sediment regulation (WSR) on the concentration and transport of dissolved heavy metals in the middle and lower reaches of the Yellow River.	China	Middle reaches (Xiaolangdi station) and lower reaches (Lijin station) of the Yellow River.		Cu, Pb, Ni, Cd, Cr, As, Mn	ICP-MS			The study found that changes in the oxidation-reduction environment of the Xiaolangdi reservoir during the water and sediment regulation (WSR) process significantly impacted the concentrations of dissolved Cu, Cd, Pb, Cr, and As at the Xiaolangdi station, while the concentration of dissolved Ni remained mostly unaffected. At the Lijin station, the dissolved heavy metal content initially increased and then decreased in the first stage due to the release of heavy metals from resuspended sediments. In the second stage, the heavy metal content gradually decreased as they adsorbed onto fine particles discharged from the reservoir.
Tepe et al. (2022)	To identify the levels of HevMetC and their possible sources in the Turnasuyu Stream sediments and to assess the environmental, ecological, and human health risks of the sediments.	Turkey	Turnasuyu Stream basin.		Al, Cr, Mn, Fe,Co,Ni, Cu, Zn, As,Cd, Pb	ICP-MS			The average concentrations of heavy metals in the sediments, were measured in mg/kg, following this order: Fe > Al > Mn > Pb > Zn > Cu > Co > Cr > Ni > Cd > As. The highest concentrations were found for Fe, Al, and Mn, while the lowest concentration was for As. Except for Pb, all metal concentrations were within the sediment quality guideline (SQG) limits. The mean Pb concentration was 60.23 mg/kg, exceeding the average levels in the Earth's crust. Cd exhibited moderate enrichment in the EF index, while Pb showed significant enrichment. The Igeo index indicated that Cd levels ranged from unpolluted to moderately polluted, and Pb levels were moderately polluted.

Wang et al. (2021)	To investigate the sediment pollution status and potential sources of heavy metals.	China	Upstream, downstream and Shajing tributary of Maozhou River.		Cr, Ni, Cu, Zn, Cd and Pb	ICP-MS			The average contents of Cr, Ni, Cu, Zn, Cd and Pb were higher than soil background values in Guangdong Province. In addition, the heavy metal pollution status in the upper part of the sediment profiles (0–2.00 m) is obviously worse than those in the bottom part (2.00–4.00 m). The ecological risk of Maozhou River was much higher than other river sediments in Guangdong Province, especially for Cu, Cd and Ni. The potential ecological risk indexes of heavy metals in the Maozhou River sediment decreased following the order: Cu > Cd > Ni > Cr > Zn > Pb, which is consistent with the proxy of EF and Igeo.
Fan et al. (2021)	To evaluate spatial and seasonal variations in heavy metals of the Minjiang River-delivered sediments and unravel potential pollution sources of the heavy metals.	China	Minjiang River		Pb, Cd, Cr, Mn, Mo, Zn, V, Co, Ni, Cu	ICP-MS			SPM samples have higher particulate heavy metal concentrations than riverbed sediments collected in pairs. Heavy metal concentrations of Cd, Zn, Cr, V, Co, Ni and Cu are higher in upstream SPM samples than those in downstream regions, whereas Pb, Mn and Mo concentrations don't show this spatial variation. Most heavy metals (e.g., Pb and Zn) show high concentrations in flood seasons and relatively low concentrations in dry seasons, revealing a hydrologic control. However, Cr and Mn show high concentrations in some dry season samples.
de Paula Filho et al. (2021)	To assess the levels and spatial distribution of a suite of heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, Zn, Al and Fe) in surface sediments.	Brazil	Parnaíba River Delta: Igaraçú river, Parnaíba river, Caju bay, Melancieiras bay and Tutóia bay.		Cd, Cr, Cu, Mn, Ni, Pb, Zn, Al and Fe	FAAS	organic carbon	Walkey–Black titration	Several factors explain the low concentrations of metals, such as the low intensity of anthropogenic activities near the PRD, the high hydrodynamics and the sediment texture, as sandy sediments tend to retain less contaminants than finer ones. The sediments of Igaracu river presented higher percentages of fine sediments and organic matter, and thus this region may become more vulnerable to urban contamination from Parnaíba city, some attention should be given to the potential anthropogenic sources of Pb, Cu and Cd.
Loureiro et al. (2021)	To evaluate the direct and indirect effects of heavy metals on aquatic insects.	Brazil	Different streams in the upper portion of the Uruguay River watershed.		Cd and Cu	GFAAS			The agricultural activity intensity in stream drainage areas influences the Cu and Cd concentrations in scraper insects. The results showed that the metal contamination of basal resources (e.g. biofilms) in aquatic environments is very high. This facilitates the incorporation of metals into the trophic chain and, depending on the characteristics of the metal, can be biomagnified to higher trophic levels.

Bissassa et al. (2021)	To evaluate the physico-chemical, geochemical and mineralogical parameters of the water and sediments of the Oued Fez and its tributaries and the Sebou River.	Morrocco	Along Oued Fez River (upstream), urban catchment output, Oued Fez–Sebou river confluence and its tributaries and the Sebou river.		As, Cd, Cr, Cu, Ni, Pb and Zn	ICP-AES			A decreasing trend in heavy metal concentrations was identified as follows: Zn > Cu > Pb > Cr > As > Ni > Cd, with a mobility sequence of Cu > Pb > Zn > Ni > Cr. Comparing the total heavy metal concentrations in the sediments of the Oued Fez and Sebou River with previous studies revealed a reduction in the harmful and polluting impact of the Oued Fez on the Sebou River, which highlighted the significant role of WWTPs and sanitation networks in enhancing the water quality of the middle Sebou River.
Köse et al. (2020)	To determine some heavy metals Zn, Cu, Ni, Cr and Pb in sediment samples and in the tissues of Carassius gibelio and Capoeta.	Turkey	Dam Lakes and Sakarya River.		Zn, Cu, Ni, Cr and Pb	AAS			The study revealed that heavy metal concentrations were higher in the gills and liver of fish compared to their muscle tissue. Specifically, Zn levels in the muscle of Carassius gibelio from Yenice Dam Lake exceeded the permissible limits established by Turkish legislation and the FAO. Moreover, Cr and Ni concentrations in sediment samples were found to be higher during the rainy season than in the dry season, with levels exceeding sediment quality guidelines.
Yang et al. (2020)	To investigate the spatial distributions of organic matter, nutrients, and heavy metal concentrations in the surface sediments.	South Korea	Yeongsan and Seomjin Rivers in the Jeollanam-do and Jeollabuk-do regions.		Pb, Zn, Cu, Cd, Hg, As, Cr, and Ni	ICP-AES	organic matter, TOC, TN, TP	LOI, Elemental analyser, AAS	Mean heavy metal concentrations in the study region followed the order Hg < Cd < As < Ni < Cu < Pb < Cr < Zn. When compared to the Canadian SQGs and Korean SQAGs, these concentrations did not show serious levels of pollution. Overall, sediment accumulation at river mouths poses risks to coastal ecosystems and marine life.
Arisekar et al. (2020)	To explore the impact of heavy metals on the fish and sediments of this region.	India	Along the Thamirabarani river, South Tamil Nadu.		Cd, As, Pb, Co, Ni, Zn, Cr, Cu, Fe, Mn	ICP-MS			Heavy metal concentration in the sediments from the downstream region of the Thamirabarani River is 20–25 times higher than that in the upstream region. It is 10–25 times higher than that in fishes. These results indicate that sediment is a key source of heavy metal pollution in the aquatic environment. The lifetime cancer risk (LCR) values for children and adults were found to be above the acceptable threshold value (ATV) and children were found to be more susceptible to health risks. For all sites except site 4, the LCR of toxic metals except Cd were within the ATV (10^{-6}–10^{-4}); the value of Cd was above the ATV, and poses a high cancer risk to the downstream inhabitants. From the point of view of human health risk, the (Target Hazard Quotient) THQ values of heavy metals are less than 1, indicating no health risks from sediment pathways and to consumers eating heavy metal-contaminated fish. The carcinogenic risk from toxic metals such as Cd, As, and Pb, is due to a higher acceptable carcinogenic risk value compared to the acceptable threshold value of 10−4.

Jasmin et al. (2020)	To evaluate the influence of heavy metal pollution on the diversity and activities of heterotrophic bacteria associated with cyanobacteria.	India	Cochin estuary (CE) during pre-monsoon season.		Zn, Cd, Pb, Cu, Ni, Mn, and Cr	ICP-OES			Significant differences in heavy metal concentration were observed between water, suspended particulate matter (SPM) and sediment. The Zn, Cd, Cu, Ni and Cr were 2- 6 times higher in the SPM compared with the sediment, while Pb was 10 to 25 times higher. Although nearly 60 % of the species diversity of microbiome was common between cyanobacteria enriched from the upstream and downstream. The results of the current study indicated that pollution can influence an ecosystem at the micro-niche level, as indicated by the disruption of the microbiome of photosynthetic unicellular cyanobacteria.
Li (2020)	To investigate the distribution, pollution status and potential sources of heavy metals in trans-Himalayan River, the Koshi River (KR).	India	Himalayan river, the Koshi River (KR).		Cr, Co, Ni, Cu, Zn, Cd and Pb	ICP-MS			The average heavy metal concentrations in the KR sediments are comparable to the natural background values and are lower than the sediment guidelines. Pollution assessment using the geo-accumulation index (Igeo), enrichment factor (EF) and pollution load index (PLI) suggested negligible anthropogenic disturbances except for slight contamination by Cd, Pb and Cu at a few sites. Principal component analysis revealed that Cr, Co, Ni and Zn were primarily from the parent rock and that Cu, Cd and Pb were derived from both natural and anthropogenic sources.
dos Santos (2019)	To evaluate the Road Deposited Sediment (RDS) metal enrichment ratio between the end of wet season and the middle of the dry season.	Brazil	Road Deposited Sediment, drainage system, river sediment, Bed sediment samples from the Pitimbu river.		Fe, Mn, Zn, Cu, Pb, Cr and Ni	FAAS			Contamination of RDS is an ongoing and cumulative process, primarily influenced by the density of vehicular traffic. The Geo-accumulation Index indicated that the RDS was moderately polluted with Cu and slightly polluted with Zn and Pb. The enrichment ratios of heavy metals in the RDS highlighted the ongoing nature of the contamination.
Oremo et al. (2019)	To access the heavy metals in benthic macroinvertebrates, water and sediments in River Isiukhu.	Western Kenya	River Isiukhu within Lake Victoria catchment in Kakamega County.	Sewage treatment plant, cottage industries, agriculture and urbanization.	Zn, Cu, Cr, Cd and Pb	AAS			Sediments presented the highest range of heavy metal concentrations compared to water and benthic macroinvertebrates and presented the only matrix with quantifiable Pb levels. Concentrations of Cr, Cu and Cd obtained from samples along the Isiukhu were higher than the WHO-recommended guideline limits for drinking water. However, heavy metal concentrations in sediments and benthic macroinvertebrates are within the WHO standard guidelines, except for Cr concentration in benthic macroinvertebrates, obtained from Savona, Shirere and Ekero sampling sites. The likely point sources of the heavy metal pollution in the rivers were sewerage plants and cottage industries within the urban centres along the river.

Liu et al. (2019)	To analyze the characteristics of the environment and macroinvertebrate community from the time scale in a river basin.	China	Huai River.	Agriculture production area, sand mining, and excessive pollutant discharge	Ni, Zn, Cu, Cr, Cd, and Pb	ICP-MS			The findings indicated that the benthic community structure was consistently dominated by gastropods and insecta throughout different seasons. Statistical analysis revealed that total nitrogen (TN) and ammonia nitrogen (NH3-N) in water, along with mercury (Hg), arsenic (As), cadmium (Cd), and zinc (Zn) in sediments, were the key factors influencing the community structure. This suggested that sediment heavy metal concentrations play a more significant role in shaping the benthic community composition compared to other factors.
Sun et al. (2019)	To assess the pollution status and the ecological risks of heavy metals in the sediments of the Songhua River.	China	The Songhua River in Jilin City.	Petrochemical industry	Cu, Zn, Pb, Ni and Cr	ICP-AES			During the freezing period and in areas near petrochemical industries, high concentrations of heavy metals were detected. The geo-accumulation index identified Cu as the most contaminated heavy metal. The potential ecological risk index indicated that both the total and individual concentrations of heavy metals in the sediment posed a low ecological risk. Principal component analysis revealed that the primary sources of pollution were industrial emissions and discharges, vehicular exhaust emissions, and residential waste.
Dirbaba (2018)	To assess the distributions and concentrations of selected heavy metals in the surface sediments of rivers and streams of the Awash River Basin.	Ethiopia	Awash River Basin.	Agriculture fields, tanneries, sugar and textile factories, waste treatment plants	As, Cd, Cr, Cu, Pb, Hg, Ni and Zn	ICP-MS	TOC	TOC analyzer	The mean enrichment values of heavy metals are in the order of Cd > Zn > Cr > Cu > Ni > Pb > As > Hg. Similar studies have shown that sediments from the Awash River Basin exhibit particularly high average levels of Cd. In general, surficial sediment contamination with heavy metals is causing high ecological hazards in the Awash River Basin. Increased urban and agricultural runoff and less-treated effluents from point sources like tanneries and sugar and textile factories were the main sources of heavy metal enrichment.
Vu et al. (2018)	To assess the environmental and ecological risks of heavy metals in the Houjing River.	Taiwan	Along the Houjing River.		As, Cd, Cr, Cu, Pb, Ni, and Zn	ICP-OES and Mercury Analyser			The concentrations of heavy metals in the water and sediments of the Houjing River ranged from non-detectable to 0.09 mg/L and from 0.05 to 677.83 mg/kg, respectively. The heavy metal levels in the sediments are locally very high, posing an environmental risk. Cd, Cu, and Zn were found in higher concentrations in the river sediments than those recommended by some sediment quality guidelines and compared to similar studies globally. Three of the 11 sampled sites showed pollution load index (PLI) valued above 1, and eight of them had 'considerable' to 'very high' risk index (RI) values, indicating a significant ecological risk.

Zhao et al. (2018)	To study the spatial distribution of grain size and heavy metals (As, Cd, Cr, Cu, Hg, Pb, and Zn) in PRD river sediments.	China	Beijiang River, Dongjiang River, Xijiang River, and Tianjiang River of Pearl River Delta (PRD)		As, Cd, Cr, Cu, Hg, Pb, and Zn	AFS (As,Hg), ICP-MS(Cd,Cu), XRF (Cr,Pb,Zn)			The observed mean elemental concentrations in the sediments are as follows: As (18 mg/kg), Cd (0.84 mg/kg), Cr (55 mg/kg), Cu (43 mg/kg), Hg (0.1 mg/kg), Pb (45 mg/kg), and Zn (136 mg/kg). The highest concentrations of As, Cr, Cu, Hg, Pb, and Zn were found in the Beijiang River, while the highest Cd concentration was detected in the Xijiang River. The overall sediment quality in the area with respect to metal concentrations generally met the primary standard criteria of China (Marine Sediment Quality), except for Cd and Cu. The spatial distribution of heavy metals was influenced by grain sizes and organic carbon (Corg) concentrations.
Bailon et al. (2018)	To assess and highlight the concentrations of the different heavy metals in the water and sediment samples.	South Korea	Hyeongsan River and its tributaries, the Gumu and Chilseong creeks.		Cr, Ni, Cu, As, Cd, Zn, Pb, Hg, and MeHg	ICP-MS and CVAFS for Hg			The metal concentrations in water samples from the Hyeongsan River, Gumu Creek, and Chilseong Creek were within the drinking water quality limits established by the US EPA and the WHO. However, sediment samples showed high levels of mercury contamination, exceeding the toxic effect threshold. Additionally, the concentration of various heavy metals increased downstream, with samples collected near the confluence of Gumu Creek and the Hyeongsan River displaying particularly elevated levels.
He et al. (2016)	To study the grain size effect on multi-element concentrations and measure the concentrations of heavy metals in the different particle size surface sediments, evaluating the pollution levels	China	Along the Kuitun River in Xinjiang.		Co, Cr, Pb, Ni, Mn, Cu and Zn	AAS			Peak concentrations of Co, Cr, Mn, Cu, and Pb were found in particles smaller than 4 μm, with their levels being 0.81, 7.96, 1.98, 3.42, and 3.50 times higher than the local soil background values, respectively. Meanwhile, Ni and Zn showed peak concentrations in the 4–63 μm and 125–250 μm size ranges, respectively, at 2.13 and 1.49 times their local soil background values. The evaluation results indicated that heavy metals in surface sediments smaller than 4 μm were moderately polluted, whereas those in the 4–63 μm, 63–125 μm, and 125–250 μm ranges were classified as low polluted.
Sharifi et al. (2016)	To study the environmental quality and risk assessment for sediment and stream water polluted by heavy metals released by a municipal solid waste composting plant.	Iran	Sanandaj-Kamyaran River.		Fe, Cd, Cr, Cu, Mn, Ni, Pb and Zn	AAS			Study revealed that the MSW composting plant in the examined area was a source of heavy metal pollution, due to inadequate control of leaching and runoff, as well as the prolonged residence time of compost stockpiles, which are underutilized by local farmers. Emissions of heavy metals had degraded water quality, polluted stream bed sediments, and increased environmental risks, as assessed by various indices. When compared to metal concentrations from similar composting plants or dumpsites, the levels of Pb, Cr, Mn, Ni, and Cu in the studied stream water and bed sediments were higher.

Khan et al. (2016)	To investigate the accumulation and sources of selected heavy metals (Zn, Ni, Cd, Cr and Pb) in the sediments of Kabul River.	Pakistan	Kabul river		Zn, Cd, Cr, Ni and Pb	AAS	OM	LOI	The concentrations of heavy metals in the sediment followed the order of Zn > Cr > Ni > Pb > Cd. Heavy metal concentrations were found in the moderately polluted category set by USEPA. However, concentrations of Cr and Ni exceeded the screening levels at locations where a larger volume of industrial effluents enters the Kabul River. Sediment organic matter (OM) showed a strong correlation with Pb, Ni, and Zn, suggesting that OM plays a crucial role in the retention and accumulation of these metals. In the study area, sewage discharge was identified as the major source of heavy metals, particularly Zn and Pb.
Wu et al. (2016)	To assess the contamination and distribution of heavy metals, polybrominated diphenyl ethers and alternative halogenated flame retardants in a pristine mangrove.	Chine	Qi'ao Island Mangrove		Cd, Cr, Cu, Mn, Pb and Zn	(Cr, Cu, Mn, Pb, Zn) by ICP-OES and Cd by AAS	TOC, PBDEs and AHFRs.	CHN elemental analyser, GC/MS-ECNI(PBDEs and AHFRs)	The sediment in the Qi'ao mangrove contained higher levels of heavy metals, PBDEs and AHFRs compared to other pristine mangroves. Heavy metal concentrations were lower in vegetated areas than in mudflats, whereas PBDE and AHFR concentrations were higher in vegetated areas. Significantly greater amounts of Cr, Cu, Mn and Zn were detected in the mudflat compared to the native mangrove areas. The results suggested that tidal flushing was an important pollution source, and while mangrove plants have the capacity to minimize the impact of heavy metals, but not PBDEs and AHFRs.
Bere et al. (2016)	To examine benthic macroinvertebrate community composition in relation to metal concentrations in stream sediments and other physico-chemical variables.	Zimbabwe.	Manyame River system.		Pb, Mg, K, Na, Cu, Zn, Fe, Cd, Ni, Cr and Co	AAS			Significantly high concentrations of metals and high magnesium/calcium (Mg/Ca) ratio were recorded in sediments for the Great Dyke site locations. Natural processes and anthropogenic impacts were influencing the water quality and heavy metal concentrations in river sediments. Some macroinvertebrate taxa were found to be affected by metals whereas the distribution of others was determined by other factors as has been reported in other studies. The Mg/Ca ratio, Ca2+, Cr3+ and K+ were found to be important metals structuring benthic macroinvertebrate communities in the study streams.
Ding et al. (2015)	To determine the critical risk depth for dredging, for the removal of river sediments contaminated by heavy metals.	China	10 rivers in Pinghu.		Cu, Zn, Pb, Cd, and Ni	AAS			The sediments in the ten rivers were heavily contaminated with heavy metals. Among the heavy metals, Cd and Zn exhibited the most severe pollution levels, with their average concentrations being 23.76 and 2.37 times higher than background levels, respectively. The study also observed that heavy metal concentrations decreased with sediment depth. Cd caused the highest ecological risk and was identified as the key element to consider for sediment dredging. The study recommended environmental dredging depths for the ten rivers, ranging from 35 to 100 cm.

Niu et al. (2015)	To establish the level of heavy metal contamination in the sediments from different inflow rivers to Lake Taihu.	China	The 11 main inflow rivers.		Cu, Zn, Pb, Ni, and Cr	ICP-OES			Among the metals analyzed, Zn exhibited the highest mean concentration, followed by Cu, Cr, Pb, and Ni. The study found that heavy metal pollution was more severe in the Wu Jingang River and Caoqiao River. When comparing the results to toxicological reference values—specifically, the Effects Range Low (ERL) and Effects Range Medium (ERM)—it was observed that the mean concentration of Zn exceeded the ERM, while the mean concentrations of the other metals were within the range between the ERL and ERM. Furthermore, the results from principal component analysis and subsequent variance analysis indicated that heavy metal concentrations in the sediment of the inflow rivers were higher than those in the lake.
Mulk et al. (2015)	To assess the impact of marble industry effluents on water and sediment quality.	Pakistan	Barandu River.	marble industry	Fe, Cu, Pb, Ni, Zn, Cr, Mn, and Cd)	AAS			In sediment samples and marble stones, all the studied metals were found within the permissible limits of Canadian Environmental Quality Guidelines (CEQG), WHO, and the United States Environmental Protection Agency (USEPA). However, their concentrations in sediments were found to be higher at the industrial site than at the other two sites. Heavy metal concentrations in both water and sediments of the river were significantly increased by marble industry wastewater. It is further concluded that the water of Barandu River is not safe for drinking purposes as well as for aquatic biota because of increased EC, TSS, total hardness, and heavy metal concentrations, particularly at the industrial site. Therefore, it was recommended that direct disposal of marble industry wastewater should be banned and all effluents must be properly treated before discharging in the river water.
Bo et al. (2015)	To investigate the performance of the heavy metal speciation and the associated mobility in sediments of rural rivers in southern Jiangsu Province.	China	Yangyuan Town of southern Jiangsu Province.	Several industrial factories (three printing and dyeing mills, three chemical plants, five garment factories, and three machinery factories)	Cd, Cr, Cu, Ni, Pb, and Zn	AAS			Study revealed that Cd was predominantly found in the acid-soluble fraction, Cr in the residual fraction, and Pb in the reducible fraction. Compared to the background values in Jiangsu Province soils, Cd exhibited the highest level of contamination, particularly in the mixed area, followed by Cu and Zn. In the agricultural area, heavy metal concentrations were no more than double the background values. The environmental risk associated with heavy metals in the three areas followed this order: mixed area > residential area > agricultural area.

Chen et al. (2014)	To evaluate the spatial variation of heavy metal levels in the estuarine environment and to determine the health of the estuary.	Taiwan	Er-Ren River.	scrap metal recycling industry	Cu, Zn, Pb, Cd, and As	ICP-OES			Through sequential extraction of the sediments, the mobility order of heavy metals was found to be Pb > Cd > As > Zn > Cu. The highest concentrations of Cu, Zn, and As were detected at a depth of 20–30 cm, while the lowest concentrations were found at a depth of 0–10 cm. However, there were no significant variations in Pb and Cd contents across different depths. Overall, the results indicated that the samples were not polluted by the selected heavy metals. The improvement in the coastal environment was attributed to pollution control measures implemented following the green oyster incident. A significant bioaccumulation of Cu and Zn was observed in oysters, particularly the Portuguese oyster (*Crassostrea angulata* Lamarck).
Zahra et al. (2014)	To determine the accumulation, spatial and temporal distribution trends, and source identification of heavy metals in sediments of the Kurang and its tributaries.	Pakistan	Kurang River and its feeding tributaries.		Cr,Mn, Co, Ni, Cu, Cd, Zn, Ca, Mg, Fe, K, Na, Pb, and Li	Fast Sequential AAS	Organic matter (OM),	Tyurin's method	In the post-monsoon season, higher mean concentrations of Ni, Mn, and Pb were observed, while the pre-monsoon season showed a metal accumulation pattern in the following order: Zn > Mn > Ni > Cr > Co > Cd > Pb > Cu > Li. The EF and Igeo values indicated that sediments were loaded with Cd, Zn, Ni, and Mn. A comparison with uncontaminated background values revealed higher concentrations of Cd, Zn, and Ni compared to the respective average shale values. The concentrations of Ni and Zn were above the ERL values, with Ni concentrations exceeding the ERM values.
Mathivanan et al. (2014)	To assess seasonal variations in physico-chemical content and determine concentrations of heavy metals in surface water and sediment from the Cuddalore coast.	India	Cuddalore coast specifically at Uppanar estuary, Gadilam River and coastal area.	55 industries present in nearby SIPCOT industrial complex, sugar cane monoculture and processing, Harbour area	Zn, Cu, Cd, Pb	AAS			Heavy metal concentrations in water and sediment at the Cuddalore coast were highest during the monsoon and exceeded WHO standards. The metal concentration ranked in order of Pb > Cu > Cd > Zn. The primary pollution source was land-based anthropogenic activities. Statistical and experimental data suggested health risks for recreational users and fisherfolk.
Sedlacek et al. (2013)	To develop an improved model of the river-catchment pollution history and to provide insights into the spatial and temporal patterns of reservoir sediment fill.	Moravia,Czech Republic	Brno Dam within the Morava River catchment.		Cr, Ni, Cu,Zn and Pb	X-ray fluorescence analysis			Heavy metals such as Pb, Cr, Zn, and Ni showed varying degrees of contamination, reflecting both historical industrial discharges and changes in environmental regulations and practices over time. The concentrations of heavy metals tended to decrease in the uppermost layers of the sediment, indicating improved environmental conditions. Phosphorus and sulfur contents increased significantly in the upper layers of the sediment, especially between the 1960s and 1970s, linked to the growing use of detergents and agricultural fertilizers, resulting in ongoing problems with water eutrophication and algal growth.

Hejabi et al. (2013)	To determine the association of metal with various geochemical phases by sequential extraction.	India	Kabini River.		Cu, Cr, Fe, Mn, Ni, Pb, and Zn	AAS			Geochemical study indicated that heavy metals were present in the least mobilizable fraction in the overlying water. The results showed that lead (Pb) and chromium (Cr) have a higher potential for mobilization from the sediment due to their higher concentrations in the exchangeable ion and sulfide ion-bound fractions. Additionally, copper (Cu) and Pb had the greatest percentage in the carbonate fraction, suggesting that the study area received inputs from urban and industrial effluents. Furthermore, zinc (Zn) and nickel (Ni) showed significant enrichment in the sediment, attributed to the release of industrial wastewater into the river. These trace metals pose a risk of contaminating the aquatic environment and entering the food chain.
Keskin, (2012)	To determine the distribution of heavy metals in Akkaya Dam sediments, by physical and chemical methods and reveal possible pollution effects.	Turkey	Akkaya Dam area.	textile industry	Mo, Cu, Pb, Zn, Ni, Co, Mn, Fe, Cr, As, V and Cd	X-Ray fluorescence spectrometry	TOC,	oxidation and back titration	The results of the study showed that sediments in the vicinity of the textile industry and discharged from the Karasu River area were found to be significantly enriched with Cu, Pb, Zn, Ni, Co, Mn, As, Cr and V. The results of correlation analysis show low–medium positive and negative correlations among metals, grain size, carbonate contents and organic carbon and indicate that heavy metals in sediments of the Akkaya Dam have different anthropogenic sources. In general, the results confirmed the source of contamination to be anthropogenic from agricultural, industrial activities and domestic wastes in surrounding Akkaya Dam sediments.
Huong et al. (2012)	To evaluate heavy metal pollution in the sediment of the Nhue River and the effects of polluted irrigation water on the quality of farmland soil.	Hanoi, Vietnam	Nhue River		Cd, Cr, Cu, Ni, Pb, and Zn	AAS	Organic carbon (OC); organic matter (OM)	Tyurin method ; OM = 1.724 x OC	The sediments in the Nhue River were heavily polluted with Cd, Cr, Cu, and Pb (71 420 mg/kg for Cu, 77–433 mg/kg for Pb, 150–350 mg/kg for Zn, 0.7–8.7 mg/kg for Cd, 80– 583 mg/kg for Cr, and 32–70 mg/kg for Ni). Most of these heavy metal concentrations exceeded the guidelines for crop growth. The heavy metal concentrations of the sediments in the Nhue River dramatically increased due to the inflow of water from the To Lich River, and were not reduced at a downstream location. The total heavy metal concentration in the sediment was found to be correlated with both the clay fraction and organic matter content. These findings suggested that higher pollution levels in the sediments resulted in increased metal concentrations in the soil.

Taghinia Hejabi et al. (2011)	To assess heavy metal pollution by determining the distribution and concentration of Cr, Cu, Fe, Mn, Ni, Pb	India	River Kabini in Karnataka.		Cr, Cu, Fe, Mn, Ni, Pb and Zn	AAS			Geochemical study indicated that heavy metals were present in the least mobilizable fraction in the overlying water. The results showed that Pb and Cr have a higher potential for mobilization from the sediment due to their higher concentrations in the exchangeable ion and sulfide ion-bound fractions. Additionally, Cu and Pb had the greatest percentage in the carbonate fraction, suggesting that the study area received inputs from urban and industrial effluents. Furthermore, Zn and Ni showed significant enrichment in the sediment, attributed to the release of industrial wastewater into the river.
Saeedi et al. (2011)	To investigate the ability of sediments to adsorb dissolved heavy metal ions at different concentrations of the adsorbents from Jajrood River.	Iran	Jajrood river		Pb, Cu, Zn, Cd, Ni and Cr	AAS	chemical composition and clay mineralogy	XRF and X-ray diffraction tests	The amount of Pb, Cu, and Zn adsorbed in the sediments was significantly higher compared to the other metals, with Cr being adsorbed the least. The adsorption capacity of the sediments for heavy metals followed the order: Pb > Cu > Zn > Cd > Ni > Cr. The release of Cr and Ni appears to pose the greatest bioecological risk. The study demonstrated that heavy metal adsorption is primarily related to the organic matter load in the Jajrood River sediments.
Aktar et al. (2011)	To determine the levels of certain heavy metals in riverine water, sediment and muscles of two different fish species.	India	River Ganges.	Industrial and residential zone	Cu, Cr, Cd, Pb and Zn	AAS			The accumulation order of these heavy metals at the impact points and the middle point was Cu > Zn > Cd > Cr > Pb for sediment. This data indicated that Cu accumulated the most in the riverine sediments, while Pb had the lowest annual average concentration. The pattern of accumulation suggested that deposition was highest for Zn and lowest for Cd in the muscles of both fish species. The levels of heavy metals in fish at certain locations were concerning.
Salati et al. (2010)	To determine the heavy metal concentrations and sediment in order to identify polluted zones and to assess the anthropogenic influence on sediment contamination.	Southwest Iran	Khoshk River water.		Cr, Mn, Ni, Cu, Zn, Pb, and Cd	ICP-MS			Urban sampling sites exhibited the highest geoaccumulation index and enrichment factor values for sediment samples. The abundance of heavy metals in sediments followed the order: Mn > Cr > Pb > Ni > Zn > Cu > Cd. According to the enrichment factor and geoaccumulation index values, sediments were particularly loaded with Cr, Zn, Pb, Cu, and Cd. The high Ni concentration in all sediment samples likely reflected the geochemical composition of the parent rock. While the elevated Cr levels in the Khoshk River were mainly attributed to anthropogenic activities, the influence of natural sources should also be considered.
Wang et al. (2010)	To assess the effect of Cu, Pb, Zn, and Cd on the health of the aquatic ecosystem.	China	Downstream of the Lanzhou region.		Cu, Pb, Zn, and Cd	ICP-AES			The mean concentrations of Cu, Pb, Zn, and Cd in the water, sediment, and muscle tissues of the two fish species were significantly below the guideline values. The aquatic ecosystem had not been substantially contaminated by these metals, with levels in fish muscles all remaining under the threshold values set by the National Standards Management Department.

Kim et al. (2010)	To investigate the chemical forms and accumulation patterns of heavy metals in the sediments of the Kumho River.	Korea	Kumho River, the main tributaries of the Nakdong River.		Cd, Co, Cr, Cu, Ni, Pb, and Zn	ICP-AES and ICP-MS			Heavy metal concentrations, with Cd, Co, Cr, Cu, Ni, Pb, and Zn averaging 1.67, 20.9, 99.7, 125, 97.6, 149, and 298 ppm respectively, the sediments were classified as heavily polluted according to EPA guidelines. The heavy metal concentrations followed the order: Zn > Pb > Cu > Ni > Cr > Co > Cd. The concentrations of heavy metals generally increased downstream, except for Cd and Pb, with the highest levels found near industrial areas.
Liu et al. (2009)	To monitor the heavy metal pollution and their fractionations in the surface sediments of Yellow River in Lanzhou Reach.	China	Lanzhou Reach of Yellow River.		As, Pb, Zn, Cr, Cu, and Mn	ICP-AES (spectroscopy			The mean sediment concentrations (in μg/g dry weight) ranged from 13.68–48.11 (As), 26.39–77.66 (Pb), 89.80–201.88 (Zn), 41.49–128.30 (Cr), 29.72–102.22 (Cu), and 773.23–1459.69 (Mn). Spatial distribution showed that each heavy metal concentration remained almost constant in this reach. Correlation coefficients indicated that metals were not strongly associated with sediment sand content or organic carbon content (foc).
Zheng et al. (2008)	To compare the characterization of heavy metal contamination in sediments in the three rivers	China	Wuli River, Cishan River and Lianshan.	chlor-alkali producing industry (Hg), Huludao Zinc Plant(Zn)	Hg, Pb, Cd, Zn and Cu	ICP-AES and GFAAS			The potential acute toxicity in the sediment of Wuli River may be primarily due to Hg contamination, which was due to previous sediment contamination related to chlor-alkali production. Hg was the major toxicity contributor, accounting for 53.3-93.2%, 7.9-54.9% of total toxicity in Wuli River and Lianshan River, respectively, followed by Cd. In the Cishan River, Cd is the major sediment toxicity contributor, however, accounting for 63.2-66.9% of total toxicity.

Table S19. Detailed inclusion criteria of the parameter EcoT.

Authors	Objectives	Location	Study site	Nearby industries /reason	Measuring methods of EcoT	Extra Parameter	Method	Key Finding
How et al. (2023)	To assess whether river sediment with a high concentration of heavy metals could be restored using microbial bioleaching	Taiwan	Erren River.	Urbanized and industrialized area	Mortality percentage of young - old elegans and growth, reproduction, and germline apoptosis assays on Larvae tested using soil nematode *Caenorhabditis elegans* (small worm).	As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn	ICP-OES	Study showed that river sediment with high heavy metal concentrations, especially highly bioavailable Cu, Ni, and Zn can be restored using microbial bioleaching with simple settings. Acidophilic sulfur-oxidizing *Acidicaldus sp.* SV5 effectively bioleached Cu, Ni, and Zn from the contaminated sediment. *Caenorhabditis elegans* ecotoxicity testing could be used as a screening tool in combination with chemical-based and bioavailability-relevant ecological safety assessment of sediment samples for better decision making.

Baran et al. (2023)	To assess the contamination levels and associated risks according to geochemical and ecological indices and the ecotoxicity using bioassays.	Poland	Bottom sediments were collected from 11 dam reservoirs located in southern Poland.		Ecotoxicity analysis was performed using three bioassays: Phytotoxkit (seed germination inhibition and root length inhibition), Ostracodtoxkit (mortality and growth inhibition), Microtox (luminescence inhibition-M 500 Analyser).	Zn, Cu, Ni, Cr, Pb, Cd	ICP-OES	In this study, among the individual geochemical indices, enrichment factor (EF) turned out to be the most useful, whereas toxic risk index (TRI) (ΣTRI) has been found to be the most important ecological index. Study concluded that Cd, Zn, and Pb taken altogether have the greatest impact on the level of sediment contamination and pose the greatest potential ecological and health risks to organisms.
Sahli et al. (2021)	To investigate the current distribution and concentration of metals in sediments and ecological risk assessment by linking sediment ecotoxicity effects.	Algeria	Rhumel river and its tributary Boumerzoug, in the Kebir Rhumel basin.		Microtox tests were conducted with a lyophilised culture of *A. fischeri* (previously named *Vibrio fischeri*),	Cd, Cr, Cu, Ni, Pb, Zn	FAAS	Study concluded that there was a significant potential risk for benthic fauna. Microtox solid and leachate phase assays showed that sediments with the highest trace metal contents appear to be potentially ecotoxic for Allivibrio fisheri.
Mata et al. (2020)	To evaluate the contamination level and potential risks at a part of a large and important river in Central Africa, the Congo River.	Democratic Republic	Seven stations located in Maluku-Kinsuka section, at the vicinity of Kinshasa.		Ostracodtox kit (following the manufacturer's recommendations).	Sr, Cr, Co, Ni, Cu, Zn, As, Cd, Pb and Hg	ICP-MS and Advanced Mercury Analyzer (Hg)	The findings indicated elevated metal concentrations in sediments from the four densely populated areas (Kinkole, Kauka fishermen, Demoulin, and Chanic). These levels surpass SQGs and probable effect levels. Ostracods exposed to these sediments experienced 100% mortality after just 6 days of incubation, demonstrating the sediment toxicity and the potential risks to aquatic life.
Urbaniak et al. (2020)	To assess the potential for application of Hudson River sediment as a plant growth medium by mixing with various proportions of soil.	New York	Hudson River		The ecotoxicity of growth medium was assessed using the following series of bioassays: Phytotoxkit, Ostracodtoxkit, and Microtox. Bioassays were conducted in accordance with the standard protocol suggested by the manufacturer of the test kits.	(TOC, TN, S),(P, K, Na, Mg, Ca,Fe, Mn, Cu, Zn, Ni, Cr, Cd),PCB	CNS analyser, ICP-OES, GC-MS/SIM(PCB)	The ecological risk assessment of six trace elements and PCBs in the sediment indicated a medium to moderate risk, emphasizing the need for ecotoxicological testing before using it as a growth medium. Ecotoxicity tests on the soil/sediment mixture showed that it was non-toxic or mildly toxic to the crustacean and the bacterium. The sediment was found suitable for use as a growth medium for non-edible plants.

Roig et al. (2015)	To design a cost-effective methodology to study the ecotoxicological status of freshwater systems.	Spain	Ebro river basin		The ecotoxicity of whole sediment has been evaluated in Vibrio fischeri (using Microtox 500 Analyser), Daphnia magna (microbiotest Daphtoxkit), in the benthic diatom Nitzschia palea and Chironomus riparius (ASTM E 1706-05 method).	As, Cd, Cr, Cu, Hg, Ni, Pb and Zn	ICP-MS	Whole sediment bioassays had shown more toxicity than pore water tests. Among the different organisms used, *P. subcapitata* and *C. riparius* were the most sensitive in pore water and whole sediment, respectively. The study concluded that when chemical stressors negatively impact ecosystem functioning, an ecotoxicological approach using appropriate bioassays in pore water and whole sediment can accurately detect these changes.
Devarajan et al. (2015)	To assess the effects of untreated hospital and urban effluent waters on the accumulation of toxic metals in the sediment receiving systems in the Cauvery River Basin.	India	Cauvery River Sediment		Mortality (%), length of the surviving ostracods and Growth inhibition were determined by using Ostracodtox kit F on benthic ostracod crustacean Heterocypris incongruens cysts	Cr, Co, Ni, Cu, Zn, As, Cd, Pb, and Hg, TOC	ICP-MS, AAS (Hg), LOI	Metal concentrations in Cauvery River Basin (CRB) sediments were lower than those in hospital outlet pipes (HOP), but both exceeded Sediment Quality Guidelines (SQGs) and the Probable Effect Concentration (PEC) for aquatic life. Ecotoxicity tests with ostracods showed mortality rates of 22–100% in HOP sediments and 18–87% in CRB sediments.
Anh et al. (2003)	To the monitoring of environmental pollution in river basin using ecotoxicological tests recently developed by the Institute for Environment and Resources (IER-CEFINEA).	Vietnam	SGDN river have been chosen, with five sites in the SaiGon river and 5 sites in the DongNai river.		Toxicity tests were undertaken by exposing three aquatic organisms (Daphnia magna, Vibrio fischeri, and Ceriodaphnia cornuta, an autochthonous daphnid) to the different samples. Organic extraction and aqueous extraction had been done following ISO 1998 and OECD protocols.	Cu, Pb,Zn,Cr and Ni ; organochlorines, organophosphorus	AAS, GC-ECD , GC-FPD	The results showed acute toxicity of the extracts from most samples of the SaiGon–DongNai river system and of rice fields. Although the pollution level does not exceed the probable effect level (PEL) value, (SGDN) sediments appear to have reached a toxicity level that should be monitored.