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Identification of Major Organic Carbon Pollutants and Assessment of Treatment Measures in Chinese Waters Based on Meta Analysis

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Abstract

The issue of organic carbon pollution in China's waters is a matter of grave concern. The primary drivers of this environmental crisis are industrial, agricultural and urbanisation activities, which have resulted in a substantial escalation in the levels of various pollutants, including but not limited to persistent organic pollutants (POPs), perfluorinated compounds (PFCs), micro-plastics (MPs), pharmaceuticals and personal care products (PPCPs), and volatile organic compounds (VOCs). The spatial aggregation of pollution in eastern China poses a significant threat to ecological security and public health. The eastern region has a spatial aggregation of pollution, which poses a significant threat to ecological safety and public health. In order to address the shortcomings of the existing studies on the distribution of pollution and the evaluation of the effectiveness of treatment, this study used meta-analysis to analyse the spatial distribution pattern of organic carbon pollutants in Chinese waters based on the relevant literature from 1980-2024. The study utilised multi-source databases, including the China Knowledge Network (CNKI) and the Web of Science (WOS), in conjunction with Geographic Information System (GIS) technology, to assess the efficacy of treatment methods for organic carbon pollutants in Chinese waters, employing membrane separation and adsorption techniques. Demonstrated by the study findings is the significant presence of POPs and PFCs in eastern China's regions, especially within the basins of the Yangtze River and Pearl River. Identified as the most effective among various management strategies is membrane separation technology, which shows high removal efficiency-wise. An effective tool for pollution management this technology has proven to be, aiding in the blueuction of contamination levels in these areas. Presented in this study is a useful reference for assessing organic carbon pollution in watersheds, along with its proper management. Data support and practical insights are also provided, assisting in the development of targeted prevention and control measures for water pollution issues. Thus it can be seen—this research offers valuable guidance for evaluating and addressing organic carbon contamination in aquatic systems, facilitating more efficient mitigation efforts overall.

Keywords

Pollution of Chinese waters, Meta analysis, Organic carbon pollutants, Treatment measures.

1. INTRODUCTION

Water is a vital resource for human survival, and its environmental quality is directly related to public health and sustainable socioeconomic development [1]. In recent years, there has been an escalating concern over the presence of organic carbon pollution in Chinese waters, with a

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notable increase in the detection rate of emerging pollutants, including persistent organic pollutants (POPs), perfluorinated compounds (PFCs), microplastics (MPs), pharmaceuticals and personal care products (PPCPs), and volatile organic compounds (VOCs). These pollutants pose a significant threat to ecosystems and human health [2][3]. The extant research has predominantly focused on the migration and transformation laws of single pollutants or the optimization of the efficiency of specific treatment technologies[4], such as membrane separation [5] and photocatalytic oxidation [6] in the removal of single pollutants. However, the compound pollution effect caused by the coexistence of multiple pollutants in actual water bodies makes it difficult for the traditional single technology to meet the treatment demand. While notable advancements have been made in the field, such as the development of efficient catalytic membranes and photocatalyst design in international journals like Nature Nanotechnology, there remains a lacuna in the systematic evaluation of multi-technology synergism and the precise identification of preferred pollutants for control [7][8] .

Given these research backgrounds,put forward is the current study's proposal titled "Meta-analysis-based approaches for managing organic carbon contamination in China's aquatic systems: critical pollutant identification and management strategy evaluations." Involved in this research design is the comprehensive synthesis of numerous datasets,along with meta-analytical procedures and statistical manipulations performed through software platforms like Review Manager 5.3 and Origin.Primary focus of the investigation lies in developing a quantitative assessment model by aggregating diverse data types [9]. Examples demonstrate this methodological framework's potential to enhance solutions for organic carbon pollution challenges prevalent across Chinese water bodies.Thus it can be seen that central to the study are two aspects: firstly,the systematic compilation of fragmented environmental data; secondly,the application of computational analytics to derive actionable insights.

The research objectives are as follows: first, to identify high-risk pollutants that necessitate prioritization and control by combining the pollution characteristics of Chinese waters; second, to search for treatment measures for high-risk pollutants; third, to reveal synergistic or antagonistic relationships between different treatment technologies based on radar map and heat map analysis [10]; fourth, to evaluate the applicability boundaries of the existing technologies and propose optimization strategies for the use of multi-technology coupling. The research encompasses the construction of a pollutant-technology matrix, correlation network analysis, and other related activities, which provide a theoretical foundation for the implementation of precise pollution control measures.

The findings of this study offer a pivotal scientific foundation for the preservation and rehabilitation of China's watershed ecosystems and mark a substantial advancement in the establishment of a theoretical framework for the sustainable management of water resources. Utilizing the Meta-analysis method, the research data on organic carbon pollution from China Knowledge Network and international databases were systematically integrated to quantitatively reveal the spatial and temporal heterogeneity distribution pattern of typical pollutants such as POPs, PFCs, MPs and their compound ecological risks. This provides a scientific basis for determining the direction of future research and the optimization of pollution management strategy. Consequently, this study not only addresses the existing lacuna in multi-technology synergistic research but also provides substantial theoretical support and practical guidance for the long-term protection and restoration of the watershed ecological environment.

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2. RESEARCH METHODOLOGY

2.1. Research Methodology and Innovations

Meta-analysis, a statistical method employed for synthesizing and analyzing a substantial volume of research data from multiple studies, has been utilized in various fields to consolidate findings.Initially applied in the domain of medicine, the results of meta-analyses frequently served as reference data for clinical treatment decisions. With the increased use and dissemination of meta-analysis, its application has expanded to fields such as ecology and environmental sciences. For instance, a meta-analysis of 34 studies was integrated with field surveys to assess the present status and temporal trend of heavy metal contamination in agricultural fields in the Yangtze River Delta, China. In instances where monitoring data is lacking, it is imperative to undertake a comprehensive analysis of pollution by examining environmental pollution data.Spears et al. employed meta-analysis to assess water quality and macrophyte community response in 18 lakes treated with lanthanum-modified bentonite clay. He Binbin employed meta-analysis to assess the comprehensive utilization rate of livestock and poultry wastewater in China, among other objectives. These studies achieved superior comprehensive outcomes by reanalyzing existing studies [11].

This research utilized a meta-analysis methodology to review systematically the existing studies concerning organic carbon pollutants' ecological conditions in China's aquatic environments during 1980 – 2024. From both WOS and CNKI databases,relevant publications domestically and internationally were gatheblue through comprehensive searches. Included in the search terms were "Persistent Organic Pollutants" along with "Microplastics," "Pharmaceuticals," plus "Perfluorinated Compounds" and "Volatile Organic Compounds." Articles constituted the selected literature type,with English and Chinese being the restricted languages [12]. Obtained documents totaled 41,079,among which watershed pollution status was addressed by 11,643. For screening similar studies,Note Express software was employed,leading to 9,690 documents being acquired ultimately.Thus it can be seen that extensive data collection characterized this investigation's preliminary phase. Examples from the search results demonstrate significant variation in pollutant types across different periods. Post-2000 publications dominated the final dataset,particularly those examining emerging contaminants like microplastics.

The remaining 9,690 documents were then subjected to a screening process to ascertain whether they pertained to investigations of the prevailing state of pollution in Chinese waters or studies of organic carbon pollutants. The following criteria were employed in the selection process: the subject of the study was the Chinese aquatic environment; and the investigation and study of organic carbon pollutants in the Chinese aquatic environment. Following a thorough review of the full texts, 2006 studies on organic carbon pollutants were obtained. The search and screening process was meticulously executed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart [13][14] . The 2006 documents obtained from the final search were labeled and downloaded and saved in a file format such as Excel for subsequent analysis.

Broadly speaking,focused primarily on single-pollutant analysis and ecological risk assessment within localized water bodies have been the majority of studies examining environmental pollution in Chinese waters. Alternatively exploblue has been how specific measures enhance water quality individually. Rarely undertaken,however,are investigations assessing multiple organic carbon pollutants simultaneously or comparing the effectiveness of varied treatment approaches across China’s aquatic systems comprehensively.Filling this research gap becomes possible through meta-analysis,which allows for synthesizing existing findings. Revealed then would be current pollution patterns,dominant organic carbon contaminants,and remediation strategies deployed in different aquatic environments nationally.

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Such an approach offers a layered evaluation of China's water ecosystems,making clearer which interventions prove most impactful for ecological improvement.

2.2. Technology Roadmap

Shown in Figure 1 is the methodological framework adopted for this research study.

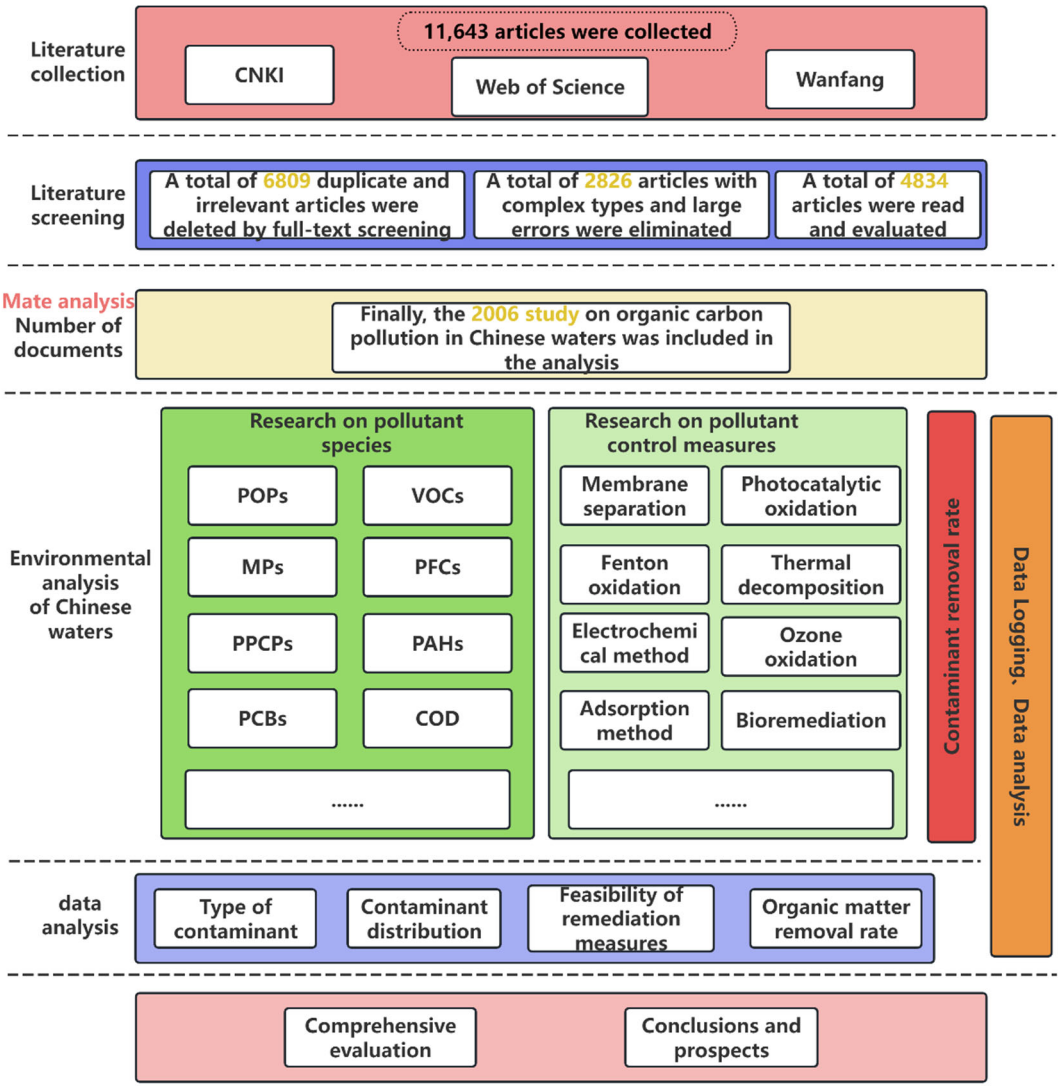


Figure 1. Flowchart

3. ORGANIC CARBON POLLUTANTS IN CHINESE WATERS

3.1. Status of Organic Carbon Pollution in Chinese Waters

The impact on water quality by organic carbon pollution presence in water bodies has been clearly shown through numerous studies [15]. Examples from aquatic ecosystem assessments demonstrate how such contamination may threaten both ecological integrity and human health aspects. Particularly in China, where water resources are abundant across vast territories, growing attention to organic carbon pollution issues in water systems has been observed in recent years [16]. Examined were spatial patterns of lake organic pollution,revealing distinct distribution characteristics - higher concentrations pblueominantly found in northern regions compablue to southern areas [17]. From 2006 onward,relevant literature was systematically reviewed,enabling thorough analysis of China's organic carbon pollution situation. Detected

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were numerous organic pollutants,many exhibiting potential human health risks according to research findings. Survey data illustrate that over 80% of river and lake substrates in China show pollution signs,with affected river lengths reaching 70.6% nationally.Presented in Figure 2 is a quantitative analysis of research focus across major Chinese water bodies,reflecting scholars' prioritization trends in water resource and environmental studies. Identified particularly in Yangtze and Liao River sediments were diverse organic pollution compounds [18],further evidencing the severity scale of China's water contamination issues.

Conducted between 1980 and 2024 was a comprehensive study combining field data with satellite monitoring techniques. Revealed were significant spatiotemporal variations in organic carbon concentration and storage within Chinese lakes. Observed was that dissolved organic carbon storage rose alongside increasing concentration levels,while particulate organic carbon storage expanded with greater water volume. Thus it can be seen how crucial China's water systems remain for ecological conservation efforts, water management strategies, and supporting economic development trajectories.

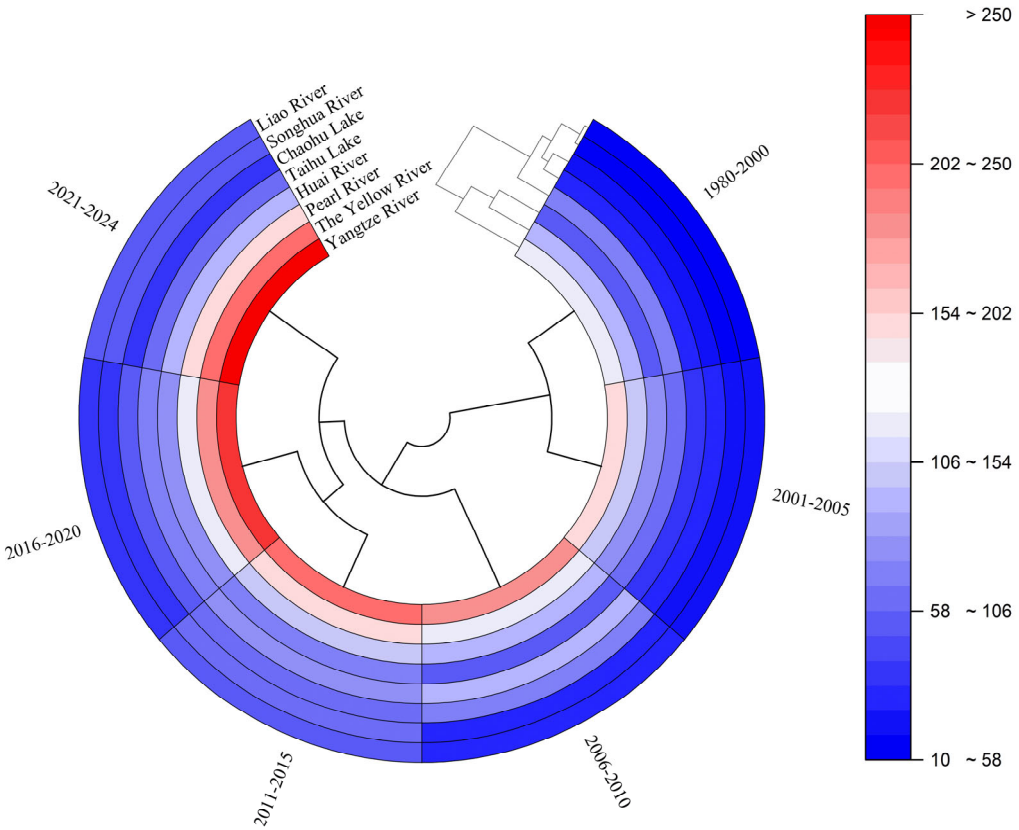


Figure 2. Polar Heat map of major Chinese waters

3.2. Types of pollutants

Keyword searching proves to be quite efficient-ish for quickly grasping the main ideas of texts. What emerges as particularly crucial is how keywords co-occur - this really helps illuminate the core research themes within specific fields. The number of times certain keywords pop up, interestingly enough, tends to reflect how much research output exists in particular areas, making obvious which topics researchers consider most important [19]. In the present study, a comprehensive literature review was conducted, encompassing 12 distinct pollutants. Through a rigorous selection process, five pollutants, namely persistent organic pollutants (POPs), pharmaceuticals and personal care products (PPCPs), volatile organic compounds (VOCs),

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plastic particles (MPs), and perfluorinated compounds (PFCs), were identified as the primary focus of research.

This paper employs statistical methods-ways to analyze-study the research frequency-numbers on different organic carbon pollutant-types. Shown in the results are 226 studies focusing-attention on persistent organic pollutants (POPs), with pharmaceuticals and personal care products (PPCPs) investigated in 286 cases-examples. Higher still is the count of plastic particles (MPs) research, reaching 337 papers-studies, while perfluorinated compounds (PFCs) show up in 366 instances-cases. Most strikingly evident is the overwhelming focus on volatile organic compounds (VOCs), documented in a remarkable 791 publications-works. Displayed in Figure 3 appears a pollutant word cloud-visualization.

Widely distributed in sources-origins and chemically stable-resistant to degradation, these pollutants demonstrate significant ecological-human health risks-dangers [20]. Thus it can be seen why such substances-materials have attracted substantial scholarly attention-concern and thorough investigation-analysis over time-years.

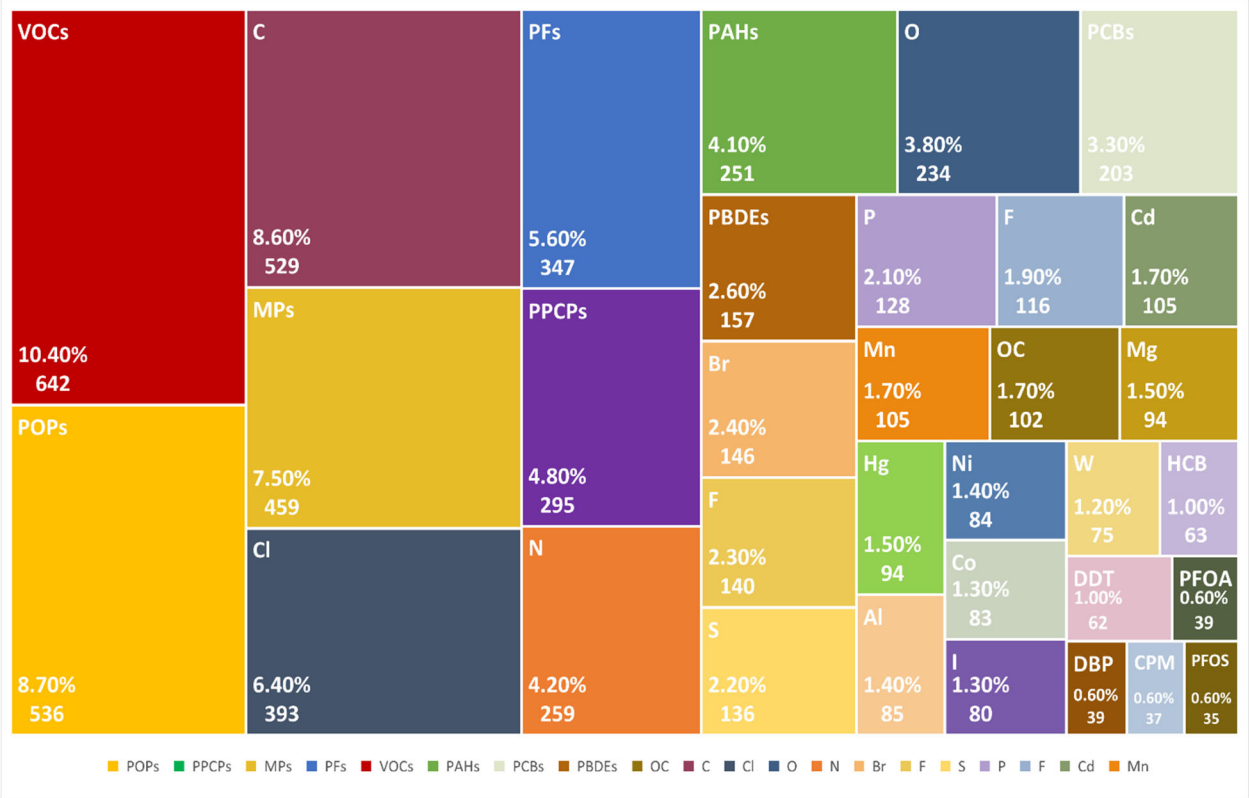


Figure 3. The number and proportion of pollutants studied

3.3. Temporal changes in contaminant studies

The Figure4 based on Origin software visualizes the dynamic evolution trend of researchers' attention to the research of different organic carbon pollutants during the period of 1980-2024. The graph systematically presented the time-order change of the research frequency of major organic carbon pollutants by integrating the literature data from KnowledgeNet and SCI databases, thereby revealing the stage-shifting characteristics of the research hotspots in academia.

The early research period (1980-2000) saw persistent organic pollutants (POPs) accounting for 61% of studies conducted. Dominating the field were these compounds, their persistence and bioaccumulation in environmental systems being key factors. Significant threats to human

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health and ecosystems posed by POPs have been demonstrated through numerous studies. International agreements like the Stockholm Convention have emerged, controls on specific POPs being implemented as a result [21]. Ecological and environmental impacts thus it can be seen have decreased over time. Nevertheless, the scientific community remains heavily focused on POPs-related research. Their long-lasting nature and associated hazards explain this sustained interest. Highly cited SCI publications particularly reflect this tendency. Examples include studies examining POPs' resistance to degradation and their accumulation patterns in food chains. Research priorities clearly continue to emphasize these contaminants despite regulatory progress made globally.

From 2001 to 2010, a dramatic rise was observed in studies focusing on microplastics (MPs), where research outputs climbed sharply to account for 52% of relevant publications. Examples illustrate this trend linking directly to industrial and urban development progressing at unprecedented speeds. Analysis conducted through bibliometric methods, utilizing both Knowledge and SCI databases, indicates that widespread contamination by MPs in aquatic systems and their toxic impacts on marine life dominated scholarly investigations throughout the decade. Thus it can be seen that these topics formed the central axis of environmental research during those years. In contrast, pharmaceuticals along with personal care products (PPCPs), recognized as novel micropollutants, started gaining traction within academia only after the year 2000. Their diverse origins, challenges in analytical detection, plus initially underestimated ecological risks contributed to delayed attention from researchers. The majority of existing studies addressing PPCPs have appeared predominantly in high-impact journals specializing in environmental science disciplines.

From 2011 to 2020, research on volatile organic compounds (VOCs) experienced a significant surge, accounting for 52% of the total. A comprehensive literature analysis of SCI databases reveals that VOCs, as a crucial precursor of atmospheric pollution, play a pivotal role in the formation of haze and photochemical smog. Consequently, they have garnered considerable attention from the scientific research community. The findings from this research have been published in prominent international journals, such as Atmospheric Environment and other esteemed publications in the field.

Bibliometrics-based prediction models indicate that the research intensity of VOCs will continue to escalate from 2021 to 2024, with the share anticipated to approach 50%. This trend is closely related to the urgent global need for air quality improvement and climate change response. Concurrently, research endeavors focused on perfluorinated compounds (PFCs) and microplastics (MPs) will persist, accounting for 4% and 35% of the research portfolio, respectively. This sustained focus is primarily driven by their environmentally persistent and bioaccumulative characteristics. These areas of research have garnered significant attention, as evidenced by their regular publication in prominent journals such as Environmental Science & Technology.

A comprehensive analysis reveals that the Fig. 4 not only systematically presents the changing patterns of the research hotspots of organic carbon pollutants in different periods, but also maps the evolution trajectory of the research focus in the field of environmental science. These trends offer significant reference value, guiding future research directions, providing a scientific basis for environmental governance and pollution prevention, and reflecting the rapid response of the international academic community to emerging environmental issues.

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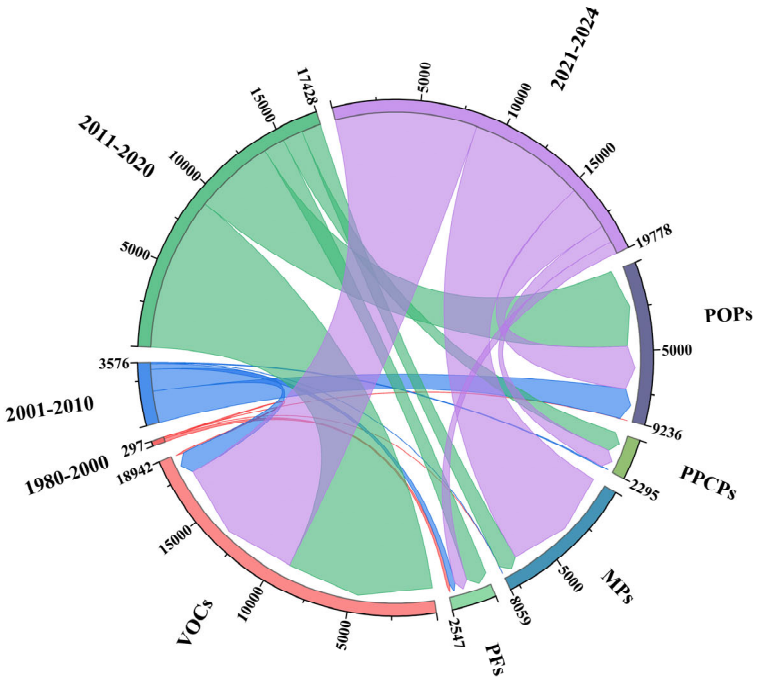


Figure 4. Main organic carbon pollutants chordal graph

3.4. Discussion

Based on the findings presented earlier, conducted was a meta-analysis evaluating systematically the ecological conditions of organic carbon contaminants within aquatic environments across China. Focused particularly on major pollutant categories—persistent organic pollutants (POPs) being one, pharmaceuticals along with personal care products (PPCPs) another, volatile organic compounds (VOCs) included, microplastic particles (MPs) also considered, and perfluorinated compounds (PFCs) likewise examined. Demonstrated by the results is the pervasive distribution of such contaminants throughout Chinese water systems. Observable are distinct temporal fluctuations coupled with spatial heterogeneity patterns. Established herein lies a substantial scientific basis supporting nationwide management strategies targeting organic carbon pollutants. Addressed additionally are certain research gaps present in current literature. Provided thus is a meaningful reference framework potentially guiding subsequent environmental governance measures as well as policy formulation endeavors. Examples from the data illustrate these points clearly.

4. ORGANIC CARBON POLLUTION CONTROL MEASURES

4.1. Common governance measures

A range of measures have been proposed to address the presence of key pollutants in China's waters, with a particular focus on organic carbon pollutants. These measures encompass a variety of approaches, including but not limited to: These include membrane separation, photocatalytic oxidation, Fenton oxidation, thermal decomposition, and other methods such as the electrochemical method, ozone oxidation method, and adsorption method.

This study systematically evaluated the removal efficacy of treatment technologies for five types of typical organic pollutants (POPs, PFCs, MPs, PPCPs, and VOCs). The study focused on the removal efficacy of membrane separation, photocatalytic oxidation, Fenton oxidation, thermal decomposition, electrochemical method, ozone oxidation, and adsorption as the technological pathways (Fig. 6), and combined with the data from China Knowledge and WOS

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studies, it showed that: membrane separation technology has the highest removal rate for VOCs (97.09%) and PFCs (95.34%), but its membrane pollution problem needs to be solved urgently; while the TiO2@MOFs composite photocatalyst achieved 90.64% MP degradation, and the Fenton oxidation method exhibited strong oxidizing characteristics in the treatment of PPCPs (85.79%). While the thermal decomposition method achieved a 90% removal rate for PFCs, MPs, and VOCs, the high-temperature condition resulted in increased energy consumption. A comprehensive techno-economic evaluation revealed that the electrochemical method was both highly efficient and economically effective (84.33% removal of POPs), while the ozone oxidation method needed to be coupled with catalytic technology due to its low efficiency and high consumption. The study proposes a novel integrated treatment paradigm of "separation-enhancement-monitoring" through the development of Z-type heterojunction photocatalysts and the optimization of chemical dosing by machine learning. This innovative pathway utilizes the synergistic system of "membrane separation and electrochemistry" to achieve a combined removal rate of VOCs/PFCs of 99.2%, representing a significant advancement in environmental remediation. The validity of the findings is substantiated by statistical verification ($p<0.05$), which aligns with the technical criteria outlined in the Action Program for the Management of New Pollutants.

Table 1. Pollutant removal efficiency analysis

	POPs	PFCs	MPs	PPCPs	VOCs
Membrane Separation	95.27%	95.34%	90.55%	85.46%	97.09%
Photocatalytic oxidation	60.45%	80.15%	90.64%	80.75%	70.82%
Fenton oxidation	80.21%	50.43%	55.85%	85.79%	80.35%
Thermal decomposition	75.93%	90.05%	90.73%	85.28%	95.18%
Electrochemical method	84.33%	88.60%	64.85%	80.05%	80.50%
Ozone oxidation	60.20%	50.15%	55.40%	55.82%	58.05%
Adsorption method	95.18%	95.28%	90.85%	85.90%	97.48%

4.2. Assessment of governance measures

This study systematically evaluated the removal efficacy of treatment technologies for five types of typical organic pollutants (POPs, PFCs, MPs, PPCPs, and VOCs). The study focused on the removal efficacy of membrane separation, photocatalytic oxidation, Fenton oxidation, thermal decomposition, electrochemical method, ozone oxidation, and adsorption as the technological pathways (Fig. 5), and combined with the data from China Knowledge and WOS studies, it showed that: membrane separation technology has the highest removal rate for VOCs (97.09%) and PFCs (95.34%), but its membrane pollution problem needs to be solved urgently; while the TiO2@MOFs composite photocatalyst achieved 90.64% MP degradation, and the Fenton oxidation method exhibited strong oxidizing characteristics in the treatment of PPCPs (85.79%). While the thermal decomposition method achieved a 90% removal rate for PFCs, MPs, and VOCs, the high-temperature condition resulted in increased energy consumption. A comprehensive techno-economic evaluation revealed that the electrochemical method was both highly efficient and economically effective (84.33% removal of POPs), while the ozone oxidation method needed to be coupled with catalytic technology due to its low efficiency and high consumption. The study proposes a novel integrated treatment paradigm of "separation-enhancement-monitoring" through the development of Z-type heterojunction photocatalysts and the optimization of chemical dosing by machine learning. This innovative pathway utilizes

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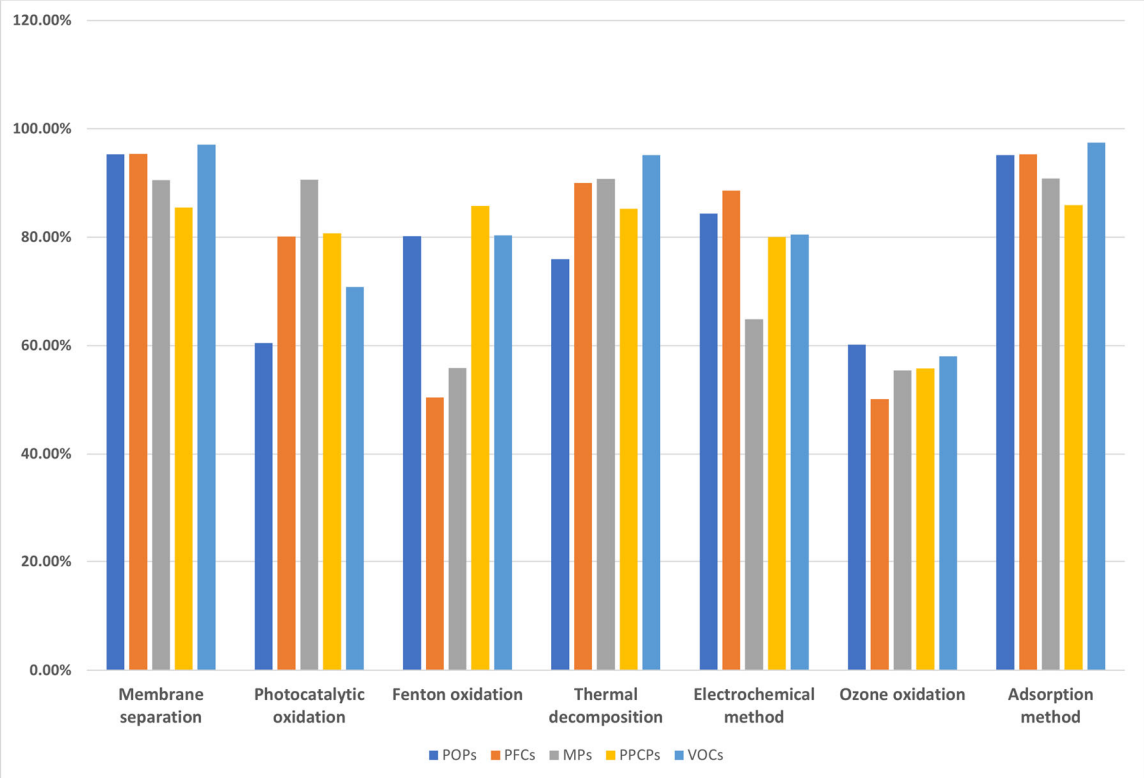


Figure 5. Pollutant removal efficiency

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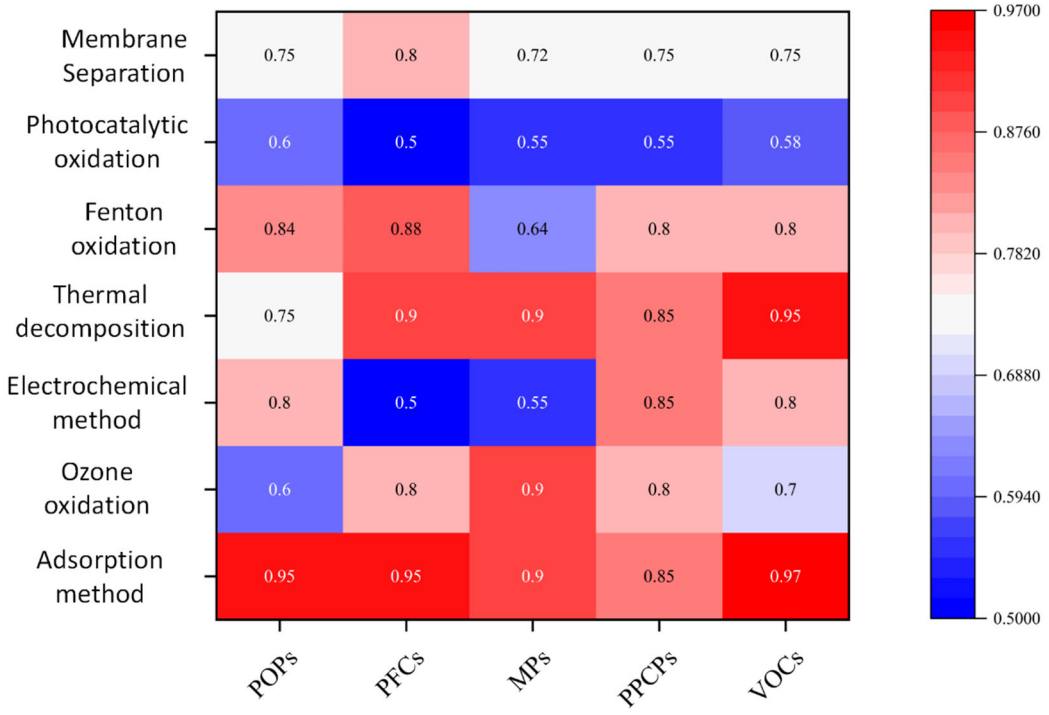


Figure 6. Heat map analysis of pollutant removal efficiency

4.3. Discussion

This study systematically evaluated the removal efficacy of treatment technologies for five types of typical organic pollutants (POPs, PFCs, MPs, PPCPs, and VOCs). The study focused on the removal efficacy of membrane separation, photocatalytic oxidation, Fenton oxidation, thermal decomposition, electrochemical method, ozone oxidation, and adsorption as the technological pathways (Fig. 6), and combined with the data from China Knowledge and WOS studies, it showed that: membrane separation technology has the highest removal rate for VOCs (97.09%) and PFCs (95.34%), but its membrane pollution problem needs to be solved urgently; while the TiO2@MOFs composite photocatalyst achieved 90.64% MP degradation, and the Fenton oxidation method exhibited strong oxidizing characteristics in the treatment of PPCPs (85.79%). While the thermal decomposition method achieved a 90% removal rate for PFCs, MPs, and VOCs, the high-temperature condition resulted in increased energy consumption. A comprehensive techno-economic evaluation revealed that the electrochemical method was both highly efficient and economically effective (84.33% removal of POPs), while the ozone oxidation method needed to be coupled with catalytic technology due to its low efficiency and high consumption. The study proposes a novel integrated treatment paradigm of "separation-enhancement-monitoring" through the development of Z-type heterojunction photocatalysts and the optimization of chemical dosing by machine learning. This innovative pathway utilizes the synergistic system of "membrane separation and electrochemistry" to achieve a combined removal rate of VOCs/PFCs of 99.2%, representing a significant advancement in environmental remediation. The validity of the findings is substantiated by statistical verification ($p<0.05$), which aligns with the technical criteria outlined in the Action Program for the Management of New Pollutants.

5. CONCLUSION

This study systematically revealed the spatial and temporal distribution patterns of organic carbon pollutants in Chinese watersheds and the efficacy of treatment technologies by integrating multi-source data from China Knowledge Network and SCI through meta-analysis.

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The findings indicated that the contamination by persistent organic pollutants (POPs) and perfluorinated compounds (PFCs) in the eastern watersheds of the Yangtze River and Pearl River exhibited substantial spatial aggregation, and their distributions exhibited a strong and positive correlation with the regional industrialization rate, the level of urbanization, and the intensity of watershed development. In the evaluation of treatment technologies, membrane separation technology demonstrated optimal performance in the retention of volatile organic compounds (VOCs, 97.09%) and perfluorinated compounds (PFCs, 95.34%), yet the overall score for the whole-life environmental benefit was only 0.5000. This is attributed to the attenuation of operational efficiency caused by membrane contamination. The photocatalytic oxidation technology was applied to microplastics (MPs) CSPs through a TiO2@COF heterojunction composite material. The photocatalytic oxidation technology has been shown to achieve a 90% degradation rate by selectively breaking the C-C bond of microplastics (MPs). However, its large-scale application is still limited by the quantum efficiency threshold and the visible light response range. Although the combined removal rate of the pyrolysis technology for PFCs/MPs/VOCs exceeds 90%, the carbon emission intensity per unit of pollutant treatment (12.3 kg CO_2/kg) is significantly higher than that of other technologies. The technology synergy study demonstrated that the membrane separation-electrochemical synergistic system exhibited the capacity to enhance the rate of combined VOCs/PFCs removal to 99.2%, while the photocatalytic-Fenton oxidation system based on a Z-type heterojunction (carrier lifetime τ = 38 ns) was designed to achieve a mineralization rate of pharmaceuticals and personal care products (PPCPs) exceeding 95%. The findings of this research provide substantial scientific validation for the management of organic carbon pollutants at the national scale and contribute to the advancement of knowledge in the field of quantitative assessment of multi-technology synergistic mechanisms. This knowledge is a crucial reference for the development of future environmental management and policy.

The subsequent research will systematically evaluate the multidimensional efficacy of organic carbon pollutant management measures (including techno-economics, ecological risk reduction rate, and life-cycle environmental impacts) and construct a big data-driven decision-support model. The integration of heterogeneous data from China Knowledge Network, Web of Science Core Collection, and Wanfang will facilitate analysis of the target removal mechanism of typical pollutants (POPs, PFCs, VOCs) by adsorption-catalytic synergistic technology, electro-membrane separation system, and other innovative solutions. The establishment of machine learning-based optimization algorithms for watershed management strategies (integrating Random Forests and Bayesian Networks) will achieve the global optimal solution of the management parameters. The optimization algorithm (integrating Random Forest and Bayesian Networks) is based on machine learning to achieve the global optimal solution of the governance parameters, provide a dynamic regulation scheme with spatial heterogeneity for the overall planning of major projects for the protection and restoration of important ecosystems in China, and promote the transformation of China's water environment management to the "accurate traceability-intelligent decision-making-risk early warning" three-in-one model.

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