



Mapping Reverse Osmosis Research for Drinking Water Treatment: A Bibliometric Analysis of Trends and Applications

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Abstract

Access to safe drinking water remains a major global challenge, while reverse osmosis (RO) has become an important technology for desalination and advanced drinking-water treatment. However, the development of RO research has not been sufficiently characterized in terms of publication growth, research themes, membrane technologies, water-source applications, and geographic distribution. This study aims to map the research landscape of RO for drinking-water treatment and to position RO relative to other treatment technologies. Bibliometric data were retrieved from OpenAlex for English-language research articles published from 1995 to 2025. After screening and inclusion criteria were applied, 192 RO-related articles were analyzed. Publication trends, citation patterns, geographic distribution, membrane types, and water-source applications were analyzed using Microsoft Excel, while keyword co-occurrence, overlay, and density analyses were conducted using VOSviewer. Comparative publication datasets were also compiled for ozonation, activated carbon adsorption, and UV disinfection. The results show a substantial increase in RO publications after 2017, reaching a peak of 20 publications in 2023. Research themes are centered on membrane technology, desalination, fouling, nanotechnology, and polyamide membranes, while groundwater, surface water, and microbial-related themes form additional clusters. Seawater is the most frequently reported water source, followed by brackish water and groundwater. Among the compared technologies, RO has the highest publication output. The findings provide a basis for identifying future research directions and supporting context-specific drinking-water treatment development, particularly in Indonesia.

Keywords: *Reverse Osmosis, Bibliometric Analysis, Drinking Water Treatment, Membrane Technology, Desalination*

INTRODUCTION

Access to safe drinking water remains a major global challenge, particularly in rural and low-income regions where inadequate infrastructure and socioeconomic constraints limit reliable water supply. Water quality is further affected by industrial, agricultural, and natural pollution, while climate variability and extreme weather events increase pressure on water resources and treatment systems (Bolatova et al., 2025; Fayomi & Onyari, 2024; Luh & Bartram, 2017; Tariq et al., 2023).

Drinking-water contamination includes microbial pollutants as well as chemical contaminants such as arsenic, fluoride, uranium, and other potentially toxic elements, creating both acute and long-term public-health risks (Daniel et al., 2022; Izah & Ogwu, 2025; Yadav et al., 2022). These challenges are closely related to Sustainable Development Goal 6 (SDG-6), which targets universal and equitable access to safe and affordable drinking water. Achieving this target requires effective treatment technologies, reliable infrastructure, and sustainable water-management strategies (Bhattacharya et al., 2024; Luh & Bartram, 2017). Conventional and advanced treatment technologies include ozonation, activated carbon adsorption, ultraviolet disinfection, and

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membrane processes. Ozonation can provide oxidation and disinfection, activated carbon is effective for adsorption of organic compounds, and UV treatment provides microbial inactivation ([Marron et al., 2019](#); [Summers et al., 2020](#); [Xu et al., 2017](#)). However, these technologies generally address specific contaminant groups and may be integrated into multi-barrier treatment systems.

Reverse osmosis (RO) provides broad separation of dissolved salts and a wide range of contaminants and is widely applied in seawater and brackish-water desalination as well as advanced potable-water treatment ([Ahsan & Imteaz, 2019](#); [Li et al., 2009](#)). RO research has consequently expanded across membrane materials, fouling control, desalination, contaminant removal, and treatment-system development. The relevance of these technologies is particularly evident in Indonesia and Southeast Asia, where groundwater and surface water are widely used but may be affected by microbial, chemical, and physical contamination. Groundwater contamination, inadequate sanitation, and variability in drinking-water quality remain important challenges in Indonesian communities ([Cronin et al., 2017](#); [Kazama & Takizawa, 2021](#); [Kurniawan et al., 2024](#)). Household treatment and decentralized systems are therefore increasingly relevant where centralized infrastructure is difficult to establish ([Daniel et al., 2023](#); [Lawrencia et al., 2023](#)).

Despite the extensive development of RO technologies, the research landscape of RO for drinking-water treatment has not been sufficiently characterized in terms of publication growth, research themes, membrane technologies, water-source applications, and geographic distribution across countries with different technological and water-management contexts. Existing studies have largely focused on individual membrane materials, fouling mechanisms, desalination performance, or specific applications, providing detailed technical knowledge but limited understanding of how these research directions have evolved collectively. A bibliometric approach can therefore provide a systematic overview of the development, thematic structure, and application context of RO research and identify areas that remain comparatively underexplored. Therefore, this study aims to map the research landscape of reverse osmosis for drinking-water treatment by analyzing publication trends, citation patterns, geographic distribution, research themes, membrane technologies, and water-source applications. In addition, publication output for RO is descriptively compared with ozonation, activated carbon adsorption, and UV disinfection to contextualize the position of RO among major drinking-water treatment technologies.

LITERATURE REVIEW

Reverse osmosis (RO) is a pressure-driven membrane separation process widely developed for desalination and drinking-water treatment. Research has progressed from conventional polyamide thin-film composite membranes toward modified and nanocomposite membranes that seek higher permeability, selectivity, and fouling resistance ([Hailemariam et al., 2020](#); [Ritt et al., 2021](#); [Mohammed et al., 2023](#)). Fouling remains a major operational challenge, with biofouling, scaling, and organic deposition affecting flux and treatment reliability; recent work therefore emphasizes fouling mechanisms, pretreatment, membrane modification, and control strategies ([Hoek et al., 2022](#); [Akhondi et al., 2014](#)).

RO is strongly associated with seawater and brackish-water desalination, but recent studies also demonstrate applications in groundwater and other freshwater matrices. Advanced membranes have been investigated for saline-water treatment and contaminant removal, while riverbank filtration and membrane integration have expanded the drinking-water application context ([Liang et al., 2021](#); [Zhai et al., 2022](#); [Soriano et al., 2020](#)). Water-quality conditions, including chemical and microbial contamination, also influence the selection and applicability of drinking-water treatment technologies ([Yadav et al., 2022](#); [Kurniawan et al., 2024](#)). These studies show continuing technical development, but individual studies do not reveal how research themes, membrane technologies, water sources, and geographic contributions have evolved collectively.

Bibliometric analysis can address this gap by mapping publication trends, citation patterns, keyword relationships, and emerging research areas ([Donthu et al., 2021](#)).

RESEARCH METHODOLOGY

Data Source and Search Strategy

Bibliometric data were retrieved from OpenAlex between November and December 2025. The search targeted open-access, English-language research articles published from 1995 to 2025. The search structure was: full text = (“drinking water” OR “drinking water treatment” OR “potable water”); title and abstract = (“reverse osmosis” AND “membrane”) NOT “review”. Country filters were Indonesia, Singapore, the United States, India, Japan, and Thailand. The RO dataset contained 192 articles. Comparative datasets for ozonation, activated carbon, and UV disinfection used corresponding title-and-abstract terms and excluded review articles ([Donthu et al., 2021](#); [van Eck & Waltman, 2010](#)).

Screening and Inclusion Criteria

Retrieved records were manually screened using title, abstract, and bibliographic information. Articles were included when RO was evaluated as a treatment process or when the study directly addressed RO membrane performance, fouling, membrane materials, water purification, desalination, or contaminant removal relevant to drinking-water production. Review articles, conference papers, duplicate records, non-English publications, and studies in which RO was only mentioned as background were excluded. Studies focused exclusively on other membrane processes, including forward osmosis, membrane distillation, and ion concentration polarization, were also excluded unless RO was explicitly evaluated.

Data Extraction and Analysis

Metadata included publication year, citation count, authorship, journal source, and country of origin. Additional variables were manually coded from titles, abstracts, and author keywords. These variables included membrane type, water-source category, and treatment technology. Microsoft Excel was used to analyze publication-year distributions, citation statistics, top-cited publications, membrane categories, and water-source categories. VOSviewer was used to construct keyword co-occurrence, overlay, and density visualizations. The comparative datasets for ozonation, activated carbon, and UV disinfection were analyzed descriptively through publication counts

FINDINGS AND DISCUSSION

Publication Trends and Citation Landscape

The publication trend shown in Figure 1 indicates a clear expansion of reverse osmosis (RO) research for drinking-water treatment during the study period. Publication output was relatively limited before 2012, generally ranging from one to three articles annually. Growth became more apparent after 2012 and accelerated substantially from 2017, when 18 publications were recorded. The dataset reached its highest annual output of 20 publications in 2023, while publication activity remained relatively high in the surrounding years. This pattern indicates that RO research has developed from a comparatively limited research area into an increasingly active field, consistent with growing attention to desalination, water scarcity, contamination control, and advanced membrane technologies.



Figure 1. Publication trends of reverse osmosis research from 1995 to 2025 (OpenAlex)

The citation landscape provides additional insight into the development of the field. Table 1 presents the 20 most-cited publications identified in the OpenAlex dataset. Highly cited studies cover several aspects of membrane research, including RO desalination, membrane materials, biofouling, pretreatment, and contaminant removal. [Malek et al. \(1996\)](#), for example, addressed the design and economics of RO seawater desalination, while [Pang et al. \(2005\)](#) examined bacterial biofilm formation associated with RO membranes. More recent highly cited studies have emphasized advanced membrane materials and performance enhancement, including nanocomposite membranes and fouling-control strategies.

Table 1. Top 20 most-cited articles in reverse osmosis research (OpenAlex dataset)

Rank	Author	Title	Year	Citations	Reference
1	Chao Feng, K.C. Khulbe, Takeshi Matsuura, R. Gopal, Sharon Kaur, Seeram Ramakrishna, M. Khayet	Production of drinking water from saline water by air-gap membrane distillation using polyvinylidene fluoride nanofiber membrane	2007	289	(Feng et al., 2007)
2	Vijay Kher	End-stage renal disease in developing countries	2002	215	(Kher, 2002)
3	A. Malek, M.N.A. Hawlader, Johnny C. Ho	Design and economics of RO seawater desalination	1996	214	(Malek et al., 1996)
4	Chee Meng Pang, Pei-Ying Hong, Huiling Guo, Wen-Tso Liu	Biofilm Formation Characteristics of Bacterial Isolates Retrieved from a Reverse Osmosis Membrane	2005	203	(Pang et al., 2005)

Rank	Author	Title	Year	Citations	Reference
5	Bedanga Sapkota, Wentao Liang, Armin VahidMohammadi, Rohit Karnik, Aleksandr Noy, Meni Wanunu	High permeability sub-nanometre sieve composite MoS ₂ membranes	2020	168	(Sapkota et al., 2020)
6	Rong Yang, Hongchul Jang, Roman Stocker, Karen K. Gleason	Synergistic Prevention of Biofouling in Seawater Desalination by Zwitterionic Surfaces and Low- Level Chlorination	2013	162	(Yang et al., 2014)
7	Vittorio Albergamo, Bastiaan Blankert, Emile Cornelissen, B. Hofs, Willem Jan Knibbe, W.G.J. van der Meer, Pim de Voogt	Removal of polar organic micropollutants by pilot-scale reverse osmosis drinking water treatment	2018	160	(Albergamo et al., 2018)
8	Ebrahim Akhondi, Bing Wu, Shuyang Sun, Brigit Marxer, Weikang Lim, Jun Gu, Linbo Liu, Michael Burkhardt, Diane McDougald, Wouter Pronk, Anthony G. Fane	Gravity-driven membrane filtration as pretreatment for seawater reverse osmosis: Linking biofouling layer morphology with flux stabilization	2014	154	(Akhondi et al., 2014)
9	Shigeki Inukai, Rodolfo Cruz-Silva, Josué Ortiz- Medina, Aarón Morelos- Gómez, Kenji Takeuchi, Takuya Hayashi, Akihiko Tanioka, Takumi Araki, Syogo Tejima, Tōru Noguchi, Mauricio Terrones, Morinobu Endo	High-performance multi-functional reverse osmosis membranes obtained by carbon nanotube-polyamide nanocomposite	2015	133	(Inukai et al., 2015)
10	Cody L. Ritt, Timothée Stassin, Douglas M. Davenport, Ryan M. DuChanois, Ines Nulens, Zhe Yang, Adi M.	The open membrane database: Synthesis- structure- performance relationships of	2021	126	(Ritt et al., 2021)

Rank	Author	Title	Year	Citations	Reference
	Ben-Zvi, Naama Segev-Mark, Menachem Elimelech, Chuyang Y. Tang, Guy Z. Ramon, Ivo F.J. Vankelecom, Rhea Verbeke	reverse osmosis membranes			
11	Mohammed Kadhom, Weiming Hu, Baolin Deng	Thin Film Nanocomposite Membrane Filled with Metal-Organic Frameworks UiO-66 and MIL-125 Nanoparticles for Water Desalination	2017	123	(Kadhom et al., 2017)
12	Bumjoo Kim, Rhokyun Kwak, Hyukjin Kwon, Van-Sang Pham, Minseok Kim, Bader Al-Anzi, Geunbae Lim, Jongyoon Han	Purification of High Salinity Brine by Multi-Stage Ion Concentration Polarization Desalination	2016	106	(Kim et al., 2016)
13	Linyan Yang, Qianhong She, Man Pun Wan, Rong Wang, Victor W.-C. Chang, Chuyang Y. Tang	Removal of haloacetic acids from swimming pool water by reverse osmosis and nanofiltration	2017	104	(L. Yang et al., 2017)
14	Can Zeng Liang, Mohammad Askari, Looh Tchuin Choong, Tai-Shung Chung	Ultra-strong polymeric hollow fiber membranes for saline dewatering and desalination	2021	86	(Liang et al., 2021)
15	Eric M.V. Hoek, T. M. Weigand, Arian Edalat	Reverse osmosis membrane biofouling: causes, consequences and countermeasures	2022	84	(Hoek et al., 2022)
16	Bing Wu, Tino Christen, Hwee Sin Tan, Florian Hochstrasser, Stanislaus Raditya Suwarno, Xin Liu, Tzyy Haur Chong, Michael Burkhardt, Wouter Pronk, Anthony G. Fane	Improved performance of gravity-driven membrane filtration for seawater pretreatment: Implications of membrane module configuration	2017	78	(Wu et al., 2017)

Rank	Author	Title	Year	Citations	Reference
17	Álvaro Soriano, Charles E. Schaefer, Ane Urtiaga	Enhanced treatment of perfluoroalkyl acids in groundwater by membrane separation and electrochemical oxidation	2020	69	(Soriano et al., 2020)
18	Se-Keun Park, Jiang Hu	Assessment of the extent of bacterial growth in reverse osmosis system for improving drinking water quality	2010	67	(Park & Hu, 2010)
19	Montserrat Vera, Sandra M. Cruz, M. Rosa Boleda, José A. García Mesa, Jordi Martín-Alonso, Sandra Casas, Oriol Gibert, José Luis Cortina	Fluorescence spectroscopy and parallel factor analysis as a dissolved organic monitoring tool to assess treatment performance in drinking water trains	2017	66	(Vera et al., 2017)
20	Jincai Su, Sui Zhang, Ming Ming Ling, Tai-Shung Chung	Forward osmosis: an emerging technology for sustainable supply of clean water	2012	61	(Su et al., 2012)

The citation pattern therefore indicates that the intellectual development of RO research is strongly associated with desalination, membrane performance, fouling control, and material innovation. This pattern is consistent with the literature, which has increasingly emphasized advanced membranes and fouling mitigation ([Hoek et al., 2022](#); [Mohammed et al., 2023](#)). The present bibliometric analysis extends these studies by connecting these technical themes with their temporal, geographic, and water-source distributions, thereby showing how the field has developed collectively rather than through isolated technical studies.

Geographic Distribution of Research

The geographic distribution in Figure 2 demonstrates that RO research is concentrated among a limited number of countries. The United States contributes the largest number of publications, followed by India, Japan, Singapore, and Indonesia. The strong representation of the United States, Japan, and Singapore is consistent with their established research capacity in membrane science, desalination, and advanced water-treatment technologies. India also demonstrates substantial research activity, indicating strong scientific engagement despite continuing water-quality challenges.

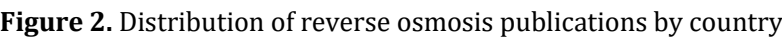




Figure 5. Density Visualization of research hotspots in reverse osmosis studies

Membrane Technologies and Water-Source Applications

The membrane distribution presented in Table 2 shows that thin-film composite (TFC) polyamide membranes represent the largest explicitly identified membrane category, followed by nanocomposite/nanomaterial-enhanced membranes and cellulose acetate membranes. The predominance of polyamide-based TFC membranes reflects the maturity of this membrane family in RO applications, while the presence of nanocomposite systems demonstrates continuing efforts to improve permeability, selectivity, and fouling resistance (Hailemariam et al., 2020; Mohammed et al., 2023). This distribution is consistent with recent research emphasizing polyamide and nanocomposite membrane development, while the present mapping additionally shows how these membrane trends are distributed across the broader RO research landscape (Ritt et al., 2021).

Table 2. Membrane types and number of associated reverse osmosis publications

Membrane Type	Number of Articles
Thin-film composite (TFC) – Polyamide	23
Cellulose acetate (CA)	12
Polysulfone (PSf)	2
Polyethersulfone (PES)	3
Polyvinylidene fluoride (PVDF)	2
Polytetrafluoroethylene (PTFE)	1
Ceramic / Inorganic membranes	6
Nanocomposite / Nanomaterial-enhanced membranes	16
Polymeric blends / Composite polymer membranes	1
Biopolymer / Natural polymer membranes	2
Silicone / Siloxane-based	1
Polycarbonate (PC)	1
Polyvinyl alcohol (PVA)	1
Other	121

A substantial proportion of the publications is classified as “Other”. This category indicates that many studies either did not provide sufficient membrane-material information or used membrane configurations that could not be consistently assigned to the defined material categories. Therefore, the explicitly identified membrane categories should be interpreted as the visible material trends within the dataset rather than as a complete representation of all membrane materials used in RO research. The water-source distribution in Table 3 demonstrates that seawater is the dominant application context, followed by brackish water and groundwater. River water and surface water also constitute substantial categories, whereas municipal and industrial wastewater occur less frequently.

Table 3. Water source categories and number of reverse osmosis publications

Water Source Category	Number of Articles
Seawater	59
Brackish water	30
Groundwater	23
Surface water	13
River water	17
Municipal wastewater	2
Industrial wastewater	3
Textile/tannery wastewater	1
Oil & gas produced water	9
Other	35

The dominance of seawater and brackish water confirms the strong relationship between RO and desalination. At the same time, the presence of groundwater, river water, and other freshwater matrices demonstrates that RO is increasingly considered for applications involving dissolved chemical contaminants and complex water-quality conditions. This diversity is relevant to Indonesia, where groundwater and surface water are important water sources and may be affected by microbial and chemical contamination ([Kurniawan et al., 2024](#); [Syahrir et al., 2024](#)).

Comparative Position of RO Among Drinking-Water Treatment Technologies

The comparative publication counts in Table 4 show that RO has the highest number of publications among the four technologies evaluated, followed by ozonation, granular activated carbon, and UV disinfection.

Table 4. Comparison of Reverse Osmosis, Ozonation, Granular Activated Carbon, and UV Disinfection Based on Publication Count (1995–2025)

Technology	Number of Publications (1995–2025)	Main Function in Drinking Water Treatment
Reverse Osmosis	192	Desalination
Ozonation	122	Disinfection
Granulated Activated Carbon	89	Adsorption
UV Disinfection	34	Microbial Inactivation

The difference in publication output provides an indication of research prominence rather than a measure of technological effectiveness. RO research is strongly represented because of its broad application in desalination and dissolved-contaminant removal, whereas ozonation,

activated carbon, and UV address more specific treatment functions. Ozonation is associated with oxidation and disinfection, activated carbon with adsorption of organic compounds, and UV with microbial inactivation. These functions can nevertheless complement RO within multi-barrier treatment systems, particularly where feedwater contains multiple contaminant classes (Marron et al., 2019; Summers et al., 2020). Overall, the findings demonstrate that the RO research landscape is characterized by sustained publication growth, strong concentration around membrane and desalination research, substantial attention to fouling and advanced materials, and dominant application in seawater and brackish-water treatment. The comparatively lower representation of decentralized systems, economic assessment, monitoring, and locally adapted treatment configurations indicates opportunities for future research.

CONCLUSION AND FURTHER RESEARCH

This study mapped the research landscape of reverse osmosis for drinking water treatment using 192 publications from 1995 to 2025. Publication output increased substantially after 2017 and peaked at 20 publications in 2023. Research focused mainly on membrane technology, desalination, fouling, nanotechnology, and polyamide membranes, while seawater was the dominant water source. RO also had the highest publication output among the compared technologies. The main contribution of this study is the integrated mapping of publication trends, research themes, membrane technologies, water sources, and geographic distribution, providing a broader view of RO research development than single-topic technical studies. For Indonesia, the findings indicate opportunities for locally adapted RO research involving feedwater characteristics, pretreatment, economic feasibility, and decentralized implementation. UPNVY can contribute by strengthening applied RO research and developing locally relevant treatment approaches, particularly through pretreatment, hybrid systems, monitoring, and optimization, supporting context specific solutions and SDG 6. The analysis was limited by the use of OpenAlex and predefined search, language, publication year, open-access, and country criteria. Manual classification may also limit detail, while technology comparisons reflected publication output rather than effectiveness, cost, or sustainability. Future studies should use multiple databases, broader geographic coverage, and more detailed classification.

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