

# MAPPING GLOBAL RESEARCH TRENDS IN GROUNDWATER QUALITY (2010–2025): A BIBLIOMETRIC PERSPECTIVE

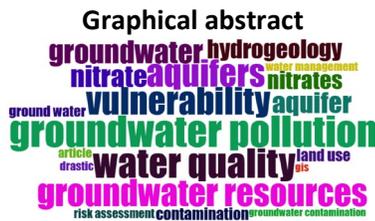
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## Abstract

Groundwater quality has garnered increasing attention as climate change intensifies its impact on water resources worldwide. This bibliometric study offers a comprehensive analysis of global research trends in groundwater quality from 2010 to 2025, focusing on the interplay between climate-induced stressors and freshwater systems. Utilizing Scopus-indexed literature and advanced bibliometric tools, the study examines publication patterns, identifies influential authors and institutions, and explores the evolution of key research themes. Through factorial analysis, the research uncovers conceptual structures shaping the field, while co-authorship networks reveal patterns of international collaboration and academic alliances. A thematic map provides insight into the maturity and relevance of research clusters, highlighting areas such as contaminant transport, hydrochemical modeling, and climate-resilient water management. The trend topic analysis pinpoints emerging themes, including microplastic pollution, extreme event-driven contamination, and AI-based groundwater monitoring techniques. Findings reflect a significant increase in interdisciplinary approaches that integrate climate science, environmental engineering, and public health. This study serves not only as a reference for researchers and policymakers but also as a strategic guide for future investigations aimed at mitigating climate-driven impacts on groundwater resources.

*Keywords:* Groundwater pollution, water quality, bibliometric analysis, trend

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## 1.0 INTRODUCTION

Groundwater serves as a critical source of drinking water and agricultural supply for billions globally, yet its quality is increasingly compromised by an evolving array of pollutants (Saimy and Raiji, 2015; Kura et al., 2018). Over the past decade, research has intensified around contaminants such as nitrates, heavy metals, pathogens, and emerging pollutants—including pharmaceuticals and microplastics—that pose significant threats to both human health and ecosystem integrity (Asadi et al., 2019; Ismanto et al., 2023). These pollutants enter aquifers through multiple pathways, including land-use change, industrial discharge, agricultural runoff, and evolving hydrological stressors.

Since 2010, the scientific response to groundwater pollution has expanded rapidly across disciplines, embracing

advances in hydrogeological modeling, geochemical analysis, and remote sensing. However, understanding the spatiotemporal dynamics of groundwater contaminants remains challenging due to the heterogeneity of aquifer systems and the diffuse, often site-specific nature of pollution sources (Bose et al., 2023). Furthermore, global research efforts remain uneven, with notable disparities in regional emphasis, thematic coverage, and collaboration density.

The primary objective of this study is to conduct a comprehensive bibliometric analysis of research on the impact of climate change on water quality published between 2010 and 2025. By systematically reviewing the academic literature, this analysis seeks to identify key trends, influential researchers and institutions, and emerging research areas. The study will employ bibliometric techniques, including co-authorship networks, citation analysis, and topic trend analysis, to uncover

how research priorities have evolved over the past decade. These findings aim to inform future research agendas, foster international collaboration, and guide the development of innovative, climate-resilient strategies to mitigate the adverse effects of climate change on water quality.

This study employs a bibliometric approach to systematically analyze the evolution of groundwater pollution research between 2010 and 2025. By extracting data from the Scopus database, the study maps publication trends, identifies influential authors and institutions, and explores emerging thematic areas through factorial analysis, collaboration networks, and trend topic mapping. The aim is to illuminate the conceptual, institutional, and geographical architecture of the field, offering clarity on prevailing research orientations and gaps.

Findings are expected to guide future investigations toward more integrated and adaptive groundwater quality strategies—particularly in regions facing compounding pressures from pollution and hydrological uncertainty. By synthesizing the global research landscape, this study contributes actionable insights for scientists, policymakers, and stakeholders seeking to safeguard one of the planet’s most vital but vulnerable resources.

## 2.0 METHODOLOGY

This study employs bibliometric techniques to systematically evaluate global scientific literature related to groundwater quality and pollution between 2010 and 2025. The methodology consists of several key stages designed to ensure the rigor and depth of the analysis:

1. **Data Collection:** A targeted search will be conducted in the Scopus database, focusing on keywords such as “groundwater pollution,” “groundwater quality,” “contaminants,” “aquifer,” and “emerging pollutants.” Inclusion criteria encompass peer-reviewed journal articles, review papers, and conference proceedings published between 2010 and 2025. The search strategy will be refined using Boolean operators and keyword co-occurrence to maximize relevance and coverage.
  2. **Data Preprocessing:** The gathered data will undergo preprocessing to guarantee precision and uniformity. This involves eliminating duplicates, filtering out unrelated publications, and validating metadata—including authors, affiliations, keywords, and publication dates. Each entry will be reviewed for thoroughness prior to analysis.
  3. **Bibliometric Analysis:** The preprocessed data will be analyzed using bibliometric techniques, including:
    - Co-authorship network analysis to map collaborative patterns between institutions and researchers
    - Citation analysis to identify highly influential publications, authors, and journals
    - Keyword co-occurrence analysis to detect core themes and emerging topics such as nitrate contamination, pharmaceutical pollutants, heavy metals, and aquifer vulnerability
    - Factorial analysis to explore the conceptual structure and intellectual organization of the field
  - Thematic mapping to classify research clusters based on centrality and density—distinguishing niche topics from well-developed areas
  - Trend topic analysis to visualize the temporal evolution of specific pollutants, modeling approaches, and monitoring technologies.
4. **Interpretation:** Visual outputs such as strategic diagrams, collaboration maps, and conceptual frameworks will be used to interpret the structure and progression of groundwater pollution research. Emphasis will be placed on identifying geographic and institutional research patterns, disciplinary intersections, and conceptual shifts over time.
  5. **Discussion:** The study’s findings will be discussed about the implications for policy development, research prioritization, and providing strategic guidance for pollution mitigation and groundwater protection policies. The gaps identified through this analysis will provide a roadmap around emerging contaminants and integrated monitoring techniques

By employing this robust bibliometric framework, the study will offer deep insights into the global research landscape of groundwater pollution, facilitating evidence-informed decisions for sustainable groundwater resource management (Gao et al., 2023). Software like R Studio enables comprehensive analysis of research trends and academic collaborations, supporting data-driven policy development for sustainable water resource planning (Bhat et al., 2023).

## 3.0 RESULTS AND DISCUSSIONS

### 3.1 Publications

From January 2010 to Jun 2025, a total of 166 papers were published (151 journal articles, 6 conference proceedings, 4 review papers and 5 other type of publications). Over this 15-year period, research exploring the link between climate change and water quality exhibited a steady but modest upward trajectory (Figure 1a). The number of publications increased from just 5 in 2010 to 16 in 2025, reflecting a gradual expansion of scholarly attention toward climate-induced water quality challenges. The early years (2010–2013) saw low and fluctuating activity, with yearly outputs ranging from 4 to 8 articles, suggesting an emerging research interest. The most notable growth periods occurred in 2016-2017 increasing from 7 to 17, possibly driven by mounting global emphasis on integrated water resource management under climatic uncertainty.

From 2010 to 2025, the bibliometric analysis revealed several prominent journals actively publishing research related to groundwater quality and pollution (Figure 1b). Among these, *Environmental Earth Sciences* led with 18 articles, underscoring its role as a multidisciplinary platform for hydrogeological and contaminant transport studies. Closely following was *Science of the Total Environment* with 17 publications, reflecting its status as a key outlet for high-impact, cross-sectoral research on water pollution under changing environmental conditions. Together, these sources represent a diverse and multidisciplinary publication landscape, spanning global research efforts on groundwater vulnerability, remediation

strategies, contaminant mapping, and climate-resilient water resource planning.

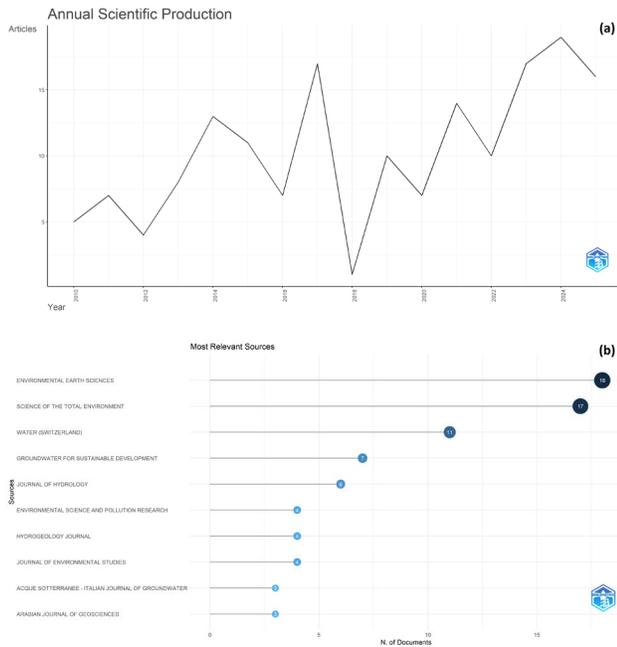


Figure 1: Publication details from 2010 to 2025 (a) Annual Scientific production and (b) Most relevant sources

Figure 2a highlights a group of authors who have played a recurrent role in advancing research at the intersection of climate change and water quality pollution. Among these, MASETTI M leads with 4 publications, followed by nine authors each contributing 3 articles, including LI Y, who notably appeared in the previous dataset as well. Authors such as BARTZAS G, JANG CS, KOMNITSAS K, and NADIRI AA reflect sustained research involvement across environmental geochemistry, hydrological modeling, and groundwater quality. Their repeated presence indicates focused academic investment in water resources under climatic variability.

A deeper evaluation of these authors' bibliographic impact—such as h-index trends, average citations per paper, and research network linkages—would further clarify their influence on the scientific discourse shaping this field.

Figure 2b showcases globally cited references that span diverse disciplines including hydrology, geochemistry, ecotoxicology, and environmental safety, reinforcing the interdisciplinary nature of climate-driven water quality degradation. The study by Neshat et al. (2014) emerged as the most influential, registering 209 citations and a robust citation rate of 17.42/year. The work's longevity and reach suggest that it addressed foundational concerns in groundwater vulnerability and contaminant transport under climate pressures. Similarly, Shrestha et al. (2016) and Lapworth et al. (2017), both published in *Science of the Total Environment*, accumulated 152 and 150 citations respectively, with strong annual citation rates above 15. These papers may have integrated empirical monitoring with predictive modeling—approaches increasingly critical in water policy and risk management frameworks.

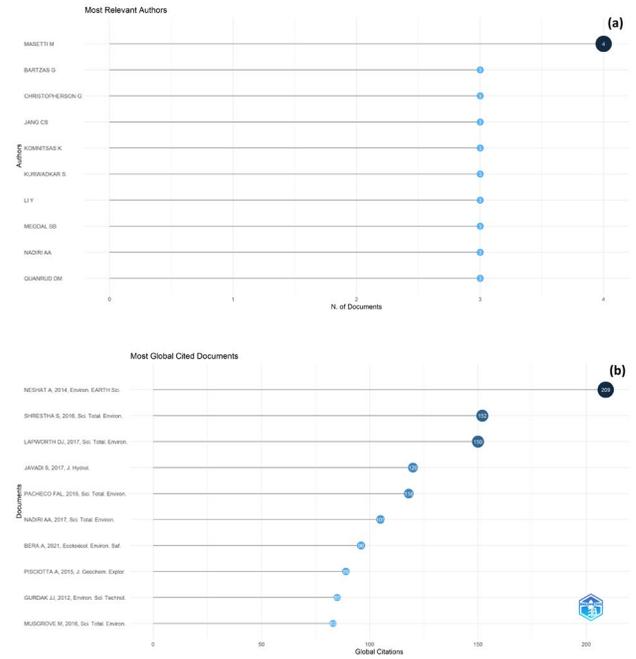


Figure 2: (a) Most relevant authors and (b) Most globally cited documents

### 3.2 Factorial analysis

In the social sciences, psychology, and data mining, factor analysis (or factorial analysis) is a statistical method used to identify patterns and simplify complex datasets. It helps uncover underlying relationships among multiple variables by grouping them into fewer, more interpretable components (Watkins, 2021). In groundwater and water quality research, factor analysis reveals a tightly integrated conceptual landscape, with all terms forming a single cohesive cluster (Figure 3). This unified structure demonstrates the field's strong thematic interconnectedness, where fundamental concepts and applied research directions maintain robust relationships. Dim1 represents a spectrum from broad conceptual terms to specialized technical keywords. Foundational concepts like "vulnerability" (-0.14) and "groundwater" (-0.22) anchor the field, while mid-range terms such as "nitrate concentration" (-0.41) and "hydrogeology" (-0.34) represent transitional technical themes. At the far extremes, highly specialized terms like "chemical" (-1.77) and "water pollutants" (-1.77) mark focused research domains. Dim2 distinguishes between studies focused on natural environmental processes and those employing controlled or modeled approaches. Terms like "aquifer vulnerability" (-0.75) and "contamination" (-0.58) cluster on the environmental process side, while "environmental monitoring" (1.01) and "water pollution" (0.62) reflect analytical and policy-oriented research. Transitional terms such as "groundwater" (0.18) and "aquifer" (0.13) bridge both orientations. The analysis also identifies key thematic groupings within the cluster. Core hydrogeological concepts ("groundwater resources," "aquifers," "recharge") form a tight subgroup, while pollution-related terms ("nitrate contamination," "aquifer pollution") dominate the environmental process quadrant. Methodological terms ("GIS," "sensitivity analysis") appear as distinct outliers, and policy-

applied concepts ("water management," "risk assessment") occupy transitional spaces between theory and practice. Notably, the positioning of terms like "ground water" (-1.42, 0.53) versus "groundwater" (-0.22, 0.18) suggests meaningful distinctions in usage between general and technical literature. The strong integration of monitoring ("environmental monitoring") with pollution studies ("chemical") and the conceptual bridges between natural processes ("recharging") and human impacts ("agriculture") underscore the field's interdisciplinary nature.

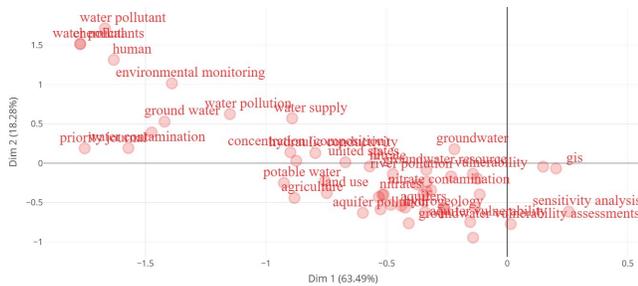


Figure 3 Factorial analysis

3.3 Collaboration Network

A collaboration network, often termed a co-authorship network (Lei et al., 2021), is a graphical model depicting the interactions and cooperative relationships between individuals, groups, or organizations based on their shared contributions to a specific domain, research initiative, or publication corpus. These networks are widely utilized in academic and scientific contexts to reveal patterns of collaboration among scholars, authors, or institutions. By analyzing such networks, researchers can gain valuable insights into collaborative structures, knowledge exchange pathways, and institutional influence within a given research ecosystem. Furthermore, these visualizations offer a lens into how entities align their efforts to foster innovation and intellectual growth within a thematic field.

In Figure 4, each node represents an individual researcher or contributor actively engaged in the collaborative landscape, while cluster membership denotes the grouping of nodes into distinct clusters—each reflecting shared thematic or institutional connections. Researchers are grouped into 13 distinct clusters, each reflecting collaboration intensity and thematic cohesion. Betweenness centrality quantifies how frequently a node lies along the shortest paths linking other nodes within a network. Nodes exhibiting high betweenness serve as vital connectors, bridging different segments of the network. In contrast, closeness centrality evaluates a node's overall proximity to all others, with elevated values signifying strong integration and efficient information propagation. The collaboration network reveals a well-structured and densely interconnected research landscape, where prominent nodes facilitate knowledge exchange across diverse institutions and thematic areas. In Cluster 1, RE V and Sacchi E demonstrate the highest betweenness centrality (2.0), making them key intermediaries within the cluster. This suggests a bridging role in connecting otherwise dispersed collaborators. - Nodes like Faye S, Gaye CB, Mas-Pla J, and Menció A show moderate closeness, implying cohesive internal connectivity but limited

outreach capacity beyond the cluster. While in Cluster 4, Masetti M stands out with a betweenness centrality of 1.143 and the highest PageRank (0.035), positioning him as a central influencer capable of facilitating cross-cluster collaborations. Dense clusters such as Clusters 1 and 4 likely drive core interdisciplinary themes such as pollutant transport, hydrological modeling, and climate-adaptive water strategies. Smaller clusters enhance the system's resilience, allowing innovation to emerge from focused investigations.

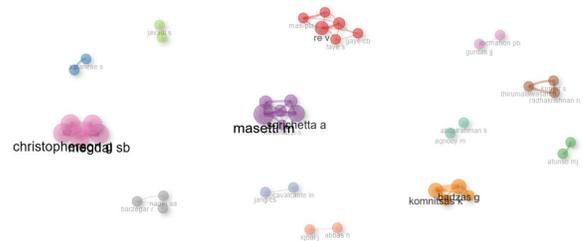


Figure 4 Collaboration Network

3.4 Thematic Map

A thematic map visually represents spatial patterns or relationships across different geographic areas, focusing on a specific theme or subject. The defining characteristic of these maps is their use of colors, symbols, or other graphical elements to convey data, enabling viewers to quickly interpret the presented information. The thematic map in Figure 5 identified these clusters reflect dominant academic preoccupations across pollution dynamics, groundwater systems, and vulnerability assessment. These clusters represent the dominant areas of research focus, as illustrated by the high frequency of keyword occurrences, centrality metrics, and interrelations among various sub-topics.

The largest and most central thematic group revolves around "groundwater pollution", "water quality", and "nitrate"—keywords that dominate both occurrence and network influence. Terms like "aquifers", "groundwater resources", and "groundwater" exhibit strong centrality values, indicating their pivotal role in framing both theoretical foundations and applied studies within this domain. High betweenness centrality scores, such as 54.803 for "groundwater" and 17.657 for "nitrate", show that these terms serve as conceptual bridges across multiple subfields—linking pollution concerns with aquifer vulnerability and hydrogeological modeling. This cluster underscores the urgency of managing contaminant migration, nutrient leaching, and aquifer degradation in light of expanding agricultural and industrial pressures.

A second thematic zone centers on keywords like "environmental monitoring", "water pollution", and "water supply". While slightly less dominant in raw occurrences, this cluster has exceptionally high betweenness centrality values—such as 207.662 for "environmental monitoring" and 177.833 for "water pollution"—emphasizing their integrative role across studies concerned with tracking pollution sources, public health, and sustainable access. The presence of generic terms like "article" and "ground water" (distinct from "groundwater") suggests the cluster may also represent a methodological or bibliographic dimension—capturing how monitoring tools and

publication outputs contribute to knowledge dissemination in the field.

The third cluster focuses on vulnerability assessment, featuring terms like “contamination”, “groundwater vulnerability”, and “risk assessment”. With strong linkage values—e.g., 169.202 betweenness for “groundwater vulnerability” and 165.642 for “contamination”—this cluster encapsulates the analytical backbone of predictive and scenario-based groundwater quality modeling. Here, research tends to emphasize hazard mapping, aquifer sensitivity under climate change, and decision-support tools for resource management. The conceptual cohesion between vulnerability and contamination highlights growing interest in proactive groundwater protection strategies and spatial risk diagnostics. All these clusters reflect a comprehensive and interconnected research ecosystem, where pollution studies (Cluster 1), monitoring systems (Cluster 2), and vulnerability modeling (Cluster 3) form the scaffolding of global groundwater research. The high centrality and integrated nature of these themes demonstrate a maturing scholarly focus on safeguarding subsurface water systems amid climatic and anthropogenic pressures.

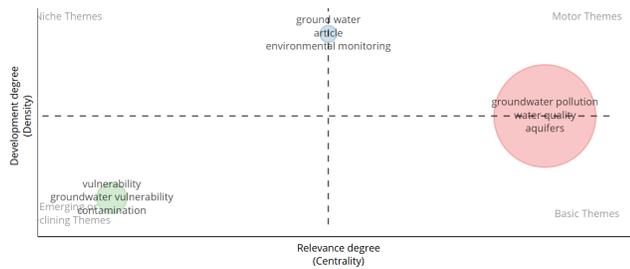


Figure 5 Thematic map

### 3.5 Trend Topic

Figure 6 presents a graphic depiction of topic evolution based on a temporal distribution of frequently occurring terms in water quality and climate resilience literature between 2010 and 2025. The analysis reveals several distinct phases, each reflecting a shift in thematic priorities and methodological advancements.

Between 2011 and 2014, the discourse was shaped by emerging concerns surrounding fertilizer application, coastal waters, and nitrate—underscoring the foundational recognition of agricultural inputs and salinity stressors in coastal and unconfined aquifer systems. The term seasonal variation (median: 2014) also gained traction, reflecting efforts to characterize temporal fluctuation in pollutant concentrations.

From 2014 onward, research themes matured to include comprehensive references to agriculture, salinity, pollution, drinking water, and groundwater geochemistry. This stage marks a turning point, with rising scholarly interest in agricultural runoff’s impact on water ecosystems, seen in increased mentions of nitrate, nitrates, and nitrate concentration (medians around 2017–2022).

Starting in 2016, the vocabulary shifted toward vulnerability, groundwater vulnerability, contamination, and land use, reflecting concerns over groundwater exposure to pollutants and the need for robust spatial risk frameworks. The rise of

terms like drastic, risk assessment, and groundwater vulnerability assessment illustrate the development of predictive tools and multi-criteria approaches.

The most recent stage captures a technological and ecological pivot (2020-2025). The emergence of drastic model (median: 2023), runoff, and health risks signifies efforts to assess climate-driven water quality changes, especially in vulnerable regions such as Morocco. The appearance of machine learning in 2024 as a frontier term marks the consolidation of AI applications in hydrological and contamination modeling. This progression reflects the growing fusion of computational techniques and environmental diagnostics, enabled by better data infrastructure and increased interdisciplinary collaboration.

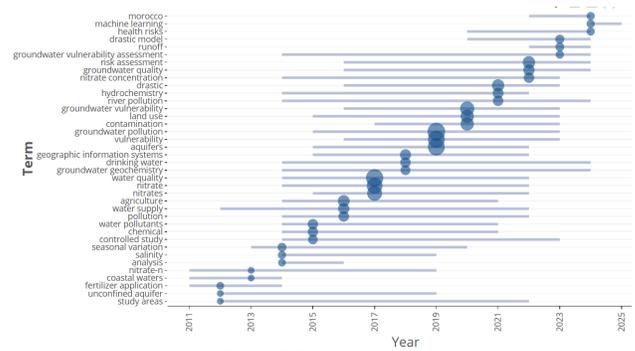


Figure 6 Trend topics

## 4.0 CONCLUSIONS

The bibliometric analysis of groundwater quality research from 2010 to 2025 underscores a dynamic evolution in scholarly focus, reflecting both disciplinary growth and increasing global concern over water security. Initial research efforts were dominated by foundational themes such as aquifer characterization, basic pollutant dynamics, and hydrological assessment. However, as the complexities of climate change, land use transformation, and agricultural intensification became more pronounced, academic discourse has pivoted toward more integrative and impact-driven inquiries.

Thematic cluster analysis revealed a consolidation of research around three dominant areas: groundwater pollution, environmental monitoring, and vulnerability assessment. Each cluster has shown increasing conceptual depth, with central terms such as groundwater, nitrate, and contamination acting as connective hubs across interdisciplinary investigations. The sustained prominence of agriculture, runoff, and land use within trend topic timelines reinforces the growing awareness of anthropogenic drivers in water quality degradation.

Importantly, recent years have seen an uptake in advanced methodologies—ranging from GIS-based mapping and hydrochemical modeling to machine learning applications and risk diagnostics—indicating a methodological maturation in the field. This evolution reflects not only technological advancement but also the pressing need for predictive tools that can guide policy and management under uncertain climatic futures.

As nutrient loading, drought stress, and regional vulnerabilities continue to shape hydrological realities, future research must prioritize holistic watershed management,

adaptive modeling frameworks, and the resilience of groundwater systems to extreme climatic events. A deeper integration of climate scenarios with contamination pathways will be essential to safeguard water resources, ensure ecosystem functionality, and support sustainable development goals in vulnerable regions across the globe.

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### Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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