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Drainage System Optimization as an Effective Flood Management Strategy in Urban Regions: A Systematic Review Utilizing PRISMA

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ABSTRACT

Flood disasters cause significant damage and losses in various cities around the world. One of the contributing factors is poor drainage system management. This literature review study aims to explore the effectiveness of drainage systems in addressing flood problems in major cities across the globe. The study utilizes a systematic literature review design with the PRISMA method. Data is sourced from the Scopus database. The document analysis process involves several stages: identification, screening, eligibility, and inclusion, ultimately resulting in 25 articles that align with the objectives of this study. The results indicate that there are three aspects to optimizing drainage systems as an effective flood management strategy in major cities: 1) Smart Technology-Based Drainage System Management, 2) Policy and Regulation-Based Drainage Management, 3) Community and Social Adaptation-Based Drainage Management, and 4) Geomorphology and Natural Process-Based Drainage Management. This literature review is expected to provide practical recommendations for improving drainage systems to be more adaptive and sustainable in addressing increasingly complex flood challenges in the future, particularly in Indonesia.

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Introduction

Flooding is a global problem that continues to cause significant losses, particularly in large cities experiencing rapid urbanization and intensifying climate change. In Indonesia, major cities such as Jakarta, Medan, and Surabaya have long faced the threat of devastating annual flooding. Jakarta, in particular, experienced major floods in 2002, 2007, 2013, 2014, and 2020, causing billions of dollars in direct and indirect economic damage and significant social upheaval (Cempaka, 2024). One of the main factors causing flooding in the city is the inability of existing drainage systems to handle the increasing volume of rainwater, which is exacerbated by rapid urbanization and climate change. Conventional drainage systems, which rely on a "flow and discharge" approach, are no longer adequate to address the complexities of urban flooding. Therefore, a more adaptive and sustainable approach to drainage management is needed to mitigate the impact of flooding and increase the city's resilience to these disasters. Flooding in Indonesia is caused not only by natural factors, such as extreme rainfall, but also by anthropogenic factors, particularly rapid urbanization and inadequate drainage management. Conventional drainage systems that rely on open channels and drainage pipes often experience blockages, damage, or insufficient capacity to accommodate large amounts of rainwater runoff. This problem is exacerbated by sedimentation, which reduces the drainage channel capacity, and poorly planned infrastructure development. Increased surface runoff due to urbanization makes urban drainage systems unable to cope with the volume of water available, leading to flooding and degraded groundwater quality (Yeom & Ahn, 2024)

Furthermore, climate change has affected rainfall patterns by increasing the intensity and changing the duration of rainfall events, causing extreme rainfall that far exceeds the capacity of existing drainage systems. Kusumastuti et al. (2015) conducted research in Ambon and showed how consecutive heavy rainfall events over a specific period can increase flood risk, despite the presence of drainage systems. Therefore, drainage management must adapt to climate change and consider more sustainable and innovative approaches to managing water flow in large cities.

Several studies have identified key problems in urban drainage management in Indonesia. A similar situation was found in Mataram, where the existing drainage systems were unable to accommodate rainwater runoff, leading to frequent flooding. On the other hand, in Jakarta, research by Pratiwi et al., (2020) showed that sedimentation in drainage channels further deteriorates the existing drainage capacity, leading to local flooding.

Several innovative approaches have emerged to address these issues. One such approach is the implementation of Green Infrastructure (GI), which has shown positive results in reducing runoff in Jakarta (Nugroho et al., 2019). An ecological drainage system using green infrastructure, such as city parks and water catchment areas, can reduce the volume of rainwater runoff, which often causes flooding. Furthermore, the Blue-Green Infrastructure (BGI) approach implemented in Surabaya uses a combination of green and blue infrastructure to manage rainwater more efficiently and in an environmentally friendly manner (Harlis & Seo, 2024). The drain tube system used in Bali also offers an innovative solution by optimally capturing and diverting runoff.

This literature review explores the effectiveness of sustainable drainage systems in addressing flooding in major cities worldwide. This study is expected to provide practical recommendations for improving drainage systems to be more adaptive and sustainable in the face of increasingly complex flooding challenges in the future, particularly in Indonesia.

Methodology

A systematic literature review approach was chosen to interpret drainage systems as an effective flood management strategy for large cities. One reason SLR has become such a popular method is that it allows for transparent literature reviews, where the quality and breadth of the results can be assessed (Priharsari, 2022; Rowley & Keegan, 2020). The data search involved several processes: identification, screening, eligibility, and inclusion. The identification stage was carried out using the single keyword "flood drainage" to obtain specific and focused literature coverage on the theme of drainage systems for flood control. The literature search was conducted through the Scopus database from 1980 to 2025, resulting in 119 articles that met the basic search criteria. The next process involved screening the 10 most recent publications. Articles published outside the 2016–2025 timeframe were excluded, reducing the number of articles to 79. In the next stage, screening was conducted to ensure a focus on drainage systems for flood management. Irrelevant articles, such as those focused on medicine, biochemistry, chemistry, accounting, art, and astronomy, were excluded, leaving 62 articles that met our criteria.

Next, an eligibility stage was conducted, where articles were assessed based on the availability of clear methodologies (e.g., the use of hydrological models or IoT technology), a primary focus on drainage systems and flood management, and availability in accessible languages, with priority given to English language articles. Of the 62 articles that passed the previous stage, 34 did not meet these criteria, leaving only 28 articles eligible for further analyses. In the inclusion stage, an in-depth analysis of these 28 articles was conducted, with three articles excluded due to insufficient data or duplication, leaving 25 articles for further analysis. This rigorous selection process revealed that only 25 articles (21%) met all the inclusion criteria, providing a strong basis for exploring drainage system models for flood management in major cities worldwide. The article selection process using the PRISMA approach is illustrated in Figure.

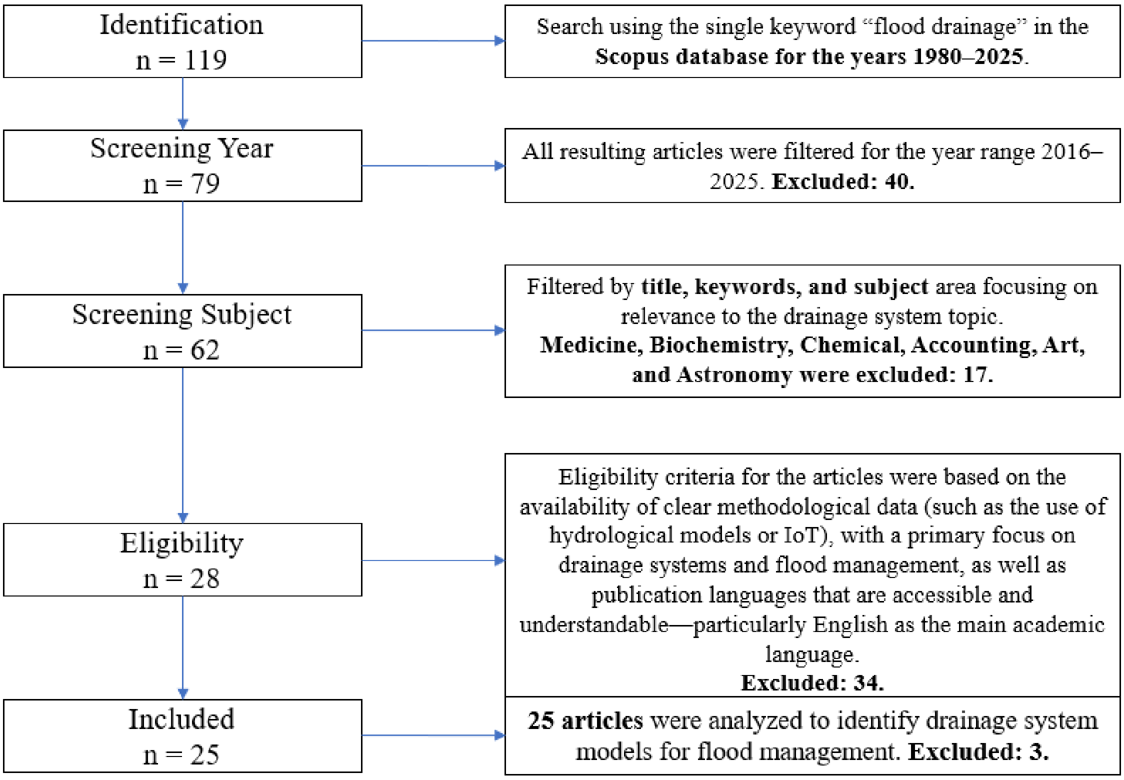

Figure 1. PRISMA Flow Diagram pada Scopus Search Document

Result and Discussion

Smart Technology-Based Drainage System Management

Flooding in large cities is often a complex and destructive problem, especially with increasing urbanization and climate change. Smart technology-based drainage management is an increasingly popular solution for flood management. Smart technology enables real-time flood monitoring and detection, which is crucial for reducing the impact of floods and improving preparedness. As discussed in Arash (2025), real-time data allow flood patterns to be analyzed and early warning predictions provided to the public and government, allowing for faster mitigation measures.

Furthermore, drainage infrastructure, such as canals, drains, and stormwater drainage systems, is increasingly being modernized using data-driven technology. Vu et al. (2024)

suggested three structural measures to reduce the impact of flooding: (1) building new culverts, (2) dredging existing rivers, and (3) constructing new flood-drainage canals. The goal of these measures is to mitigate the impact of flooding in residential areas that frequently experience inundation, as shown in Figure 2.

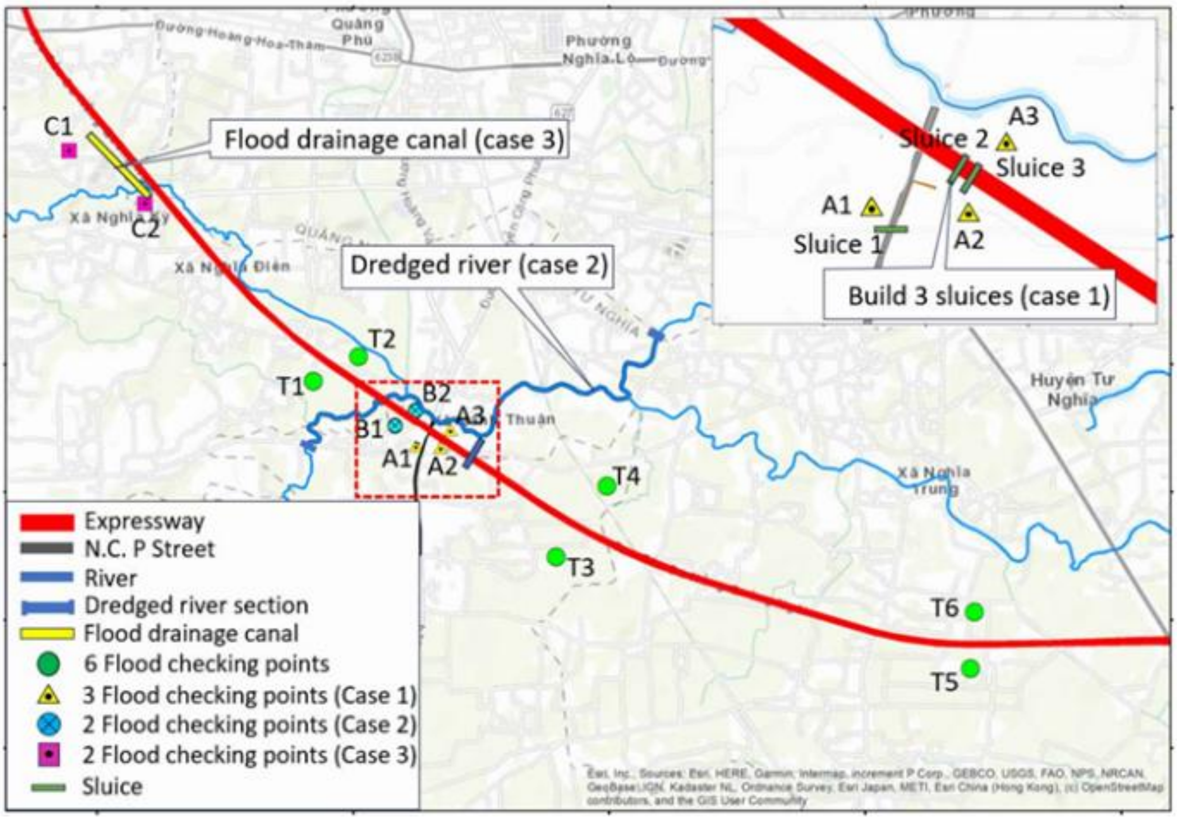

Figure 1. Flood Mitigation Sites in the Tra Khuc–Ve River Basin, Vietnam (Vu et al., 2024)

The use of hydrodynamic models, such as Delft3D, allows for a more in-depth analysis of the influence of estuary morphology on flood flow and drainage. This technology helps design more efficient drainage management by considering sedimentation and estuary deformation. This is particularly important in flood-prone coastal areas, where morphological changes can affect natural drainage capacity and exacerbate flood impacts (Hung et al., 2024).

In the context of infrastructure management, an integrated hydro-hydraulic model was used to evaluate the impact of infrastructure on the drainage system in the Kone-Ha Thanh River Basin in Vietnam (Hung et al., 2024). This model showed that major roads were a barrier to flood drainage, with existing culverts unable to handle floods of the intended intensity. This study emphasizes the importance of drainage infrastructure planning that considers flood potential, as well as the need for adjustments in infrastructure design to mitigate flood impacts. However, technology can also be used to address other issues in drainage systems, such as pressurization in sewers. The pressurization process in sewers can be improved by understanding the flow and pressure that occur, which in turn reduces problems in urban drainage systems (Montes et al., 2022). With this technology, large cities can reduce the risk of damage to the drainage infrastructure and increase the resilience of the system to flooding.

Furthermore, the use of artificial intelligence (AI) has significantly contributed to the design of stormwater detention facilities in large cities. Yang et al. (2019) demonstrated how AI can be used to design multi-objective pump management to manage flood drainage by improving the operational efficiency of pumping stations during storm events. This technology enables more efficient drainage resource management and is responsive to extreme weather changes in the area.

Finally, a more integrated drainage corridor design can reduce the impact of flooding, as proposed by Hoang and van Ann (2019) in Da Nang City, Vietnam. This approach involves developing drainage corridors through physical planning, including widening river channels, providing protection along riverbanks, and constructing new drainage channels. Using mathematical models, GIS, and hydrometeorological data, the proposed drainage system can reduce flooding in Da Nang by 5-10%, which is part of a climate change adaptation strategy. Thus, the integration of smart technology into drainage systems can optimize flood disaster management. In the context of Indonesian implementation, the approach is gradually becoming more realistic, such as using GIS technology and relatively simple hydraulic models to prioritize corridor widening, riverbank protection, and new channel construction in the short term, and gradually integrating more advanced simulation platforms and AI-based decision-making support as data availability, institutional capacity, and funding increase. Thus, integrated drainage corridor design combined with context-appropriate smart technology can optimize flood disaster management while remaining feasible in developing countries.

Policy- and Regulation-Based Drainage Management

Policy- and regulation-based drainage management plays a crucial role in addressing the increasingly complex problem of flooding, particularly in densely populated cities. A crucial aspect of drainage management is the allocation of drainage rights, which ensures that floodwaters are managed equitably and efficiently across the region. This is linked to policies that consider not only technical aspects but also the social and economic factors influencing floodwater distribution and access to the necessary infrastructure. For example, in Barcena (2025), flood-drainage management focused not only on infrastructure development but also on social and political changes in the city. Drainage projects have played a role in social transformation, creating space for community participation in the planning and implementation of infrastructure policies. This demonstrates that drainage management can be an arena for changing social and political relations, ultimately improving social justice and access to public infrastructure in the area.

Furthermore, the concept of flood-drainage rights (FDR) is crucial in policy- and regulation-based drainage management. FDR refers to a region's right to drain floodwater into rivers based on applicable laws and regulations. FDR allocation is used as part of a sustainable flood management policy that considers economic, social, and environmental factors. This approach not only manages floodwater discharge more equitably but also optimizes the allocation of drainage resources, which is crucial in the face of climate change, which can increase the flood intensity and frequency (Huang et al., 2024).

Policy- and regulation-based drainage management must also consider a more inclusive and community-based approach (Ket et al. 2024). This study criticized the ineffective use of top-down warning systems and suggested an approach that better engages local communities in flood-risk management. This suggests that policies prioritizing public awareness and active participation are more effective in mitigating flood impacts. Policy- and regulation-based approaches also utilize advanced technologies such as deep learning to optimize the allocation of flood-drainage rights in flood-prone areas (Zhang et al., 2022). The use of deep learning to allocate FDR provides a more efficient solution for floodwater management, particularly in areas vulnerable to climate change and urbanization. Zhang et al., (2021) also emphasize the importance of fairness in the management of drainage rights in river basins. Using a harmonic allocation method, this study proposes a way to resolve conflicts between competing regions over flood-water discharge management. This approach optimizes the distribution of floodwater discharge rights to ensure that each region receives drainage rights appropriate to its local conditions and flood-management capacity.

Overall, policy- and regulation-based drainage management encompasses not only the planning and design of drainage infrastructure but also equitable distribution of floodwater discharge rights. Through policies that integrate social, economic, and environmental factors, along with advanced technologies such as floodwater discharge rights and deep learning, drainage management can become more efficient and sustainable. Inclusive and community-based policies will ensure better preparedness and response to flood disasters, especially in densely populated megacities that are vulnerable to the impacts of climate change. In the context of Indonesia, flood-drainage rights (FDR) policies can be implemented by integrating them into spatial planning regulations, building standards, and watershed management plans. The combination of strict flood-drainage rights (FDR) regulations and the use of technology for real-time flood forecasting and system optimization can make drainage management more efficient, equitable, and sustainable, particularly in densely populated metropolitan areas such as Jakarta, which are increasingly vulnerable to the impacts of climate change and urbanization.

Community-Based Drainage Management and Social Adaptation

Community-based drainage management and social adaptation are important approaches to address flooding, particularly in areas vulnerable to flooding, such as dense urban areas and informal settlements. This approach emphasizes the importance of community participation in the planning and management of sustainable drainage systems, where communities are not merely policy objects but also active subjects adapting to social and environmental changes. One example of this approach is the study by Fox et al. (2023). In this study, communities in informal settlements conducted re-zoning or re-blocking to reduce flood risk and improve drainage systems in their neighborhoods. This demonstrates that active community involvement in designing drainage solutions is crucial for creating effective systems that meet local requirements.

Although more focused on infrastructure, To et al. (2022) emphasized the importance of policy and community participation in flood risk management. This research demonstrates that adaptation to changing watershed management patterns must involve local communities to mitigate the impacts of flooding, particularly in areas affected by rapid urbanization. Communities involved in decision-making will better understand their needs and can contribute to creating more effective and sustainable solutions.

In terms of community-based flood risk management, a study conducted in China showed that regions with a better capacity to manage waterlogging risk tend to have better infrastructure and are better prepared to deal with flood disasters (Liu et al., 2021). The use of analytical methods, such as TOPSIS-PCA, to assess each province's capacity to manage waterlogging risk allows for a data-driven approach to drainage management, capacity evaluation, and regional preparedness.

Other studies, such as Dai et al. (2021), assessed the importance of inlet grate design in urban drainage systems for reducing waterlogging. The results of this experiment highlighted that drainage system efficiency is significantly influenced by appropriate inlet design, which is also part of adapting to the physical conditions of the city and the needs of the local community. In this context, drainage designs that consider local characteristics will be more effective in addressing waterlogging problems in urban areas that frequently experience flooding. Public awareness also plays a crucial role in flood risk management. Chacowry (2016) revealed how media coverage can influence public perceptions of flood risk and educate people about the importance of disaster adaptation. This study shows that effective communication can increase public awareness of flood risk management and encourage them to be more actively involved in disaster mitigation efforts.

Overall, community-based drainage management and social adaptation offer a holistic and participatory approach to addressing flooding. By involving communities in planning, risk management, and decision-making, the resulting solutions are more relevant and tailored to the local conditions. This approach not only increases flood resilience but also strengthens the community’s capacity to cope with climate change and improve existing infrastructure.

Drainage Management Based on Geomorphological Studies and Natural Processes

Drainage management based on geomorphological studies and natural processes focuses on understanding how natural factors such as soil erosion, geological changes, and climate dynamics affect drainage systems and flood management. Understanding relevant geomorphological processes, such as gully erosion and valley formation, provides important insights into designing drainage systems that are more effective and responsive to changing natural conditions. For example, in a study by McCloskey et al. (2016) in Australia, gully erosion occurring in the riparian zone of the Victoria River can affect the natural drainage system in the area. This erosion process can reduce the soil's ability to absorb rainwater and drain it into the river, which, in turn, affects the water flow in the area. Understanding erosion patterns and geomorphological changes is crucial for designing drainage systems that can accommodate these changes and prevent water-logging.

Rainfall variability is also a significant factor in geomorphological-based drainage management. The uneven distribution of rainfall between light and extreme rainfall events in urban India indicates that irregular rainfall patterns increase the challenges in drainage management, especially during extreme rainfall events that can cause waterlogging and flooding (Kalamalla & Satyanarayana, 2025). Therefore, drainage management must consider this uneven rainfall variability so that drainage systems can be designed to cope with extreme rainfall events, which are becoming more frequent owing to climate change.

Drainage management also requires an understanding of the changes occurring in geological formations. Livingstone & Clark, (2016) In relation to flood management, understanding the formation and morphology of tunnel valleys can help design more effective drainage systems, especially in areas with a history of natural channel formation such as tunnel valleys. These channels can be used as more efficient drainage pathways to channel rainwater and runoff, thereby reducing the risk of flooding in Canada. Rulleau (2025) explained that sustainable drainage systems are designed to mimic natural water processes, providing benefits such as flood prevention and improved water quality. This illustrates the crucial role of understanding drainage design through geomorphological studies. Panin et al. (2020) provided a broader overview of how climate change affects drainage systems across a wider region and how drainage planning must adapt to these changes.

Overall, drainage management based on geomorphological studies and natural processes offers a comprehensive and sustainable approach to designing drainage systems that are not only responsive to local physical and geological conditions but also adaptable to increasingly unpredictable climate and weather changes. By understanding the natural processes that influence water flow and the formation of drainage systems, we can design more targeted and effective solutions to reduce flood risks and protect communities and the environment from the impacts of natural disasters.

Conclusion

Drainage management is crucial for mitigating the impact of flooding, particularly in densely populated urban areas. Approaches based on technology, policy, regulation, community, and geomorphological studies offer diverse solutions for addressing flood challenges. Smart technology-based drainage management, such as real-time monitoring with sensors and the use of hydrodynamic models, allows for early detection and more efficient flood mitigation planning. Policy- and regulation-based management, through the inclusive allocation of drainage rights and policies, ensures equitable and sustainable resource distribution. Community-based management and social adaptation enhance community involvement in designing drainage solutions tailored to local needs, thereby strengthening social resilience to disasters. Geomorphological studies-based management provides important insights into understanding natural changes, such as erosion and geological changes, that affect natural drainage systems and need to be considered in more responsive drainage designs to environmental dynamics.

This literature review article has limitations, particularly its limited focus on drainage technologies and policies, without addressing the social, cultural, and economic aspects that influence the effectiveness of drainage systems in various regions. This study is important because socio-cultural factors greatly influence technology adoption and the program's long-term sustainability. Although numerous technologies and approaches have been identified, the practical application and evaluation of solutions in local contexts have not been discussed in depth. Further literature review studies should examine the influence of socio-economic factors and the integration of technology with community-based policies for sustainable flood management in Pakistan. Short-term recommendations include the implementation of smart technologies, such as sensor-based drainage monitoring, modernization of drainage infrastructure with mapping technology, and community outreach on flood risk management. In the long term, it is important to integrate flood-drainage rights (FDR)-based policies, green infrastructure development for climate adaptation, and the application of geomorphological studies in drainage design that considers natural changes and local morphology.

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Ethical Consideration

This literature review was conducted following the principles of academic integrity. All sources of literature and data used in this study have been properly cited and acknowledged to avoid any plagiarism. The authors declare no conflicts of interest that could have influenced the work reported in this study. The analysis and interpretation presented are based solely on the reviewed literature and are the authors' own scholarly work.

Competing Interests

The author(s) declare no competing interests.

Data Availability

All data underpinning the findings of this study are fully available in the Scopus database and can be accessed by searching the article title, DOI, or authors' names.

Author Contributions

All authors contributed equally to the conceptualization, writing, and critical revision of this manuscript. All the authors have read and approved the final manuscript.

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