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# WATER INFRASTRUCTURE ASSET MANAGEMENT (WIAM) AND APPLICATION USING DIGITAL TWIN: SYSTEMATIC REVIEW

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## Abstract.

The global water industry increasingly embraces digital asset management practices to enhance efficiency, sustainability, and reliability in water services. This shift is driven by several factors, including the need to address aging infrastructure, floods, droughts, rising operational costs, regulatory requirements, and the growing demand for water amidst climate change and population growth in developing and developed countries. Adaptation of digital asset systems by water infrastructure assets management (WIAM) plays a pivotal role in ensuring the reliability, efficiency, and sustainability of water infrastructure systems. Integrating Digital Twin (DT) technology into WIAM creates virtual replicas of physical assets, enabling real-time monitoring, predictive analytics, and informed decision-making. This study employs a systematic literature review (SLR) to explore the optimal use of digital (DT) technologies in water infrastructure management. Utilising the PRISMA model, it systematically selected and analysed 12 published papers from 2014 to 2023, gathered from databases such as Emerald Insight, Engineering Village, Sage Journals, Science Direct, and Scopus. The descriptive analysis reveals that European countries, particularly Spain, Italy, and the UK, lead in this research area. In contrast, African countries are notably underrepresented, indicating a need for future development. The findings revealed that the benefits of integrating digital twin applications into water infrastructure asset management enhance performance by enabling real-time monitoring, predictive maintenance, informed decision-making, efficient resource allocation, and advanced water infrastructure planning and monitoring. It also supports risk management, technological integration, skill development, and sustainable practices, all contributing to optimal and efficient water infrastructure management.

**Keywords:** Infrastructure, Asset management, Digital Twin, Water 4.0, Systematic Literature Review, Sustainability, Developing & developed countries

## 1. Introduction

Water infrastructure is critical in ensuring the sustainable provision of safe and reliable water resources to communities worldwide (Mishra et al., 2021). Moreover, managing water effectively is a key part of sustainable development. It involves using water wisely to meet current needs without compromising the ability of future generations to meet their own needs (Nwsany et al., 2019). However, water infrastructure asset management encounters varied challenges within water utilities in both developed and developing countries. Arnell et al. (2023) asserted that water utilities face higher service expectations while water resources are fading and deteriorating due to climate change. Moreover, Akhtar et al. (2021) and Ferrante et al. (2020) stressed that urban water systems face aging infrastructure, significant water loss, and increasing water quantity and quality demands. In developing countries, Bulti et al. (2023) highlighted that climate change, water loss, corruption in project development, and deficiencies in skills and technology for water utility management are posing significant challenges to the effective operation of the existing water system. Furthermore, Williams et al (2024) articulated that water infrastructure systems in Sub-Saharan Africa (SSA) are commonly described as inadequate, unreliable, and requiring substantial improvement. In addition, Laolang et al (2022) enunciated that access to safe drinking water in developing nations, notably in Sub-Saharan Africa, is hampered by urbanisation, population expansion, climate change, and poor governance. More so, Mnguni (2018) further stated that most South African water utilities have well-developed infrastructure asset management (IAM) strategies, they confront issues such as financial limitations that impede plan implementation and a shortage of skilled personnel within the utilities. In Nigeria, Adeoti et al. (2023) identified technical, economic, environmental, social, political, and institutional factors as predominant challenges in achieving water infrastructure sustainability. In India, Dishkar (2019) highlighted a lack of integration between the design, operation, and management of the water supply and sanitation system during the planning stage. Moreover, in South Korea, Kang (2019) stressed challenges in water infrastructure, particularly deficiencies in information management systems, resulting in subjective decision-making, absence of long-term planning, and fragmented maintenance responsibilities across institutions. Similarly, Won et al. (2022) added that, in South Korea, major urban areas are witnessing a surge in flood damage due to increased urbanisation and intensified rainfall patterns resulting from climate change, leading to casualties and extensive property damage. Nevertheless, the escalating challenges in water management have spurred demand for innovative solutions, encompassing monitoring, maintenance enhancement, sustainable practices, and integrating modern technologies into water infrastructure asset management. Raspati et al. (2022) articulated that implementing infrastructure asset management (IAM) principles enhances water utility managers in making informed decisions, avoiding reactive approaches, and improving the planning process for water distribution network (WDN) rehabilitation. More so, Le Gat et al. (2023) define infrastructure asset management (IAM) as a set of activities focused on ensuring the long-term upkeep of infrastructure capacity to deliver efficient services to users while keeping costs and environmental impacts within acceptable limits for society. According to Ugarelli and Sægrov (2022) the evolution of infrastructure asset management (IAM) is delineated into three distinct periods, each contributing to the advancement of urban water management: (a) initial stages focused on data collection and the development of computerised information systems, along with statistical methods for information management; (b) subsequent phases introduced risk analysis, encompassing identification of hazards and their potential consequences; and (c) current developments involve a holistic sustainable perspective integrating governance, social and economic considerations (such as circular economy principles), environmental impacts, and the condition of physical assets, including digital systems. Jorge et al. (2021) asserted that the performance of urban water systems is crucial for addressing both current and future challenges in urban areas.

Alabi et al. (2019) enunciated that the water industry is transitioning from conventional water solutions to a new era of smart water systems driven by digital advancements. This shift aims to gain fresh insights that enhance water management, quality, and operational efficiencies (Pesantez et al., 2020). The fourth industrial revolution has significantly shifted towards digital water utility infrastructure and management (Suprun et al., 2020). However, digital twins (DT) are becoming increasingly important in various fields as production becomes more digitalised and advanced data analysis techniques such as machine learning and visualisation are applied (Sharifi et al., 2024). Moreover, David et al. (2022) contended that the introduction to digital technologies has been globally involved in resource-efficient water management for a significant period, encompassing tasks such as managing water losses and enhancing utilities' energy efficiency. In addition, Walter (2024) further asserted that adopting digital technologies (DT) in the water sector presents an opportunity to address 21$^{st}$ century water risks by improving water supply, demand, and related data by informing public policy and guiding new investments. These technologies use physical models, operational history, sensor updates, and real-time high-resolution data along with model-based simulations to represent and forecast the conditions of their physical counterparts accurately, allowing users to make real-time operational decisions by analysing and managing information (Wang, 2020; Berglund et al., 2020 & Lu et al., 2020). Ramos (2023) emphasised that digital twins (DT) are constantly efficient with operational data collected from sensors, meters, and other measuring devices, generating a model that is interconnected with digital infrastructure to facilitate the management processes of smart water networks, including planning, design, construction, and operation. Park and You (2023) highlighted that the water management sector, much like others, is witnessing a surge of substantial digital innovations.

Efforts are being made to explore smarter and more efficient platforms for water resource management by harnessing advanced digital technologies such as digital twins (DT). Curl et al. (2019) examined the Digital Twin (DT) concept within the context of water resource recovery facilities (WRRF). They identified key components of a DT, including a virtual system simulating a physical system, data exchange in real-time, predictive capabilities, and intelligent actions. The study emphasised the importance of establishing a consensus on the essential components of a DT to prevent misuse of the concept, noting that efforts to reach a consensus have already begun in the water and wastewater network sector. A similar study in Portugal by Ramos et al. (2023) on smart water grids and digital twin for the management of system efficiency in water distribution networks, found that the developed methodology resulted in a notable reduction in water losses, leading to improved system efficiency and significant economic gains through cost savings attributable to reduced water loss volume and compliance with regulatory pressure limits. These trends are consistent with findings from other prominent authors who have extensively researched the application of digital twin (DT) in water infrastructure management, with notable researchers in recent years including (Riaz et al., 2024: Bartos & Kerkez, 2021: Conejos et al., 2020 & Piadeh et al., 2023). These researchers highlight the integration of digital twin frameworks to incorporate digitisation and applications in water infrastructure. In response to challenges faced in water sectors in both developed and developing economies, adopting infrastructure asset management (IAM) principles has become a strategic approach to optimise the performance and longevity of water infrastructure systems. Additionally, the integration of Digital Twin technology has emerged as a promising solution to enhance the efficiency and effectiveness of water infrastructure management. This study aims to explore the intersection of water infrastructure asset management (WIAM) and Digital Twin (DT) applications in the context of water infrastructure, examining their potential benefits for sustainable water resource management. Through a systematic review of existing literature, this research seeks to provide insights into the integration of WIAM and Digital Twin (DT) technologies and their benefits for advancing water infrastructure management practices.

## 2. Review Method

A Systematic Literature Review (SLR) was conducted following the PRISMA model to ensure a comprehensive and unbiased selection of relevant studies. The study utilised a Systematic Literature Review (SLR) to explore the current state-of-the-art in water infrastructure asset management and the application of digital twin technologies within water infrastructure management. Carrera et al. (2022) articulated that the SLR method enables researchers to thoroughly investigate existing scholarly articles, providing a comprehensive understanding of the current state of knowledge. More so, Pati and Lorusso (2018) define Systematic Literature Review (SLR) as a research process that systematically collects, identifies, and critically evaluates current research papers such as articles, conference proceedings, books, and dissertations. In addition, Page et al. (2021) further explain that (SLR) offers transparent and clear protocols that guide researchers in systematically searching for and evaluating studies relevant to a specific research topic, ensuring thoroughness and rigour in the review process. For this study, a systematic literature review (SLR) was performed with adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Figure 1). The choice of this analysis technique was influenced by earlier studies conducted by (Pérez et al., 2024 & Atkinson et al., 2022). The section below outlines all the steps of the Systematic Literature Review (SLR).

### 2.1. Research Question

The research question that this study aims to address is:

Q1: What are the key benefits of integrating Digital Twin technology into water infrastructure asset management?

### 2.2. Search String and process

Boolean operators are fundamental to mathematical sets and database logic, connecting search terms and refining search results. The three basic Boolean operators are AND, OR, and NOT. Boolean logic, a form of algebra, uses three fundamental Boolean operators—AND, OR, and NOT—to combine search terms or keywords, as demonstrated by (Lian & Wang, 2022: Chigbu et al., 2023).

For this study databases such as Emerald Insight, Engineering Village, Sage Journals, Science Direct, and Scopus provide citation counts for articles. Keyword searches were conducted across these platforms to retrieve relevant articles for the SLR.

**Table 1:** Search databases and strings

| Database | Website | Search String |
|---|---|---|
| Emerald Insight | https://www.emerald.com/insight/ | Water infrastructure asset management and application using digital twin |
| Engineering Village | https://www.engineeringvillage.com | Water infrastructure asset management and application using digital twin |
| Sage Journals | https://journals.sagepub.com/ | Water infrastructure asset management and application using digital twin |
| Science Direct-Elsevier | https://www.sciencedirect.com | Water infrastructure asset management and application using digital twin |
| Scopus | https://www.scopus.com | TITLE-ABS-KEY (Water AND infrastructure AND management AND digital AND twin) |

### 2.3. Inclusion and exclusion criteria

The inclusion and exclusion criteria were meticulously curated and strictly followed. These criteria were designed to exclude studies that did not pertain to the research questions and to ensure the selection of the most up-to-date, influential, topic-relevant, and accurate data. This approach aims to provide the best contribution and dissemination of information in water infrastructure asset management applications using digital twin technology. The table below outlines the defined inclusion and exclusion criteria adopted for the study.

**1 Table 2:** Inclusion and Exclusion Criteria

| **Criteria** | **Assessment Criteria** |
|---|---|
| **Inclusion** | research articles relating to water infrastructure asset management (WIAM) and applications using digital twin |
| | The publications made between the year 2014 and 2023 |
| | Publications that are written in English |
| | Peer-reviewed publications |
| | Publications which are conference papers or journal articles |
| | subject areas of Engineering, Environmental Sciences and Social Sciences |
| | Open Access publications |
| **Exclusion** | Papers that are not entirely written in English |
| | Papers from newspapers, blogs and technical reports |
| | Publications where the full paper cannot be located |
| | Papers not within a selected discipline |
| | Papers not within the 10-year range |

### 2.4. Data analysis

For this study, a quantitative approach was adopted. Haradhan (2020) defines quantitative research methods as systematically analysing phenomena and their interactions through numerical data and measurable variables. The data from the studies was used to compile the information received for each data item. This made data synthesis and analysis more efficient. Furthermore, Microsoft Excel (M.S. Excel) was utilised for data analysis and presentation of total publications by year, country of origin, publication type, and research methods. More so, De Paula and Marques (2022) contended that the quantitative analysis included a bibliometric and semantic analysis, presenting key issues related to the research theme through content analysis. VOSviewer was utilised for semantic analysis. Therefore, the study utilized VOSviewer to evaluate the frequencies, thematic affinities, and relationships of the author's keywords only. The authors were not analysed. Bukar et al. (2023) affirmed that VOSviewer is an exceptional tool for scientific knowledge mapping, offering features such as network visualization and density visualisation. In addition, Kirby (2023) added that VOSviewer is one of the best tools for performing science mapping analysis.

## 3. Results

### 3.1. Selected Studies

The process of selecting studies to include in the review is summarized in Figure 1 below.

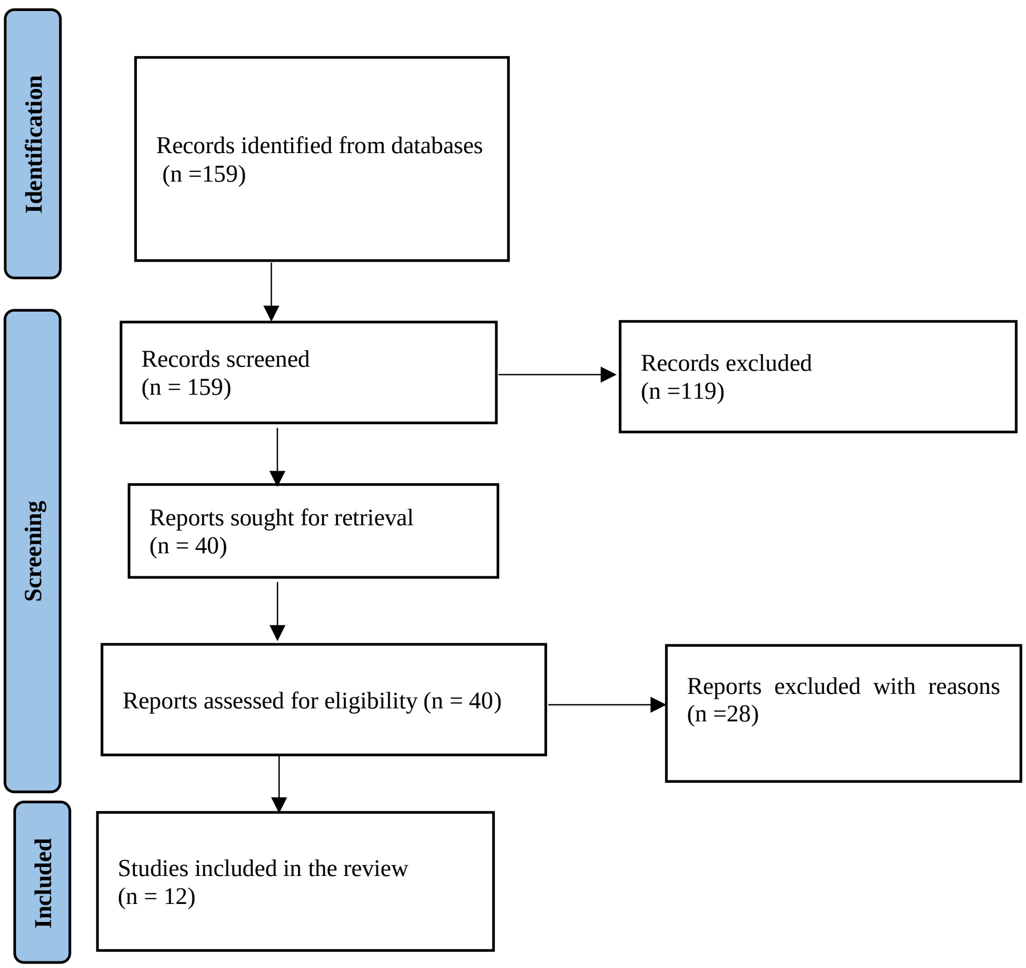



**Fig. 1:** PRISMA Model

[Source; Sheng et al. (2022)]

### 3.2. Descriptive Analysis (Quantitative Review)

Figures 2 to 5 provide descriptive information about the 12 publications. Figure 2 shows the annual publications, with the highest number of papers (seven) published in 2023. Figure 3 details the publications by country. Spain leads with 4 publications, followed by Italy and the United Kingdom with 3 each. Brazil, Colombia, Ireland, Serbia, and the United States each have 2 publications. Denmark, Germany, the Netherlands, Portugal, South Korea, and Uruguay each have 1 publication. However, none of the African countries met this criteria. Figure 4 indicates the type of publications, showing that all 12 are journal articles. Figure 5 shows that out of the 12 publications, 11 used qualitative research methods, while only 1 used a quantitative method.

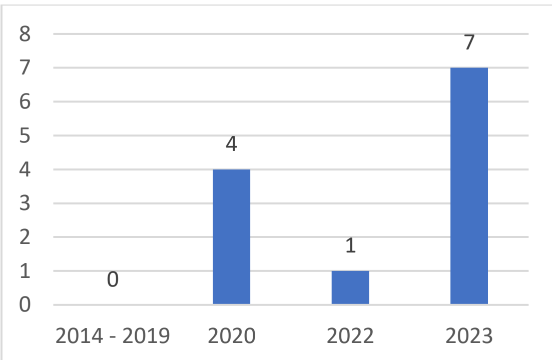



**Fig. 2:** Number of publications per year

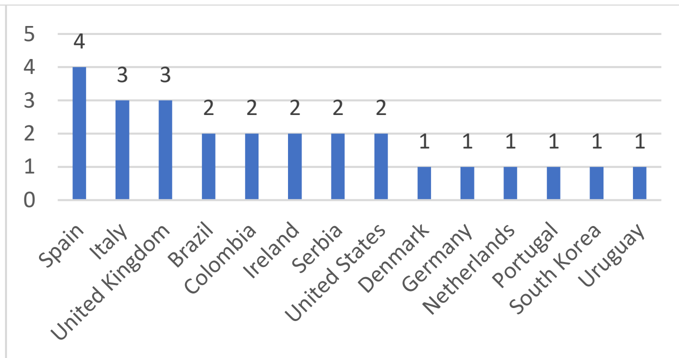



**Fig. 3:** Publications made per country

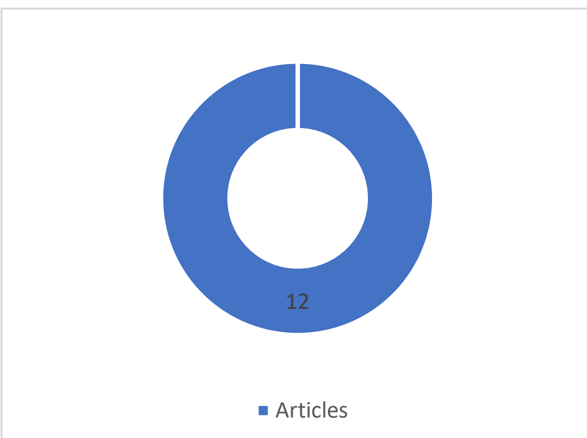



**Fig. 4:** Selected publication type

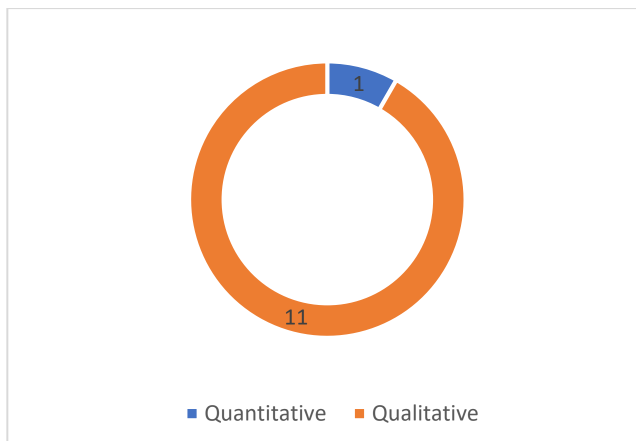
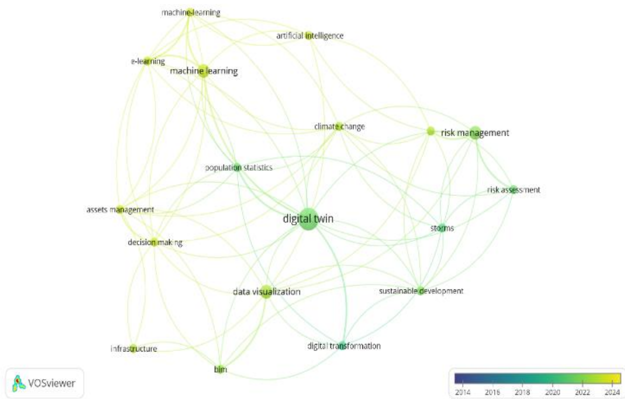



**Fig. 5:** Research Methods

### 3.3. Semantic Analysis

Figure 6 shows an overlaying visualisation of the author's keywords from 2014 to 2023. Figure 7 shows a network visualisation of the author's co-occurrence keywords with four clusters, colours and terms. Cluster (A) in red consists of 6 items namely; climate change, floods, risk assessment, storms and sustainable development. Cluster (B) in green consists of 5 items namely; asset management, BIM, data visualisation, decision making and infrastructure. Cluster (C) in blue consists of 4 items namely; artificial intelligence, e-learning, machine learning and machine learning. Cluster (D) in yellow consists of 3 items namely; digital transformation, digital twin and population statistics.



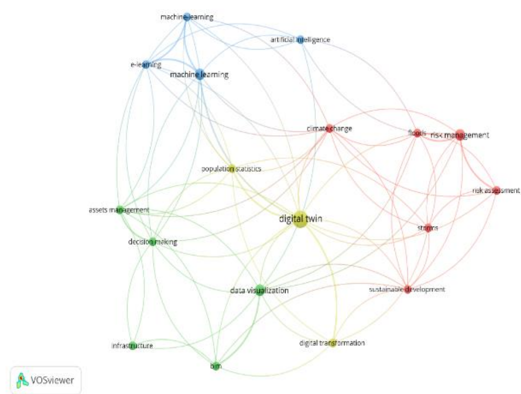




**Fig. 6:** Overlaying visualisation of keywords network

**Fig. 7:** Network visualisation of cluster co-occurrence keywords

## 4. Discussion of findings

The study on water infrastructure asset management (WIAM) and the application of Digital Twin technologies span from 2014 to 2023, focusing on publications retrieved from databases such as Emerald Insight, Engineering Village, Sage Journals, Science Direct, and Scopus. A total of 12 journal articles were identified and analysed using descriptive and semantic analysis methods. The descriptive analysis of the results reveals a clear trend in the research on water infrastructure asset management (WIAM) and Digital Twin applications. From 2014 to 2019, no publications were recorded, indicating an initial lack of focus on this topic. However, significant interest emerged in 2020 with four publications, in 2022 with 1 publication and this interest grew steadily, reaching a peak in 2023 with seven publications. Geographically, Spain leads with four publications, followed by Italy and the United Kingdom with three each. Brazil, Colombia, Ireland, Serbia, and the United States each contributed two publications, while Denmark, Germany, the Netherlands, Portugal, South Korea, and Uruguay each had one. However, none of the African countries met this criteria. Dogo, et al. (2019) and Alabi et al. (2019) concurred that the readiness for adaptation of water digitalisation in developing economies, including the water industry in Africa, is still at the foundational level and remains in its developmental stage. Significant progress is required to fully leverage the potential of digital technologies in water infrastructure management. Furthermore, the analysis highlighted the predominant use of qualitative research methods, with 11 out of 12 publications, suggesting that the field is still exploratory, focusing on conceptual development and understanding frameworks. Only one study employed quantitative methods. The semantic analysis in Figure 6 highlights key themes and trends, reflecting a global and increasing interest in leveraging digital twin technology for effective WIAM. The semantic analysis in Figure 7 presents a network visualisation of the authors' co-occurrence keywords, categorised into four distinct clusters, each identified by colour and specific terms. The findings revealed the benefit of integrating Digital Twin applications into water infrastructure asset management (WIAM) significantly enhances performance through real-time monitoring, predictive maintenance, informed decision-making, and efficient resource allocation. These technologies also support advanced planning and monitoring, risk management, technological integration, skill development, and sustainable practices, contributing to optimal and efficient water infrastructure management. Digital Twin technology is a central node, linking environmental challenges, technical and managerial aspects, advanced technologies, and broader digital transformation efforts. The trend towards integrating Digital Twin with AI and machine learning, along with an emphasis on educational initiatives, underscores the importance of continuous learning and development to achieve long-term sustainability and resilience in water infrastructure.

## 5. Conclusion and recommendations

The study on water infrastructure asset management (WIAM) and Digital Twin (DT) technologies, spanning from 2014 to 2023, highlights a significant increase in research interest beginning in 2020, with a peak in 2023. The geographic distribution of research indicates that European countries, especially Spain, Italy, and the UK, are leading in adapting and applying digital twin technology. While African countries are notably underrepresented, suggesting areas for future development. The predominance of qualitative methods indicates an exploratory phase focused on conceptual development, stressing the need for more empirical, quantitative studies. The semantic analysis identifies key themes, including environmental challenges, technical and managerial aspects, advanced technologies, and broader digitalisation trends, each represented by distinct clusters of keywords. The findings revealed that the key benefits of integrating Digital Twin applications into water infrastructure asset management enhance performance by enabling real-time monitoring, predictive maintenance, informed decision-making, efficient resource allocation, and advanced water infrastructure planning and monitoring. It also supports risk management, technological integration, skill development, and sustainable practices, all contributing to optimal and efficient water infrastructure management. The study recommends that future research focus on bridging the methodological gap by incorporating more quantitative studies and expanding research efforts to underrepresented regions, such as African countries. To leverage the benefits of Digital Twin (DT) technology in water infrastructure asset management (WIAM), African countries should focus on capacity building through training programs and academic collaborations, promote research initiatives and partnerships, develop supportive policies and regulatory frameworks, attract investment and foster public-private partnerships, enhance digital infrastructure, and adopt open standards. Launching pilot projects and scaling successful models can demonstrate the technology's advantages while creating knowledge hubs and promoting regional collaboration can facilitate knowledge sharing. Furthermore, aligning Digital Twin (DT) initiatives with sustainable development goals (SDGs), particularly those related to clean water and sanitation (SDG 6) and industry, innovation, and infrastructure (SDG 9), and addressing local challenges will further enhance the efficiency and effectiveness of WIAM in Africa.

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