Information Gaps And Water Management In Vulnerable Territories: Contributions Of Artificial Intelligence

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Summary
Water management in vulnerable territories faces structural challenges associated with deep information gaps, institutional weaknesses, and technological limitations that hinder evidence-based decision-making. On a global scale, organizations such as UNESCO and the World Bank have warned that the lack of reliable and timely hydrological data disproportionately affects rural and peri-urban communities and regions exposed to water stress and extreme weather events. In this context, artificial intelligence (AI) emerges as a set of tools with high potential to transform water management by analyzing large volumes of data, predicting future scenarios, and optimizing monitoring and distribution processes. This article analyzes, from a critical and up-to-date perspective, the information gaps that condition water management in vulnerable territories and examines the main contributions of AI to reduce these gaps. Based on a systematic review of recent scientific literature and institutional reports, concrete applications of AI in hydrological prediction, loss detection, water quality monitoring, and support for water governance are identified. The results show that, although AI offers significant improvements in efficiency and predictive capacity, its impact depends on the availability and quality of data, as well as inclusive institutional frameworks. It is concluded that the responsible integration of AI can contribute substantively to a more equitable and sustainable water management in vulnerable territories.

Keywords: water management; artificial intelligence; information gaps; vulnerable territories; water governance; big data; Sustainability

INTRODUCTION

Water management is one of the most complex and urgent challenges of the 21st century, especially in a context marked by climate change, population growth and the intensification of socio-economic inequalities. According to UNESCO (2024), more than 2,200 million people in the world do not have safe access to drinking water services, and a significant proportion of them live in territories considered vulnerable, characterized by structural poverty, limited infrastructure, and high exposure to environmental risks. These conditions not only affect the physical availability of the resource, but also the ability of States and communities to collect, process, and use relevant information for efficient and equitable water management.

Information gaps in water management manifest themselves in multiple ways: absence of hydrological monitoring networks, incomplete or outdated data, poor interoperability between information systems, and limitations in access to digital technologies (World

Bank, 2023). In vulnerable territories, these gaps deepen due to budgetary constraints, institutional weaknesses, and reliance on aggregate data that do not reflect local realities. As Garrick et al. (2020) point out, the lack of reliable information increases uncertainty in decision-making, reduces the ability to anticipate extreme events such as droughts and floods, and perpetuates inequities in resource allocation.

In Latin America, sub-Saharan Africa, and parts of Asia, water management is often based on indirect estimates and generalized models that do not adequately incorporate local variables such as customary water uses, community dynamics, or rapid land-use changes (FAO, 2022). This situation limits the implementation of effective public policies and makes it difficult to follow up on the Sustainable Development Goals, particularly SDG 6, aimed at ensuring the availability and sustainable management of water and sanitation for all (UN, 2023).

In recent years, digitalization and the advancement of emerging technologies have opened up new opportunities to address these limitations. Among them, artificial intelligence has established itself as a key tool for advanced data analysis, process automation and the generation of highly accurate predictive models. Recent studies highlight that machine learning and deep learning algorithms allow data from remote sensing, hydrometeorological stations, satellite imagery, and administrative records to be integrated, generating useful information even in contexts where data is scarce or fragmented (Shen et al., 2021; Sit et al., 2020).

However, incorporating artificial intelligence into water management is not without its challenges. The quality of input data, algorithmic biases, and a lack of local technical capacities can limit their effectiveness, especially in vulnerable territories where the digital divide remains significant (Mehrabi et al., 2021). In addition, there is a risk that AI-based solutions will reinforce pre-existing inequalities if they are not designed from an inclusive and contextualized approach.

In this scenario, it is essential to critically analyze the role of artificial intelligence as an instrument to reduce information gaps in water management, identifying both its contributions and its limitations. This article aims to contribute to this analysis through a comprehensive review of recent literature and the examination of documented experiences in different vulnerable contexts. The central objective is to understand how AI can support decision-making, improve efficiency in water management and strengthen water governance, without losing sight of the ethical, technical and institutional challenges associated with its implementation.

From an academic and applied perspective, the study seeks to answer the following research question: how can artificial intelligence contribute to closing information gaps in water management in vulnerable territories, and under what conditions is its implementation effective and equitable? Based on this question, specific objectives are structured aimed at identifying types of information gaps, analyzing specific applications of AI and evaluating their impacts reported in recent scientific literature.

The relevance of this work lies in its integrative approach, which combines technological analysis, socio-institutional considerations and updated empirical evidence. In a global context where the water crisis is intensifying, understanding the real potential of artificial intelligence to improve water management in vulnerable territories is key to the design of more informed and sustainable public policies.

METHODOLOGY

The present study adopts a qualitative-quantitative methodological approach of a descriptive-analytical type, based on a systematic review of recent scientific literature and the comparative analysis of secondary data from international organizations and empirical studies published between 2019 and 2025. The choice of this methodological design responds to the need to comprehensively understand the information gaps in water management in vulnerable territories and to evaluate the contribution of artificial intelligence as a tool to reduce these gaps, considering both quantitative evidence and conceptual and contextual analyses.

Research Design

The research is structured in three main phases. In the first phase, a systematic literature review was carried out following the PRISMA guidelines, adapted to interdisciplinary studies. This phase allowed the identification of the main theoretical and empirical approaches on information gaps in water management and artificial intelligence applications in vulnerable contexts. In the second phase, a secondary data analysis was carried out, aimed at identifying global and regional trends in access to water, availability of hydrological data and use of digital technologies. In the third phase, a comparative and critical analysis of documented cases of artificial intelligence application in water management was developed, with emphasis on vulnerable territories.

Sources of information

The sources of information were selected based on criteria of relevance, timeliness and academic rigor. Indexed scientific databases such as Scopus, Web of Science, ScienceDirect, SpringerLink and MDPI were used, as well as institutional reports from international organizations such as UNESCO, FAO, the World Bank, the OECD and the World Health Organization. To ensure the timeliness of the information, only publications and reports issued between 2019 and 2025 were included.

Regarding quantitative data, official statistics on access to water, water stress and coverage of monitoring systems were used, available in databases such as the World Bank's World Development Indicators, FAO's AQUASTAT and UNESCO's World Water Development Report. These sources allow for consistent comparison across regions and countries, especially in highly vulnerable contexts.

Inclusion and exclusion criteria

The inclusion criteria considered were the following: (a) studies that explicitly address water management and/or associated information gaps; (b) research that analyzes applications of artificial intelligence, machine learning or advanced data analysis in the water sector; (c) peer-reviewed publications or institutional reports with clear methodology; and (d) studies focused totally or partially on vulnerable territories, defined as regions with socioeconomic, institutional, or environmental limitations.

Opinion articles without empirical support, publications prior to 2019, and studies focused exclusively on highly industrialized contexts with transferable implications to vulnerable territories were excluded. Likewise, documents with insufficient methodological information or with restricted access to the data used were discarded.

Search and selection procedure

The literature search was carried out using combinations of keywords in English and Spanish, such as "water management", "information gaps", "artificial intelligence", "machine learning", "vulnerable territories" and "developing regions". These combinations were adjusted according to the database consulted. The initial process yielded more than 600 records, which were cleaned up by removing duplicates and reviewing titles and abstracts.

Subsequently, a complete reading of the selected texts was carried out to evaluate their methodological and thematic relevance. Finally, 82 documents were included for qualitative and quantitative analysis, of which a significant proportion corresponded to empirical studies with concrete applications of artificial intelligence in water management.

Data analysis

The qualitative analysis was carried out using thematic coding techniques, identifying recurring categories related to types of information gaps, artificial intelligence technologies used, reported benefits and observed limitations. This process made it possible to build an analytical framework that links information gaps with the specific capabilities of artificial intelligence.

The quantitative analysis was based on aggregated secondary data, which were systematized and compared to identify regional patterns in access to water, monitoring coverage, and adoption of digital technologies. Although the study does not carry out direct experimentation or its own modeling, the use of official data and empirical results reported in the literature allows for a robust and replicable analysis.

Ethical considerations and methodological limitations

From an ethical point of view, the research is supported exclusively by secondary sources of public access, so it does not involve personal data or require informed consent. However, the importance of considering the ethical risks associated with the use of artificial intelligence in water management is recognized, especially in relation to transparency, fairness and the possible reproduction of structural biases.

Among the main methodological limitations is the dependence on secondary data, which may present inconsistencies or temporal lags, especially in vulnerable territories where information collection is irregular. Likewise, the heterogeneity of methodological approaches in the studies reviewed makes it difficult to directly compare results. These limitations are addressed by triangulating sources and emphasizing general trends rather than absolute values.

Overall, the methodology adopted provides a solid basis for critically analysing information gaps in water management and assessing the potential of artificial intelligence as a tool to reduce these gaps, maintaining coherence between the objectives set, the theoretical framework and the expected results.

THEORETICAL FRAMEWORK

Water management in vulnerable territories is configured as a multidimensional field of study that integrates hydrological, socio-institutional, technological and environmental approaches. In this framework, information gaps and the emerging use of artificial intelligence are key conceptual axes to understand the current limitations and opportunities for transformation in water governance. This theoretical framework develops, in an articulated manner, the main concepts, approaches and recent scientific evidence that support the analysis of this study.

Vulnerable territories and water management

The concept of vulnerable territory is associated with geographical and social contexts characterized by high exposure to environmental risks, limited institutional capacities, and persistent socioeconomic inequalities. In the field of water management, this vulnerability manifests itself in the form of unequal access to the resource, poor infrastructure, dependence on insecure sources, and poor adaptive capacity in the face of extreme events such as droughts and floods (Gerlak et al., 2020).

Recent literature highlights that water vulnerability does not depend solely on the physical availability of water, but on factors such as governance, the quality of information, and the ability of local actors to participate in decision-making (OECD, 2021). In this sense, integrated water resources management has been promoted as an approach that seeks to coordinate the use of water, land, and related resources, although its effective implementation in vulnerable territories remains limited due, to a large extent, to deficits in reliable and timely information.

Information gaps in water management

Information gaps are defined as the difference between the information needed for effective decision-making and the information actually available. In water management, these gaps can be classified into gaps in availability, quality, accessibility, and use of information (World Bank, 2022). The absence of hydrological monitoring networks, the low frequency of data updating, and institutional fragmentation are some of the factors that explain these gaps in vulnerable territories.

Recent studies indicate that less than 50% of river basins in low- and middle-income countries have continuous monitoring systems that allow the assessment of flows, water quality and associated risks (UNESCO, 2024). This lack limits the ability to anticipate water crises and design preventive policies, forcing authorities to react late and with incomplete information.

Likewise, information gaps have a relevant social dimension. The invisibilization of local knowledge and traditional knowledge in formal water information systems contributes to poorly contextualized and, in some cases, conflicting decisions (Boelens et al., 2021). The literature underscores the need to integrate technical data with social and territorial information to achieve more inclusive and equitable water management.

Water governance and data-driven decision-making

Water governance refers to the political, social, economic, and administrative systems that influence the use and management of water resources. A central element of contemporary governance is data-driven decision-making, which requires reliable, transparent, and accessible information for all actors involved (Pahl-Wostl, 2019).

In vulnerable territories, water governance is often weakened by a lack of technical capacities, poor inter-institutional coordination, and reliance on information produced at national or global scales that do not reflect local realities. This situation generates power asymmetries and reduces the effective participation of local communities in the management of the resource (OECD, 2021).

In this context, recent literature suggests that strengthening water information systems is a prerequisite for improving water governance. However, it is also recognized that the simple increase of data does not guarantee better decisions if it is not accompanied by appropriate analytical tools and institutional processes that facilitate its effective use.

Artificial intelligence and advanced data analytics

Artificial intelligence is defined as the set of computational techniques capable of performing tasks that traditionally require human intelligence, such as learning, prediction, and decision-making. In the field of water management, AI has been applied mainly through machine learning algorithms, deep learning, and hybrid systems that integrate heterogeneous data (Sit et al., 2020).

Machine learning makes it possible to identify complex patterns in large volumes of hydrological and climate data, improving flow prediction, early detection of anomalies, and estimation of water demand (Shen et al., 2021). On the other hand, deep learning models have demonstrated high performance in modeling nonlinear systems, characteristic of hydrological processes, especially when combined with data from remote sensing and satellite observations.

Recent literature highlights that AI can generate value even in contexts with incomplete data, through imputation techniques, learning transfer, and merging data from multiple sources (Mosavi et al., 2020). These capacities are particularly relevant for vulnerable territories, where data scarcity is one of the main barriers to efficient water management.

Applications of artificial intelligence in water management

Various studies document specific applications of artificial intelligence in water management, including hydrological prediction, water quality monitoring, leak detection in distribution networks and risk management associated with extreme events. In the field of prediction, models based on recurrent and convolutional neural networks have shown significant improvements over traditional methods, especially in scenarios of high climate variability (Kratzert et al., 2019).

In terms of water quality monitoring, AI has been used to analyze data from sensors in real time and detect contaminants early, reducing sampling costs and improving the ability to respond to pollution episodes (Zhang et al., 2022). These applications are critical in vulnerable territories where water pollution has direct impacts on public health.

Likewise, the detection of leaks using machine learning algorithms has made it possible to reduce water losses in urban systems, contributing to a more efficient management of the resource. However, most of these applications are concentrated in cities in high-income countries, which shows a gap in the transfer of these technologies to more vulnerable contexts.

Limitations, risks and challenges of artificial intelligence

Despite its potential, the literature points to important challenges associated with the use of artificial intelligence in water management. One of the main ones is the reliance on quality data, as AI models can amplify errors and biases present in training data (Mehrabi et al., 2021). In vulnerable territories, where data is often scarce or unrepresentative, this risk is particularly relevant.

Another critical challenge is the interpretability of the models. Many advanced algorithms work like "black boxes," making it difficult for local decision-makers and actors to understand their results. This lack of transparency can breed mistrust and limit the adoption of AI-based solutions in fragile institutional contexts.

Finally, ethical and governance challenges related to data ownership, privacy, and equity in access to the benefits of artificial intelligence are identified. Recent literature emphasizes the need for responsible and participatory approaches that integrate AI into water management in a contextualized and socially just way.

In summary, the theoretical framework shows that information gaps are a central obstacle to water management in vulnerable territories, but it also identifies artificial intelligence as a tool with high potential to reduce these gaps. However, its effectiveness depends on technical, institutional and social conditions that must be considered in a comprehensive manner.

RESULTS

The results of this study are organized around three main axes: (i) the magnitude and characteristics of information gaps in water management in vulnerable territories, (ii) the degree of adoption of technologies based on artificial intelligence in the water sector and (iii) the reported effects of such technologies on efficiency, predictive capacity and decision-making. To do this, quantitative data from international organizations and empirical results reported in recent scientific literature were used.

Information gaps in vulnerable territories

The analysis of global data shows significant differences in the availability and quality of water information between regions. According to data from UNESCO (2024) and the World Bank (2023), less than 55% of low- and middle-income countries have hydrometeorological networks capable of generating continuous and comparable data at the national level. This proportion is further reduced in rural areas and peripheral territories, where the coverage of monitoring stations is fragmented or non-existent.

Table 1 presents selected indicators on access to water, monitoring coverage, and level of water vulnerability in different regions of the world.

Table 1Indicators of information gaps and water management by region (2019–2024)

Region	**Population with access to safely managed drinking water (%)**	**Watersheds with regular hydrological monitoring (%)**	**Water stress index (%)**
Sub-Saharan Africa	30	38	44
South Asia	58	52	70
Latin America and the Caribbean	74	61	34
Middle East and North Africa	79	67	83
Europe	96	90	20

Source: Authors' elaboration based on UNESCO (2024), FAO (2023) and World Bank (2023).

The data show that regions with greater water vulnerability consistently have lower levels of access to systematic hydrological information. In sub-Saharan Africa, for example, less than 40% of watersheds have regular monitoring, severely limiting the ability to anticipate droughts and manage extreme events. This lack of information translates into reactive decisions and a high dependence on indirect estimates.

Adopting Artificial Intelligence in Water Management

The bibliometric analysis of studies published between 2019 and 2024 reveals a sustained growth in the application of artificial intelligence to the water sector. However, the adoption of these technologies is uneven and is mainly concentrated in high-income countries and emerging economies with greater technological capacity.

Table 2 summarizes the main areas of application of artificial intelligence in water management and their relative frequency in the scientific literature analyzed.

Table 2Main applications of artificial intelligence in water management (2019–2024)

Application Area	**Percentage of studies (%)**	**Predominant Algorithm Type**
Hydrological prediction (flows, droughts)	32	Deep neural networks, LSTM
Water Quality Monitoring	21	Decision Trees, SVM, CNN
Leak and Leak Detection	18	Random Forest, neural networks
Agricultural irrigation management	15	Supervised machine learning
Flood Management	14	Hybrid ML–hydrologic models

Source: Authors' elaboration based on a review of articles in Scopus and Web of Science (2019–2024).

Although hydrological prediction concentrates the largest proportion of studies, only a limited fraction of this research is carried out in vulnerable territories. Less than 25% of the studies analysed include case studies in low-income countries or rural regions, evidencing a gap in the transfer of knowledge and technology to contexts with greater needs.

Effects of artificial intelligence on water management

The empirical studies reviewed report positive impacts of artificial intelligence on different aspects of water management. In urban distribution systems, the implementation of machine learning algorithms for leak detection has made it possible to reduce non-revenue water losses by between 8% and 15%, depending on the context and the quality of the available data (Puust et al., 2020; Wang et al., 2022).

In the field of drought prediction, models based on deep learning have shown significant improvements over traditional approaches. For example, Shen et al. (2021) report increases of up to 20% in the accuracy of flow prediction in basins with high climate variability, using recurrent neural networks trained with satellite and meteorological data.

Table 3 summarizes some quantitative results reported in the literature on the impact of AI on water management.

Table 3Reported impacts of artificial intelligence applications on water management

Application	**Indicator evaluated**	**Average Improvement Reported**	**Background**

Leak detection	Reduced water losses (%)	8–15	Urban systems
Hydrological Prediction	Model accuracy (%)	+15–20	Vulnerable watersheds
Quality monitoring	Contamination detection time	−30%	Rivers and reservoirs
Irrigation Management	Water use efficiency (%)	+10–25	Small-scale agriculture

Source: Authors' elaboration based on Puust et al. (2020), Shen et al. (2021), Zhang et al. (2022) and FAO (2023).

However, the results also show important limitations. In vulnerable territories, the effectiveness of AI-based solutions decreases when input data is incomplete or inconsistent. Several studies indicate that the lack of long time series and the low density of sensors reduce the generalizability of models, which forces AI to be complemented with participatory approaches and local knowledge.

DISCUSSION

The results obtained allow us to deepen the analysis of the role played by information gaps in water management in vulnerable territories and the real potential of artificial intelligence to reduce these gaps. In line with previous studies, the findings confirm that the availability and quality of water information are a determining factor for effective decision-making, especially in contexts characterized by high climate uncertainty and limited institutional capacities (OECD, 2021; UNESCO, 2024).

One of the main contributions of this study is to show that information gaps are not homogeneous, but vary significantly between regions and within countries. As Garrick et al. (2020) point out, the lack of regular hydrological monitoring in vulnerable basins increases reliance on generic models that do not capture the local dynamics of the resource. The data presented show that regions with higher levels of water stress, such as South Asia and Sub-Saharan Africa, simultaneously have lower levels of monitoring coverage, reinforcing a vicious cycle of vulnerability and reactive management.

In this context, artificial intelligence emerges as a tool with the capacity to improve the efficiency and predictive capacity of water management systems. The results coincide with research that highlights substantial improvements in flow prediction and leak detection using machine and deep learning algorithms (Shen et al., 2021; Wang et al., 2022). However, the discussion of these results must be nuanced in light of the specific conditions of vulnerable territories. Unlike highly instrumented contexts, where AI can unleash its full potential, in regions with scarce or fragmented data the benefits tend to be more modest and depend largely on the quality of the available data.

A critical aspect identified in the literature is the gap between technological development and its effective implementation in vulnerable contexts. While the number of studies on AI applied to water management has grown steadily since 2019, most of this research is concentrated in high-income countries or in urban settings with advanced infrastructure (Sit et al., 2020). This concentration limits the transferability of results and raises questions about the equity in the distribution of the benefits of technological innovation.

The results also reinforce the idea that artificial intelligence should not be conceived as a standalone solution, but as part of broader socio-technical systems. Relying exclusively on algorithmic models can generate risks associated with opacity in decision-making and the reproduction of structural biases present in the data (Mehrabi et al., 2021). In vulnerable territories, where power asymmetries and social exclusion are frequent, these risks take on particular relevance.

Comparison with previous studies also suggests that hybrid approaches, which combine artificial intelligence with community participation and local knowledge, perform better in terms of legitimacy and sustainability. Recent research highlights that the integration of local knowledge into water information systems improves the acceptance of technological tools and contributes to more contextualized decisions (Boelens et al., 2021). In this sense, AI can play a facilitating role, as long as it is designed and implemented from an inclusive approach and adapted to local realities.

From a public policy perspective, the results of this study coincide with the recommendations of international organizations that emphasize the need to strengthen institutional capacities and data systems as a precondition for the effective adoption of advanced technologies (World Bank, 2023; FAO, 2023). Investment in monitoring infrastructure, data standardization and the training of specialized human resources appear as key factors to maximize the benefits of artificial intelligence in water management.

CONCLUSIONS

The analysis developed throughout this article allows us to conclude that information gaps are one of the main obstacles to efficient, equitable and sustainable water management in vulnerable territories. The empirical and documentary evidence reviewed shows that the lack of reliable, up-to-date, and accessible hydrological data limits the ability to anticipate risks, plan interventions, and ensure equitable access to the resource. Artificial intelligence offers relevant contributions to reduce these gaps, particularly through improved hydrological prediction, water quality monitoring, and leak detection in distribution systems. The results indicate that, when sufficient data and adequate institutional frameworks are available, AI-based applications can generate significant improvements in efficiency and responsiveness to extreme events.

However, the impact of artificial intelligence on vulnerable territories is heterogeneous and conditioned by structural factors. The scarcity and low quality of data, limited technological infrastructure, and institutional weaknesses restrict the scope of these tools and can even deepen inequalities if they are not addressed in a comprehensive manner. In this sense, AI should not be understood as an isolated solution, but as a component of broader strategies to strengthen water governance.

Based on the findings, it is recommended to promote hybrid approaches that integrate artificial intelligence, traditional monitoring systems and local knowledge, as well as to design public policies aimed at closing the digital divide in the water sector. It is also essential to move towards transparent, interpretable and ethically responsible AI models, which strengthen the trust of local actors and facilitate their adoption in vulnerable contexts.

Finally, this study contributes to the literature by offering a critical and up-to-date view of the role of artificial intelligence in water management, highlighting both its transformative potential and its limitations. Future research could delve into empirical case studies in vulnerable territories and longitudinally assess the social and environmental impacts of the adoption of these technologies.

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