
Artificial Intelligence Applications in Water Resources Management: Global Advances and Perspectives for Morocco.

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Abstract

As water resources become scarcer, population growth, and climate change, complex water resources challenges have been turning to Artificial Intelligence (AI) as a promising solution. Water resources are becoming scarce and with the growing population and climate change, complex water resources challenges are turning to Artificial Intelligence (AI). This research seeks to analyze recent advancements in the use of AI and evaluate their feasibility for water management in Morocco. To conduct a systematic literature review, the PRISMA framework was used and searched through three databases: Scopus, Web of Science, and Google Scholar databases. Following this, 20 peer-reviewed and published studies between 2020 and 2025 were identified from an initial sample of 347 records based on pre-defined inclusion and exclusion criteria. The studies that were selected are the ones analyzed in this review and they fall into three application areas: hydrological prediction, smart water distribution, and water quality monitoring. The results show that the machine learning and deep learning models are much more effective at prediction accuracy, anomaly detection and real-time decision support than the traditional methods. Several issues remain, though, such as the lack of data, model interpretability and the high cost of implementation, especially in less developed countries. AI technologies have the potential to address forecast and prediction inaccuracies, mitigate water loss, and enhance water quality monitoring in the Moroccan context, but require investments in data infrastructure, human capacities, and regulations. In conclusion, the study suggests that, while there are significant technical and institutional hurdles to overcome, AI can play a role in enhancing water resources management to become more efficient and sustainable.

Keywords: Artificial Intelligence, Water Resources Management, Machine Learning, Hydrological Prediction, Smart Water Systems.

1. Introduction

The water demand, the growing population and the effects of climate change have made water resources management to be one of the most urgent challenges in the world. The conventional water management methods tend to be inefficient in managing dynamic and complex hydrological systems. In this regard, there is growing interest in advanced technologies to enhance the effectiveness and sustainability of water management practices[1].

Artificial Intelligence is one of these technologies that have become potent and can analyze significant amounts of data and discover intricate patterns that are hardly possible to detect using traditional means. Other approaches such as Machine Learning, Deep Learning are widely applied to various water resources management domains including hydrological forecasting, optimal water distribution and water quality monitoring [2].

The latest research has shown that AI can greatly enhance the accuracy of predictions, decision-making, and the creation of intelligent water management systems. Nevertheless, even with these developments, there are still several issues that need to be addressed especially with regard to availability of data, model interpretability and practicality [3].

Therefore, a comprehensive overview of the potential use of AI to address the vast range of water management challenges in a variable environment is required. This paper aims to explore the main application of AI in water resources management, highlight its pros and cons, and discuss prospects, while focusing on the potential of AI in developing countries, such as Morocco.

2. Methodology

This review is based on a structured literature review protocol, which is based on PRISMA guidelines. The search was carried out in four scientific databases (Scopus, Web of Science, and Google Scholar). The following Boolean query was used: ("artificial intelligence" OR "machine learning" OR "deep learning") AND ("water resources management" OR "hydrological prediction" OR "water quality" OR "water distribution").

The inclusion criteria for the study were: (i) peer-reviewed journal articles; (ii) published between 2020 and 2025; (iii) primary focus on AI/ML application in at least one water management domain; (iv) written in English or French. Exclusion criteria: (1) review articles that do not include primary data or a comparative analysis; (2) studies that are missing model performance metrics; (3) papers that are only about irrigation scheduling and not include a larger scope of water management.

An initial query yielded a result of 347 possible relevant records. Some duplicates (n = 58) and titles and abstracts that were unsuitable for the study (n = 183) were removed and articles with abstracts that were not read in full texts were excluded (n = 86 assessed for eligibility, 66 not meeting all inclusion criteria). After reading and excluding full texts, 20 articles were retained for qualitative synthesis. The Critical Appraisal Skills Programme (CASP) checklist was used to assess the clarity of the study design, the reproducibility of the results, and the generalizability of the findings. Selected studies are summarized in Figure 1 .

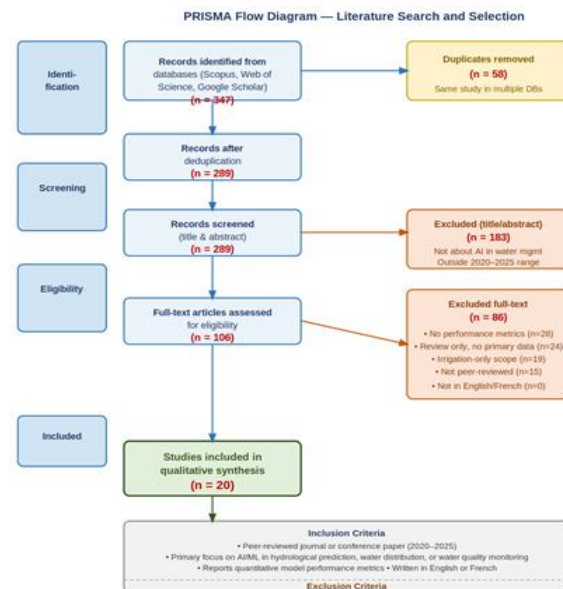


Figure 1 : PRISMA Flow Diagram: Literature Search and Selection Process

1. Results

Artificial intelligence is now one of the facilitating factors in current water resources management, providing sophisticated features to examine dynamic and intricate hydrological systems. In the last few years, the synergy of technologies such as machine learning and deep learning has emerged as a very effective, accurate, and adaptive way to do water management practices. [2].

Artificial intelligence uses in this area can be classified into three major areas namely hydrological prediction, smart water distribution systems and water quality monitoring. These applications are based on data-driven models to work with heavy amounts of environmental and operational data to enable more accurate prediction, optimized resource allocation, and real-time decision-making. Artificial intelligence, as noted in the recent literature, does not only improve the performance of the conventional water management methods, but also assists in the shift towards more sustainable and resilient water systems[4], [5].

1.1 Smart water distribution :

Artificial intelligence (AI) is progressively being considered to fill the inadequacies of water systems which now deny about a quarter of the global population access to drinking water, about half of sanitation services, and about a third of sanitary amenities[6]. The potential uses of artificial intelligence include better comprehension of water resources, watershed management, and emergency response; optimization of design, operation, and maintenance of wastewater treatment facilities and distribution networks; and service availability, demand management, and equal access to water[7]. Artificial intelligence (AI) can provide new ways of minimizing unaccounted-for water losses (both physical, i.e., leakage and pipe disconnections, and commercial, i.e. illegal connections or meter errors). The distribution network

analysis and work is being changed by the integration of AI in several key ways[8]:

Online identification and detection of anomalies: AI algorithms are able to analyze the data observed by sensors in the field (pressure, consumption, flow) to identify spatiotemporal patterns and specific anomalies. This can digitally localize the parts of the pipeline that may have a leak, and AI is becoming built into equipment (including acoustic correlators) to automatically process noises of leaks rather than having humans do so.

Ongoing probabilistic calibration: AI is not based on only a static analysis, it employs state estimation and stochastic optimization strategies to evaluate the most probable state of the network. The algorithm can extract valuable information by probabilistically analyzing the error structure (the discrepancy between actual measurements and the theoretical predictions of the model) by running continuous, probabilistic calibration.

Distincting Between the Types of Losses: Depending on the density and frequency of measurements in each part of the network, AI can determine the difference between an actual physical leak and unauthorized usage (water theft). Residual values can also be used to detect faulty sensors or unusual consumption patterns, which can be analyzed using AI. Specific optimization of field interventions: Digital identification does not completely reduce the work of field technicians; however, it saves a lot of time and money by accurately guiding the movement of leak detectors. It is also useful in maximizing the division of the distribution networks and replacement programs of old pipes.

The hybrid model: Hydraulic Modeling 2.0: To make this analysis work, AI will be used to develop a new generation of the model that integrates the basic physical principles of hydraulics with machine learning capabilities. This system assists in designing an optimum monitoring

network beforehand by showing precisely where to install a minimum number of low cost sensors (e.g. pressure gauges) to obtain the greatest amount of value information on losses, and at minimum cost in investment.

The Suan Lee and Byeonghak Kim [9] created AI-based models that could recognize leaks in real time and save a lot of water by the XG boost model with an impressive accuracy of 99.79 per cent in detecting water leaks using vibration sensors. This is a significant breakthrough as compared to the traditional techniques that rely on manual inspection or acoustic sensors, which are usually vulnerable to errors and environmental noise interference. It is interesting to note that this model skillfully detects water leaks within water pipelines that contain both metallic and non-metallic components- a common problem in older water distribution systems. Makropoulos and Bouziotas [10] also demonstrated that AI can be used to improve the efficiency of operations due to the use of data to make decisions, which presents a potential area of application of reinforcement learning in hydro informatics.

3.2 Water quality monitoring :

AI methods are extensively used in the evaluation and control of water quality. Predictable parameters of water quality include pH, turbidity and dissolved oxygen that can be predicted using machine learning models.

Mathaba & Banza (2023)[11] discuss the role of artificial intelligence (AI) and machine learning (ML) in optimizing the process of water treatment. The authors examine ten years of studies (2013-2023) to prove that these digital models are more efficient in predicting the water quality and in controlling of complex systems like membrane filtration or adsorption. The paper sheds light on

the fact that, despite the fact that these technologies are providing more accuracy in eliminating pollutants, significant barriers like the unavailability of standardized data and the obscurity of algorithms are working against their implementation at large scale in industries. Lastly, the paper suggests ways in which the reproducibility and transparency of models can be enhanced so that there is sustainable access to drinking water in future.

Recent reports indicate that there is an increasing dominance of artificial intelligence methods compared to the traditional statistical methods in predicting water quality. As an example, Xiaohui Yan (2024)[12] gives a detailed summary of the most recent developments in machine learning that can be used to predict water quality and discusses the challenges and developments that have occurred in predicting water quality in coastal areas. In order to enhance the accuracy of machine learning predictions, the following areas can then be considered: (a) diversification

of data sources and increasing the volume of data since remote sensing satellite images can be used as a reference to invert optical parameters, which needs further research to acquire data on non-optical water quality parameters rapidly and effectively in the coastal areas; (b) Missing data can be handled by interpolation techniques like using univariate inputs, k-nearest-neighbor interpolation, and multi-input denoising techniques

Revathi G. Maraju (2023)[13] focuses on the quality of drinking water through artificial intelligence, which can be used to prevent microbiological contamination of drinking water sources or mitigate such contamination to safe human health levels. Infrastructure development and capacity building policies should be incorporated in policy guidelines to implement AI in solutions to water related issues to achieve positive development. This technology can help communities to flourish provided that they can offer clean, affordable, and sustainable water to the whole ecosystem. These applications contribute to the protection of the environment and to the proactive approach in water quality management.

3.3 Hydrological prediction

The use of artificial intelligence has greatly enhanced hydrological predictions. Common models used in rainfall-runoff modeling, flood prediction and streamflow estimation include Artificial Neural Networks (ANN) and Long Short-Term Memory (LSTM) networks. The hydrological prediction based on AI enhances the early warning systems, minimizes the risks of disasters, and optimizes water resources planning.

Other studies like Mosavi et al. (2020)[5] gives an overview of the machine learning models employed in flood forecasting. Four key trends identified in the literature in this context will seek to enhance the quality of predictions. The former is novel hybridization, either in terms of combining two or more machine learning techniques, or in terms of combining one or more machine learning techniques with more traditional techniques and/or fuzzy logic. The second is the introduction of data decomposition methods in order to enhance the quality of the dataset which has greatly helped in enhancing the prediction accuracy. The third is that a set of methods is used, and this has greatly enhanced the ability of models to generalize as well as minimized the uncertainty. The fourth important technology was that of complementary optimization algorithm to enhance the quality of machine learning algorithm especially of better tuning artificial neural networks (ANNs) to obtain optimal neural architectures.

Hanlin Yin et al. (2021) [14] illustrate that LSTM models perform better than conventional hydrological models since they consider nonlinear temporal relationships on data. Of the data-

driven rainfall-runoff models, recently, the models that are based on the long short-term memory (LSTM) network are performing well.

To give a structured overview of the existing literature, the main applications of artificial intelligence in water resources management were summarised in Table 1. The chosen articles indicate the variety of AI methods, such as machine learning models and deep learning methods, used in various fields, such as hydrological prediction, smart water distribution systems, and water quality monitoring. Such studies illustrate the fact that AI is a potent tool in enhancing the accuracy of prediction, optimization of the performance of the system and in helping to make decisions based on the available data. More important, the table reflects the evolution of the research work in this field during the years, in which more recent research work is being dedicated to more complex models and real-time applications.

Author	Technique	Application	Data/Geographic scope	Key Performance results	References
Richards et al. (2023)	AI-enabled demand management	Water distribution equity	Global review	Improved service delivery and loss reduction insights	[6]
Lee & Kim (2023)	AI model	Leak detection		Real-time detection	[9]
Hubert Jenny (2023)	Hydraulic Modeling 2.0 (ML and hydraulic simulation)	Water distribution optimization	Urban networks, Asia	Optimized sensor placement; reduced intervention cost	[8]
Mathaba & Banza (2023)	SVM, ANN, ensemble ML	Water treatment optimization	Treatment plants, 2013–2023 review	Superior effluent prediction vs. empirical models	[15]
Xiaohui Yan (2024)	CNN, RF, LSTM + remote sensing	Coastal water quality prediction	Coastal zones, China & global	Enhanced WQ parameter inversion from satellite data	[12]
Revathi G. Maroju (2023)	AI-based early warning systems	Drinking water safety	Drinking water systems, global review	Up to 40% reduction in contamination response time	[13]
Mosavi et al (2020)	Hybrid ML, ANN, ensemble methods	Flood prediction	Global literature review	Improved accuracy via hybridization & decomposition	[5]
Hanlin Yin et al. (2021)	LSTM multi-state-vector Seq2Seq	Rainfall–runoff modeling	Multiple river basins, China	Outperforms standard LSTM and conceptual models	[14]

Table 1 : Summary of Artificial Intelligence Applications in Water Resources Management

2. Cross-Cutting Limitations and Challenges

This is a significant question as AI is often overpromised as a solution to water crises. Though AI can be a potent instrument in predicting, identifying leaks, and optimization, its restrictions in terms of managing water are significant and can be based on the

physical, social, and political facts of the industry. Although it has its benefits, AI in water management suffers several limitations, including:

- Availability of data is indeed a big challenge, especially in developing countries with fewer monitoring systems. For AI model training, vast amounts of data are needed, but may be difficult to access or incomplete. The absence of historical data hinders the capacity of ML algorithms to make reliable forecasts and impacts model accuracy and efficiency.[16].
- Model interpretability is a very serious problem. Such complicated systems, like deep learning, can be viewed as black boxes, so decision-makers cannot rely on their results, which is especially problematic when it comes to such a critical water process as drinking water treatment, and it is a matter of public trust and legal responsibility[17].
- Possible challenges with AI/ML models: The models tend to lack reproducibility because of their customized functions and random weights, meaning that they are not readily applicable to other industries and that their results are hard to validate since it is challenging to develop standardized forms[15].
- The complexity of real-world water issues and the necessity to select the suitable DL models to particular water systems make it difficult to develop appropriate algorithms to be applied to the water systems[18].
- Multi- Agent Systems: The potential of multi-agent systems is curtailed by the under-use of multi-agent systems particularly in complex, dynamic water systems[19].
- Barriers to adoption are the implementation costs and technical expertise. The creation and upkeep of AI systems is costly and needs personnel with high abilities[19].
- It is not easy to integrate with the existing infrastructure since most water management systems are based on old technologies[16].
- Intelligent systems lack the resources that are used in data management and data storage to run machine learning models[15].
- The need to work with large volumes of data and identify meaningful correlations between water quality measures and satellite images is a significant breakthrough[3].

To mitigate these challenges, some of the practical solutions to these issues are to encourage sharing and collaboration of data and other stakeholders, which include government agencies, research institutions, and companies. This will increase the availability of data and ensure better quality of data to develop AI models. Investment in data integration systems, signal processing tools, and tools that are capable of the management of various datasets and the interoperability of them may greatly enhance the performance of WM applications. In addition, the combination of remote sensing and IoT can bridge very important data gaps, particularly in regions with less historical data, with real-time and high-quality data sources that are essential to make informed decisions[20].

3. Perspectives for Morocco :

Acute water stress is a current situation in Morocco as the estimated renewable freshwater availability is below 1000 m³ per capita per year, which is considered as the threshold of water scarcity [1]. Geographic differences make this structural deficiency worse, with the relatively dry southern semi-arid areas getting less than 200 mm annual rainfall and the Atlantic watershed in the north being relatively well-watered. The 2030 National Water Plan assumes a 4-5 billion m³ per year deficit, due to the combination of the growth of urban population, the growth of agriculture (that currently consumes about 87% of the water withdrawn) and the higher frequency of droughts expected as a result of climate change.

In this context, AI-powered tools have a specific application potential in various fields. The LSTM-based models could be very useful for streamflow prediction at the seasonal time scale for the Moroccan watersheds (Oum Er-Rbia watershed, Sebou watershed and Draa watershed) where runoff is highly variable and the monitoring networks are limited. Better forecasts would directly help to improve reservoir operation scheduling and hydropower production efficiency at the big dams, such as Al Wahda and Bin El Ouidane.

In urban networks, Morocco's national electricity and water company ONEE (National Office of Electricity and Drinking Water) records non-revenue water (NRW) losses of 25-35%, which represents significant physical and commercial losses. If incorporated into the pressure monitoring infrastructure, the losses could be significantly curtailed with the use of AI systems for anomaly detection, as shown by Lee and Kim [9]. In Intracervical cities, such as Casablanca, Marrakech, and Agadir, where ONEE is currently implementing infrastructure modernization programs, it is possible to identify entry points for pilot deployments.

Monitoring of water quality has become an increasing concern in Morocco, especially for nitrate contamination of agricultural groundwater in the Souss-Massa and Gharb plains, and

wastewater discharges in coastal environments in the vicinity of Tangier and Safi. Low-cost sensor arrays with IoT technology and machine learning-based systems for water quality early warning could be used to enhance the available regional water agency laboratory resources. But there needs to be a response to structural constraints to take advantage of these opportunities. There is a shortage of data scientists and AI engineers with a background in hydrology in the water management sector in Morocco. The Ministry of Equipment and Water has very few historical hydrological data that have been digitized or are available to researchers. There is still a lack of regulations that govern the use of AI in decision-making processes for public utilities. Solving these barriers will need concerted investment in three areas : (i) open data platforms on national hydrological data ; (ii) partnerships between universities and industry to develop water-AI skills; and (iii) a regulatory sandbox for the controlled pilot deployment of AI in ONEs and agencies of the basin.

Conclusion

In this paper, several AI applications are discussed, with a specific emphasis on water resources management, including hydrological prediction, smart water distribution systems, and water quality monitoring [15]. Recent papers have shown that AI techniques, such as machine learning and deep learning models, can greatly increase the accuracy of predictions and make operations and decision-making more efficient [3].

It also reveals, from the literature, the increasing trend of using data-driven approaches, as well as the increasing sophistication of computational models being incorporated into the solution of complex water management problems. Although these are exciting developments, there are many shortcomings, especially with regard to the availability of data, interpretability of the models and costs of implementation [17]. Technical and institutional resources may not exist in developing countries where the problems are particularly acute. Future research is required to explore what further actions need to be taken with regard to data infrastructure, as well as the use of more explainable and transparent AI models, and to ease the use of these AI technologies in the existing water management systems [20].

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