



Climate-Resilient Plant Water Resource Management Using Explainable AI Technique

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Abstract

Climate change intensifies global water insecurity through escalating hydrological extremes, deteriorating water quality, and aging infrastructure, necessitating transformative solutions. This systematic review evaluates the role of artificial intelligence (AI) in advancing climate-resilient water management. Key findings reveal that AI models—particularly long short-term memory (LSTM) and hybrid physics-informed neural networks—achieve superior accuracy in hydrological forecasting (Nash–Sutcliffe efficiency > 0.90), enabling reliable predictions of water availability, droughts, and floods. AI-driven optimization enhances water distribution efficiency by 15–30% in case studies, while IoT-integrated systems reduce agricultural water waste by 20–40%. However, critical challenges persist: (1) data inequity, with 70% of AI applications concentrated in temperate, data-rich regions, neglecting arid and low-income areas; (2) model interpretability gaps, as “black-box” algorithms hinder stakeholder trust; and (3) policy-technical misalignment, where siloed governance stifles scalable AI adoption. The review underscores the urgency of hybrid AI-physics frameworks to balance accuracy with explainability, decentralized data ecosystems to empower marginalized communities, and ethical governance protocols to address algorithmic bias and equity. Future research should prioritize integrating multi-source data to enhance model transparency, to ensure sustainable and inclusive water management strategies. By bridging technological innovation with systemic resilience, AI emerges as a critical tool in mitigating climate impacts and securing global water security.

Introduction

Changes in the precipitation pattern have, in some areas, led to increased cases of droughts and, in others, increased cases of floods [1]. The effects of glacial melt on freshwater resources are the general reduction of water and increased water scarcity during the dry season [2]. Zoning means that extreme climate rises threaten most water conservancy projects, such as dams and reservoirs, due to events such as floods [3]. According to a bibliometric study, climate change

greatly impacts the failure rates of water supply systems, thus mandating adaptive approaches [4]. Lack of fresh water can cause competition, triggering social disturbance and wars. The DWUs experience impediments in delivering sustainable services; this projection is aligned with projected future climatic stressors within a water-scarce region [5]. Effective water management provides a safe water supply and enhances agriculture water use and sustainable

water yield for ecosystems. Sustainable water management plays a critical role in sustainable development goals and human development factors because the availability of clean water influences human health, food security, and resilience [6, 7]. Multiple connections between water energy and food webs mean these problems must be solved in a more complex scheme [8, 9]. The need for innovative solutions is underscored by the diverse challenges faced by different regions, highlighting the importance of tailored approaches to water management [10, 11]. Water resources planning and management models are increasingly artificial intelligence (AI) to resolve climate change-affecting water quality and hydropower generation problems. AI technologies make decision-making more effective because they optimize water distribution, forecast water availability, and detect pollutants, promoting environmentally sustainable practices [12, 13].

Proposed System

Figure 5 presents a conceptual framework for climate-resilient plant water resource management using Explainable Artificial Intelligence. The framework begins with the collection of data from multiple sources, including weather and climate information, plant and soil characteristics, water resource availability, remote sensing observations, IoT-based field sensors, and historical agricultural records. These diverse datasets are preprocessed

through data cleaning, normalization, feature engineering, and integration to ensure high-quality inputs for AI models. Advanced machine learning algorithms, such as Random Forest, XGBoost, Long Short-Term Memory (LSTM), and hybrid models, are then applied to predict water demand, plant water stress, drought and flood risks, and irrigation requirements. Explainable AI techniques, including SHAP, LIME, and feature importance analysis, enhance the transparency and interpretability of model predictions, enabling users to understand the factors influencing AI-based decisions.

The framework further illustrates how AI-generated insights support intelligent decision-making for climate-resilient agriculture. The decision support system provides scenario analysis, optimized irrigation scheduling, water allocation and prioritization, risk alerts, and user-friendly dashboards to assist farmers, water managers, and policymakers. Continuous monitoring and feedback enable the system to evaluate model performance, incorporate new environmental data, and adapt to changing climate conditions over time. These integrated processes contribute to efficient water use, improved plant health and crop productivity, enhanced climate resilience, and sustainable water resource management. Overall, the framework demonstrates how Explainable AI can provide transparent, reliable, and data-driven solutions for strengthening agricultural water management under climate change.

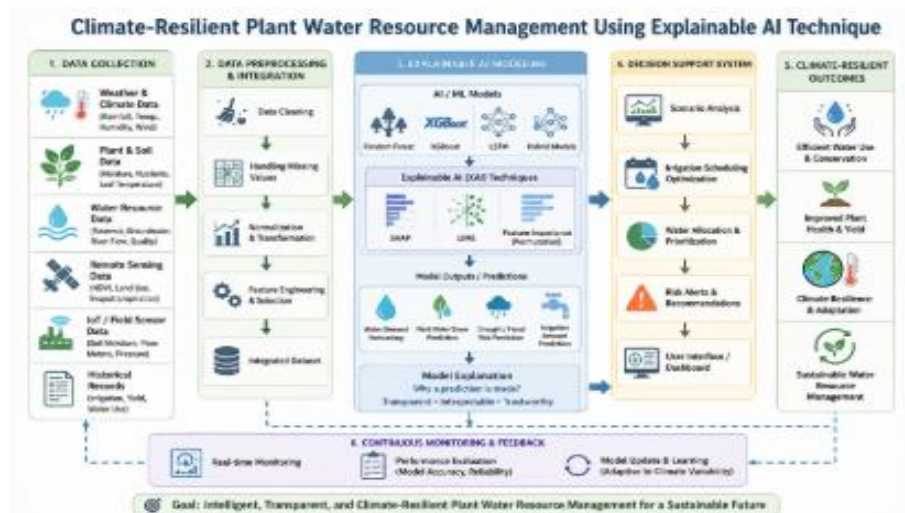


Figure 1. Conceptual Framework of Climate-Resilient Plant Water Resource Management Using Explainable Artificial Intelligence.

1. Artificial Intelligence for Water Supply Resilience Against Climate Change

AI applications in climate-resilient water management including predictive modeling, optimization, early warning systems, and water

treatment while evaluating model efficacy through standardized statistical metrics. Figure 2 illustrates how climate change creates significant challenges for water resources, including irregular rainfall, prolonged droughts, floods,

and declining water quality. These issues increase the pressure on freshwater availability and make effective water resource management essential. As a result, there is a growing need for sustainable management practices that ensure water is used efficiently, conserved properly, and remains accessible for future generations. The figure also highlights the role of Artificial Intelligence (AI) in addressing these challenges. AI supports efficient water use by optimizing

consumption, predicts droughts through data analysis, assesses water quality by detecting contamination, and improves water distribution systems by minimizing losses and ensuring reliable supply. Together, these AI-driven applications strengthen the resilience of water resources, helping communities adapt to climate change while maintaining a sustainable and secure water supply.

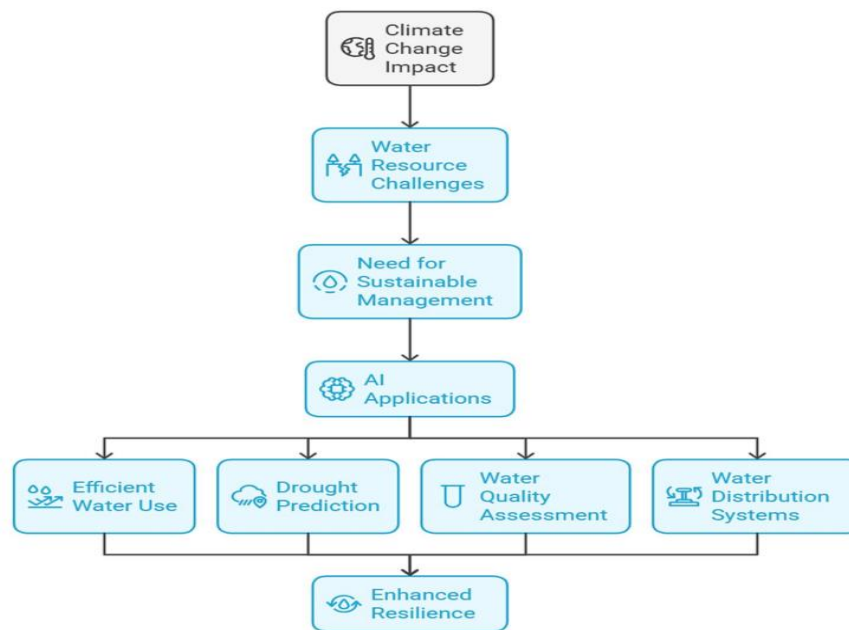


Figure 2. AI to enhance water supplies against climate change.

2. Conceptual Framework of Smart Water Management for Sustainable and Climate-Resilient Futures

The conceptual framework of this review Fig.3 illustrates the evolution of irrigation water quality management from static chemical assessments toward integrated systems that connect environmental resilience, data intelligence, and adaptive policy. It highlights dynamic feedback loops among climate drivers, water quality, soil-crop processes, and decision-support systems guided by smart technologies. The diagram integrates climate resilience, irrigation water quality, agroecosystem intelligence, and the soil-water-crop nexus. Arrows represent bidirectional feedback among water sources, soil properties, crop responses, and smart monitoring technologies. The outer ring emphasizes alignment with the Sustainable Development Goals SDGs.

A conceptual framework for smart water management that integrates irrigation water quality, agroecosystem intelligence, climate resilience, and the soil-water-crop nexus to

support the Sustainable Development Goals (SDGs). At the center of the framework is smart water management, which connects these key components through continuous data exchange, monitoring, and decision-making. The framework emphasizes that improving irrigation water quality and understanding interactions within agricultural ecosystems are essential for increasing water-use efficiency, protecting natural resources, and ensuring sustainable agricultural production.

Climate resilience and agroecosystem intelligence work together to enhance irrigation water quality while strengthening the soil-water-crop nexus, which is critical for maintaining healthy ecosystems and productive agriculture under changing climatic conditions. By integrating these interconnected elements, smart water management provides a comprehensive approach to improving water security, supporting environmental sustainability, and ensuring long-term resilience against climate change.

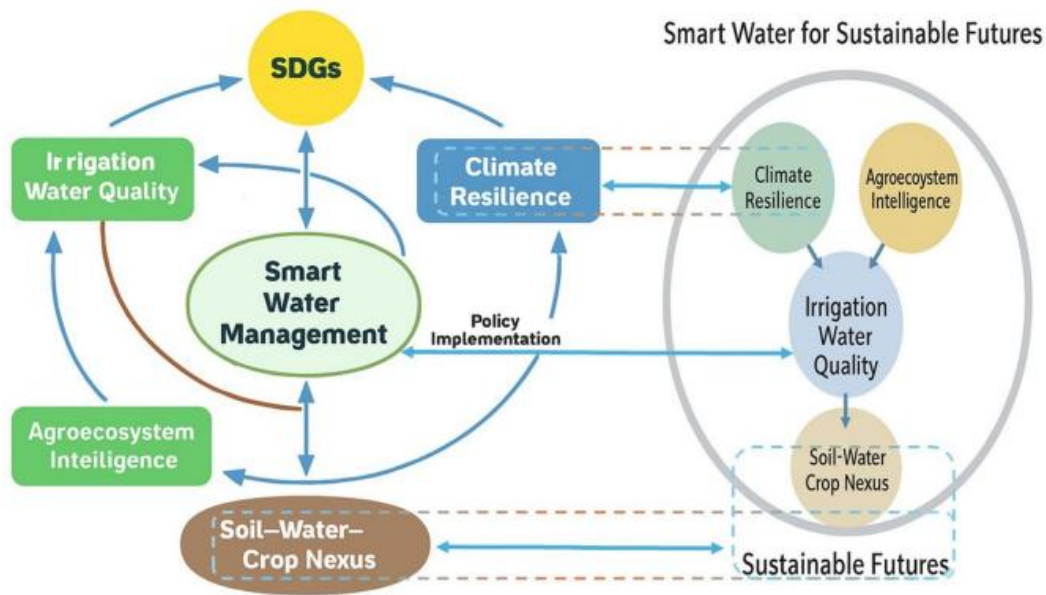


Figure 3. Conceptual framework of smart water for sustainable futures.

Results

Figure 4 illustrates the publication trends of research articles related to artificial intelligence (AI), climate change, water security, water quality, modeling, and other associated themes between 2020 and 2025. The chart indicates that the number of publications remained relatively

low from 2020 to 2022, with only a few studies published across all research areas. A noticeable increase begins in 2023, reflecting growing academic interest in the application of AI and digital technologies to address climate-related water resource challenges.

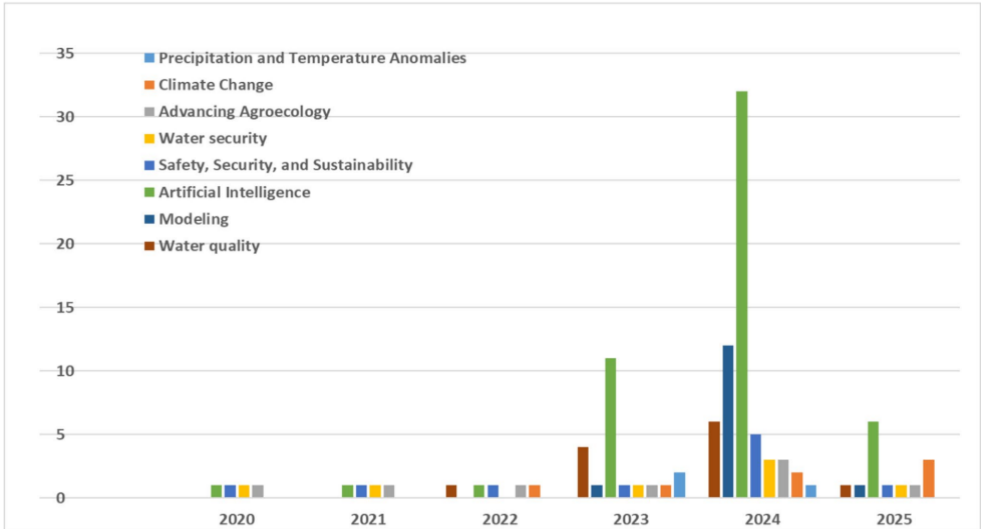


Figure 4. Publication trends of articles from 2020 to 2025, focusing .

The most significant growth is observed in 2024, where publications on Artificial Intelligence dominate all other topics, highlighting AI's emerging role in sustainable water management. Research on modeling, water quality, and precipitation and temperature anomalies also shows substantial growth, while studies on climate change, water security, and sustainability continue to increase steadily. Although the publication counts appear slightly lower in 2025,

this may be because the data represent only part of the year. Overall, the figure demonstrates a strong upward trend in interdisciplinary research focused on AI-driven solutions for climate-resilient water resource management. Figure 4 presents the growth in the number of research studies involving artificial intelligence and hybrid techniques over the past 25 years. The graph shows a gradual increase in publications during the early 2000s, followed by

a steady acceleration after 2010. This trend reflects the growing adoption of AI-based methods across various scientific and

engineering disciplines as computational capabilities, data availability, and machine learning algorithms have advanced.

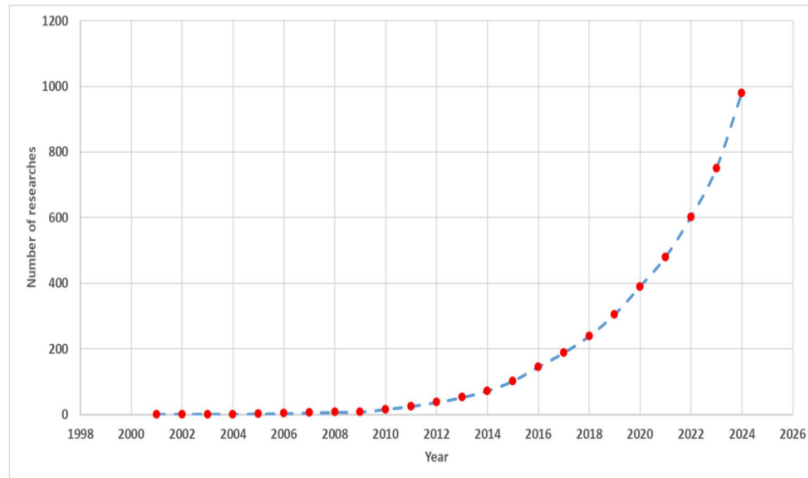


Figure 5. Growth of AI and new hybrid techniques over studies conducted in the last 25 years.

A rapid and exponential increase is evident from 2018 onward, with the number of studies rising sharply and reaching its highest level in 2024. This remarkable growth highlights the expanding importance of AI and hybrid computational approaches in solving complex real-world problems, including climate change adaptation, water resource management, agriculture, and environmental monitoring. The figure demonstrates that AI has become a key research area, driving innovation and supporting the development of intelligent, data-driven solutions for sustainable development.

Conclusion

These AI systems and IoT networks combined with public water distribution optimization frameworks demonstrate their operational capability through improved efficiency and reduced agricultural water consumption by 20–40% under these conditions. Data acquisition leads to developing sustainable methods that maintain resource sustainability. However, significant barriers hinder equitable and scalable AI adoption. Data inequity remains a critical issue, with 70% of AI applications concentrated in temperate, data-rich regions, exacerbating vulnerabilities in arid and low-income areas. However, significant barriers hinder equitable and scalable AI adoption. Data inequity remains a critical issue, with 70% of AI applications concentrated in temperate, data-rich regions, exacerbating vulnerabilities in arid and low-income areas. The “black-box” nature of many AI algorithms also limits stakeholder trust, necessitating hybrid frameworks that integrate physical processes with machine learning to

enhance interpretability. Furthermore, siloed governance and policytechnical misalignment stifle innovation, highlighting the need for decentralized data ecosystems and ethical governance protocols to address algorithmic bias and ensure inclusivity.

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