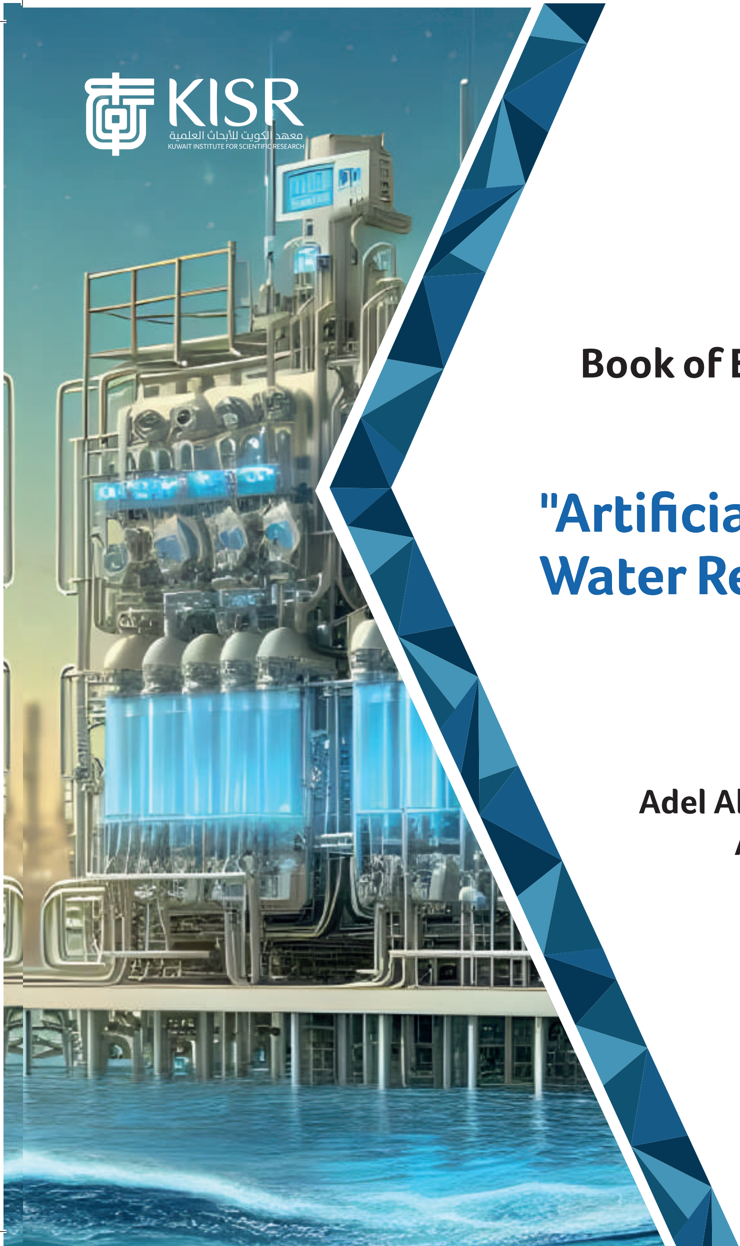

جمعية علوم وتقنية المياه
Water Sciences and Technology Association

Book of Extended Abstracts and Workshop Report

Scientific Program
"Artificial Intelligence (AI) for Sustainable Water Resources Management (SWRM) in the GCC Countries"

16-17 December 2025

Edited by:
Adel Al-Haddad, Muhammed Al-Rashed, Waleed Al-Zubari, Adnan Akber, Amjad Aliewi, and Naser Almarri

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Scope of the Workshop

The Gulf Cooperation Council (GCC) countries face severe water scarcity due to their arid climate, limited renewable freshwater resources, and growing demand resulting from urbanization, agriculture, and industry. This new era of water management necessitates innovative and intelligent solutions. Artificial intelligence (AI) presents transformative opportunities to enhance water resources management through predictive analytics, automation, and real-time decision-making. By utilizing AI concepts and tools in the GCC region, it is possible to develop and optimize water distribution systems, improve desalination efficiency, detect leaks, forecast demand, and mitigate risks related to water contamination. To address these challenges, the Kuwait Institute for Scientific Research (KISR), in collaboration with the Water Sciences and Technology Association (WSTA), organized this workshop during 1617- December in Kuwait, with the aim of equipping stakeholders with practical AI tools for water management, showcasing successful case studies of AI applications in the water sector, fostering collaboration between policymakers, researchers, industry leaders, and other stakeholders, and developing actionable strategies for AI integration in GCC water management systems.

Topics:

- **AI Fundamentals for Water Resources Management**
  - Overview of artificial intelligence (AI), machine learning (ML), and Internet of Things (IoT) in water resources management (WRM).
  - AI applications in desalination, wastewater treatment, and integrated water resources management.
- **AI Technologies in Practice**
  - Machine learning for water demand forecasting (case studies from smart cities).
  - Predictive maintenance in water infrastructure (reducing downtime and costs).
  - Smart sensors and IoT for real-time monitoring (detecting leaks and contamination).
- **Case Studies and GCC-Specific Applications**
  - AI in desalination plants (optimizing energy use).
  - AI for agricultural water efficiency (irrigation automation).
  - AI-powered early warning systems (flood and drought prediction).
- **Interactive Workshop and Tool Demonstration**
  - Hands-on training on AI tools (e.g., Python-based ML models for water analysis).
  - Group exercise: Designing an AI solution for a GCC water challenge.

Workshop Organizing and Scientific Committees

ORGANIZING COMMITTEE
Dr. Mohammad Al-Rashed, WRC/KISR
Dr. Adel Al-Haddad, WRC/KISR
Mr. Adnan Akber, WRC/KISR
Dr. Amjad Aliewi, WRC/KISR
Mr. Yaqoub Al-Foudari, WRC/KISR
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Ms. Noura H. Mohammad, MCS/KISR
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Ms. Fida Sulaiman, WRC/KISR
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SCIENTIFIC COMMITTEE
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Dr. Adel Al-Haddad, WRC/KISR
Mr. Adnan Akber, WRC/KISR
Dr. Amjad Aliewi, WRC/KISR

Day 1: 16 December 2025

Session 1: Data Governance, National Readiness, and AI Applications

Session Chairperson: Dr. AbdulAziz Al-Turbak

Session Co-Chairman: Dr. Mohammed Al-Rashedi

10:00 – 10:20	National Readiness for Artificial Intelligence Adoption **Dr. Zeyad Al-Shibaany, UK**
10:20 – 10:40	Leveraging AI and Digital Sovereignty for Smart and Sustainable Water Governance in the MENA Region **Dr. Mustafa Ezziyani**
10:40 –11:00	AI as a Tool for Economic Sustainability and Water Security in the GCC Countries **Dr. Mohamed Al-Rashed**
11:00 – 11:20	Unlocking the Potential of Emerging Technologies and Cutting Edge AI for Sustainable Water Management **Prof. Waleed Alzubari**
11:20 – 11:40	Sultanate of Oman: The Impact of Applying AI Technology on the Overall Performance of Small and Medium-sized Water-Related Enterprises in the Sultanate of Oman–A Case Study of Azr Engineering, Investment, and Holding Company **Dr. Ali Al-Hamdi**
11:40 – 12:00	**Session 1:** Discussion (Q&A with All Speakers)
12:00 – 13:00	**Prayer Break**

Day 1: 16 December 2025

Session 2: Conventional Water and WEFE-AI Applications

Session Chairperson: Dr. Mohammad Al-Rashed

Session Co-Chairman: Dr. Ali Al-Hamdi

13:00 – 13:20	Integrated Flood Management: Data, Models, and AI (Uncertainty and Knowledge) **Prof. Driss Ouzar**
13:20 – 13:40	An Artificial Intelligence Framework for the Economic/Optimal Design of Dual-Well Systems in Kuwait's Aquifers **Dr. Amjad Aliewi**
13:40 – 14:00	AI- Driven Approaches for Sustainable Water Management: Insights from Groundwater Modelling, Agricultural Drainage Treatment, and Smart Hydroponic Systems **Prof. Hoda Farouk**
14:00 – 14:20	AI-Driven Solutions for Sustainable Water Management in Arid Regions: Harnessing Smart Technologies for a Resilient Future **Eng. Adnan Akbar**
14:20 – 14:40	Leveraging Artificial Intelligence for Sustainable Water Management in Saudi Arabia **Dr. Mohammad Al-Omair**
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15:00	**Lunch and End of Day 1**

Day 2: 17 December 2025
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Session Chairperson: Dr. Waleed Zubari
Session Co-Chairman: Dr. Adel Al-Haddad

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Session 1: Data Governance, National Readiness, and Artificial Intelligence Applications

National Readiness for AI Adoption

Dr. Zeyad Al-Shibaany
International Expert in Digital and Intelligent Systems, United Kingdom

Artificial Intelligence (AI) is no longer a distant technology; it has become a strategic enabler for nations striving to build resilient, efficient, and sustainable systems. In the Gulf Cooperation Council (GCC) region, the water sector exemplifies both the urgency and the opportunity for AI adoption. This keynote explores the fundamental pillars of national readiness for AI adoption, examining both the enabling conditions and the risks that must be mitigated.

The presentation addresses the following themes:

- Digitization, Digitalisation, and Digital Transformation: Clarifying the distinctions and interconnections between these concepts, with a focus on how governments and utilities can progress from basic digitization to comprehensive transformation.
- Implementing Digital Transformation: Frameworks and stepwise approaches for policymakers, utilities, and national agencies to successfully implement digital transformation initiatives, including change management and capacity building.
- The Impact of Poor-Quality Data: Real-world examples illustrating how incomplete, inaccurate, or poorly governed data can undermine digital initiatives and AI applications, particularly in the context of water resource management.
- National Readiness Dimensions: Policy, infrastructure, regulatory environment, human capital, and institutional readiness as critical enablers of AI adoption at a national scale.

The discussion provides a structured understanding of the prerequisites for AI readiness at a national scale, with actionable insights on designing AI-friendly policies and regulatory frameworks; establishing data governance and trust mechanisms; building national and sector-specific capacities for digital transformation; and avoiding common pitfalls to ensure the sustainability of AI investments.

The keynote highlights the strategic role of leadership, collaboration, and governance in ensuring that AI adoption in the water sector not only enhances operational efficiency but also strengthens national resilience and sustainability.

Keywords: Digitisation versus Digitalisation, Digital Transformation, Artificial Intelligence, National Digital Readiness, Holistic AI Framework.

Leveraging AI and Digital Sovereignty for Smart and Sustainable Water Governance in the GCC and MENA Region

Dr. Mustafa Ezziyani
Abdelmalek Essaadi University, Morocco

Water scarcity constitutes an existential challenge for the Gulf Cooperation Council (GCC) and the wider Middle East and North Africa (MENA) region, exacerbated by climate change, population growth, and economic development. With renewable freshwater resources among the lowest globally, the region's heavy reliance on energy-intensive desalination, over-exploited groundwater, and vulnerable rain-fed agriculture creates a precarious water security landscape. Projections indicate that climate-induced water stress could cost MENA economies up to 6% of their GDP by 2050 in the absence of transformative intervention. Addressing this multifaceted crisis necessitates a fundamental paradigm shift, that is, from reactive, siloed water management to proactive, integrated, and intelligence-driven governance. This paper argues that the strategic integration of Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT) is pivotal for this transformation. Crucially, it posits that technological adoption must be coupled with digital sovereignty–the capacity of nations to control their digital infrastructure, data, and algorithms–to ensure that solutions are secure, equitable, and aligned with long-term national interests.

The foundation of this shift is the move towards data-driven decision-making. AI and ML algorithms possess the unique ability to process vast, heterogeneous datasets from satellites, IoT sensor networks, and smart meters, converting raw data into actionable insights. This ensures a transition from crisis response to predictive governance. For instance, predictive analytics can forecast urban and agricultural water demand with high accuracy, allowing for optimized reservoir management and production scheduling. ML models can analyze patterns in historical and real-time data to detect anomalies indicative of leaks or infrastructure failures, enabling predictive maintenance. This approach is already yielding results: Barcelona's AI-powered smart water network reduced non-revenue water by 25% through early leak detection, while utilities in Doha and Cairo have implemented similar systems to minimize unplanned downtime and prioritize repairs in ageing infrastructures.

The application of AI spans the entire water value chain, offering significant operational efficiency and sustainability gains. In water production, AI optimization of desalination processes is critical for the GCC, where desalination provides over 70% of the potable water supply. AI algorithms can optimize feed pressure, chemical dosing, and membrane cleaning cycles in reverse osmosis plants, drastically reducing energy consumption–a major component of operational costs and the overall carbon footprint. The Saline Water Conversion Corporation (SWCC) in Saudi Arabia operates one of the world›s largest AI-driven monitoring systems, processing billions of data points per day to achieve up to 15% energy savings. Similarly, in wastewater treatment, AI enhances process control and operational efficiency for efficient reuse, as demonstrated in Windhoek, Namibia, where AI-supported treatment systems produce potable water meeting stringent quality standards and supplying over one-third of the city's total water demand.

Agriculture, consuming 70-80% of the region's freshwater, presents a prime opportunity for AI-driven improvements in water-use-efficiency. Precision irrigation systems, powered by AI models that integrate satellite imagery, soil moisture sensors, and weather forecasts, enable «right crop, right place, right time» water application. In Morocco, under the Green Generation Plan, such platforms have improved water-use efficiency by up to 40% in high-value crops such as citrus and olives. Oman reports 35% water savings in date palm cultivation using AI-managed irrigation systems. These technologies not only conserve water but also enhance crop resilience and yield stability, directly supporting regional food security.

Furthermore, AI is a powerful tool for enhancing climate resilience and adaptive capacity. It improves the accuracy of early warning systems for droughts and floods. Morocco National Drought Observatory uses satellite data and AI-based predictive models to forecast drought severity several months in advance, informing proactive and strategic resource allocation. The UAE National Center of Meteorology employs AI-based systems integrating radar and satellite data for advanced flood forecasting, protecting lives and critical infrastructure. These applications underscore AI's role in strengthening adaptive capacity against increasing climate variability and extremes.

However, the path to AI-enabled smart water governance in the MENA and African contexts is fraught with significant structural and institutional challenges. The efficacy of AI is fundamentally dependent on data quality and availability. Many regions suffer from fragmented, inconsistent, or siloed data collection, hindering the development of robust models. Infrastructure deficits, particularly the lack of reliable IoT connectivity in rural and agricultural areas, further limit real-time monitoring capabilities. There is an acute shortage of skilled professionals, including AI engineers, data scientists, and water informatics specialists, which constrains local innovation and reinforces dependency on foreign vendors, eroding digital sovereignty.

Financial constraints within public utilities often restrict the scale-up of successful pilot projects. Moreover, the digitalization of critical water infrastructure introduces serious cybersecurity risks, making robust data protection frameworks essential. Finally, social and ethical considerations must be addressed to ensure that AI solutions are transparent, inclusive, and do not exacerbate existing inequalities in water access.

To overcome these hurdles and harness AI's full potential, the paper advocates for a coherent policy framework centered on local innovation and digital sovereignty. Key recommendations include the following:

1. Building Regional Data Ecosystems: Establishing shared, interoperable platforms for hydrological, climatic, and infrastructure data across borders to fuel more accurate and context-specific AI models.
2. Fostering Public-Private Partnerships (PPPs): Leveraging the agility of technology startups and the research capacity of academic institutions, alongside the operational experience of water utilities.
3. Developing National AI Governance Frameworks: Creating clear regulations on data ethics, privacy, security, and ownership to build trust and guide responsible deployment.
4. Investing in Human Capital: Launching dedicated education and training programs to build a local pipeline of AI and water technology expertise.

5. Promoting Open-Source and Collaborative R&D: Encouraging regional collaboration on developing open-source tools tailored to arid environments, reducing lock-in to proprietary foreign systems.

In conclusion, the convergence of AI and digital sovereignty offers a transformative pathway for water governance in the GCC and MENA regions. By embedding intelligence into water systems, countries can achieve unprecedented levels of efficiency, resilience, and sustainability. Yet, technology alone is not a panacea. Success hinges on parallel investments in institutional coordination, human capability, and robust governance, which prioritize strategic autonomy, equity, and security. The future of water security in these regions will be shaped by the ability to judiciously harness digital transformation, ensuring that it serves as a tool for inclusive prosperity and ecological sustainability for generations to come.

Keywords: Artificial Intelligence, Digital Sovereignty, Water Governance, Smart Water Management, Machine Learning, Internet of Things, Desalination and Wastewater Treatment, Predictive Analytics, Climate Resilience, MENA and African Water Security.

AI as a Tool for Economic Sustainability and Water Security in the GCC Countries

Dr. Mohammad F. Al-Rashed

Water Research Center, Kuwait Institute for Scientific Research, Kuwait

Water scarcity is one of the most pressing challenges facing the Gulf Cooperation Council (GCC) countries. Extreme aridity, limited renewable freshwater resources, rapid population growth, and climate change have led to a heavy dependence on energy-intensive desalination and increasingly stressed water distribution systems. At the same time, GCC states are pursuing ambitious economic diversification agendas, which emphasize sustainability, efficiency, and resilience. Within this context, artificial intelligence (AI) has emerged as a strategic tool capable of addressing water security challenges while delivering significant economic benefits.

The global smart water management market is expected to grow rapidly, driven by the need to optimize infrastructure performance and reduce non-revenue water (NRW). AI alone is projected to contribute hundreds of billions of dollars to the Middle East economy by 2030, with environmental and water-related applications representing a major share of this value. In the GCC, AI adoption is closely aligned with national development visions such as Saudi Vision 2030, UAE Centennial 2071, and Kuwait Vision 2035, where water security is increasingly viewed as a foundation of economic stability and national security.

This paper examines the role of AI in enhancing water sustainability and economic performance across the GCC, focusing on desalination, water distribution systems, agriculture, water quality monitoring, and AI-enabled decision-support frameworks.

Desalination is the backbone of potable water supply in the GCC, yet it is highly energy-intensive and costly. AI-driven optimization of desalination plants enables improved demand forecasting, energy management, fault detection, and predictive maintenance. Evidence from recent studies indicates that AI applications can reduce desalination energy consumption by approximately 10–20%, with advanced systems achieving even greater savings. These improvements translate into substantial reductions in operational costs, lower carbon emissions, and enhanced reliability of water supply, which are critical benefits for a region where desalination accounts for a significant share of energy use.

Reducing NRW is another area where AI delivers strong economic and environmental returns. Many urban water systems lose 20-40% of produced water due to leaks, bursts, and unauthorized connections. By integrating sensor networks, Internet of Things (IoT) devices, and machine-learning algorithms, AI enables early leak detection, the prediction of pipe failures, and targeted maintenance. Studies show that AI-based anomaly detection can reduce undetected leaks by more than 40% and lower NRW by over 20%, saving millions of dollars annually for utilities while conserving scarce water resources.

Agriculture, the largest consumer of water globally, presents a critical opportunity for AI-enabled efficiency gains in the GCC. AI-powered precision irrigation systems use real-time data on soil moisture, weather conditions, and crop water requirements to optimize irrigation schedules. In arid environments, such systems can reduce irrigation water use by 30–50% while increasing crop yields by 5-25%. These improvements enhance farm profitability, reduce energy consumption, and support food security objectives, particularly in countries that rely heavily on food imports.

AI also strengthens infrastructure asset management through predictive maintenance. By forecasting failures in pumps, pipelines, and treatment facilities, AI reduces unplanned downtime, extends asset lifetimes, and lowers maintenance costs by approximately 20–30%. This proactive approach allows utilities to prioritize investments, avoid costly emergency repairs, and defer capital-intensive infrastructure expansion, resulting in a more efficient use of public funds.

Water quality monitoring represents another domain where AI generates economic and social value. The integration of AI with sensors, remote sensing, and environmental databases enables real-time monitoring and early detection of contamination events. Recent reviews report predictive accuracies approaching 94%, alongside reductions in field sampling and laboratory costs of up to 60%. Improved water quality management reduces public health risks, environmental damage, and associated economic losses.

Across the GCC, governments and institutions are increasingly deploying AI in water and related sectors. Saudi Arabia has invested heavily in AI-enabled desalination optimization and data-driven water governance through national AI initiatives. The UAE has implemented AI-based smart irrigation systems, disaster preparedness tools, and utility management platforms.

Qatar has applied AI to water quality monitoring and integrated water-energy systems, while Kuwait is advancing national AI and digital transformation strategies under its Vision 2035 framework. These initiatives demonstrate the region's growing capacity to harness AI for sustainable and resilient water management.

Despite its potential, the deployment of AI in the water sector faces several challenges. AI systems depend on high-quality, representative data and may suffer from bias or limited transparency. The energy and water footprint of AI infrastructure, particularly data centers, is a growing concern; without mitigation, AI-related water use in the GCC could rise substantially by 2030. Data privacy and cybersecurity are also critical issues, as water-use data can reveal sensitive information about individuals and communities.

This paper argues that AI should be deployed as a decision-support tool rather than an autonomous decision-maker, with human expertise remaining central to operational and policy decisions. Responsible adoption requires strong data governance frameworks, energy- and water-efficient AI infrastructure, incremental implementation through pilot projects, and sustained investment in human capacity and institutional trust.

In conclusion, AI offers the GCC a powerful pathway to enhance water security, reduce operational costs, and support long-term economic sustainability. When integrated thoughtfully into water systems, AI can help transform water management from a reactive, resource-intensive process into a proactive, efficient, and resilient system. Balancing AI's benefits with its environmental and social costs will be essential to ensure that digital transformation contributes meaningfully to sustainable development in the GCC.

Keywords: Artificial Intelligence, Water Sustainability, Water Security; Economic Sustainability, Desalination, Smart Water Management, Non-Revenue Water, Precision Irrigation, GCC Countries.

The Smart Water Revolution: Harnessing Emerging Technologies for Sustainable Water Management in the GCC

Prof. Waleed Al-Zubari
Arabian Gulf University, Kingdom of Bahrain

The water sector in the Gulf Cooperation Council (GCC) countries is characterized by a complex set of critical and largely chronic challenges, including the depletion of fossil groundwater reserves, escalating municipal water demand met by costly and environmentally intensive desalination, and water losses at the supply and demand sides of the water systems. These issues are exacerbated by climate change impacts, such as reduced precipitation and increased flooding, and by systemic vulnerabilities in water supply infrastructure. A transformative shift from traditional, reactive water management to an optimized, predictive, and integrated system is therefore considered essential for regional water security. This transformation is envisioned to be driven by the strategic adoption of Fourth Industrial Revolution (4IR) technologies.

A paradigm shift from siloed, descriptive data analysis to a new era of predictive intelligence is explored. Emerging technologies, including Artificial Intelligence (AI), GeoAI, the Internet of Things (IoT), blockchain, robotics and drones, big data analytics, and so on, are positioned as powerful enabling tools for diagnostic, analytical, and predictive functions across the entire water supply chain.

Specific GCC challenges and the targeted applications of emerging technologies are examined. For the critical issue of extensive agricultural water consumption, solutions, such as precision agriculture using IoT and AI for irrigation scheduling, GeoAI for monitoring groundwater extraction via satellite imagery, and AI-driven crop selection algorithms, are presented. To combat groundwater depletion and saltwater intrusion, the concept of a "Digital Twin for Groundwater Monitoring and Modelling" is introduced. This AI-powered virtual replica of the physical and management system enables real-time monitoring, optimal pumping schedules, and robust «what-if» scenario analysis.

In the municipal water sector, applications for optimizing desalination plant operations through predictive maintenance of membranes and AI-driven energy optimization are demonstrated. The enhancement of distribution network efficiency through real-time leak detection and pressure management using AI and IoT is also demonstrated. Furthermore, an innovative AI-driven "Smart Water Contract" system is presented, which utilizes IoT sensors and blockchain to enforce consumption thresholds and incentivize conservation among households and companies.

The vulnerability of water infrastructure to threats ranging from maritime pollution and cyber-attacks to urban flooding is also addressed. Here, AI is leveraged for emergency response plan optimization, and GeoAI models are used for predicting flood-prone areas and managing drainage systems. The inadequate utilization of treated wastewater is tackled with proposals for AI-driven maintenance of collection networks and blockchain-based systems for traceability and quality assurance of reused water.

Finally, it is argued that this technological transformation must be supported by a parallel evolution in water education. The current skills gap necessitates the cultivation of a new generation of «Water Data Scientists,» fluent in data literacy, computational skills, and systems thinking. The embedding of 4IR technologies in water education is proposed through curriculum modernization, «Living Lab» universities leveraging GCC infrastructure, and immersive learning using digital twins. In conclusion, emerging technologies are demonstrated to provide the critical tools necessary to diagnose/analyze, optimize, predict, and secure the urban and agricultural water supply chain in the GCC countries.

Keywords: Emerging Technologies, Cutting-Edge AI, Groundwater, Desalination, Treated Wastewater; Infrastructure Vulnerability, Climate Change.

Sultanate of Oman: The impact of Applying AI Technology on the Overall Performance of Small and Medium-Sized Water-Related Enterprises in the Sultanate of Oman– A Case Study of Azr Engineering, Investment, and Holding Company

أثر تطبيق تقنية الذكاء الاصطناعي على الأداء العام للشركات في سلطنة عمان دراسة حالة شركة أزر للهندسة والاستثمار القابضة

د. علي بن محمد الحامدي
عضو مجلس إدارة جمعية علوم وتقنية المياه الخليجية، سلطنة عمان

تُعدُّ تطبيقات الذكاء الاصطناعي من بين المستهدفات الاستراتيجية في رؤية عمان 2040، التي تهدف إلى بناء اقتصاد رقمي مستدام. مع ذلك، فإن تبني هذه التقنية بشكل فعلي يتطلب جهوداً كبيرة وقناعة راسخة من قبل صناع القرار في القطاعين العام والخاص. تهدف هذه الدراسة إلى قياس أثر تطبيق تقنية الذكاء الاصطناعي على الأداء العام للشركات في السلطنة، وذلك من خلال دراسة حالة متعمقة لشركة أزر للهندسة والاستثمار القابضة. وركز التحليل على ثلاثة محاور رئيسية: الكفاءة التشغيلية كماً ونوعاً، والأثر المالي والاقتصادي (مع التركيز على العائد على الاستثمار وتوفير التكاليف)، والأثر على الموارد البشرية (سواء عبر الإحلال أو الإثراء الوظيفي).

يُعرَّف الذكاء الاصطناعي باعتباره فرعاً من فروع علوم الحاسب الآلي يُعنى بتصميم أنظمة قادرة على أداء مهام تتطلب ذكاءً بشرياً، مثل التعلم واتخاذ القرارات. وهو يمثل مزيجاً من القدرات التقنية والمعايير الأخلاقية، ويُعدّ محركاً أساسياً للتحول الرقمي في المؤسسات الحديثة، حيث يسهم بشكل مباشر في رفع الكفاءة التشغيلية وتحسين جودة الخدمات واتخاذ القرارات القائمة على البيانات. ويأتي هذا البحث في سياق بيئة أعمال محلية نشطة، حيث أظهرت الإحصاءات الرسمية لنهاية عام 2024 وجود أكثر من 441 ألف سجل تجاري تراكمي، وما يزيد على 146 ألف منشأة صغيرة ومتوسطة. وتُعرَّف المؤسسات الصغيرة والمتوسطة في عُمان بأنها تلك التي يعمل بها أقل من 99 موظفاً وتحقق إيرادات سنوية تقل عن ثلاثة ملايين ريال عُماني.

وتمثل شركة أزر للهندسة والاستثمار القابضة، التي تأسست في ديسمبر 2021، حالة دراسية ملائمة. فهي شركة مساهمة مقفلة مملوكة بالكامل لرجال أعمال عمانيين، ويعمل بها 220 موظفاً، ويتجاوز إيرادها السنوي مليوني ريال عُماني. تعمل الشركة في مجالات تمديد وصيانة وتشغيل شبكات المياه، وتقدم خدمات المياه الصالحة للشرب لأكثر من ثلاثة آلاف مشترك، وتمتلك مصنعاً لتعبئة المياه. وقد تبنت الشركة عدداً من أدوات الذكاء الاصطناعي في أنشطتها الإلكترونية، شملت: تقنيات الرقمنة والتعرف البصري على الحروف (OCR) لمعالجة فواتير الموردين والمصروفات، وروبوت المحادثة المباشر

(Chatbot) للتواصل مع العملاء، وأنظمة المعرفة وجداول البيانات لربط وتحليل المعلومات، وواجهات برمجة التطبيقات الخارجية للتكامل مع منصات الشركاء، وأداة باور بي آي (Power BI) لتحليل البيانات والمؤشرات.

تنبثق مشكلة الدراسة من التطور السريع والمتسارع لتقنية الذكاء الاصطناعي وقدرتها على إحداث تحول جذري في عمليات صنع القرار الاستراتيجي والتشغيلي. لذا، تسعى هذه الدراسة إلى الكشف عن مدى قدرة الشركات المتوسطة والصغيرة على الاستفادة من هذه التقنية وتوظيفها في عملياتها الإدارية والمالية والتشغيلية المختلفة.

واعتمدت منهجية البحث على دراسة الحالة من خلال التحليل المتعمق لشركة أزر، مع الأخذ في الاعتبار العوامل المؤسسية والثقافية والتنظيمية المحيطة بتطبيق التقنية. وهدفت الدراسة بشكل أساسي إلى تحقيق هدفين: الأول هو بيان أثر استخدام الذكاء الاصطناعي على أداء الشركات الصغيرة والمتوسطة عبر المحاور الثلاثة المذكورة، والثاني هو تحديد التحديات التي تواجه هذه الشركات أثناء التطبيق.

أظهرت نتائج الدراسة وجود أثر إيجابي ملموس لتطبيق الذكاء الاصطناعي على أداء الشركة. فعلى صعيد الكفاءة التشغيلية، ساهم التطبيق في رفع جودة التقارير الفنية والإدارية والمالية مع تقليل الأخطاء، وتسريع إنجاز المخاطبات الرسمية، ودعم إعداد الخطط الاستراتيجية والتنفيذية وصياغة العقود، وتحسين جودة وسرعة العمليات الإدارية واتخاذ القرار، كما حسّن خدمات المشتركين في قطاع المياه من خلال سرعة الاستجابة وتقليل الحاجة للحضور الشخصي.

أما على المستوى المالي والاقتصادي، فقد أدى التطبيق إلى خفض التكاليف التشغيلية عبر خطط استراتيجية للحد من الهدر في الموارد، وساعد في السعي نحو تحقيق رؤية الشركة بخفض المصاريف التشغيلية بنسبة 10% سنوياً (وهو هدف قيد الدراسة). كما أظهرت النتائج إمكانية تحسين العائد على الاستثمار في حلول الذكاء الاصطناعي الخاصة، خاصة في مجالات إدارة فاقد المياه في الشبكات، وتقليل الفاقد التجاري، وإعداد الدراسات المتعلقة بالطلب وتقييم المخاطر. وفيما يتعلق بالموارد البشرية، أدى التطبيق إلى تعزيز الإثراء الوظيفي من خلال تطوير مهارات الموظفين المستخدمين للتقنية، حيث لوحظ فارق أداء ملحوظ لصالح الموظفين المتبنين لهذه التطبيقات مقارنة بزملائهم.

وعلى الرغم من هذه النتائج الإيجابية، فقد واجهت الشركة عدة تحديات خلال مرحلة التطبيق. تمثلت التحديات المؤسسية في صعوبة دمج تقنيات الذكاء الاصطناعي مع الأنظمة القديمة الموجودة (Legacy Systems) والتحديات المرتبطة بتأمين البيانات. وبرزت تحديات بشرية تمثّلت في مقاومة التغيير من قبل بعض الموظفين. كما واجهت تحديات بيئية تمثلت في ندرة الكفاءات الوطنية المتخصصة في مجال الذكاء الاصطناعي، وقلة الموردين المحليين للحلول التقنية المتقدمة، مما يرفع من تكاليف التزويد والدعم الفني.

بناءً على هذه النتائج، تقدم الدراسة مجموعة من التوصيات، أهمها: تطوير أفضل الممارسات والدلائل الإرشادية الخاصة بتطبيق الذكاء الاصطناعي في نطاق الشركات الصغيرة والمتوسطة، وتعزيز الدعم الحكومي عبر برامج تدريبية متخصصة وورش عمل لبناء القدرات، وتقديم حوافز تشجيعية مادية أو معنوية للشركات التي تتبنى مسار التحول الرقمي والذكي، وبناء شراكات استراتيجية فعالة بين القطاعين العام والخاص لتسريع وتيرة التحول الرقمي المستدام.

وفي الخلاصة، تؤكد تجربة شركة أزر أن تطبيق تقنيات الذكاء الاصطناعي يمكن أن يُحدث أثراً تحويلياً إيجابياً على الأداء العام للشركات المتوسطة والصغيرة في عُمان، عبر تعزيز الكفاءة التشغيلية، وخفض التكاليف، ورفع العائد الاستثماري، وإثراء رأس المال البشري. بيد أن تحقيق أقصى استفادة ممكنة من هذه التقنية يتطلب العمل الجاد على تجاوز التحديات المؤسسية والتقنية والبشرية القائمة، وضرورة تفعيل دور الدعم المؤسسي الحكومي وبناء الشراكات الفاعلة على المستوى الوطني لخلق بيئة محفزة للابتكار والتحول الذكي.

اهم المصطلحات: الذكاء الاصطناعي، الشركات الصغيرة والمتوسطة، الأداء العام، شركة أزر للهندسة والاستثمار القابضة.

Session 2: Conventional Water and WEFE AI Applications
Integrated Flood Management: Data, Models, and AI (Uncertainty and Knowledge)

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Water is a fundamental requirement for survival in the next millennium due to freshwater shortage, increased human population, human activities, and consequent quality degradation. The situation is most critical in semiarid to arid regions. Water shortage will adversely affect living standards and economic activities. If not properly mitigated, it will trigger social unrest and negatively impact national stability. In parallel, although most people commonly consider water a beneficial resource, it can also pose a high risk. Excess water can pose many problems to human beings and socioeconomic activities, as observed all over the world over the last two decades.

Climate change has induced increasingly pronounced water hazards over the last decade. The main hazards include: i) droughts (scarcity), ii) floods (the most common natural disaster), iii) pollution, and iv) water quality degradation. For water as a risk, it is worth mentioning that the frequency and intensity of floods in recent years have increased significantly around the world. This has caused substantial loss of life and material goods, and the deterioration of socioeconomic infrastructures. Dam failure is considered a special flood associated with the mechanical failure of a dam due to either man-made or natural hazards. Flooding is considered the most widespread natural disaster (representing almost 37%). Fighting against flooding is, therefore, of utmost importance. Traditionally, policies have focused on structural measures, such as infrastructure (dams, river works, and restoration) to store water and facilitate flow to reduce flooding, and, to a lesser degree, watershed management. These are essentially preventive measures. Drought issues are also of paramount importance. However, in this presentation, we focus on flood hazards.

The know-how is limited and closely related to human mismanagement of resources (competence, know-how, modelling and simulation tools, and data), and the limited use of emerging tools. Therefore, flood control and protection requirements have increasingly attracted the attention of the scientific community to deal with flooding issues as both an engineering pursuit and a social endeavor through scientific research investigations. In the past, physically based flood control through the construction of levees, dykes, diversion channels, dams, and related structures was considered the main mitigation measure. However, with the continued increase of flood losses, a new approach emerged, utilizing the concept of risk in decision-making. Flood cannot be defined as an independent object of society but must be considered as a constraint that is itself part of the historical evolution of a territory. Now, some questions can be raised: i) To what extent and how do human actions affect the risk of flooding? and ii) To what extent and how does flood hazard, in turn, affect human activities, particularly with respect to opportunities for spatial and territorial development?.

The diversity of societal responses to flood hazard and the prescription of preventive policies is dependent on perceptions, political processes, and local issues. It should be noted that flood defense projects are of special concern as they are very complex, environmentally sensitive, and under close public scrutiny. Accurate and timely warnings are critical for mitigating these risks, especially for floods events that require a quick response through early warning, preparation, and population evacuation plans. Engineers and scientists have traditionally addressed these problems through the transfer paradigm, only involving: i) inputs (data), ii) process (black box or hydrological process), and iii) outputs (results). Hydrology and hydraulics models are considered the main basis for addressing water hazards issues. Hydrological simulation models typically must be calibrated to long data records to ensure the reliability of predictions.

AI has become one of the main complementary tools to help with water hazard management and the mitigation of related risks. The main advantages of using AI for water hazards stem from the following: i) AI and big data enable the integration of heterogeneous sources (conventional data, weather forecasts, satellite imagery, and local sensors [IoT]) to better predict droughts, floods, and other water-related risks. This adds significant value for planning and disaster response, including population evacuation in a timely manner; ii) AI-driven platforms can extract better insights from heterogeneous data sources (diverse datasets, reports, sensors, etc.) to create more precise and timely water risk maps; iii) AI enhances flood forecasts, particularly for ungauged basins, and can provide flood warnings earlier and over larger and more impactful events. An integrated flood management approach is of paramount importance for addressing flood risk. This paper covers some aspects, namely, data and big data, models, uncertainty, and knowledge (notably AI).

Key challenges and open issues for AI applications will be thoroughly discussed, in particular:

- Data availability and quality: AI models need high-resolution, accurate, timely data. In many regions, sensor networks are sparse, data are not publicly available, and historical records are incomplete.
- Regulation and policy gaps: There is often no requirement for AI infrastructure (data centers) to report water usage; environmental impact assessments may not cover water usage specifically.
- Trade-offs: There is always a trade-off between performance, cost, speed versus environmental impact. Cooling via water is often cheaper and more efficient than alternatives, which makes it difficult to shift to less water-intensive systems without additional cost.
- Climate variability and uncertainty: As weather patterns change, AI models trained on past data may not always predict well under new extremes.
- Geographic inequity: Impacts are uneven; water stress is more severe in some places. These places may also have less capacity to regulate, adapt, or invest in mitigation.

AI applications for water as both an opportunity and a risk can be a great asset for: i) governance and sustainable water use, ii) management actions, iii) augmented models with scenarios and impact analysis, from data to results, iv) monitoring and geospatial databases (data and metadata foundations, reliability, accessibility, transparency, and water data) as well as v) guideline development and capacity-building enhancements.

Keywords: Integrated Water Resources Management, AI, Water as a Resource and as a Risk, Integrated Modelling, Data, Uncertainties.

An Artificial Intelligence Framework for the Economic/Optimal Design of Dual-Well Systems in Kuwait's Aquifers

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Groundwater constitutes one of Kuwait's most strategically important natural resources, particularly for non-potable uses in domestic, industrial, agricultural, and strategic sectors. Annual extraction from brackish groundwater systems is estimated at approximately 732 Mm^3/year, of which only 220–353 Mm^3/year is recorded officially, leaving a substantial volume of unmonitored extraction dominated by private agricultural wells. This growing pressure on groundwater, intensified by urbanization, industrial growth, aridity, and persistent water scarcity, necessitates a transition from conventional well design practices toward economically optimized and hydrogeologically sustainable methods. Traditional well design overwhelmingly prioritizes maximizing initial pumping yield, often with little consideration for long-term operational energy costs, drawdown behavior, or long-term aquifer integrity. In response to these gaps, this work presents a novel artificial intelligence (AI)-based framework that redefines well design through economic optimization tailored to Kuwait's dual-aquifer system: the Kuwait Group (KG) and the Dammam (DM) formations.

The core argument advanced in this research is grounded in a fundamental economic principle: optimal well design should aim to minimize the total lifetime cost of groundwater extraction, rather than maximize immediate yield. Achieving this requires a rigorous balance between capital expenditures (including drilling, casing, screens, and construction) and the discounted present value of all future operational costs, especially pumping energy consumption over a typical 20–25-year well lifespan. The proposed AI framework operationalizes this principle by formulating a comprehensive mathematical model, which integrates all cost components into a Total Present Value (TPV) equation. This TPV formulation explicitly links well design parameters, including screen length (Ls), open-hole length, borehole depth, and pumping rate (Q), to hydrogeological responses such as drawdown, head losses, and energy requirements.

The capital cost component of the model follows practical construction realities in Kuwait. It is divided into fixed costs (including mobilization, conductor pipe, gravel pack, and pump installation) and variable costs driven by the design geometry.

The drilling cost is controlled by the expression, Dbore = DSWL + 1.2Sw + Ls, where Sw = 2Q/(KLs), clearly showing the interplay between pumping rate, aquifer hydraulic conductivity (K), and screen length. Casing and screen costs are parameterized using locally established Kuwaiti unit rates for varying diameters and materials (including steel, PVC, and stainless steel). This allows the model to accurately reflect real-world construction economics rather than relying on generalized or idealized cost functions.

Operational costs are dominated by energy consumption, which is highly sensitive to drawdown and often exceeds capital costs by up to an order of magnitude when discounted over decades. In the Shigaya H wellfield case study, for example, the calculated present value of operating cost was nearly ten times higher than the capital cost. This finding underscores the importance of incorporating long-term pumping costs into design optimization, especially in electric-energy-intensive environments such as Kuwait.

AI-based optimization is used to solve the TPV minimization problem by differentiating the TPV equation with respect to screen length and solving d(TPV)/dLs = 0. This enables the model to identify the optimal configuration that reduces the total cost over the well's lifespan. The framework was applied to a real dual-completion well targeting both the Kuwait Group and the Dammam aquifers in the Shigaya H wellfield. Key hydrogeological parameters included a static water level of 170 m below ground level, a hydraulic conductivity of up to 50 m/day, and a target pumping rate of 3,000 m^3/day. Economic parameters included a 25-year design life and a 5% discount rate.

The optimal design identified by the AI model consisted of a total screen/open-hole length of 65 m, divided between the productive zones of the Ghar Formation in the Kuwait Group and the stable Dammam aquifer, where an open-hole completion is considered cost-effective. The results demonstrate how extending screen length, while increasing capital cost, significantly reduces lifetime energy consumption by lowering drawdown, thereby minimizing head loss during pumping. The optimized design achieves the lowest TPV by balancing additional construction costs against reduced operating costs.

A comprehensive multi-parameter sensitivity analysis was performed to evaluate the robustness of the optimal solution and identify the dominant parameters influencing Ls and Q. The most influential parameters affecting screen length were found to be hydraulic conductivity (K) and pumping rate (Q).

Lower K values require substantially longer screens to maintain the same pumping efficiency, while higher Q values increase both drawdown and energy consumption, necessitating longer screens to reduce losses. Economic parameters also exert meaningful influence: lower discount rates and longer project lifetimes increase the weight of future operating costs, favoring longer screen lengths, while higher energy cost coefficients (λ) reinforce the economic value of minimizing drawdown through additional screen length.

Sensitivity analyses were extended to the optimal pumping rate using the reformulated objective function $V = TPV/Q$, representing the cost per cubic meter of water. Solving $dV/dQ = 0$ yields a meaningful economic optimum, which avoids the faulty and insignificant solution produced by minimizing TPV directly with respect to Q. Results show dramatic shifts, with up to 91% variation in optimal pumping rates, depending on K, λ, and Ls. The base-case optimal pumping rate was determined to be approximately Q = 7,700 m^3/day, offering the lowest cost per cubic meter under average conditions (K = 50 m/day, Ls = 65 m, $\lambda = 0.0005$, r = 0.05, and n = 25 years). These findings highlight the necessity of site-specific hydrogeological and economic characterization; generalized design rules are insufficient for sustainable groundwater extraction in Kuwait.

In practical terms, these results offer important implications for wellfield development. For low-K formations (<10 m/day), optimal screen lengths may exceed 200 m, while high pumping demands (>4,000 m^3/day) typically require screen lengths greater than 90 m. Moreover, sensitivity to energy costs suggests that future increases in electricity pricing or the adoption of renewable-powered pumping systems may significantly alter optimal designs.

Overall, the proposed AI-driven framework delivers a transformative approach to groundwater well design in Kuwait. Unlike traditional methods that emphasize maximizing initial yield, this methodology emphasizes economic sustainability, optimizing well design based on minimizing the cost per unit volume of water extracted over the system's lifetime. The framework provides a transparent, data-driven decision-support tool, which can be applied to new wellfields as well as the upgrades or expansions of existing groundwater systems across Kuwait. By explicitly integrating hydrogeological properties, design parameters, and long-term cost behavior, this AI-enhanced methodology advances both economic efficiency and groundwater sustainability. It also aligns with national water security goals, supporting Kuwait's strategic efforts to manage scarce groundwater resources responsibly.

Keywords: Artificial Intelligence, Well Design Optimization, Total Present Value, Kuwait Aquifers, Dual-Completion Wells.

AI-Driven Approaches for Sustainable Water Management: Insights from Groundwater Modelling, Agricultural Drainage Treatment, and Smart Hydroponic Systems

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Sustainable water resource management has emerged as a global imperative as freshwater scarcity intensifies under the combined pressures of climate change, population growth, agricultural expansion, and pollution. These pressures are especially severe in arid and semiarid regions, where hydrological systems are intrinsically fragile and surface water supplies are limited. Within this context, innovative and data-driven tools that enhance water-use efficiency, optimize resource allocation, and strengthen environmental monitoring have become essential. Artificial Intelligence (AI), supported by advanced statistical analysis, predictive modelling, and smart agricultural technologies, offers a powerful pathway toward strengthening decision-making and improving the sustainability of water systems.

Over the past decade, our collective research has developed, applied, and validated a series of AI-driven methodologies aimed at addressing critical water challenges, including groundwater salinization, drainage water reuse, agricultural pollution, and water-efficient forage production. This extended abstract synthesizes these contributions into a unified scientific narrative, demonstrating how AI, Internet of Things (IoT) technologies, and integrated modelling can reshape sustainable water management and precision agriculture.

1. AI-Based Prediction of Groundwater Salinity for Irrigation Decision Support.
Groundwater constitutes a vital strategic resource in water-scarce environments; however, its usability is often restricted by increasing salinity levels. Conventional laboratory-based hydrochemical assessments, while accurate, are resource-intensive, time-consuming, and often impractical for continuous monitoring. Our research introduced an innovative alternative by leveraging Artificial Neural Networks (ANNs) to predict groundwater salinity using only simple, easily measurable parameters.

Among these parameters, pH was identified as a highly accessible and reliable predictor in arid and semiarid regions. By training ANN models on historical groundwater datasets, we achieved highly accurate salinity forecasts that rival conventional laboratory measurements. This approach demonstrates a significant advancement in rapid, low-cost groundwater assessment, enabling farmers, water managers, and decision-makers to classify water suitability for irrigation rapidly and reliably.

2. AI-Enhanced Assessment and Management of Agricultural Drainage Water.
Agricultural drainage water represents one of the most promising yet underutilized unconventional water resources. Its reuse potential is particularly valuable in regions where expanding irrigation demands are severely constrained by limited freshwater supplies. However, drainage water typically contains variable concentrations of salts, nutrients, agrochemicals, and suspended solids, requiring careful evaluation before reuse.

Our research examined this challenge comprehensively by combining AI techniques, statistical modelling, and hydrochemical analysis. A systematic review of global ANN applications for drainage water treatment and quality assessment provided a foundation for developing locally adaptable models capable of predicting key water quality parameters.

The ANN models developed in our studies successfully identified complex trends influencing drainage water chemistry and accurately predicted critical indicators such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), and nutrient concentrations. These insights allow water managers to rapidly evaluate reuse potential, identify pollution sources, and design more targeted treatment strategies.

3. Smart Agriculture and IoT-Enabled Hydroponic Systems for Water-Efficient Fodder Production.
Given that agriculture consumes approximately 70% of global freshwater withdrawals, transitioning toward water-efficient cultivation systems is essential. To address this challenge, our collaborative research expanded beyond water quality assessment to the design of smart agricultural solutions capable of significantly reducing water use while improving crop productivity.

One major outcome was the development of an IoT-enabled hydroponic system optimized for producing high-quality barley green fodder. This system incorporates real-time sensors that continuously monitor environmental and nutrient parameters. Automated data collection and intelligent control mechanisms adjust irrigation frequency, nutrient dosing, and microclimate conditions with precision. This results in substantial improvements in water-use efficiency, uniform plant growth, and the high nutritional value of the produced fodder.

4. Integrating AI, IoT, and Statistical Modelling

A central strength of our research is the integration of AI, IoT signalling, hydrochemical analysis, and advanced statistical methods into comprehensive decision-support frameworks. Multivariate analyses allowed us to identify key contributors to water quality variability, classify water sources, track pollution pathways, and evaluate environmental risks associated with salinity, nutrient loading, and agrochemical runoff.

5. Toward an Integrated AI-Based Strategy for Sustainable Water Management

The collective work demonstrates a cohesive research vision in which AI, predictive modelling, IoT technologies, and smart agriculture converge to address multidimensional water challenges. Key contributions include rapid groundwater assessment, AI-enhanced drainage water evaluation, IoT-enabled fodder systems, and scalable hybrid models suitable for water-stressed regions. This extended abstract consolidates a decade-long journey of research and innovation focused on applying AI and smart systems to advance sustainable water resource management.

Keywords: Artificial Neural Networks, Sustainable Water Management, Water Quality Prediction, Groundwater Salinity, IoT-enabled Hydroponics.

AI-Driven Solutions for Sustainable Water Management in Arid Regions: Harnessing Smart Technologies for a Resilient Future

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Arid and hyperarid regions across the globe are experiencing escalating pressures on their already limited freshwater reserves as a result of rapid population growth, accelerated urban development, intensified agricultural production, industrial expansion, and the compounding impacts of climate change. Water consumption in many of these regions now exceeds natural rates of replenishment, while climate-driven warming continues to increase the severity and recurrence of droughts, alter rainfall patterns, and expose the vulnerabilities of conventional water-supply systems. Under such conditions, traditional hydrological monitoring networks and water-management practices, although foundational and historically effective, are no longer capable of delivering the spatially and temporally refined information required for real-time decision-making. Sparse observation networks, aged infrastructure, long-term data gaps, and reactive operational strategies reveal inherent limitations that hinder sustainable water governance, thereby highlighting the urgent need for a shift toward more intelligent, data-driven, and adaptive water-management systems.

Against this backdrop, artificial intelligence (AI), advanced data analytics, and digital technologies are emerging as transformative tools capable of reshaping the way water resources are monitored, managed, and protected in arid and semiarid environments. Advances in machine learning, deep learning, data assimilation, sensor networks, remote sensing, and cloud-computing platforms are expanding the horizons of forecasting, anomaly detection, system optimization, and automated operational control. When effectively integrated with hydrological science and domain-specific expertise, AI offers sophisticated analytical capabilities across the entire water-resources lifecycle, from source development and treatment to distribution, reuse, and long-term planning, thereby enabling more efficient, reliable, and resilient management of water systems.

One of the most impactful applications of AI in arid regions lies in the desalination sector, which serves as the primary water-supply backbone for the Gulf Cooperation Council (GCC) countries and many other water-scarce nations. AI enhances desalination performance through intelligent prediction of membrane fouling, dynamic energy optimization, early detection of pump or valve failures, and automated control of brine-management systems. Predictive maintenance significantly reduces plant downtime, while reinforcement-learning approaches enable real-time adjustments of multi-stage desalination processes, ultimately lowering operational costs and improving system reliability. In thermal desalination, which remains widely used in the Gulf region, AI supports the optimization of steam cycles, detection of tube scaling, and regulation of heat flows under variable climatic and operational conditions. Beyond desalination, AI strengthens the strategic integration of nonconventional water sources, including treated wastewater, managed aquifer recharge (MAR), rooftop harvesting, and wadi-runoff storage, by evaluating their contributions to national water-security portfolios under diverse climate and demand scenarios.

In wastewater treatment and reuse systems, AI-driven solutions are increasingly adopted to improve process stability, operational efficiency, and effluent reliability. Machine learning classifiers provide early detection of anomalies in aeration basins, membrane bioreactors, and nutrient-removal units, thus minimizing operational failures. Predictive control algorithms optimize aeration intensity, chemical-dosing strategies, and hydraulic loading, reducing energy consumption while maintaining regulatory compliance. Deep learning models enhance forecasting of influent characteristics associated with industrial discharges, a growing challenge in rapidly industrializing arid countries. Water reuse, now a central component of sustainable water-security strategies across arid regions, further benefits from AI through real-time monitoring, automated risk assessment, and optimization of blending strategies with desalinated or groundwater supplies. These capabilities collectively support the transition toward circular water systems, enhancing both water-use efficiency and long-term resource sustainability.

Groundwater, a critical lifeline in arid environments, is particularly difficult to monitor and manage due to its deep and often fossil aquifers, limited replenishment, and complex hydrogeological conditions. AI provides alternate pathways for characterizing and predicting groundwater behaviour in data-scarce regions. Machine-learning algorithms improve the estimation of recharge rates, detection of anomalies in water-level trends, identification of salinity-intrusion processes, and forecasting of long-term drawdown under various pumping and climate scenarios.

In MAR applications, AI supports site selection and recharge performance evaluation by analysing geological, hydrogeochemical, soil, and climatic datasets. It predicts infiltration capacity, clogging risk, mounding effects, and long-term aquifer responses, providing critical insights for arid countries aiming to store excess treated water or desalinated production as strategic reserves. Remote-sensing products, such as GRACE gravimetry, InSAR deformation imagery, and multispectral datasets, when combined with AI-based data-fusion techniques, enhance the understanding of groundwater dynamics in regions with limited in situ measurements.

Equally transformative is the emergence of digital twins, high-resolution virtual replicas of water-distribution networks, treatment facilities, reservoirs, and entire utility systems. When paired with AI, digital twins allow utilities to simulate demand fluctuations, optimize pump scheduling, detect leaks, manage pressure zones, and evaluate emergency-response strategies under extreme climate scenarios. GCC utilities are already demonstrating measurable improvements through AI-supported digital twins, particularly in reducing non-revenue water, enhancing leak detection, and improving service continuity. These technologies allow utilities to transition from reactive management to predictive, optimization-driven operational modes, thereby improving resilience and reducing financial and operational burdens.

Despite its substantial promise, the application of AI in water-resources management in arid and semiarid regions is constrained by several challenges, which must be acknowledged to avoid unrealistic expectations or overreliance. One of the most significant obstacles is severe data scarcity. AI models require robust, continuous, and high-quality datasets for training, validation, and ongoing updating. Most arid regions, however, suffer from sparse monitoring networks, short and discontinuous time series, weak characterization of subsurface conditions, and climatic variability that violates the assumptions of model stationarity. Under these circumstances, AI models may become unstable, biased, or poorly generalizable, producing outputs that appear statistically acceptable but fail under real-world operational or extreme-event conditions.

Harsh environmental conditions further undermine the reliability of AI-driven water systems. Sensors and Internet of Things (IoT) devices deployed in arid settings are exposed to extreme heat, dust storms, high salinity, evaporation effects, and sedimentation, all of which can lead to calibration drift, data loss, or system failure. Remote locations often lack stable power or communication infrastructure, resulting in incomplete or noisy datasets that ultimately degrade the model performance.

Hydrogeological complexity also limits the applicability of AI models, as ancient fossil aquifers, heterogeneous stratigraphy, episodic recharge events, and flash flood hydrology challenge the generalization and transferability of models trained on limited data.

Another concern is model drift, where AI models gradually lose predictive accuracy due to evolving environmental conditions, operational changes, or sensor degradation. Without continuous retraining and recalibration, decision-support systems may misinterpret anomalies or trigger inappropriate automated responses. In water-scarce regions with limited redundancy, such failures could jeopardize desalination operations, groundwater sustainability, or the safety of flood-management systems.

Institutional and financial barriers pose additional constraints. Many water agencies lack personnel with sufficient AI literacy, face high capital and maintenance costs for sensors and digital infrastructure, and operate within fragmented governance structures that impede data sharing and integrated decision-making. Cybersecurity vulnerabilities further complicate deployment, as digital water networks connected to Supervisory Control and Data Acquisition (SCADA) systems, cloud platforms, and IoT devices expand exposure to cyber threats. Manipulation of sensor data, unauthorized operational control, and service interruptions pose serious risks to public safety and institutional credibility.

Finally, there is the risk of overreliance on AI at the expense of hydrological and domain expertise. While AI offers powerful analytical capabilities, it cannot replace the conceptual understanding, contextual judgment, and field-based knowledge required for safe and sustainable water management, especially in regions where hydrological processes are complex, episodic, and highly uncertain.

In conclusion, AI holds significant potential to transform water-resources management in arid and semiarid regions by enhancing forecasting accuracy, operational efficiency, system optimization, and long-term strategic planning. Its applications span desalination, wastewater treatment, reuse systems, groundwater protection, hydrological modelling, and utility modernization through digital twins. However, its benefits can only be fully realized when the limitations posed by data scarcity, environmental stressors, hydrogeological complexity, institutional constraints, cybersecurity risks, and potential overreliance are carefully addressed. AI should be regarded as a powerful complementary tool that augments, rather than replaces, hydrological science and engineering judgment.

Successful adoption requires robust datasets, strong governance frameworks, technical capacity building, sustained human oversight, and realistic expectations. When these prerequisites are met, AI can become a cornerstone of resilient and sustainable water-management strategies in climate-stressed arid regions.

Keywords: Water Scarcity, Artificial Intelligence, Wastewater Treatment and Reuse, Seawater Desalination, Groundwater Conservation, Arid-Region Hydrology.

Leveraging Artificial Intelligence for Sustainable Water Management in Saudi Arabia

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Water scarcity is a defining challenge for the Gulf Cooperation Council (GCC) countries, and Saudi Arabia stands at the forefront of this crisis. With agriculture consuming the largest share of water resources, the call for a sustainable, technologically driven water management system has become increasingly urgent. In response, the Saudi Irrigation Organization (SIO), as the national authority responsible for irrigation and water efficiency, is leading a bold transformation. Guided by Saudi Arabia Vision 2030 and the National Data and AI Strategy, the SIO is leveraging artificial intelligence (AI), advanced analytics, and robust data governance to optimize water use, modernize irrigation systems, and ensure long-term resource sustainability.

The evolution of SIO reflects this transformative agenda. Originally established in 1971 to manage three regionally focused irrigation projects, SIO's mandate expanded significantly over the decades. In 2018, SIO assumed responsibility for the reuse of Treated Sewage Effluent (TSE), and by 2023, its scope included the operation and construction of dams across the Kingdom. This progression highlights SIO's central role in addressing the Kingdom's water challenges across multiple domains, including irrigation, wastewater reuse, and critical infrastructure.

A cornerstone of SIO's transformation is its alignment with Saudi Vision 2030 and the National Data Strategy developed under the leadership of the Saudi Data and AI Authority (SDAIA). These national initiatives emphasize the importance of data-driven governance and technological innovation in public sector reforms. In compliance with SDAIA's directives, the SIO established its Data Management Office (DMO) in 2022, initiating a comprehensive data strategy tailored specifically to the irrigation sector. This strategy encompasses the definition of key data domains, the development of a standardized business glossary, the implementation of data governance frameworks, and the establishment of a robust data architecture optimized for AI applications.

One of the pivotal projects undertaken by the SIO is the creation of the National Irrigation Database. This centralized platform consolidates data from across the Kingdom's agricultural regions, establishing a single source of truth for irrigation management and water resource planning. Complementing this initiative is the Agricultural Water Consumption Platform, an advanced system that provides accurate, near-real-time insights into water consumption patterns. These tools empower policymakers and planners with evidence-based intelligence, enabling more informed decision-making and enhancing national water sustainability.

To operationalize these data-driven initiatives, SIO developed a centralized Data Warehouse and Business Intelligence (BI) platform. This platform unifies disparate data sources, offering near-real-time monitoring of water usage metrics, dynamic Key Performance Indicator (KPI) dashboards for executives, trend analysis capabilities for seasonal planning, and transparent water allocation reports. As a result, operational efficiency has improved significantly, with reporting cycles reduced from several weeks to a matter of hours. Moreover, decision-making has become more responsive, collaborative, and informed by accurate, real-time data.

Building on this foundation, the SIO has pioneered the integration of AI into water management operations. The establishment of a dedicated AI Unit reflects a strategic commitment to AI innovation. This unit collaborates extensively with academic institutions, such as the King Abdullah University of Science and Technology (KAUST), to ensure that cutting-edge research is translated into practical applications. One notable project with KAUST involves real-time AI-driven anomaly detection systems for monitoring the quality of reused water, ensuring compliance with health and safety standards from source to end-user.

Another groundbreaking initiative is the e-ReWater Project, developed in collaboration with the International Water Management Institute (IWMI) and Google. This project utilizes AI to optimize treated wastewater reuse across multiple regions, demonstrating the power of global partnerships in driving regional sustainability outcomes. These collaborations highlight the strategic importance of cross-sector and international cooperation in tackling complex environmental challenges.

SIO's Quantitative Irrigation Advisory System (QIAS) Project represents a flagship application of satellite data and machine learning. By integrating remote sensing technologies with AI algorithms, QIAS provides high-resolution, field-level estimates of agricultural water consumption. This innovation supports policy enforcement and irrigation planning at a national scale, offering a scalable model for other GCC countries facing similar challenges.

Beyond irrigation, the SIO is also exploring the role of AI in risk management and infrastructure protection, particularly in relation to dam safety. Through the support of the Research, Development, and Innovation Authority (RDIA), the SIO is engaged in early-stage projects applying predictive analytics to assess structural vulnerabilities, develop early-warning systems for flood prevention, and enhance climate resilience. These initiatives are crucial for safeguarding critical infrastructure in the face of increasing climate variability and extreme weather events.

The SIO is also leading the development of the Irrigation Data Platform, an open data initiative aimed at fostering innovation and public engagement. This platform is built on publicly available data sources and is designed to provide interactive and visualized access to irrigation and water reuse data. Using business intelligence tools, advanced analytics, and AI, the platform enables researchers, policymakers, and innovators to explore trends, evaluate performance, and develop new solutions. As a public-facing tool, it exemplifies transparency and supports open innovation by making data created and shared by SIO accessible to a wide range of stakeholders.

Looking ahead, the SIO envisions an expanded role for AI in shaping the future of intelligent water management. Key priorities include the regional-scale deployment of successful AI models, the seamless integration of AI with smart sensors and automated irrigation systems, and the refinement of demand forecasting using machine learning and historical data.

SIO's journey is a compelling example of how national entities can integrate data governance, business intelligence, and AI to address critical sustainability challenges. The organization's strategic vision, supported by strong government mandates and public-private partnerships, is transforming irrigation management into a smart, adaptive, and efficient system. These efforts not only respond to immediate operational needs but also lay the foundation for long-term resilience in the face of environmental uncertainty.

To date, the SIO has achieved significant milestones. Its data governance framework has been successfully implemented, and pilot AI projects have demonstrated measurable improvements in water efficiency and resource optimization. These outcomes have positioned Saudi Arabia as a regional leader in AI-powered water management, setting a benchmark for sustainable practices across the GCC.

In conclusion, SIO's efforts represent a bold and necessary step toward ensuring water security in one of the world's most water-scarce regions. By harnessing the transformative power of AI and data science, SIO is redefining the future of water management, not only for Saudi Arabia but also for the entire Gulf region. As the organization continues to scale its innovations and foster international collaboration, it invites stakeholders from across sectors to join this journey toward a more sustainable, resilient, and intelligent water future.

Keywords: Artificial Intelligence, Water Management, Data Governance, Irrigation Efficiency, Sustainable Development.

Session 3: Nonconventional Water Resources, Agricultural Applications, and Awareness Raising and Education

Strengthening Climate Resilience and Water-Smart Irrigation through the WEFE Nexus

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The management of interconnected water, energy, food, and ecosystem (WEFE) systems presents a paramount challenge for the Gulf Cooperation Council (GCC) countries, which face acute water scarcity, climate variability, and growing resource demands. The intricate interdependencies within the WEFE nexus necessitate innovative, integrated management strategies that transcend sectoral silos to ensure security and sustainability. In this context, artificial intelligence (AI) emerges as a transformative tool capable of modelling complex synergies and trade-offs, optimizing resource allocation, and supporting resilient decision-making.

This work presents the AI-driven framework developed under the SURENEXUS project (Ensuring a Fair NEXUS Transition for Climate Change Adaptation and Sustainable Development through Coupled Nature-Based Solutions [NbS] and Bioeconomy»), led by the United Nations Educational, Scientific and Cultural Organization (UNESCO) Chair on Sustainability at the Universitat Politècnica de Catalunya. Funded by the Partnership for Research and Innovation in the Mediterranean Area (PRIMA) initiative, the project responds to the pressing need for strategies that sustain food production and water security with a minimal ecological footprint. The core innovation is an AI-powered decision-support system designed to evaluate and optimize the performance of the WEFE nexus through advanced simulation modelling and participatory stakeholder engagement.

The methodological cornerstone of this approach is the creation of a digital twin, that is, a dynamic virtual replica of the WEFE system. This tool is built using a rigorous, transparent process. Initially, stakeholder inputs, defining priorities, system boundaries, and local data, are formalized using the Specification and Description Language (SDL). This provides a clear conceptual map of WEFE interactions. The SDL model is then operationalized into a computerized simulation environment within the NECADA platform, an advanced AI-powered modelling system co-developed by the UNESCO Chair and the InLab research group at the Universitat Politècnica de Catalunya (UPC).

NECADA functions as a multi-agent system that integrates environmental, technical, and socioeconomic parameters to simulate the performance of various interventions under diverse scenarios. A pivotal component is the Compensation Block, a modular library of configurable solutions encompassing NbS, water treatment technologies, energy recovery systems, and bioeconomy practices. This block enables a semi-automated technology selection process. The AI model, through the digital twin, runs simulations to assess the performance of different solution portfolios against a harmonized set of WEFE metrics, such as water savings, energy generation, crop yield, and ecosystem services. It quantifies trade-offs and synergies, applies stakeholder-defined weightings, and aggregates outcomes into a balanced, decision-ready score. This process is iterative and validated with stakeholders, continuously incorporating new data from sensors, operational logs, and updated policies to ensure both scientific robustness and social legitimacy.

The relevance and impact of this AI framework are profound, particularly for water-scarce regions like the GCC. First, it enhances strategic decision-making for complex WEFE nexus management. By moving beyond single-sector analysis, it allows policymakers and planners to visualize the cascading effects of decisions across water, energy, food, and ecosystems. This is critical for developing integrated national strategies that avoid unintended consequences and maximize co-benefits.

Second, the framework provides a scalable tool for optimizing water-smart agriculture and irrigation. For GCC countries, where agricultural water use constitutes a significant portion of total demand, the ability to model and identify optimal irrigation strategies is vital. The AI tool can integrate data on soil moisture, crop requirements, weather forecasts, and energy costs for desalination or groundwater pumping to recommend irrigation schedules, which maximize crop per drop while minimizing energy consumption and ecological impact. The project's demonstration sites in Morocco and Tunisia, focusing on smart irrigation and subsurface irrigation, serve as practical living laboratories for these applications, with lessons that are directly transferable to the GCC context.

Third, the project emphasizes capacity building and transdisciplinary collaboration. The participatory methodology ensures that the models are grounded in local realities and stakeholder needs. The «learning by doing» activities connected to real demonstration sites foster practical knowledge transfer among researchers, engineers, policymakers, and farmers. This is essential for building local expertise and ensuring the sustainable adoption of AI-driven solutions.

Fourth, the framework promotes scalable and cost-effective sustainable innovations. By prioritizing and modelling the performance of NbS and bioeconomy practices, such as constructed wetlands for water treatment or agroforestry for ecosystem services, the tool guides investment toward resilient, adaptive, and often more affordable strategies tailored to local socioeconomic conditions.

In conclusion, the integration of AI into WEFE nexus management, as exemplified by the SURENEXUS project and the NECADA platform, offers a powerful paradigm shift. It enables a move from reactive, siloed resource management to proactive and systemic optimization. The key advantages include: (1) supporting informed, evidence-based decision-making for complex interconnected systems; (2) providing a transparent, participatory, and adaptable digital-twin environment for scenario exploration; (3) enabling semi-automated identification of optimal technology and NbS portfolios through the compensation module; and (4) strengthening climate resilience by providing robust strategies that balance competing resource demands under conditions of uncertainty.

For the GCC countries, embarking on ambitious water security and food diversification programs, such an AI-driven WEFE nexus approach is not merely an academic exercise but a practical necessity. It provides the analytical backbone for designing policies and projects, which can simultaneously advance water conservation, energy efficiency, food security, and ecosystem preservation, thereby paving the way for a more sustainable and resilient future in the face of climate change.

Keywords: AI, WEFE Nexus, Resilience, Water Scarcity, Water Management, Digital Twin, NECADA, Smart Irrigation, Nature-Based Solutions.

Smart Use of Nonconventional Water and AI-Driven Agriculture for Food Production in the GCC

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The Gulf Cooperation Council (GCC) member states experience severe shortages of renewable water resources, while their food requirements continue to rise, and environmental conditions worsen, threatening agricultural sustainability. This paper proposes an integrated framework built on the smart use of nonconventional water resources (NCWR), including, but not limited to, desalinated seawater and desalinated saline groundwater, treated wastewater, brackish groundwater, fog and dew harvesting, rainwater harvesting on micro- and macro-catchments, greywater reuse, and artificial aquifer recharge, together with artificial intelligence (AI)-driven agriculture, as two synergistic drivers to enhance resource efficiency and food production in hyper-arid environments.

The proposed framework connects water quality indicators to crop tolerance limits and irrigation system requirements through its two fundamental principles, which are «fit-for-purpose» and «matching quality to use». The system uses optimized blending methods to reach desired quality standards while minimizing costs, and it uses precise irrigation and fertigation systems, which operate in closed- loop configurations to recover nutrients and reduce waste. The system controls salt levels through leaching operations and the addition of gypsum and organic matter to the soil. The system also requires suitable drainage systems for its effective functioning.

The framework at the digital level combines sensing technology with the Internet of Things (IoT) systems, which include soil moisture and electrical conductivity (EC) sensors, water pressure/flow sensors, and micro-meteorological stations for monitoring purposes. The system uses remote sensing technology through satellite imagery and unmanned aerial vehicles (UAVs), which apply Normalized Difference Vegetation Index (NDVI) and evapotranspiration indices for data collection. The system uses predictive analytics together with digital modelling to manage controlled-environment agriculture operations. Deep-learning algorithms enable forecasting of crop water requirements according to growth stage and weather, selection of the lowest-cost and quality-compliant water source mix, predictive control of irrigation and fertigation schedules, and early fault detection (blockages/leaks), all visualized through hierarchical dashboards (farm → program → national).

The framework requires the implementation of a human-in-the-loop governance system, which keeps farmers actively involved in decision-making processes and allows them to review AI suggestions through manual validation during the initial deployment phase. The system reduces the risk of overreliance on automated recommendations because it enables users to learn AI system administration and build their skills for operating these systems.

The decision-support platform of AI-driven agronomy operates as a single system, which merges pest and disease identification with yield prediction and complete field tracking capabilities. The combination of drone visual data with field camera images and satellite images allows machine-learning algorithms to detect pests, diseases, and crop stress, which results in better crop defense and lower pesticide application. AI predictive analytics help farmers optimize their fields through real-time data analysis, which combines historical yield information with sensor readings, weather patterns, and pest and disease data to create yield prediction models. The system enables farmers and institutions to predict their production results so that they can develop strategies for irrigation and input usage, harvesting, supply chain management, and financial planning. Remote sensing technologies working with AI systems enable real-time monitoring of large agricultural fields, which provide enhanced disease detection and yield prediction through instant analysis of satellite, drone, and weather data. The system delivers precise agricultural treatments, which optimize sustainable resource management to achieve better total system operational performance.

As an illustrative application of AI-driven agronomy, the framework includes labor-intensive weed control solutions based on AI-enabled automatic weeding, where laser weeding technologies use deep learning and computer vision to distinguish crops from weeds and enable chemical-free weed elimination without harming the soil. This approach reduces weeding costs while supporting organic and regenerative farming practices and improving crop performance and quality.

The proposed framework requires an environment, which addresses three established obstacles that research evidence demonstrates exist: the framework requires better physical infrastructure, dependable high-quality data, and ongoing staff training with technical assistance. Organizations need to establish their digital foundation through basic digital infrastructure and data management systems, which support AI deployment through simultaneous training programs for farmers together with their staff.

The policy and regulatory framework needs to establish data governance and cybersecurity standards because AI-enabled smart farming systems depend on sensor connections and digital platforms, which generate continuous data streams that create privacy vulnerabilities, regulatory deficiencies, and cyber threats, including data breaches and cyberattacks. The system requires developers to create protected data transfer protocols, and organizations need to define their legal duties and establish strong regulatory frameworks, which follow current legal requirements and provide specific training for staff who work with digital and restricted systems to handle these technologies properly.

The framework becomes operational through a unified platform, which combines AI-based crop management software with farm management systems to process field sensor data, weather station information, machinery operations, and satellite images for generating specific recommendations about crop selection and planting, irrigation strategies, and disease and pest management responses. The system enables farmers to perform specific interventions while minimizing their use of chemical pesticides.

The framework will use AI-based mobile applications and chatbots to deliver immediate decision assistance about weather conditions, crop illnesses, market value, and farming techniques, which will make agricultural knowledge accessible to all farmers and operators.

The framework should include variable-rate fertilization, seeding, and irrigation systems, which use sensor data and map information to optimize input application across management zones based on soil characteristics and topography. The system should prevent excessive water usage while minimizing the consumption of water, agricultural resources, and chemicals.

The system needs real-time processing of pressure and time flow data to identify network failures and water leaks that will trigger alerts, which help decrease crop stress through weather monitoring and crop water usage evaluation.

The paper presents measurable Key Performance Indicators (KPIs): water productivity (kg/m^3), energy intensity (kWh/kg, kWh/m^3), nutrient use efficiency (%), production stability under heat and salinity stress, soil equivalent EC trends, and the cost of agriculturally produced cubic meters of water. It also maps carbon mitigation pathways resulting from the shift to renewable energy in desalination and pumping, reduced water and fertilizer losses through precision control, and the adoption of lower-emission energy options for irrigation pumping and on-farm operations. The framework adheres to Measurement, Reporting, and Verification (MRV) protocols and promotes soil and biomass carbon stock enhancement.

To ensure credibility and enable carbon finance opportunities, the framework adopts rigorous MRV methodologies with clearly defined baselines and system boundaries, uncertainty management, and automated data tracking with audit trails. The proposal presents three deployment models, which enable extensive implementation and provide financial support for the solution.

The proposal presents three implementation models, which support large-scale deployment through two methods that combine multiple sites into one package to cut costs, service contracts with payment systems that charge based on performance, and public climate and commercial funding to decrease expenses and accelerate solution deployment. The framework extends beyond the farm gate to analyze food supply chains and track products, where AI systems predict market demand and manage storage levels to reduce post-harvest spoilage and minimize food waste. The system enables end-to-end product tracking from farms to consumers through blockchain technology, which provides both better food safety and improved regulatory compliance.

Finally, the paper recommends a set of enabling policies for GCC countries: updating water reuse standards to embody the “fit-for-purpose” concept and ensure safety; simplifying licensing pathways and clarifying responsibilities for the operation of NCWR sources, drainage, and salinity management under clear protocols; mandating unified MRV-based measurement and reporting frameworks with secure data-sharing protocols; aligning desalination and pumping operations with renewable energy availability to minimize emissions where feasible; and building farmer, operator, and data specialist capacities to sustain daily precision irrigation, blending, and fault-detection operations. This integrated approach provides a practical and measurable pathway toward enhanced food production, reduced environmental impact, and the translation of efficiency gains into carbon credits and financing opportunities that support long-term sustainability.

Keywords: AI-Driven Precision Agriculture, Climate-Smart Agriculture and Carbon Finance, Digital Agriculture Platforms and Data Governance, Fit-for-Purpose Water Quality Management, Non-Conventional Water Resources.

Challenges of Artificial Intelligence in Managing Irrigation Water in GCC Countries

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Global freshwater scarcity, exacerbated by agricultural water consumption, necessitates innovative irrigation management strategies, particularly in arid regions. This review systematically examines the applications of Artificial Intelligence (AI) in optimizing irrigation water management, focusing on the calculation of water requirements, soil moisture monitoring, irrigation water quality, and crop coverage assessment. AI-driven systems demonstrate significant potential for enhancing water-use efficiency, reducing energy consumption, and improving crop productivity through precise and adaptive irrigation scheduling in many countries around the world. In the USA and Australia, the use of AI has increased water-use efficiency and water conservation by more than 25%.

However, the widespread adoption of AI in arid agricultural landscapes faces substantial challenges, including data scarcity and quality issues, complexities in sensor calibration and reliability, and limitations in computational resources and infrastructure. Socioeconomic factors, such as economic feasibility for smallholder farmers and ethical considerations regarding data governance, also present significant challenges. Thus, the challenges and limitations of AI in irrigation water management can be summarized as follows:

- Data availability: AI algorithms require large volumes of data to learn and make accurate predictions. However, in many regions, data on crop water requirements, soil moisture, weather patterns, and crop growth may be limited or unreliable, which can impact the accuracy of the predictions.
- Sensor reliability: Sensors collect data on soil moisture and other environmental factors. However, sensors can be expensive to install and maintain, and their accuracy can be affected by temperature, humidity, and salinity in arid regions.
- Cost: Implementing an AI-powered irrigation system can be expensive, and the initial investment may be

difficult to justify for small-scale farmers.

- Limited technical expertise: Farmers may lack the technical expertise required to operate and maintain AI-powered irrigation systems, which can limit their adoption.

This review discusses these challenges in detail and proposes future research directions, emphasizing the development of robust, data-efficient AI models, improved sensor technologies, standardized frameworks, and integrated policy approaches to foster sustainable agriculture in water-stressed environments.

Keywords: Artificial Intelligence, Irrigation Water Management, Arid Regions, Crop Water Requirements, Soil Moisture, Crop Coverage, Challenges.

From Losses to Efficiency, the Role of Automatic Power Factor Correction towards Enhancing the Reliability of Desalination and Pumping Systems

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The increasing integration of variable-frequency drives (VFDs) into desalination and water-distribution infrastructure has transformed how pumps and motors are controlled, offering significant reductions in energy consumption and improved operational flexibility. However, this technological shift has introduced persistent power-quality challenges, particularly in systems where nonlinear electrical loads dominate. In many water facilities across the GCC region, including the pilot-scale desalination and pumping test facility in Jubail, harmonic distortion, low and unstable power factor, and voltage waveform degradation were repeatedly observed during field measurements. These issues threaten both the reliability and efficiency of mission-critical pumping assets, which operate continuously under variable load conditions.

The work presented in this extended abstract describes the development, deployment, and evaluation of an Active Power Factor Correction (APFC) system designed specifically to address these challenges. By combining fast digital signal processing with active harmonic cancellation and dynamic reactive-power compensation, the APFC system aims to deliver stable operation in environments dominated by VFD-driven induction motors. Baseline measurements from the Jubail pilot facility revealed that the electrical network was heavily affected by nonlinear distortions generated by the VFDs controlling the main pumps. Current and voltage waveforms displayed clear switching artifacts, sharp irregularities, and oscillations inconsistent with an ideal sinusoidal shape. These distortions resulted in total harmonic distortion (THD) levels, which regularly exceeded recommended thresholds, especially during low-speed pump operation, where pulse width modulation (PWM)-induced harmonics are most severe. At the same time, the facility experienced poor power factor performance, fluctuating between 0.82 and 0.90. This instability increased copper losses, stressed upstream transformers, and triggered penalty charges due to inefficient reactive-power behaviour. Traditional capacitor-based power factor correction (PFC) banks, which had been installed previously, failed repeatedly due to resonance interactions between the capacitor circuits and dominant harmonic frequencies produced by the drives. These failures not only damaged equipment but also caused unplanned downtime and costly maintenance cycles.

To address these issues, the APFC system introduced in this study was engineered around a dynamic, real-time compensation strategy. Instead of relying on passive energy storage elements, such as capacitors and inductors, the APFC continuously measures instantaneous voltage and current waveforms using high-speed sensors. A digital signal processor (DSP) decomposes these waveforms, identifies harmonic and reactive components, and injects precisely shaped compensating currents into the system. In effect, the APFC makes the nonlinear electrical load "appear" linear to the upstream supply, dramatically improving the quality of the voltage and current waveforms. This approach eliminates the risk of resonance, which is the primary cause of capacitor explosions, and ensures that power factor remains near unity even under rapidly changing load conditions. During implementation, the APFC controller was configured using operational parameters characteristic of the Jubail pilot facility, including a DC-link voltage of 200 V, a fundamental frequency of 60 Hz, and a switching frequency of 3 kHz. These values reflect both the plant's electrical specification and the operating profile of the VFDs used to control the pumps. The controller's internal algorithms were tested through simulation and then deployed on-site. Field installation required integration with existing switchgear, current transformers, and monitoring systems to ensure that the controller's compensation actions did not interfere with protective devices or the drives themselves.

Once activated, the APFC system produced immediate and measurable improvements. The distorted, jagged waveform observed before compensation transitioned into a smooth, sinusoidal signal after compensating currents were applied. Fast Fourier Transform (FFT) analysis confirmed a substantial reduction in the amplitude of the 5th, 7th, and 11th harmonics, which were the most dominant prior to correction. The THD reduction ranged between 28% and 40%, depending on pump speed and the operational schedule. This reduction translated into lower thermal stress on cables and transformers, improved system stability, and a marked decrease in electrical noise emitted by the motors, an observation confirmed by on-site technicians.

One of the most significant results was the stabilization of the power factor. While the plant previously experienced wide fluctuations caused by dynamic load changes and nonlinear switching, the APFC maintained a PF consistently between 0.98 and 1.00, across all operating conditions. This improvement eliminated PF-related utility penalties and significantly reduced the apparent power drawn from the electrical network. Over time, this stability has the potential to extend transformer lifespan, reduce heat-related degradation, and improve the overall operational readiness of the facility.

Beyond measurable electrical improvements, operators at the Jubail plant reported that nuisance tripping of motor drives decreased noticeably following the APFC installation. Reduced voltage fluctuations gave the VFDs a more stable electrical environment, resulting in smoother torque delivery to the motors. The electrical vibration dampening incorporated into the APFC also contributed to reduced audible noise and fewer transient oscillations. These improvements enhance both operational safety and the long-term reliability of pumps, which are critical to water production and distribution.

Although the APFC demonstrated strong performance at the pilot scale, it remains important to recognize the boundaries of the current study. The Jubail facility represents a controlled test environment with moderate electrical load levels. Larger desalination plants, particularly those with multi-megawatt pumping systems and extensive VFD networks, may present different harmonic aggregation behaviours and grid-interaction dynamics. Further research is required to validate APFC scalability in such environments. In addition, the long-term behaviour of the APFC under extreme grid disturbances, such as voltage sags, rapid switching events, and distributed energy integration, should be explored more thoroughly. Despite these considerations, the results obtained from the Jubail pilot facility strongly indicate that APFC systems offer a robust and adaptable solution for improving power quality in modern water infrastructure.

Looking ahead, the integration of intelligent control strategies presents an opportunity to further enhance the capabilities of active compensation systems. With the increasing availability of high-resolution operational data, machine-learning models could be incorporated into APFC controllers to predict harmonic patterns and adjust compensation profiles preemptively. Such predictive capabilities would be particularly valuable in facilities with rapidly fluctuating load patterns or in hybrid energy environments where renewable sources contribute variable power profiles. Moreover, as water utilities continue to digitize operations, APFC units could be integrated into Supervisory Control and Data Acquisition (SCADA systems to provide real-time power-quality analytics and actionable insights, which support maintenance planning and energy-optimization decisions.

In conclusion, the deployment of the APFC system at the Jubail experimental desalination facility successfully demonstrated its ability to mitigate harmonic distortion, stabilize power factor, eliminate resonance, and enhance the overall quality of electrical waveforms in a VFD-dominated environment. The results confirm that active compensation significantly outperforms traditional PFC methods in terms of adaptability, reliability, and long-term operational value. By improving waveform purity, stabilizing voltage and current, and protecting the integrity of electrical assets, the APFC provides a compelling solution for water utilities seeking to modernize their infrastructure and ensure sustainable, efficient operation. The findings of this study support the broader adoption of APFC technology across desalination plants and pumping stations throughout the region, particularly as electrical networks become increasingly complex and nonlinear loads become more prevalent. The results from the Jubail pilot clearly demonstrate that active harmonic mitigation and power-factor correction are essential components of next-generation water infrastructure.

Keywords: Energy Consumption, Environments, Baseline Measurements, Voltage, Copper Losses.

Artificial Intelligence-Supported Environmental Education for Promoting Water Conservation Values among Younger Generations in GCC Countries

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Water sustainability is among the most critical challenges confronting the Gulf Cooperation Council (GCC) countries. Natural water scarcity, climate change impacts, population growth, and expanding economic activities have placed increasing pressure on already limited freshwater resources. As a result, GCC countries rely heavily on desalination technologies, which, while effective, are expensive and environmentally intensive. These realities make sustainable water management not only a technical or policy issue but also an educational and ethical challenge, which requires long-term behavioural change across society.

Environmental education has traditionally been regarded as a key mechanism for raising awareness about water conservation. However, prevailing educational approaches in many contexts remain largely knowledge-based, focusing on information delivery rather than the cultivation of values, ethical responsibility, and sustainable behaviour. Such methods have shown limited effectiveness, particularly among the younger generation whose learning styles are shaped by digital interaction, personalization, and experiential engagement. This gap highlights the urgent need for innovative educational models capable of transforming water-related knowledge into internalized values and sustained everyday practices.

Purpose and Objectives

This paper proposes a contemporary educational approach referred to as AI-supported Value-Based Environmental Education, with a specific emphasis on water conservation in GCC countries. The central purpose is to explore how artificial intelligence (AI) can function as an integrated educational platform that connects cognitive learning with ethical awareness and behavioural change.

The study seeks to:

1. 1Examine the conceptual convergence between AI, environmental education, and value formation.
2. Explain how AI technologies can enhance the effectiveness of water conservation education among the younger generation.
3. Present practical educational application models that demonstrate AI-supported value-based learning.
4. Identify key opportunities and challenges associated with integrating AI into environmental education systems.
5. Offer future-oriented recommendations tailored to the educational and cultural context of GCC countries.

Conceptual Framework

The proposed framework is grounded in modern theories of environmental and sustainability education, particularly the concept of learning for sustainability, which emphasizes the transition from rote learning to transformative educational experiences. In this perspective, education aims not only to inform learners about environmental issues but also to shape their values, attitudes, and ethical decision-making.

Water education is positioned as a central domain within this framework due to water's vital importance and increasing scarcity in the Gulf region. The formation of water conservation values involves fostering awareness that water is a limited and precious resource, encouraging responsible consumption behaviours, and promoting moral and social responsibility toward future generations.

AI plays a transformative role in this process by enabling adaptive learning, real-time feedback, behavioural analysis, and immersive simulations. These capabilities allow education to become more learner-centered, interactive, and contextually relevant, thereby increasing its potential to influence long-term behaviour.

AI-Supported Educational Application Models

The paper presents three complementary application models illustrating how AI can operationalize value-based water education:

1. Simulation of Ethical Environmental Decision-Making. AI-powered simulations place learners in realistic or semi-realistic scenarios involving water scarcity, such as communities facing limited water supply. Students are required to make decisions that balance environmental, economic, and social considerations. The AI system analyzes these choices and provides feedback on their ethical and environmental consequences. This approach strengthens critical thinking, ethical reasoning, and a sense of shared responsibility for water resources.
2. Value-Based Personalized Learning Paths. Through adaptive learning algorithms, AI designs individualized educational pathways based on learners' understanding, behaviors, and decision patterns. Environmental value gaps, such as weak awareness of water conservation, are identified and addressed through customized content and challenges. This personalized approach increases engagement and enhances the likelihood of deep value internalization and sustainable behavioral change.
3. Data-Driven Behavioral Learning. This model connects learning directly to real-world water consumption data from homes or schools. AI systems analyze usage patterns and transform them into educational feedback, indicators, and challenges. By linking daily behavior with measurable outcomes, learners gain a tangible understanding of the impact of their actions, reinforcing accountability and sustained conservation practices.

Opportunities and Challenges

The integration of AI into value-based environmental education offers significant benefits. AI enhances learner motivation through interactive and immersive experiences, supports precise monitoring of learning and behaviour, and enables the assessment of value-oriented outcomes that are difficult to measure using traditional methods.

At the same time, several challenges must be addressed. These include protecting learners' privacy, ensuring ethical data use, avoiding cultural misalignment in educational content, and preventing overreliance on technology at the expense of human judgment. There is also a need for clear ethical and legal frameworks to regulate data collection and algorithmic decision-making, particularly when working with children and adolescents.

Future Directions and Recommendations

The paper recommends the development of a unified GCC framework for integrating AI into environmental education. Such a framework should incorporate cognitive, value-based, and behavioral dimensions while remaining flexible enough to reflect local cultural and social contexts. It also emphasizes the importance of preparing educators to use AI responsibly, encouraging regional research collaboration, and involving students in the design of educational applications to strengthen ownership and engagement.

Conclusion

AI represents a powerful catalyst for reimagining environmental education in GCC countries. When integrated within a value-based and human-centered educational philosophy, AI has the potential to transform water conservation from abstract knowledge into ethically grounded everyday practice. Investing in AI-supported environmental education is ultimately an investment in a sustainable future, that is, one shaped by a generation that understands the value of water and acts responsibly to preserve it for the benefit of present and future societies.

Keywords: Artificial Intelligence, Environmental Education, Water Conservation, Value-Based Learning, Sustainable Water Management, Behavioural Change, Gulf Cooperation Council.

Artificial Intelligence for Sustainable Water Resource Management: A Saudi Arabian Perspective

الذكاء الاصطناعي لإدارة الموارد المائية المستدامة: منظور المملكة العربية السعودية

أوس الفوزان
طالب في الثانوية العامة، المملكة العربية السعودية

تأتي هذه الورقة العلمية في إطار المشاركة في ورشة العمل الإقليمية المعنية بعنوان «الذكاء الاصطناعي ودوره في استدامة موارد المياه في دول مجلس التعاون الخليجي»، التي ينظمها معهد الكويت للأبحاث العلمية يومي 16–17 ديسمبر 2025، وهي فعالية علمية تستهدف تسليط الضوء على أحدث ما توصلت إليه التقنيات الرقمية الحديثة وأساليب الذكاء الاصطناعي في دعم منظومة إدارة المياه، ورفع كفاءة استغلال مواردها في دول مجلس التعاون. وتنعقد هذه الورشة في وقت يشهد فيه العالم، والمنطقة الخليجية على وجه الخصوص، تحولًا غير مسبوق في أنماط إدارة الموارد الطبيعية، مدفوعًا بالتطور السريع في العلوم الرقمية، وبروز الذكاء الاصطناعي كفاعل رئيس في تعزيز الاستدامة وحكومة الموارد.

وتتسم قضايا المياه في دول الخليج بأهمية خاصة، نظرًا لطبيعة المناخ الصحراوي الحاد، ونُدرة الموارد المائية التقليدية، والاعتماد الكبير على تحلية مياه البحر كمصدر رئيس لإمدادات المياه الصالحة للاستهلاك. وفي ظل الزيادة المطّردة في عدد السكان، والتوسع الحضري والعمراني، وارتفاع معدلات الاستهلاك، تواجه دول المجلس تحديات متصاعدة تتطلب حلولًا مبتكرة تتجاوز الأساليب التقليدية في التخطيط والإدارة والتشغيل. ومن هنا تأتي الحاجة الملحّة إلى توظيف الذكاء الاصطناعي والأنظمة الذكية في إدارة قطاع المياه، لما لها من قدرة على تحسين الكفاءة التشغيلية، ودعم القرارات الاستراتيجية، والتنبؤ بالطلب، وتحديد التسربات، وتقليل الهدر، وتحقيق الاستخدام الأمثل للموارد.

وتسعى هذه الورقة إلى استعراض الدور المتنامي للذكاء الاصطناعي في دعم التحول الذكي لقطاع المياه في المملكة العربية السعودية، بما ينسجم مع مستهدفات رؤية المملكة 2030 التي جعلت من الاستدامة البيئية والأمن المائي وتبني التقنيات المتقدمة محاور رئيسة في خططها المستقبلية. فقد أدركت المملكة مبكرًا أهمية دمج التقنيات الرقمية، ومن بينها الذكاء الاصطناعي، في تطوير القطاعات الحيوية وفي مقدمتها قطاع المياه، الذي يُعد أحد القطاعات الأكثر استهلاكًا للطاقة والأكثر احتياجًا للتطوير المستمر لضمان الأمن المائي والاستدامة البيئية.

وفي سياق هذا الاهتمام، اتجهت المملكة إلى تعزيز البنية الرقمية عبر مجموعة من المبادرات الضخمة التي تشمل تطوير منظومات البيانات المكانية والهيدرولوجية، وتوسيع نطاق استخدام العدادات الذكية، واعتماد أنظمة مراقبة الشبكات والتحكم بها عن بعد، واستحداث منصات لتحليل البيانات الضخمة المتعلقة بالاستهلاك، والعمليات التشغيلية، وجودة المياه. وقد أثمرت هذه الجهود عن تقدم ملموس في تحسين كفاءة إدارة المياه، وتقليل الفاقد المائي، والحد من استهلاك الطاقة، لاسيما في منشآت التحلية التي تُعد الأكبر على مستوى العالم. وتتجلى أهمية الذكاء الاصطناعي هنا في كونه يمثّل نقلة نوعية تتجاوز حدود الأتمتة التقليدية إلى مستوى أعمق من التحليل والتنبؤ واتخاذ القرار. فالذكاء الاصطناعي لا يقتصر على تنفيذ المهام التشغيلية، بل يسهم في بناء نماذج تنبؤية دقيقة تعتمد على البيانات التاريخية والآنية لتقدير الطلب المستقبلي على المياه، وتحديد مستويات الإنتاج المثلى في محطات التحلية، وتوقع الأعطال قبل حدوثها، وإدارة توزيع المياه بكفاءة عالية. كما يقدم حلولًا مبتكرة في مجالات الري الذكي، والقضاء على الهدر، وتقييم جودة المياه عبر تقنيات الرصد اللحظي والتحليل الذكي.

وإلى جانب ذلك، تشكل منظومات البيانات الضخمة أساسًا رئيسًا لعمل تقنيات الذكاء الاصطناعي في قطاع المياه؛ فكلما زادت دقة البيانات وتكاملها وتحديثها، ازدادت قدرة النماذج الذكية على تحقيق نتائج دقيقة وموثوقة. ولذلك تؤكد هذه الورقة على أهمية بناء قواعد بيانات وطنية موحدة، تشمل البيانات الهيدرولوجية والهندسية والتشغيلية والاستهلاكية، بحيث تكون قابلة للتحليل من خلال الخوارزميات المتقدمة التي تستخلص الأنماط والاتجاهات وتدعم متخذي القرار.

وتُبرز هذه الورقة أيضًا الأهمية الاستراتيجية للتطبيقات العملية للذكاء الاصطناعي، سواء في مجال تحلية المياه، حيث تُسهم النماذج الذكية في تحسين أداء الأغشية وتقليل استهلاك الطاقة، أو في شبكات التوزيع، حيث تساعد تقنيات الكشف الذكي على تحديد مواقع التسربات بدقة عالية، أو في القطاع الزراعي، الذي يُعد من أكثر القطاعات استهلاكًا للمياه، إذ تقدم تقنيات الري الذكي حلولًا توفر كميات كبيرة من المياه عبر برمجة عمليات الري بناءً على احتياجات التربة والنبات الفعلية.

كما تسلط الورقة الضوء على جملة من المشاريع والمبادرات الوطنية التي تبنتها المملكة لتطوير تقنيات إدارة المياه، مثل مشاريع التحلية باستخدام التقنيات المتقدمة، وتطوير منصات رقمية للرقابة والتحكم، وإطلاق برامج بحثية مشتركة بين الجامعات والمراكز البحثية وشركات القطاع الخاص. وتؤكد هذه المشاريع أن المملكة ماضية في بناء منظومة مائية رقمية تعتمد على الابتكار، وتعزز من قدرتها على مواجهة التحديات المستقبلية.

وعلى الرغم من التقدم الملحوظ، تشير الورقة إلى وجود مجموعة من التحديات التي ينبغي التعامل معها لضمان فاعلية حلول الذكاء الاصطناعي في قطاع المياه. فهناك تحديات تتعلق بتكامل البيانات بين الجهات المختلفة، وتحديات تقنية مثل محدودية المعايير والضوابط الموحدة، إضافة إلى تحديات بشرية تتمثل في نقص الكفاءات المتخصصة في علوم البيانات والهندسة الرقمية. كما يشكل الأمن السيبراني عنصرًا بالغ الأهمية، في ظل اعتماد قطاع المياه على أنظمة رقمية متصلة قد تكون عرضة لتهديدات أمنية تتطلب تعزيز أنظمة الحماية وبناء قدرات وطنية متقدمة في هذا المجال.

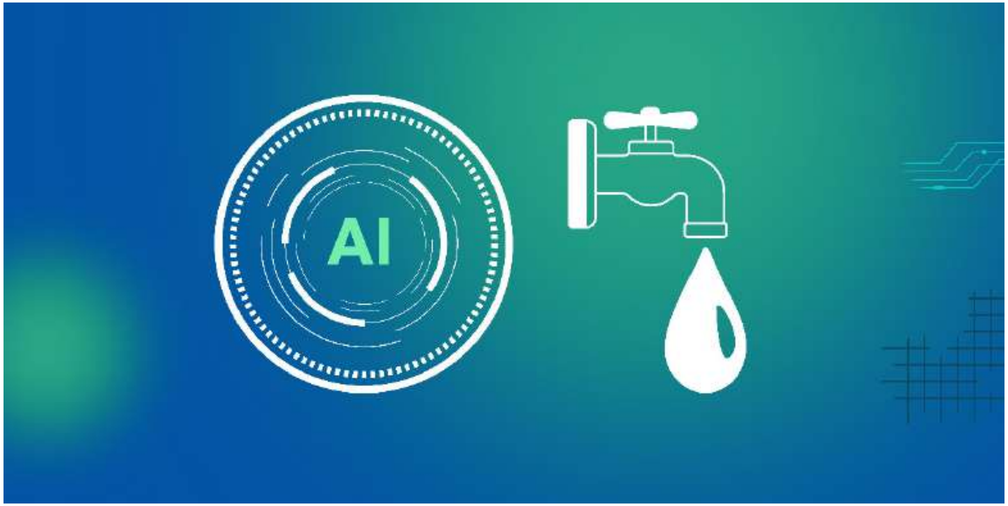
وتقترح الورقة، بناءً على التحليل والمعطيات المتاحة، ضرورة إعداد استراتيجية وطنية متكاملة للذكاء الاصطناعي في قطاع المياه، بحيث تشمل بناء القدرات البشرية، وتطوير المناهج التعليمية والتدريبية، وتعزيز الشراكات بين القطاع الحكومي والخاص، وتوسيع دور مراكز الأبحاث والتطوير، وتوفير سياسات واضحة لإدارة البيانات وتبادلها، ودعم رواد الأعمال في المجالات التقنية المائية. إن اعتماد هذه الاستراتيجية من شأنه أن يعزز من قدرة المملكة على تحقيق الأمن المائي والاستدامة البيئية، ويجعلها نموذجًا عالميًا في إدارة المياه الذكية.

وتساهم هذه الورشة الإقليمية في فتح آفاق واسعة للتعاون بين دول مجلس التعاون الخليجي في مجال الاستفادة من الذكاء الاصطناعي في إدارة موارد المياه، من خلال تبادل الخبرات، ومناقشة التحديات المشتركة، واستعراض قصص النجاحات الإقليمية والدولية. وفي ضوء ما تمتلكه دول الخليج من خبرات كبيرة في مجال التحلية، إلى جانب اهتمامها المتزايد بالابتكار الرقمي، فإن التعاون الإقليمي في هذا المجال يمكن أن ينتج مشاريع مشتركة رائدة تعزز مكانة المنطقة كمركز عالمي لتقنيات المياه.

وتختتم الورقة بالتأكيد على أن التحول الذكي في قطاع المياه لم يعد خيارًا مستقبليًا، بل ضرورة ملحة تمليها التحديات البيئية والاقتصادية، وأن الذكاء الاصطناعي يشكل محورًا جوهريًا لتحقيق هذا التحول، سواء من خلال رفع كفاءة الإنتاج، أو تحسين جودة الخدمات، أو حماية الموارد الطبيعية. وبالنظر إلى الإنجازات التي حققتها المملكة ودول الخليج في مجال التحول الرقمي، فإن المستقبل يحمل فرصًا كبيرة لتطوير منظومات مائية أكثر كفاءة واستدامة، تساهم في تحقيق الأهداف الوطنية والإقليمية في الأمن المائي والتنمية المستدامة.

أهم المصطلحات: الذكاء الاصطناعي، استدامة المياه، الأمن المائي، تحلية المياه، إدارة الطلب على المياه، البيانات الضخمة، الأنظمة الذكية، الكشف عن تسربات المياه، الري الذكي، كفاءة الطاقة، التحول الرقمي، رؤية المملكة العربية السعودية 2030.

Bibliography
Artificial Intelligence for Sustainable Water Resources Management for GCC Countries



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16 – 17 December 2025

Introduction:

Artificial Intelligence (AI) is increasingly becoming a vital tool for Sustainable Water Resources Management (SWRM) in the Gulf Cooperation Council (GCC) countries, where water scarcity, arid climates, and growing populations place intense pressure on limited freshwater resources. AI technologies can analyze large volumes of data from sensors, satellites, and historical records to improve water demand forecasting, optimize desalination processes, and enhance groundwater monitoring. By using machine-learning models, decision-makers can predict water consumption patterns, detect leaks in distribution networks, and respond more quickly to droughts or extreme weather events. This data-driven approach helps reduce water losses, improve efficiency, and support long-term planning in a region heavily dependent on limited water sources.

In addition, AI supports sustainability goals in GCC countries by improving the energy efficiency and environmental performance of water systems. For example, AI-driven optimization can reduce the high energy costs associated with desalination plants, which are a major source of potable water in the region. Intelligent systems can also help manage treated wastewater reuse for agriculture and urban landscaping, reducing reliance on freshwater supplies. By integrating AI into water governance, GCC countries can enhance resilience to climate change, support economic diversification, and ensure water security for future generations while aligning with national sustainability visions and smart city initiatives.

The annotated bibliography aims to assist the Water Research Center during the 16–17 December 2025 workshop titled **"Artificial Intelligence for Sustainable Water Resources Management for GCC Countries"** by providing a list of the most recent articles that cover the topic of Water Resources Management.

This annotated bibliography contains abstracts of articles published between 2025 and 2026.

E-resources used: Scopus

For access to full-text articles, please contact NSTIC.

Abstracts of Articles

1. Cao, Y.; Yuan, Y.; Dong, H.; Yuan, X. Water Extraction Games in River Basins from the Perspective of Complex Network Analysis: A Case Study in the Hanjiang River Basin, China. J. Hydrol. **2025**, 663, 134252. https://doi.org/10.1016/j.jhydrol.2025.134252

Abstract

As the global water crisis intensifies, human water extraction activities exert an increasingly profound impact on the sustainability of water resources. The distribution of water user groups in river basins exhibits distinct network characteristics, with pronounced asymmetric externalities in water extraction. However, current research has not adequately investigated the impact of these features. This study develops an evolutionary game model on weighted, directed water-use networks, using the Hanjiang River Basin in China, as a case study, to analyze network characteristics and water extraction dynamics. The results reveal that the network exhibits significant strength assortativity and small-world properties. The network topology and player payoff structures jointly drive water extraction dynamics, leading to diverse behavioral patterns. Under baseline initial conditions, cooperative water extraction emerges as the dominant strategy in the network, with an average cooperation ratio of 0.7031 over 100 rounds in noise-free simulations. Cooperation is primarily observed in the midstream and downstream reaches of the basin. Key parameters that drive cooperation, including marginal benefits, penalty coefficients, and marginal costs, reflect important institutional and environmental factors shaping water users' decisions. As noise intensifies, decision randomness increases, significantly undermining the strategic superiority of the dominant strategy and reducing the amplitude of phase oscillations among nodes. When cooperative extraction is favored under the given network and payoff structures, reducing controllable uncertainty can effectively promote cooperation. The study provides key insights for sustainable river basin management.

2. Chen, Q. Financial Cost Optimization of Urban Water Resource Scheduling Using Genetic Algorithms: A Metaheuristic Approach. Expert Syst. Appl. **2026**, 296, 128617. https://doi.org/10.1016/j.eswa.2025.128617

Abstract

Urban water resource scheduling presents a complex optimization challenge, encompassing supply-demand balance, cost efficiency, conservation, and environmental sustainability. This study proposes a financial cost optimization model utilizing a genetic algorithm, an evolutionary metaheuristic technique within the broader domain of artificial intelligence, to effectively address these challenges. The model integrates critical variables such as reservoir storage capacity, water treatment plant operational strategies, and both direct and indirect financial cost components. Through iterative processes, including population initialization, fitness evaluation, selection, crossover, and mutation, the genetic algorithm identifies an optimal scheduling scheme, which minimizes financial costs while ensuring water supply reliability and resource efficiency. A case study demonstrates that infrastructure construction costs can be reduced to 4.23 million, with improved water consumption outcomes across domestic, industrial, agricultural, and ecological domains. Comparative results indicate that the genetic algorithm outperforms other AI-based optimization methods, such as support vector machines and particle swarm optimization, particularly in terms of financial cost reduction and operational performance. Although genetic algorithms are a subclass of artificial intelligence techniques, this study is confined to their specific application and does not incorporate or evaluate other AI methodologies. Accordingly, the conclusions drawn reflect only the effectiveness of genetic algorithms in optimizing the financial costs of urban water resource scheduling.

3. Choudhary, R.; Kumar, A.; C, P.; Naik, M. M.; Choudhury, M.; Ahmad Khan, N. A. Predicting Water Quality Index Using Stacked Ensemble Regression and SHAP-Based Explainable Artificial Intelligence. Sci. Rep. **2025**, 15 (1), 9463. https://doi.org/10.1038/s41598-025-09463-4

Abstract

Effective forecasting of the Water Quality Index (WQI) considerably impacts water resource management as well as public health safety. This study proposes a novel approach for WQI forecasting using stacked ensemble regression modelling integrated with Shapley Additive explanations (SHAP), a form of Explainable Artificial Intelligence (XAI). The model was developed using a dataset of 1,987 water quality samples from Indian rivers (2005–2014), processed through six optimized machine-learning algorithms: XGBoost, CatBoost, Random Forest, Gradient Boosting, Extra Trees, and AdaBoost, combined using linear regression as the meta-learner. The model was trained using seven normalized physicochemical parameters as predictors, and the computed WQI (via the weighted arithmetic method) served as the response variable. The stacked ensemble model outperformed all individual models, achieving the highest performance across all evaluation metrics, with R^2 reaching 0.9952, adjusted R^2 at 0.9947, MAE recorded at 0.7637, and RMSE reduced to 1.0704. Among the individual models, CatBoost and Gradient Boosting demonstrated the strongest standalone performance. CatBoost achieved an R^2 of 0.9894, adjusted R^2 of 0.9883, MAE of 0.8399, and RMSE of 1.5905, while Gradient Boosting attained an R^2 of 0.9907, adjusted R^2 of 0.9898, MAE of 1.0759, and RMSE of 1.4898, respectively. SHAP analysis revealed that dissolved oxygen (DO), biological oxygen demand (BOD), electrical conductivity, and pH were the most influential parameters contributing to the prediction of WQI. This integrated framework improves the existing approaches by providing high predictive accuracy and model interpretability, along with real-time environmental monitoring capabilities. It fosters anticipatory environmental surveillance, enables automated policy frameworks, and builds confidence among stakeholders regarding the sustainability of water resources.

4. Elshaboury, N.; Bazrafshan, O.; Bahrami, M.; Berhail, S.; Pande, C. B.; Alammar, M. M. Hybrid Bio-Inspired Optimization with Artificial Neural Networks for Efficient Flood Routing in Watershed Management. Int. J. Energy Water Resour. **2025**, 9 (4), 2079–2094. https://doi.org/10.1007/s42108-025-00376-6

Abstract

Flood routing is a critical component of watershed management, requiring accurate predictive models to mitigate risks and enhance disaster preparedness. This study integrates artificial neural networks (ANNs) with metaheuristic optimization algorithms and signal-processing techniques to improve flood prediction accuracy. Hybrid models combining ANNs with the genetic algorithm, firefly algorithm, artificial bee colony (ABC), JAYA optimization, and variational mode decomposition (VMD) were developed and tested on hourly flood data from the Kızılırmak and Mera Rivers in Turkey. The results indicate that the ABC-ANN model performed best for the Mera River, achieving R2 = 0.893, MSE = 0.006, MAE = 0.067, and KGE = 0.916, demonstrating highly accurate flood predictions. For the Kızılırmak River, the VMD-ANN model outperformed the others, with R2 = 0.445, MSE = 285.035, MAE = 14.511, and KGE = 0.239. These findings suggest that integrating optimization algorithms with ANNs enhances prediction reliability, particularly in complex hydrological systems. Furthermore, the study confirms that downstream flood conditions can be effectively predicted based on upstream streamflow variations, contributing to improved flood control strategies. The results underscore the effectiveness of hybrid modelling approaches in flood risk assessment and management, offering valuable insights for early warning systems, infrastructure resilience, and sustainable water resources planning.

5. Hu, K.; Xu, Q.; Zhu, K.; Wang, Z.; Chu, Y.; Qian, Y.; Zhang, X.; Wang, B.; Zhang, H. Recent Advances of Artificial Intelligence in Aquatic Bioindicators and Ecological Assessment. Water Air Soil Pollut. **2026**, 237 (5), 907. https://doi.org/10.1007/s1127008907--025-x

Abstract

Aquatic ecosystems—critical to biodiversity and human health—face escalating threats from pollution, eutrophication, and climate change. Aquatic bioindicators, such as macroinvertebrates, phytoplankton, and microbial communities, are critical tools for assessing ecosystem health and detecting anthropogenic pressures. By reviewing the literature over the past decade, this study systematically explored how artificial intelligence (AI) methods, such as machine learning (ML), deep learning (DL), and hybrid models, have transformed the detection, prediction, and management of aquatic ecosystems. By synthesizing cutting-edge applications and addressing existing barriers, this review highlights AI's potential in achieving intelligent aquatic ecosystem management. However, significant gaps remain, particularly regarding the lack of standardization in data processing, model development, and validation frameworks across studies. Future advancements in multi-omics integration, climate-resilient modelling, and participatory AI systems are excepted to facilitate the transition from reactive monitoring to proactive stewardship, ensuring the sustainability of water resources in an era of global environmental change.

6. Li, K.; Wang, J.; Ochir, O.; Li, C.; Bavuu, E.; Tsengel, G. Discovery of Groundwater Storage Changes and Zoning Feature Variations over the Past Two Decades in the Mongolian Plateau for SDG 6.6. Remote Sens. Environ. **2025**, 331, 115026. https://doi.org/10.1016/j.rse.2025.115026

Abstract

Groundwater is a critical resource for supporting the Sustainable Development Goals (SDGs) in arid and semiarid regions, such as the Mongolian Plateau (MP), which accounts for over 82% of the total water usage in Mongolia; however, its spatiotemporal dynamics remain underexplored. In this study, aimed at enhancing the connection between groundwater storage (GWS) and local SDG implementation, we established an integrated analytical framework encompassing groundwater change detection, driving force analysis, and groundwater sustainability assessment. This framework quantifies groundwater storage changes across the MP from April 2002 to December 2023. Results reveal an overall groundwater change rate of -2.96 mm/yr in the MP, which increases in the west and north and decreases in the east, center, and south. The Gobi area has shown increasing trends in GWS. Attribution analysis reveals that areas with increasing GWS are more influenced by climatic conditions, such as higher precipitation and lower evapotranspiration, while regions with significantly decreasing GWS are associated with insufficient natural recharge and intensified human activities. In contrast, winter precipitation recharge played a crucial role in slowing the decline in groundwater storage. In the five major basins of the MP, the dominant factors leading to groundwater depletion varied and were driven by various socioeconomic factors, such as population growth, livestock pressure, agricultural activities, and mining. A dual-index classification combining precipitation minus evapotranspiration (P-ET) and GWS trends provides a convenient, interpretable, and objective approach to assessing groundwater sustainability, offering strong correspondence with the Reliability-Resilience-Vulnerability (RRV) framework. The findings of the present study provide an accurate assessment framework and valuable scientific evidence for groundwater resource management in arid and semiarid regions.

7. Mamun, M. A.; Aktar, M. N.; Uddin, M. N.; Chowdhury, M. H.; Islam, M. S.; Rahman, M. S.; Uddin, M. R.; Hossain, M. J.; Zahid, A.; Senapathi, V.; Islam, A. R. M. T. Hybrid Data-Driven Framework for Interpretable Prediction of Nitrate and Sulfate Risks in Coastal Aquifers. Sci. Total Environ. 2026, 1011, 181190. https://doi.org/10.1016/j.scitotenv.**2025**.181190

Abstract

Coastal aquifers in southern Bangladesh are increasingly threatened by groundwater overexploitation, saltwater intrusion, and diffuse contamination, posing serious threats to safe drinking-water supply. While earlier studies have primarily examined salinity and overall water quality degradation, the spatial dynamics and controlling factors of nitrate (NO_3) and sulfate ($SO_4$2) contamination remain poorly constrained. This study introduces a novel explainable artificial intelligence (XAI) framework that integrates Conditional Inference Trees (CIT), Multiple Correspondence Analysis (MCA), and advanced machine-learning (ML) algorithms to predict NO_3 and $SO_4$2 concentrations and elucidate their governing hydrogeochemical mechanisms. A total of 590 groundwater samples and 11 hydrochemical and environmental predictors were analyzed using CatBoost, Gradient Boosting Regression (GBR), and Artificial Neural Network (ANN) models. The tree-based CatBoost and GBR models were used for structured learning, while ANN captured complex non-linear dependencies, enabling a robust comparative assessment. Results show that saltwater intrusion and domestic wastewater discharge are the dominant drivers of SO_4^{2-} enrichment, whereas agricultural fertilizer inputs and salinity gradients control NO_3^- variability. MCA delineated contamination hotspots linked to anthropogenic activities and hydrogeochemical interactions. This study presents one of the first XAI-driven evaluations of NO_3^- and $SO_4$2- contamination in coastal Bangladesh. By coupling interpretability with predictive modelling, it advances the understanding of multi-source groundwater contamination processes and provides a transferable decision-support framework for sustainable groundwater management in vulnerable coastal environments.

8. Pande, C. B.; Mohd Sidek, L. M.; Halder, B.; Katipoglu, O. M.; Rajput, J.; Alshehri, F.; Chakrabortty, R.; Pal, S. C.; Dom, N. M.; Scholz, M. Prediction of Monthly River Water Level Using Ensemble Decomposition Modeling. Sci. Rep. **2025**, 15 (1), 10893. https://doi.org/10.1038/s41598-025-10893-3

Abstract

The decomposition, artificial intelligence (AI), and machine learning (ML) modelling techniques play an important role in hydrological and river-basin-related prediction and forecasting, supporting flood management and sustainable water resources development. In this paper, two combinations of variables, namely, lags and intrinsic mode functions (IMFs), are used for the development of different models for river water level prediction. Hence, these models are compared, and their performance is evaluated based on various statistical metrics. Therefore, the performance of hybrid models is measured based on the coefficient of determination (R2); the results indicate that CEEMDAN-SVM-LINEAR (R2=0.87), CEEMDAN-SVM-RBF (R2 = 0.91), CEEMDAN-RF (R2=0.98), and CEEMDAN-RS (R2=0.88) perform best under the second combination of variables, while standalone model performance is shown by SVM-Linear (R2 = 0.84), SVM-RBF (R2 = 0.87), RF (R2 = 0.97), and RS (R2 = 0.86) during the training phase under the first combination of variables. Similarly, in the testing phase, the best-performing models were CEEMDAN-RF (R2:0.94) and CEEMDAN-RS (R2:0.90) under the second combination of variables, while under the first combination of variables, SVM-Linear (R2:0.93) and RF (R2:0.89) exhibited higher performance than other models. Finally, the CEEMDAN-RF hybrid model emerged as the best-performing model, based on the lowest observed errors, including root mean square error (RMSE)= 0.13, mean square error (MSE)= 0.02, and high R2= 0.94; hence, this model is appropriate for the prediction of river water level. The results further demonstrate that the CEEMDAN data decomposition technique is highly effective in improving prediction performance for complex river water level forecasting by separating the dataset into various sub-frequencies, allowing a better understanding of trends, seasonality, and fluctuations in the data.

9. Patra, S. R.; Chu, H.; Tatas, U. Long-Term Projections of Global Groundwater Storage under Future Climate Change Scenarios Using Deep Learning. Sci. Total Environ. **2025**, 1009, 181043. https://doi.org/10.1016/j.scitotenv.2025.181043

Abstract

As climate change accelerates, understanding its impact on groundwater dynamics is essential for sustainable water management. This study employs a climate-induced AI model to project global variations in GRACE-derived groundwater storage (GWS) under future scenarios, e.g., CMIP6 Shared Socioeconomic Pathways (SSPs), until 2100. The model demonstrates robust predictive performance, yielding normalized root mean square error (NRMSE) values below 0.1 and an index of agreement (IOA) exceeding 0.9 across most regions worldwide. A feature sensitivity analysis revealed maximum temperature (Tmax) as the dominant driver: an increase in Tmax led to the largest absolute changes in GWS, followed by precipitation and minimum temperature. Spatial maps of projections at the global scale under the high-emission SSP585 scenario indicate that tropical and temperate regions may face the most pronounced GWS declines, particularly when Tmax exceeds 3 °C. Arid zones are projected to experience moderately high losses in comparison, while colder regions may see slight gains. Temperature extremes are projected to increase evaporative demand, crop water requirements, and domestic and irrigation dependence, thereby intensifying groundwater stress, particularly in densely populated and agriculture-dependent regions. By 2100, over half of the world›s population is expected to inhabit regions facing a decline in GWS, while major aquifers are projected to experience substantial losses, with the Ogallala Aquifer potentially losing up to 40% under severe warming conditions. These findings underscore the importance of integrating climate-induced groundwater changes into future global water resource planning.

10. Razavi-Termeh, S.; Sadeghi-Niaraki, A.; Ali, F.; Pirasteh, S.; Shirmohammadi, M.; Choi, S. Spatially Explicit and Interpretable GeoAI Models for Understanding Factors Controlling Groundwater Availability. J. Hydrol. 2026, 665, 134683. https://doi.org/10.1016/j.jhydrol.**2025.**134683

Abstract

Groundwater is a vital source of freshwater in semiarid regions, where water shortages are common. Accurately identifying areas with high groundwater potential is crucial for water resource management and agricultural sustainability. This study introduces an advanced geospatial artificial intelligence (GeoAI)-based approach to predict groundwater-prone areas. We optimized the CatBoost algorithm using the Fruit Fly Optimization Algorithm (FOA) to improve prediction accuracy. Additionally, we employed Shapley Additive exPlanations (SHAP) to enhance model interpretability and identify key factors influencing groundwater distribution. Our approach was applied in Kazerun and Kooh-Chenar counties, Iran, using 16 environmental factors related to groundwater potential. The results showed that the CatBoost-FOA model performed significantly better than the standalone CatBoost model, achieving higher predictive accuracy (RMSE = 0.086, MAE = 0.068, AUC-ROC = 0.838 versus RMSE = 0.219, MAE = 0.17, and AUC-ROC = 0.741). SHAP analysis revealed that factors such as low elevation, high vegetation index (NDVI), high rainfall, and proximity to rivers significantly affect groundwater availability. Lower elevation areas facilitate surface water accumulation and infiltration, higher NDVI values indicate regions with greater soil moisture availability, increased rainfall enhances groundwater recharge, and proximity to rivers improves hydraulic connectivity, thereby supporting groundwater occurrence. This study provides a more accurate and interpretable framework for groundwater potential mapping, contributing to improved water resource planning and management.

11. Sadeghi, H.; Sadeghfam, S.; Sharafati, A.; Seyfari, Y. Prediction of Urban Water Consumption Using AI-Based Multiple Modeling Based on Deep Learning. Int. J. Environ. Sci. Technol. **2026**, 23 (2), 6809. https://doi.org/10.1007/s137623-06809-025-

Abstract

Accurate prediction of urban water consumption supports sustainable water resource management and aligns with the United Nations Sustainable Development Goals (SDGs). This study applies the inclusive multiple modelling approach using deep learning models, implemented in MATLAB, to improve prediction robustness in the Mahabad water distribution network in West Azerbaijan Province, Iran. At the first level, Long Short-Term Memory (LSTM) and Group Method of Data Handling (GMDH) models predicted water consumption using precipitation, temperature, and population data. The second level employed a deep neural network, taking both the inputs and outputs from the first-level models. Model performance was evaluated using the Nash–Sutcliffe efficiency (NSE), root mean square error (RMSE), residual homoscedasticity, Taylor diagram, and peak demand analysis. The results indicate that the inclusive multiple modelling framework enhances prediction robustness by leveraging the strengths of individual models and reducing individual errors. The deep neural network at the second level outperformed other models, achieving an overall NSE of 0.956 and RMSE of 0.046, compared to LSTM (NSE = 0.887, RMSE = 0.074) and GMDH (NSE= 0.875, RMSE = 0.078). Residual analysis confirmed stable error distributions for the deep neural network and GMDH, while LSTM showed heteroscedasticity. The Taylor diagram confirmed higher correlation and better standard deviation matching for the deep neural network. The approach also accurately predicted extreme water demand peaks, demonstrating its potential as a robust and transferable tool for urban water management under changing climatic and demographic conditions.

12. Saville, R.; Fujiwara, A.; Hatanaka, K.; Wada, M.; Yaman, A.; Puspasari, R.; Albasri, H.; Dwiyoga, N. AI-Powered Decision Support System for Mariculture: Real-Time Fish Mortality Prediction with Random Forest. Aquacult. Eng. **2026**, 112, 102621.https://doi.org/10.1016/j.aquaeng.2025.102621

Abstract

Fish mortality is a significant issue in mariculture, affecting productivity and sustainability. Predicting mortality risk in real-time is crucial for improving decision-making and operational efficiency in mariculture management. This paper presents the development of a real-time fish mortality risk prediction model, designed as part of a Decision Support System using the Random Forest machine-learning algorithm. The innovative aspect of this study lies in the real-time processing of sensor data to deliver daily mortality risk predictions, allowing for immediate adjustments to management practices. This study integrates water quality parameters (seawater temperature, salinity, conductivity, chlorophyll-a, turbidity, and dissolved oxygen) monitored through a sensor network, with daily fish mortality records input by farmers. The Random Forest model predicted fish mortality risk across five levels, with an overall accuracy of 78.6% and precision exceeding 70% for each level. The model›s feature importance analysis highlights seawater temperature, salinity, and turbidity as key predictors of fish mortality risk. This system supports fish farmers and site managers in daily operational decision-making, particularly regarding feed and labor management. Future improvements in data collection and continuous model updates are expected to enhance the accuracy and utility of the Decision Support System in mariculture management.

13. Sekar, S.; Surendran, S.; Roy, P. D.; Muthukumar, M.; Kumar, P.; Elzain, H. E.; Arumugam, B.; Kamaraj, J.; Upendra, B.; Jothimani, M. Machine Learning–Based Prediction of Seasonal Groundwater Quality for Urbanized Parts of Melur (Tamil Nadu), India. Results Eng. **2025**, 28, 108222. https://doi.org/10.1016/j.rineng.2025.108222

Abstract

Groundwater contamination has become a critical global challenge due to population growth, industrialization and climate variability, while in India it is further intensified by urbanization, over-extraction, and heavy metal pollution. Accurate prediction of water quality is critical for the sustainable groundwater management. This research used artificial intelligence (AI)-derived machine-learning (ML) models, such as Artificial Neural Network (ANN), Decision Tree (DT), Random Forest (RF), and eXtreme Gradient Boosting (XGBoost), to predict groundwater quality (bore wells and open wells) in two seasons in the urbanized area of Melur, in the state of Tamil Nadu, India. Hydrogeochemical parameters, heavy metal contents, and weight-based groundwater quality index (WQI) were used to develop predictive models for both seasons. ANN was the most effective among the prediction algorithms for the pre-monsoon, achieving the highest accuracy (R^2 =0.95). Its performance, however, declined significantly (R^2 = 0.68) for the post-monsoon, compared with XGBoost (R^2 = 0.87). This approach of using different ML models for the accurate prediction of water quality in different seasons demonstrates the robustness of the forecasts for efficient water resource management practices.

14. Xia, X.; Liu, X.; Liu, J.; Fang, K.; Lu, L.; Oymak, S.; Currie, W. S.; Liu, T. Identifying Trustworthiness Challenges in Deep Learning Models for Continental-Scale Water Quality Prediction. Nexus 2025, 2 (4), 100104. https://doi.org/10.1016/j.ynexs.**2025**.100104

Abstract

Water quality is foundational to environmental sustainability, ecosystem resilience, and public health. Deep learning offers transformative potential for large-scale water quality prediction and scientific insight generation. However, its widespread adoption in high-stakes operational decision-making, such as pollution mitigation and equitable resource allocation, is constrained by unresolved trustworthiness challenges, including performance disparity, robustness, uncertainty, interpretability, generalizability, and reproducibility. In this work, we present a multi-dimensional, quantitative evaluation of trustworthiness, benchmarking three state-of-the-art deep learning architectures: recurrent (LSTM), operator-learning (DeepONet), and transformer-based (Informer), trained on 37 years of data from 482 US basins, to predict 20 water quality variables. Our investigation reveals systematic performance disparities tied to process complexity, data availability, and basin heterogeneity. Management-critical variables remain the least predictable and most uncertain. Robustness tests reveal pronounced sensitivity to outliers and corrupted targets; notably, the architecture with the strongest baseline performance (LSTM) proves most vulnerable under data corruption. Attribution analyses align for simple variables but diverge for nutrients, underscoring the need for multi-method interpretability. Spatial generalization to ungauged basins remains poor across all models. This work serves as a timely call to action for advancing trustworthy data-driven methods for water resources management and provides a clear pathway to offering critical insights for researchers, decision-makers, and practitioners seeking to leverage artificial intelligence (AI) responsibly in environmental management.

[1]Emerging Technologies include: Geo AI, Internet of Things (IoT), Blockchain Quantu Computing, Big Date Analytics, Robotics/ Drones.

15. Zhao, S.; Wang, Q.; An, Z.; Wang, X.; Su, Y.; Li, J.; Wen, G. Water Quality Estimation and Algae Bloom Prediction Using Machine Learning: A Case Study. J. Water Process Eng. **2025**, 80, 109161. https://doi.org/10.1016/j.jwpe.2025.109161

Abstract

Nutrient runoff from croplands is a major driver of eutrophication and freshwater degradation, underscoring the need for developing efficient water quality assessment methods. While traditional models often fail to capture nonlinear interactions, their predictive capacity for handling multiple environmental variables is limited. This study advanced water quality assessment by evaluating four machine-learning (ML) models, i.e., Support Vector Machine (SVM), Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Artificial Neural Network (ANN), which were chosen for their proven ability to capture nonlinear relationships, handle multivariate data, and perform robustly in both classification and regression tasks. Using 127 site-years of water monitoring data, we identified key drivers of eutrophication and developed data-driven models for chlorophyll and algae density prediction. Results showed that total nitrogen (TN), total phosphorus (TP), and organic pollutants were the key drivers of higher chlorophyll concentrations and algae density. In addition, water bodies near croplands had 48% and 61% higher TN and TP levels, along with 181% more chlorophyll and 633% higher algae density. These results indicate that agricultural nutrient runoff is a major pollution source for algal blooms. Among the tested models, RF achieved the best performance (R2 = 0.78 for chlorophyll and 0.88 for algae density) with the lowest error metrics. These findings demonstrate that ensemble ML models, particularly RF, can improve water quality classification and eutrophication prediction. It also highlights the practical potential of ML-based frameworks for real-time water monitoring and the importance of sustainable nutrient management. Future research should integrate remote sensing data with artificial intelligence-driven models to enhance large-scale, data-informed water resource management.

Workshop Report and Recommendations

Title: Artificial Intelligence for Sustainable Water Resources Management in the GCC Countries
Organizers: Kuwait Institute for Scientific Research (KISR), in cooperation with the GCC Water Science and Technology Association (GCC-WSTA) and the GCC Secretariat General (GCC SG)
Date: December 16–17, 2025
Venue: Kuwait Institute for Scientific Research, Al-Shuwaikh
Attendees: 360 participants from Kuwait and other GCC countries

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Executive Summary

The Regional Workshop on **«Artificial Intelligence for Sustainable Water Resources Management in the GCC Countries»** convened international and regional experts, to explore the transformative potential of the Fourth Industrial Revolution (4IR) emerging technologies and cutting-edge artificial intelligence (AI) applications in the water sector. The discussions were supported by applied research contributions and practical case studies from across the Gulf cooperation Council (GCC) region, demonstrating tangible benefits, implementation pathways, and lessons learned for AI-enabled water resources management in arid and semiarid environments. Against a backdrop of acute water scarcity, climate change, and steadily increasing water demand, the discussions underscored the role of AI, not merely as a mere technological upgrade but as a strategic enabler that must be embedded within strong data governance frameworks, skilled human capital, sound policy environments, and effective regional cooperation mechanisms to achieve water security, economic sustainability, and climate resilience. The workshop discussions and technical contributions highlighted the role of AI as an economic optimization and decision-support tool, enabling more cost-effective and efficient planning and operation across key water sector domains, including desalination, groundwater management, infrastructure operation, and agricultural water use. The deliberations also revealed a clear consensus: the **successful integration of AI into water resources management requires a holistic and coordinated approach that combines advanced technological solutions with sustained foundational investments in data governance, institutional and**

human capacity development, enabling policies, and regional cooperation. Furthermore, the discussions addressed the importance of managing risks and ensuring the responsible and ethical use of AI technologies. This report consolidates the key recommendations derived from the workshop presentations and discussions, organized into three main thematic areas addressed during the event **(refer to Annex A for the list of presentations)**:

Justification for Additions to the Executive Summary

The two added statements in the “Executive Summary” were introduced to strengthen alignment between the “Final Report” and the substantive technical content of the “Book of Abstracts” and the workshop discussions, without altering the agreed narrative or overall structure of the Summary, as follows:

- The first addition reinforces a key cross-cutting insight emphasized during the workshop, namely, the successful deployment of AI within the GCC context, particularly in arid and hyperarid environments, requires context-aware and data-efficient approaches tailored to regional hydroclimatic and institutional conditions, rather than the direct transfer of solutions developed for data-rich settings.
- The second addition complements this strategic framing by explicitly reflecting the economic dimension highlighted in several presentations, which demonstrated the role of AI as a decision-support and optimization tool capable of enhancing cost-effectiveness and operational efficiency across major water sector domains, such as desalination, groundwater management, infrastructure operation, and agricultural water use.

Together, these additions enhance the Executive Summary’s completeness and policy relevance by accurately capturing the workshop’s evidence-based discussions, while preserving coherence, avoiding redundancy, and maintaining the originally agreed language and flow.

1. Data Governance, National Readiness, and Emerging Technologies

The session established the foundational pillars for successful AI adoption, emphasizing that effective AI implementation must be grounded in robust data availability, sound institutional frameworks, and adequate human capacities. It also highlighted key opportunities for applying emerging technologies and AI solutions to address the principal water-related challenges facing the GCC countries. Additionally, the discussions underscored the importance of data integrity, interoperability, cybersecurity, and clear governance arrangements as critical enablers for trustworthy and sustainable AI deployment.

2. Applications in the Water Sector and the WEFE Nexus

The session showcased the transformative potential of emerging technologies and AI in optimizing the entire water value chain, while effectively managing the critical interlinkages between water, energy, food, and ecosystems (WEFE nexus). Recognizing that agriculture accounts for the largest share of water consumption in the GCC, this session focused, in particular, on the role of AI and AI-based models, especially artificial neural networks (ANNs) integrated with the Internet of Things (IoT), as a key enabler for unlocking significant efficiency gains and enhancing the sustainability of water use within the agricultural sector. The discussions further emphasized the need to move beyond isolated pilot projects toward integrated, system-wide deployment of AI-enabled solutions across the water sector.

3. AI Capacity Development, Education, and Awareness Raising

This session emphasized that successful technological transformation is ultimately dependent on human capital, highlighting the need to address ethical considerations and promote the responsible use of AI as an integral component of AI adoption. Participants also highlighted the importance of managing risks associated with AI adoption, including over-reliance on automated systems, data bias, and the need to preserve and strengthen core hydrological and engineering expertise alongside digital capabilities.

In addition, two short post-workshop training sessions were conducted on “Emerging Technologies’ Applications for Water Management” and “GeoAI Applications in the Water Sector”, which were attended by 83 participants (refer to Annex B for the topics covered in the training sessions).

Cross-Cutting Insights from Workshop Sessions

Across the three technical sessions, the workshop clearly demonstrated that the application of AI in water resources management within GCC countries is transitioning from isolated pilot initiatives toward more integrated, system-level approaches. While the maturity of AI adoption varies across countries and sectors, common trends emerged, emphasizing the growing role of AI as a decision-support tool, which complements, rather than replaces, conventional hydrological knowledge and engineering expertise. The discussions highlighted that effective AI deployment depends not only on algorithmic sophistication but also on the availability of high-quality data, interoperable digital infrastructure, and institutional readiness. Participants repeatedly emphasized that AI solutions must be embedded within broader governance and operational frameworks to ensure transparency, accountability, and long-term sustainability. Several contributions, including those addressing AI-driven solutions for arid and hyperarid environments, emphasized that successful AI deployment in the GCC must prioritize context-aware and data-efficient models tailored to regional hydroclimatic conditions, rather than replicating generic solutions developed for data-rich settings. These approaches were presented as essential for safeguarding digital sovereignty while ensuring that AI systems remain practical, resilient, and institutionally sustainable. Furthermore, the sessions underscored the importance of aligning AI-driven water management strategies with national development priorities, climate adaptation objectives, and regional cooperation frameworks within the GCC.

Evidence-Based Applications from the GCC Context

The technical contributions provided concrete examples of AI applications relevant to the GCC water sector. These included AI-enabled optimization of desalination plant operations, leading to measurable reductions in energy consumption, predictive analytics for reducing non-revenue water in distribution networks, and machine-learning-driven precision irrigation systems capable of significantly improving water-use efficiency in agriculture. Additional applications encompassed AI-supported groundwater assessment and well optimization in data-scarce environments, flood forecasting and early warning systems using remote sensing and geospatial analytics, and decision-support tools integrating economic, environmental, and operational criteria. Case studies also illustrated the emerging role of AI in capacity building, education, and behavioural change, as well as the potential for small and medium enterprises to contribute innovative AI solutions tailored to regional water challenges. Collectively, these examples demonstrate that AI adoption in the GCC water sector is already delivering tangible benefits, while offering promising scope for further scaling and integration.

Shared Challenges and Enabling Conditions

Despite the promising applications presented, the workshop discussions revealed several common challenges that must be addressed to fully harness the potential of AI in water resources management. These challenges include data fragmentation and limited accessibility, uncertainties associated with model performance under non-stationary climatic conditions, cybersecurity risks, and the environmental footprint of digital infrastructure. Participants were also cautioned against over-reliance on automated systems without sufficient human oversight and domain expertise.

To overcome these challenges, the workshop emphasized the need for robust data governance frameworks, sustained investment in human capital development, ethical and regulatory safeguards, and enhanced regional collaboration. Establishing standardized data protocols, strengthening institutional coordination, and fostering knowledge exchange across GCC countries were identified as critical enabling conditions for the responsible and effective deployment of AI in the water sector.

Justification for Additions and Refinements to the Technical Sessions and Synthesis Sections The additions and refinements introduced across the technical session summaries, cross-cutting insights, evidence-based applications, and shared challenges sections were made to strengthen the Final Workshop Report's alignment with the breadth and depth of contributions documented in the "Book of Abstracts", while preserving the original structure, tone, and synthesis-oriented nature of the report. These enhancements explicitly capture several recurring themes emphasized during the workshop discussions, including the transition from isolated AI pilot initiatives toward integrated, system-level deployment; the critical importance of robust data governance, institutional readiness, and human capacity as foundational enablers; and the need for context-aware and data-efficient AI approaches tailored to arid and hyperarid environments characteristic of the GCC. Additional refinements were introduced to more clearly reflect the strategic role of groundwater as a core water security asset, the growing use of AI as an economic optimization and decision-support tool across the water value chain, and the increasing relevance of flood risk management and climate-related water hazards. The section on shared challenges was further strengthened by explicitly acknowledging key constraints, including uncertainty, climate non-stationarity, cybersecurity concerns, and the emerging water and energy footprint of digital and AI infrastructure, all of which were raised during workshop deliberations. Collectively, these additions improve the coherence, completeness, and policy relevance of the Final Report, ensure faithful representation of workshop outcomes, and enhance its value for decision-makers, without introducing redundancy or altering the agreed narrative framework.

Recommendations

Building on the technical discussions, case studies, and cross-cutting insights presented, the workshop proposed the following recommendations to guide the strategic adoption of AI in water resources management across GCC countries:

A. Data Governance, National Readiness, and Emerging Technologies

1. Establish Robust National Data Governance Frameworks (Water Data Observatories):

- Develop and implement comprehensive national data strategies (as exemplified by Saudi Arabia›s alignment with the Saudi Data and AI Authority [SDAIA]), to ensure water and meteorological data harmonization procedures, embodying data quality, interoperability, security, and ethical use. These elements are fundamental prerequisites for the development, deployment, and sustainability of reliable AI models.
- Establish centralized and authoritative data platforms (e.g., Saudi Arabia National Irrigation Geo Databases) to serve as a single, trusted source of water-related data, thereby supporting evidence-based planning, management, and decision-making.

These frameworks should incorporate clear data ownership, cybersecurity safeguards, and ethical oversight mechanisms to ensure trustworthy and responsible AI deployment.

2. Assess and Build National AI Readiness:

- GCC Countries should undertake systematic assessments of their digital maturity across data acquisition and control, policy, infrastructure, regulatory environments, human capital, and institutional capacity.

Progressing beyond basic digitization toward comprehensive digital transformation is critical.

- Strong leadership and clearly defined governance structures are essential to guide this transformation, reduce the risks associated with poor-quality or fragmented data, and ensure the reliability and sustainability of AI investments and potential impacts.

These assessments should inform clear national roadmaps that support the scaling and institutionalization of AI solutions beyond pilot initiatives.

3. Adopt a Portfolio of Emerging Technologies:

- In addition to core AI solutions, GCC water sectors should strategically explore, pilot, and integrate complementary 4IR technologies, including the IoT for sensing and monitoring, blockchain for traceability and smart contracts, drones and remote sensing technologies for large-scale monitoring and assessment, and digital twins for system simulation.

Priority should be given to technologies that demonstrate clear operational value and can be integrated into existing water management systems. In parallel, the water and energy footprint of digital and AI infrastructure, including data centers and communication networks, should be considered within national planning frameworks to ensure alignment with sustainability and efficiency objectives.

B. Applications of Emerging Technologies in the Water Sector and the WEFE Nexus

1. Deploy AI for System-Wide Optimization and Resilience:

- Implement AI-driven digital twins (virtual replicas) of integrated Water-Energy-Food-Ecosystem (WEFE) systems to simulate complex synergies, assess trade-offs, and support the transition from siloed, sector-specific management toward proactive and integrated system-wide governance, including applications for flood risk management, early warning systems, and climate-related water hazards.
- By integrating and prioritizing bundled Socio-Ecological Technologies (SETs), AI can transform complex

data into accessible visual interfaces that outperform isolated interventions. This approach fosters informed dialogue among diverse stakeholders, reduces institutional fragmentation, and ensures more effective outcomes across the WEFE Nexus.

- Leverage and reinforce AI for predictive maintenance and operational optimization of critical water infrastructure, including desalination plants (where energy consumption can be reduced by approximately 10–20%) and water distribution networks (where AI applications can contribute to reducing non-revenue water by more than 20%).
- Apply AI-based tools to enhance groundwater sustainability through economic well design optimization and advanced modeling of aquifer behavior, particularly in data-scarce and hydrogeologically complex environments.
- Develop AI-based scenarios for groundwater contamination issues, specifically for coastal aquifers, to avoid excessive salinity that compromises agricultural suitability.

These applications should be progressively integrated into national water planning and operational frameworks to ensure continuity, scalability, and long-term institutional ownership.

2. Leverage AI for the Safe and Efficient Use of All Water Sources:

- Develop AI models to support the predictive blending of conventional and non-conventional water sources, including treated wastewater, brackish groundwater, and harvested water, based on clearly defined «fit-for-purpose» water quality requirements.
- Use AI-driven, real-time monitoring and anomaly detection systems in wastewater treatment and reuse operations to safeguard water quality, enhance process stability, and strengthen public confidence in reclaimed water systems.

Robust quality assurance protocols and regulatory oversight should accompany these applications to manage risks and maintain trust in AI-supported water reuse systems.

3. Scale AI-Powered Precision Agriculture:

- Promote the widespread adoption of AI-enabled precision irrigation systems that integrate soil moisture sensors, weather forecasting data, and satellite-derived indicators (e.g., NDVI) to achieve significant reductions in water use (typically in the range of 30–50%) and optimized fertilizer requirements, while maintaining or enhancing agricultural productivity and crop yields.
- Support the development and deployment of integrated AI-agronomy platforms that offer comprehensive decision-support tools for crop selection, early detection of pests and diseases, yield forecasting, and optimization of agricultural inputs.

Targeted policies, incentives, and service-based business models should be introduced to support large-scale adoption and ensure accessibility for small- and medium-scale farmers.

4. Address the Specific Challenges of AI in Arid Agriculture:

- Recognize and address the key barriers to the adoption of AI technologies in arid agricultural settings, including high initial investment costs, limited sensor reliability under harsh environmental conditions, data scarcity on crop water requirements, and insufficient technical capacity among farmers, through targeted sensitization and dissemination training programs.
- Advocate for supportive policies and innovative business models (e.g., service-based contracts, performance-based payment schemes), which enhance the economic feasibility and accessibility of AI solutions for small- and medium-scale farmers.

Pilot demonstration farms, localized validation of AI tools, and extension services should be strengthened to build trust, demonstrate value, and accelerate adoption under real arid-field conditions.

C. AI Capacity Development, Education, and Awareness Raising

1. Integrate Fourth Industrial Revolution (4IR) Technologies and AI into Water Education and Training:

- Modernize/update academic curricula to develop a new generation of water data scientists and water professionals, who are proficient in data literacy, AI, and system-based thinking.

- Establish immersive learning environments, such as «Living Labs», which utilize real GCC water infrastructure and digital twin technologies for pilot demonstration, to effectively bridge the gap between theoretical knowledge and practical applications.
- Provide targeted professional, on-the-job training programs, short courses, and micro-credentials for water sector professionals, focused on the application of emerging technologies and the operation and management of smart water systems.
- Fund knowledge exchange initiatives to transfer knowledge between academic institutions and industrial partners. These initiatives will accelerate AI adoption and reduce associated risks

Capacity-building initiatives should be aligned with national digital transformation strategies to ensure consistency, relevance, and long-term impact.

2. Develop Value-Based and Engaging AI Educational Tools:

- Design AI-enabled environmental education programs that extend beyond traditional knowledge transfer by promoting water conservation values and encouraging behavioral change among younger generations through personalized learning approaches and interactive simulations.
- Implement comprehensive capacity-building initiatives targeting water sector professionals, policymakers, and farmers to ensure they are equipped with the skills and competencies required to effectively use, manage, and oversee AI-based systems.

These programs should explicitly address ethical considerations, data responsibility, and the limitations of AI to promote informed and responsible use. Capacity development efforts should also emphasize the management of uncertainty, continuous model validation, and the preservation of human oversight to ensure that AI systems remain adaptive, reliable, and supportive of professional judgment, rather than replacing it.

3. Foster a Culture of Innovation and Collaboration:

- Promote open innovation by developing public-facing data platforms and providing targeted support for local technology startups and entrepreneurs operating within the water sector.
- Strengthen public-private-academic partnerships to accelerate research and development (R&D) activities and facilitate the deployment of AI solutions that are specifically tailored to the needs and challenges of the water sector.

Clear governance arrangements and performance evaluation mechanisms should be established to ensure that collaborative initiatives deliver measurable and scalable outcomes.

Across all recommendation areas, participants emphasized the importance of moving from isolated pilots toward integrated, system-wide AI deployment, supported by strong governance, risk management, and sustained regional cooperation. To support and operationalize this transition, it was further emphasized that countries should establish clear performance indicators, monitoring frameworks, and periodic evaluation mechanisms to assess the effectiveness, scalability, and long-term impacts of AI-enabled water solutions, ensuring transparency, accountability, and continuous improvement.

Justification for the Additions

The additions introduced to the Recommendations section were made to ensure full alignment between the Final Workshop Report and the breadth of technical discussions and evidence presented in the Book of Abstracts, while preserving the agreed structure and policy-oriented tone of the section. These refinements explicitly reflect recurring workshop themes, which were previously implicit, including the role of AI in addressing flood risk and climate-related water hazards, the importance of managing uncertainty through continuous model validation and human oversight, and the need to consider the water and energy footprint of digital and AI infrastructure within sustainability planning. In addition, the introduction of a cross-cutting recommendation on performance indicators and monitoring frameworks strengthens accountability and supports evidence-based evaluation of AI investments, which was emphasized across multiple presentations. Collectively, these targeted additions enhance the coherence, traceability, and policy relevance of the Recommendations, without introducing redundancy or altering the agreed narrative, and ensure that the section faithfully represents the workshop outcomes for decision-makers and regional stakeholders.

Overarching Conclusions and Strategic Pathways Forward

The workshop presentations collectively outlined a clear and coherent pathway for the water sector in the GCC countries to effectively harness the potential of emerging technologies and cutting-edge AI in the water sector, based on applied research, case studies, and evidence-driven insights, in order to enhance water sustainability and security across the region.

1. **From Pilots to Systems:** Transition beyond isolated and fragmented pilot initiatives toward fully integrated, AI-enabled water governance systems, which are predictive, proactive, and resilient in addressing complex water challenges.
2. **Balance Opportunity with Prudence:** Proactively manage the risks associated with AI deployment, including data bias, cybersecurity vulnerabilities, model drift, environmental impacts (energy/water footprint of data centers), and the risk of over-reliance on AI at the expense of essential hydrological and engineering expertise.
3. **Prioritize Digital Sovereignty:** Build in-house capacity and strengthen regional collaboration to develop solutions tailored to the GCC›s unique arid context, thereby reducing dependence on foreign proprietary systems and ensuring long-term control over critical digital infrastructure and data assets.
4. **Embrace Regional Cooperation:** Leverage shared challenges and opportunities across GCC countries by promoting collaborative action, including the establishment of shared data platforms, harmonization of policies, co-development of open-source tools, and sustained knowledge exchange through regional platforms such as Water Sciences and Technology Association (WSTA).

Finally, it is important to note that achieving these strategic pathways will require sustained political commitment, coordinated institutional action, and long-term investment in governance frameworks, human capital, and regional cooperation mechanisms, supported by clear performance indicators and continuous monitoring to track progress and inform adaptive decision-making.

Justification for Additions to the Overarching Conclusions and Strategic Pathways Forward Section

The additions to the Overarching Conclusions and Strategic Pathways Forward section were introduced to strengthen the linkage between the workshop's strategic messages and the evidence-based discussions documented in the Book of Abstracts, while preserving the original structure and intent of the conclusions. The reference to applied research, case studies, and evidence-driven insights reinforces that the proposed strategic pathways are grounded in demonstrated practice, rather than conceptual projections alone. The inclusion of explicit reference to performance indicators and continuous monitoring further aligns the conclusions with the Recommendations section by emphasizing accountability, adaptive management, and the need for measurable progress in implementing AI-enabled water solutions. Collectively, these additions enhance the coherence, policy relevance, and internal consistency of the Final Workshop Report, without introducing new concepts or altering the agreed narrative, and ensure that the conclusions clearly reflect both the strategic and operational dimensions emphasized during the workshop.

Conclusion

The integration of AI into water resources management has moved beyond being a future option for the GCC to become an immediate necessity. Through the strategic, evidence-informed application of these technologies within a framework founded on **strong governance** structures, **resilient infrastructure**, sustained **investment in human capital**, and effective **regional cooperation**, the GCC has the potential to convert its water challenges into a leading model of sustainable and intelligent water resources management for arid regions around the world.

Next Steps and Way Forward

The workshop organizers, KISR, WSTA, and the GCC Secretariat General (GCC SG), will build on the outcomes of the workshop to further advance and strengthen the implementation of emerging technologies and cutting-edge AI within the water sector across GCC countries. To this end, the following initiatives have been agreed upon:

1. Develop a "**Policy Brief**" on AI Applications in the Water Sector in the GCC Countries to raise awareness of the potential of AI, its prerequisites, and associated challenges. The Policy Brief will be targeted at policymakers and water sector specialists, **with the WSTA Scientific Committee leading the process and contributions provided by all workshop speakers**. The suggested title of the Policy Brief is **Artificial Intelligence for Sustainable Water Resources Management in the GCC: Priorities, Policies, and the Path Forward**
2. Prepare a comprehensive **bibliography** of all emerging technologies and AI applications in the water sector and all AI-Water initiatives, covering the GCC countries and potentially extending to the Arab and other regions. **KISR will take the lead in compiling this bibliography**.
3. Follow up on the workshop outcomes during **WSTA's upcoming 16th Gulf Water Conference** (Oman, April 2026), through appropriate formats such as a dedicated physical or virtual special session, panel discussion, or related activities, with coordination **led by the WSTA Scientific Committee**.
4. Submit the Workshop Conclusions and Recommendations to the GCC SG. **KISR, jointly with WSTA, will submit these to the GCC SG (Dr. Mohammed Al-Rashidi).**
5. KISR-WSTA will further engage with the GCC SG to explore support opportunities for existing and new initiatives aimed at enhancing the adoption of AI and other emerging technologies in the water sector, with **WSTA's Scientific Committee preparing proposals in this regard.**

Acknowledgments

The workshop organizers, together with the members of the Organizing and Scientific Committees, extend their sincere appreciation and gratitude to the workshop sponsors for their generous support, which played a significant role in the successful conclusion of this important event. Their sponsorship contributed substantially to achieving the workshop's objectives and ensuring the quality of its outcomes, reflecting a clear commitment to supporting scientific and knowledge-based initiatives of strategic value. As a result of this support, the workshop organizers were able to deliver a high-quality and impactful event with tangible scientific and practical value for all participants. We take pride in this fruitful partnership and look forward to strengthening collaboration with these organizations in the future, while exploring new opportunities for joint initiatives of a similar nature.

Sponsors

- Kuwait Petroleum Corporation and Subsidiaries
- Kuwait Foundation for the Advancement of Sciences
- Federation of Arab Scientific Research Councils
- Kuwait United Poultry Company

Annex A

List of Workshop Speakers and Their Presentation Titles

- National Readiness for Artificial Intelligence Adoption, Dr. Zeyad Al-Shibaany, International Expert in Digital and Intelligent Systems
- Leveraging AI and Digital Sovereignty for Smart and Sustainable Water Governance in the MENA Region, Dr. Mustafa Ezzyani, Professor of Computer Science, FST Tangier, Morocco
- AI as a Tool for Economic Sustainability and Water Security in the GCC Countries, Prof. Mohamed Al-Rashed, Kuwait Institute for Scientific Research, Kuwait
- The Smart Water Revolution: Harnessing Emerging Technologies for Sustainable Water Management in the GCC Countries, Prof. Waleed Al-Zubari, Arabian Gulf University, Kingdom of Bahrain
- The Impact of Applying AI Technology on the Overall Performance of Small and Medium-Sized Water-Related Enterprises in the Sultanate of Oman: A Case Study of Azr Engineering, Investment, and Holding Company, Dr. Ali Al-Hamdi, CEO, Azer Engineering and Investment Holding
- Integrated Flood Management: Data, Models, and AI (Uncertainty and Knowledge), Prof. Driss Ouazar, Hassan II Academy of Science and Technology, Morocco
- An Artificial Intelligence Framework for the Economic/Optimal Design of Dual-Well Systems in Kuwait›s Aquifers, Dr. Amjad Aliewi, Kuwait Institute for Scientific Research, Kuwait
- AI- Driven Approaches for Sustainable Water Management: Insights from Groundwater Modeling, Agricultural Drainage Treatment, and Smart Hydroponic Systems, Prof. Hoda Farouk Zahran, Pollution Management Department, Environment and Natural Materials Research Institute (ENMRI), City of Scientific Research and Technological Applications (SRTA), Egypt
- AI-Driven Solutions for Sustainable Water Management in Arid Regions: Harnessing Smart Technologies for a Resilient Future, Eng. Adnan Akber, Kuwait Institute for Scientific Research, Kuwait
- Leveraging Artificial Intelligence for Sustainable Water Management in Saudi Arabia, Dr. Mohammad Al-Omair, Saudi Irrigation Organization, Kingdom of Saudi Arabia

- AI for WEFE Nexus: Strengthening Climate Resilience and Water-Smart Irrigation, Prof. Jordi Morato Morató, UNESCO Chair on Sustainability, Universitat Politècnica de Catalunya, Spain
- Smart User of Nonconventional Water and AI-Driven Agriculture for Food Production, Dr. Kamel Mostafa Amer, Arab Organization of Agricultural Development
- Challenges of AI in Managing Irrigation Water, Prof. Abdrubalrasoul Al-Omran, King Saud University, Riyadh, Saudi Arabia
- From Losses to Efficiency, the Role of Automatic Power Factor Correction towards Enhancing the Reliability of Desalination and Pumping Systems, Eng. Ahmed Al Ghamdi, Renewable Energy Group Leader, WTIIRA, Kingdom of Saudi Arabia
- The Educational Role of Artificial Intelligence Technologies in Promoting Water Conservation Values and Their Importance among Young Generations, Dr. Najwa Al-Mutairi, Academic and Educational Researcher, Kingdom of Saudi Arabia
- Artificial Intelligence for Sustainable Water Resource Management: A Saudi Arabian Perspective, Aws Al-Fouzan, Student (11th Grade), Kingdom of Saudi Arabia

Annex B
Post-Workshop Training Sessions

Training 1: Emerging Technologies' Applications for Water Management, by Prof. Adel Bouhoula, Arabian Gulf University.

This training session explored how emerging technologies are revolutionizing water management. Machine learning enables water management to shift from a reactive to a proactive approach, enhancing efficiency, sustainability, and resilience. Blockchain technology offers transparency, decentralization, and robust security for water data, with smart contracts enabling automated, reliable, and transparent water allocation and management processes. The Internet of Things (IoT) helps reduce costs, promote resource conservation, and minimize waste through smart monitoring. Quantum computing brings precision in contaminant detection, enables detailed simulations for sustainability, and solves complex problems more efficiently. Together, these technologies drive innovative and sustainable water management solutions.

Training 2: GeoAI Applications in the Water Sector, by Dr. Manaf Alkhuzai, Arabian Gulf University.

The workshop contents were as follows: Water Challenges and Why GeoAI? What is GeoAI? GeoAI Basics in Simple Terms; Types of Geographic Data for Water Management; Common AI Methods in GeoAI; The GeoAI Workflow: From Data to Decisions; Validation and Accuracy (How We Know GeoAI Works); Limitations and Considerations; Live Demonstrations: Demo A: Coastal Water Quality Monitoring, Demo B: Urban Flash Flood Susceptibility Mapping, Demo C: Water Leak Hotspot Detection (Non-Revenue Water), Demo D: Groundwater Salinity Prediction; Implementation Roadmap; Costs and Return on Investment; Critical Success Factors; Common Pitfalls to Avoid; Key Takeaways and Discussion; References and Further Reading.

تقرير ورشة العمل والتوصيات

العنوان: **الذكاء الاصطناعي للإدارة المستدامة للموارد المائية في دول مجلس التعاون الخليجي**

الجهات المنظمة: **معهد الكويت للأبحاث العلمية بالتعاون مع جمعية علوم وتقنيات المياه الخليجية والأمانة العامة لمجلس التعاون لدول الخليج العربية**

التاريخ: **16-17 ديسمبر 2025**

المكان: **معهد الكويت للأبحاث العلمية، الشويخ**

الحضور: **(360) مشارك من دول مجلس التعاون الخليجي**

الملخص التنفيذي

انعقدت الورشة الإقليمية بعنوان «الذكاء الاصطناعي من أجل الإدارة المستدامة للموارد المائية في دول مجلس التعاون الخليجي» بمشاركة نخبة من الخبراء الدوليين والإقليميين، وذلك لاستكشاف الإمكانات التحويلية لتقنيات الثورة الصناعية الرابعة (4IR) والتطبيقات المتقدمة للذكاء الاصطناعي في قطاع المياه. وقد استندت المناقشات إلى مساهمات بحثية تطبيقية ودراسات حالة عملية من مختلف دول مجلس التعاون الخليجي، أظهرت منافع ملموسة، ومسارات تنفيذ واضحة، ودروساً مستفادة في توظيف الذكاء الاصطناعي في إدارة الموارد المائية في البيئات الجافة وشبه الجافة. وفي ظل التحديات المتنامية المتمثلة في شح المياه، وتغير المناخ، والارتفاع المطّرد في الطلب على الموارد المائية، أكدت المناقشات أن دور الذكاء الاصطناعي لا ينبغي أن يُنظر إليه بوصفه مجرد تطوير تقني، بل كعامل تمكيني استراتيجي يتعين دمجه ضمن أطر متينة لحوكمة البيانات، ورأس مال بشري مؤهل، وبيئات سياسات رشيدة، وآليات فاعلة للتعاون الإقليمي، بما يسهم في تحقيق الأمن المائي، والاستدامة الاقتصادية، وتعزيز القدرة على التكيّف مع التغيرات المناخية. كما أبرزت مناقشات الورشة والمساهمات الفنية الدور المتنامي للذكاء الاصطناعي بوصفه أداة لتحسين الكفاءة الاقتصادية ودعم اتخاذ القرار من خلال التمكين لتخطيط وتشغيل أكثر كفاءة وفعالية من حيث التكلفة عبر مجالات رئيسية في قطاع المياه، بما في ذلك تحلية المياه، وإدارة المياه الجوفية، وتشغيل البنية التحتية، واستخدامات المياه في القطاع الزراعي. وأظهرت المداولات كذلك وجود توافق واضح في الآراء مفاده أن الدمج الناجح للذكاء الاصطناعي في إدارة الموارد المائية يتطلب اتباع نهج شمولي ومنسق يجمع بين الحلول التكنولوجية المتقدمة، والاستثمارات التأسيسية المستدامة في حوكمة البيانات، وبناء القدرات المؤسسية والبشرية، ووضع السياسات التمكينية، وتعزيز التعاون الإقليمي. علاوة على ذلك، تناولت المناقشات أهمية إدارة المخاطر المصاحبة لتبني تقنيات الذكاء الاصطناعي، وضرورة ضمان الاستخدام المسؤول والأخلاقي لهذه التقنيات. ويهدف هذا التقرير إلى تجميع وصياغة أبرز التوصيات المستخلصة من العروض الفنية للورشة ومناقشاتها، وذلك ضمن ثلاثة محاور موضوعية رئيسية تم تناولها خلال فعاليات الحدث (يرجى الرجوع إلى الملحق (أ) للاطلاع على قائمة العروض التقديمية).

1. حوكمة البيانات، الجاهزية الوطنية، والتقنيات الناشئة

أرست هذه الجلسة الركائز الأساسية للتبني الناجح لتطبيقات الذكاء الاصطناعي، مؤكدةً أن التنفيذ الفعّال لهذه التطبيقات يجب أن يستند إلى توافر بيانات موثوقة، وأطر مؤسسية سليمة، وقدرات بشرية كافية. كما سلّطت الضوء على الفرص الرئيسية لتوظيف التقنيات الناشئة وحلول الذكاء الاصطناعي في معالجة أبرز التحديات المرتبطة بقطاع المياه التي تواجه دول مجلس التعاون الخليجي. بالإضافة إلى ذلك، شددت المناقشات على أهمية نزاهة البيانات، وقابليتها للتكامل والتشغيل البيني، وأمنها السيبراني، ووضوح ترتيبات الحوكمة، بوصفها عوامل تمكينية رئيسية لضمان نشر موثوق ومستدام لتطبيقات الذكاء الاصطناعي.

2. التطبيقات في قطاع المياه وترابط المياه والطاقة والغذاء والنظم البيئية (WEFE Nexus)

استعرضت هذه الجلسة الإمكانات التحويلية للتقنيات الناشئة وتطبيقات الذكاء الاصطناعي في تحسين كفاءة سلسلة القيمة المائية بأكملها، مع الإدارة الفعّالة للترابطات الحرجة بين المياه والطاقة والغذاء والنظم البيئية. ونظراً لأن القطاع الزراعي يستحوذ على الحصة الأكبر من استهلاك المياه في دول مجلس التعاون الخليجي، فقد ركّزت هذه الجلسة بشكل خاص على دور الذكاء الاصطناعي والنماذج القائمة عليه، لا سيما الشبكات العصبية الاصطناعية المتكاملة (ANNs) مع تقنيات إنترنت الأشياء (IoT)، بوصفها أداة رئيسية لتحقيق مكاسب كبيرة في الكفاءة وتعزيز استدامة استخدام المياه في القطاع الزراعي. كما شددت المناقشات على ضرورة الانتقال من المشاريع التجريبية المستقلة إلى النشر المتكامل والشامل لحلول الذكاء الاصطناعي على مستوى المنظومة الكاملة لقطاع المياه.

3. تنمية القدرات في مجال الذكاء الاصطناعي، والتعليم، ورفع الوعي

أكدت هذه الجلسة أن التحول التكنولوجي الناجح يعتمد في جوهره على رأس المال البشري، مشددةً على ضرورة معالجة الاعتبارات الأخلاقية وتعزيز الاستخدام المسؤول لتقنيات الذكاء الاصطناعي باعتباره عنصراً أساسياً من عناصر تبني هذه التقنيات. كما أبرز المشاركون أهمية إدارة المخاطر المرتبطة بتبني الذكاء الاصطناعي، بما في ذلك الإفراط في الاعتماد على الأنظمة المؤتمتة، والتحيز في البيانات، والحاجة إلى الحفاظ على الخبرات الأساسية في مجالي الهيدرولوجيا والهندسة وتعزيزها جنباً إلى جنب مع القدرات الرقمية.

بالإضافة إلى ذلك، تم تنظيم جلستين تدريبيتين قصيرتين بعد انعقاد الورشة حول «تطبيقات التقنيات الناشئة في إدارة المياه» و«تطبيقات الذكاء الاصطناعي الجغرافي في قطاع المياه» شارك فيهما 83 متدرباً (يرجى الرجوع إلى الملحق (ب) للاطلاع على مواضيع التدريب).

الرؤى المشتركة المستخلصة من جلسات الورشة

أظهرت الورشة بوضوح، من خلال جلساتها الفنية الثلاث، أن تطبيقات الذكاء الاصطناعي في إدارة الموارد المائية بدول مجلس التعاون الخليجي تشهد تحولاً تدريجياً من مبادرات تجريبية منفصلة إلى نهج أكثر تكاملاً على مستوى النظم. وعلى الرغم من تفاوت مستوى نضج تبني الذكاء الاصطناعي بين الدول والقطاعات المختلفة، فقد برزت توجهات مشتركة تؤكد على الدور المتنامي للذكاء الاصطناعي كأداة داعمة لاتخاذ القرار، تكمل المعرفة الهيدرولوجية التقليدية والخبرات الهندسية، ولا تحل محلها. كما أبرزت النقاشات أن النشر الفعّال لتطبيقات الذكاء الاصطناعي لا يعتمد فقط على تطور الخوارزميات، بل يتطلب أيضاً توافر بيانات عالية الجودة، وبنية تحتية رقمية قابلة للتكامل، وجاهزية مؤسسية مناسبة. وقد شدد المشاركون في الورشة على ضرورة دمج حلول الذكاء الاصطناعي ضمن أطر حوكمة وتشغيل أوسع، بما يضمن الشفافية والمساءلة والاستدامة على المدى الطويل. كما أكدت عدة مداخلات، بما في ذلك تلك التي تناولت الحلول المدعومة بالذكاء الاصطناعي في البيئات الجافة وشبه الجافة، أن نجاح تطبيق الذكاء الاصطناعي في دول مجلس التعاون الخليجي يتطلب إعطاء أولوية للنماذج الواعية بالسياق والفعّالة في استخدام البيانات، والمصممة خصيصاً لتتلاءم مع الخصائص الهيدرومناخية الإقليمية، بدلاً من استنساخ حلول عامة تم تطويرها لبيئات غنية بالبيانات. وقد طُرحت هذه المقاربات باعتبارها ضرورية للحفاظ على السيادة الرقمية، مع ضمان أن تظل أنظمة الذكاء الاصطناعي عملية ومرنة ومستدامة مؤسسياً. علاوة على ذلك، أكدت الجلسات على أهمية مواءمة استراتيجيات إدارة الموارد المائية المعتمدة على الذكاء الاصطناعي مع أولويات التنمية الوطنية، وأهداف التكيف مع التغير المناخي، وأطر التعاون الإقليمي داخل دول مجلس التعاون الخليجي.

تطبيقات قائمة على الأدلة من سياق دول مجلس التعاون الخليجي

قدمت النقاشات الفنية خلال فعاليات الورشة أمثلة عملية وملموسة لتطبيقات الذكاء الاصطناعي ذات الصلة بقطاع المياه في دول مجلس التعاون الخليجي. وشملت هذه الأمثلة تحسين تشغيل محطات تحلية المياه باستخدام تقنيات الذكاء الاصطناعي، بما أثمر عن تحقيق انخفاض قابل للقياس في استهلاك الطاقة، واستخدام التحليلات التنبؤية للحد من فاقد المياه غير المحسوبة في شبكات التوزيع، إلى جانب أنظمة الري الدقيق المعتمدة على التعلم الآلي، والقادرة على تحسين كفاءة استخدام المياه في القطاع الزراعي بشكل ملحوظ. كما شملت تطبيقات أخرى تقييم المياه الجوفية، وتحسين تصميم وتشغيل الآبار باستخدام أدوات مدعومة بالذكاء الاصطناعي في البيئات الشحيحة البيانات، وأنظمة التنبؤ بالفيضانات والإنذار المبكر المعتمدة على الاستشعار عن بُعد والتحليلات الجيوفضائية، وأدوات دعم القرار التي تدمج الأبعاد الاقتصادية والبيئية والتشغيلية. وأظهرت دراسات الحالة أيضاً الدور المتنامي للذكاء الاصطناعي في بناء القدرات، والتعليم، وتغيير السلوك، فضلاً عن الإمكانات التي تتيحها الشركات الصغيرة والمتوسطة لتقديم حلول مبتكرة للذكاء الاصطناعي مصممة خصيصاً لمواجهة تحديات المياه الإقليمية. وبصورة عامة، تُظهر هذه الأمثلة أن تبني الذكاء الاصطناعي في قطاع المياه بدول مجلس التعاون الخليجي بدأ بالفعل في تحقيق فوائد ملموسة، مع توفر فرص واعدة لمزيد من التوسع والتكامل مستقبلاً.

التحديات المشتركة والعوامل التمكينية

على الرغم من التطبيقات الواعدة التي تم استعراضها، كشفت مناقشات الورشة عن عدد من التحديات المشتركة التي يتعين معالجتها للاستفادة

الكاملة من إمكانات الذكاء الاصطناعي في إدارة الموارد المائية. وتشمل هذه التحديات تجزؤ البيانات، ومحدودية توفرها، وعدم اليقين المرتبط بأداء النماذج في ظل الظروف المناخية غير المستقرة، ومخاطر الأمن السيبراني، إضافة إلى الأثر البيئي للبنية التحتية الرقمية. كما حذّر المشاركون من الاعتماد المفرط على الأنظمة المؤتمتة دون توفير إشراف بشري كافٍ وخبرات تخصصية داعمة. ولمواجهة هذه التحديات، شددت الورشة على أهمية تطوير أطر قوية لحوكمة البيانات، والاستثمار المستدام في تنمية رأس المال البشري، ووضع الضمانات الأخلاقية والتنظيمية المناسبة، وتعزيز التعاون الإقليمي. كما تم التأكيد على أن توحيد بروتوكولات البيانات، وتعزيز التنسيق المؤسسي، وتشجيع تبادل المعرفة بين دول مجلس التعاون الخليجي تُعد من العوامل التمكينية الأساسية لضمان النشر المسؤول والفعّال لتطبيقات الذكاء الاصطناعي في قطاع المياه.

التوصيات الرئيسية والتفصيلية للورشة

استناداً إلى المناقشات الفنية، ودراسات الحالة، والرؤى المشتركة التي تم استعراضها، خلصت ورشة العمل إلى التوصيات التالية لتوجيه التبني الاستراتيجي لتقنيات الذكاء الاصطناعي في إدارة الموارد المائية بدول مجلس التعاون الخليجي:

أ. حوكمة البيانات، الجاهزية الوطنية، والتقنيات الناشئة

1. إرساء أطر وطنية متينة لحوكمة البيانات (مراصد بيانات المياه)

- تطوير وتنفيذ استراتيجيات وطنية شاملة للبيانات (كما هو الحال في مواءمة المملكة العربية السعودية مع الهيئة السعودية للبيانات والذكاء الاصطناعي – SDAIA)، بما يضمن توحيد إجراءات مواءمة البيانات وبيانات الأرصاد الجوية وفق متطلبات جودة البيانات، وقابليتها للتكامل والتشغيل البيني، وأمنها، واستخدامها الأخلاقي. وتُعد هذه العناصر متطلبات أساسية لتطوير ونشر نماذج ذكاء اصطناعي موثوقة.
- إنشاء منصات بيانات مركزية وذات صفة مرجعية (مثل قواعد البيانات الجغرافية الوطنية للري في المملكة العربية السعودية) لتشكل مصدراً موحداً وموثوقاً للبيانات المتعلقة بقطاع المياه، بما يدعم التخطيط والإدارة واتخاذ القرار المستندة إلى الأدلة.

وينبغي أن تتضمن هذه الأطر تحديداً واضحاً لملكية البيانات، وضمانات للأمن السيبراني، وآليات للرقابة الأخلاقية، بما يكفل النشر الموثوق والمسؤول لتطبيقات الذكاء الاصطناعي.

2. **تقييم وبناء الجاهزية الوطنية لتبني الذكاء الاصطناعي:**

- ينبغي على دول مجلس التعاون الخليجي إجراء تقييمات منهجية لمستوى نضجها الرقمي عبر مختلف المحاور، بما يشمل جمع البيانات وإدارتها والتحكم بها، والسياسات، والبنية التحتية، والأطر التنظيمية والتشريعية، ورأس المال البشري، والقدرات المؤسسية. ويُعد الانتقال من مجرد الرقمنة الأساسية إلى التحول الرقمي الشامل أمراً بالغ الأهمية.
- تُعد القيادة القوية ووجود هياكل حوكمة واضحة ومحددة عناصر أساسية لتوجيه هذا التحول، والحد من المخاطر المرتبطة بتدني جودة البيانات أو تجزئتها، وضمان موثوقية واستدامة الاستثمارات في الذكاء الاصطناعي وآثارها المحتملة.

وينبغي أن تُسهم هذه التقييمات في إعداد خارطة طريق وطنية واضحة تدعم توسيع نطاق حلول الذكاء الاصطناعي وترسيخها مؤسسياً بما يتجاوز المبادرات التجريبية.

3. **اعتماد حزمة متكاملة من التقنيات الناشئة:**

- إلى جانب حلول الذكاء الاصطناعي الأساسية، ينبغي على قطاعات المياه في دول مجلس التعاون الخليجي استكشاف التقنيات التكميلية للثورة الصناعية الرابعة بصورة استراتيجية، وتجربتها، ودمجها، بما يشمل تقنيات إنترنت الأشياء (IoT) لأغراض الاستشعار والمراقبة، وتقنيات سلاسل الكتل (Blockchain) لتعزيز التتبع والعقود الذكية، والطائرات دون طيار وتقنيات الاستشعار عن بُعد للرصد والتقييم على نطاق واسع، إضافة إلى التوائم الرقمية (Digital Twins) لمحاكاة الأنظمة.

ويتعين إعطاء الأولوية للتقنيات التي تُظهر قيمة تشغيلية واضحة وقابلية للاندماج ضمن أنظمة إدارة المياه القائمة. وبالتوازي مع ذلك، ينبغي أخذ البصمة المائية والطاقية للبنية التحتية الرقمية وبنية الذكاء الاصطناعي، بما في ذلك مراكز البيانات وشبكات الاتصالات، في الاعتبار ضمن أطر التخطيط الوطنية، بما يضمن الاتساق مع أهداف الاستدامة والكفاءة.

ب. تطبيقات التقنيات الناشئة في قطاع المياه وترابط المياه والطاقة والغذاء والنظم البيئية (WEFE Nexus)

1. **توظيف الذكاء الاصطناعي لتحقيق التحسين الشامل على مستوى المنظومة وتعزيز المرونة**

- تنفيذ التوائم الرقمية المدعومة بالذكاء الاصطناعي (نماذج افتراضية) للأنظمة المتكاملة للمياه والطاقة والغذاء والنظم البيئية (WEFE Nexus)، وذلك لمحاكاة أوجه التآزر المعقدة، وتقييم المقايضات، ودعم الانتقال من الإدارة القطاعية المجزأة إلى حوكمة استباقية ومتكاملة على مستوى المنظومة ككل، بما في ذلك تطبيقات إدارة مخاطر الفيضانات، وأنظمة الإنذار المبكر، ومخاطر المياه المرتبطة بتغير المناخ.
- من خلال دمج وترتيب أولويات حزم «التقنيات الاجتماعية والبيئية» (Socio-ecological Technologies SETs)، يمكن للذكاء الاصطناعي تحويل البيانات المعقدة إلى واجهات بصرية مبسطة وسهلة الاستخدام تتفوق على الإجراءات المنفردة، بحيث يسهم هذا النهج في تعزيز الحوار القائم على

المعرفة بين مختلف الأطراف المعنية، ويحد من التشتت المؤسسي، ويضمن تحقيق نتائج أكثر فعالية عبر ترابط الأنظمة المتكاملة للمياه والطاقة والغذاء والنظم البيئية (WEFE Nexus).

- توظيف وتعزيز استخدام الذكاء الاصطناعي في الصيانة التنبؤية والتحسين التشغيلي للبنية التحتية المائية الحيوية، بما في ذلك محطات تحلية المياه (حيث يمكن خفض استهلاك الطاقة بنحو 10–20%)، وشبكات توزيع المياه (حيث يمكن لتطبيقات الذكاء الاصطناعي الإسهام في تقليل الفاقد من المياه بما يتجاوز 20%).
- تطبيق أدوات قائمة على الذكاء الاصطناعي لتعزيز استدامة موارد المياه الجوفية من خلال تحسين التصميم الاقتصادي للآبار، والنمذجة المتقدمة لسلوك الخزانات الجوفية، لا سيما في البيئات ذات البيانات الشحيحة والمعقدة هيدروجيولوجياً.
- تطوير سيناريوهات مدعومة بالذكاء الاصطناعي لمعالجة قضايا تلوث المياه الجوفية، لاسيما في الخزانات الجوفية الساحلية، للحد من مخاطر الزيادة في الملوحة بما يؤثر على المتطلبات الزراعية.

وينبغي دمج هذه التطبيقات تدريجياً ضمن أطر التخطيط والتشغيل الوطنية لقطاع المياه، بما يضمن الاستمرارية، وقابلية التوسع، وترسيخ الملكية المؤسسية على المدى الطويل.

2. توظيف الذكاء الاصطناعي لضمان الاستخدام الآمن والفعّال لمختلف مصادر المياه:

- تطوير نماذج مدعومة بالذكاء الاصطناعي لدعم المزج التنبؤي بين مصادر المياه التقليدية وغير التقليدية، بما في ذلك مياه الصرف الصحي المعالجة، والمياه الجوفية قليلة الملوحة، ومياه الحصاد المجمعة، وذلك استناداً إلى متطلبات جودة مياه محددة بوضوح وفق مبدأ «الملاءمة للغرض» (Fit-for-Purpose).
- استخدام أنظمة المراقبة اللحظية وكشف الشذوذ المعتمدة على الذكاء الاصطناعي في عمليات معالجة مياه الصرف الصحي وإعادة استخدامها، بما يضمن سلامة جودة المياه، ويعزز استقرار العمليات التشغيلية، ويسهم في تعزيز ثقة المجتمع في أنظمة المياه المعاد استخدامها.

وينبغي أن تصاحب هذه التطبيقات بروتوكولات صارمة لضمان الجودة وأطر رقابية وتنظيمية فعّالة لإدارة المخاطر والحفاظ على الثقة في أنظمة إعادة استخدام المياه المدعومة بالذكاء الاصطناعي.

3. توسيع نطاق الزراعة الدقيقة المدعومة بالذكاء الاصطناعي:

- تعزيز التبني الواسع لأنظمة الري الدقيق المعتمدة على الذكاء الاصطناعي، والتي تدمج مجسّات رطوبة التربة، وبيانات التنبؤات الجوية، والمؤشرات المستمدة من صور الأقمار الصناعية مثل مؤشر الغطاء النباتي المعياري (NDVI)، بما يسهم في تحقيق خفض ملموس في استهلاك المياه (يتراوح عادة بين 30–50%)، وترشيد احتياجات الأسمدة، مع الحفاظ على الإنتاجية الزراعية أو تحسينها وزيادة غلات المحاصيل.
- دعم تطوير ونشر منصات متكاملة تجمع بين الذكاء الاصطناعي وعلوم الزراعة (AI–Agronomy)، وتوفّر أدوات شاملة لدعم اتخاذ القرار، تشمل

اختيار المحاصيل، والكشف المبكر عن الآفات والأمراض، والتنبؤ بالإنتاجية، وتحسين مدخلات الإنتاج الزراعي.
وينبغي اعتماد سياسات وحوافز موجهة، ونماذج أعمال قائمة على تقديم الخدمات، لدعم التوسع في تبني هذه الحلول على نطاق واسع وضمان إتاحتها لصغار ومتوسطي المزارعين.

4. معالجة التحديات الخاصة بتطبيقات الذكاء الاصطناعي في الزراعة بالمناطق الجافة:

- الإقرار بالتحديات الرئيسية التي تعيق تبني تقنيات الذكاء الاصطناعي في البيئات الزراعية الجافة والعمل على معالجتها، بما في ذلك ارتفاع تكاليف الاستثمار الأولية، ومحدودية موثوقية أجهزة الاستشعار في ظل الظروف البيئية القاسية، وشح البيانات المتعلقة بالاحتياجات المائية للمحاصيل، وضعف القدرات الفنية لدى المزارعين، وذلك من خلال التخطيط لبرامج توعوية وأنشطة تدريبية لنشر المعرفة وبناء القدرات.
- الدعوة إلى تبني سياسات داعمة ونماذج أعمال مبتكرة (مثل العقود القائمة على تقديم الخدمات، ونُظم الدفع المرتبطة بالأداء) بما يعزز الجدوى الاقتصادية ويُحسّن إمكانية الوصول إلى حلول الذكاء الاصطناعي لصغار ومتوسطي المزارعين.

كما ينبغي تعزيز المزارع النموذجية التجريبية، والتحقق المحلي من فعالية أدوات الذكاء الاصطناعي، وتطوير خدمات الإرشاد الزراعي، بما يسهم في بناء الثقة، وإبراز القيمة المضافة، وتسريع وتيرة التبني في ظروف الحقول الجافة الواقعية.

ج. تنمية القدرات في مجال الذكاء الاصطناعي، والتعليم، ورفع الوعي

1. دمج تقنيات الثورة الصناعية الرابعة (4IR) والذكاء الاصطناعي في التعليم والتدريب المائي:

- تحديث وتطوير المناهج الأكاديمية لإعداد جيل جديد من «علماء بيانات المياه» والمتخصصين في قطاع المياه، يتمتعون بالكفاءة في ثقافة البيانات، وتطبيقات الذكاء الاصطناعي، والتفكير القائم على النظم.
- إنشاء بيئات تعليمية تفاعلية متقدمة مثل «المختبرات الحية» (Living Labs) التي توظف البنية التحتية المائية الفعلية في دول مجلس التعاون الخليجي، وتقنيات التوائم الرقمية لأغراض التجارب التطبيقية، بما يسهم في سد الفجوة بين المعرفة النظرية والتطبيقات العملية.
- توفير برامج تدريب مهني متخصصة أثناء العمل، ودورات قصيرة، وشهادات مصغّرة (Micro-credentials) للعاملين في قطاع المياه، تركز على تطبيق التقنيات الناشئة وتشغيل وإدارة أنظمة المياه الذكية.
- تمويل مبادرات تبادل المعرفة لنقل الخبرات بين المؤسسات الأكاديمية والشركاء الصناعيين، بما يسهم في تسريع تبني تقنيات الذكاء الاصطناعي والحد من المخاطر المصاحبة لذلك.

وينبغي مواءمة مبادرات بناء القدرات مع استراتيجيات التحول الرقمي الوطنية، بما يضمن الاتساق والملاءمة وتحقيق أثر مستدام على المدى الطويل.

2. تطوير أدوات تعليمية قائمة على القيم وجاذبة في مجال الذكاء الاصطناعي:

- تصميم برامج تعليمية بيئية مدعومة بالذكاء الاصطناعي تتجاوز أساليب نقل المعرفة التقليدية، من خلال تعزيز قيم ترشيد استهلاك المياه، وتشجيع التغيير السلوكي لدى الأجيال الشابة، وذلك عبر مناهج تعليمية مخصصة ومحاكاة تفاعلية.
- تنفيذ مبادرات شاملة لبناء القدرات تستهدف المتخصصين في قطاع المياه، وصناع السياسات، والمزارعين، لضمان تزويدهم بالمهارات والكفاءات اللازمة للاستخدام الفعّال وإدارة والإشراف على الأنظمة المعتمدة على الذكاء الاصطناعي.

وينبغي أن تتناول هذه البرامج بصورة صريحة الاعتبارات الأخلاقية، ومسؤولية التعامل مع البيانات، وحدود قدرات الذكاء الاصطناعي، بما يعزز الاستخدام الواعي والمسؤول لهذه التقنيات. كما ينبغي أن تركز جهود تنمية القدرات على إدارة عدم اليقين، والتحقق المستمر من النماذج، والحفاظ على الإشراف البشري، بما يضمن بقاء أنظمة الذكاء الاصطناعي مرنة وموثوقة وداعمة للحكم المهني بدلاً من أن تحل محله.

3. تعزيز ثقافة الابتكار والتعاون:

- تعزيز الابتكار المفتوح من خلال تطوير منصات بيانات متاحة للجمهور، وتقديم دعم موجه للشركات الناشئة ورواد الأعمال المحليين العاملين في قطاع المياه.
- تعزيز الشراكات بين القطاعين العام والخاص والمؤسسات الأكاديمية لتسريع أنشطة البحث والتطوير، وتيسير نشر حلول الذكاء الاصطناعي المصممة خصيصاً لتلبية احتياجات وتحديات قطاع المياه.

وينبغي إرساء ترتيبات حوكمة واضحة، وآليات لتقييم الأداء، بما يضمن أن تسفر المبادرات التعاونية عن نتائج قابلة للقياس والتوسع.

وضمن إطار هذه التوصيات، شدد المشاركون على أهمية الانتقال من المبادرات التجريبية المنفصلة إلى النشر المتكامل لتطبيقات الذكاء الاصطناعي على مستوى المنظومة ككل، بدعم من حوكمة قوية، وإدارة فعّالة للمخاطر، وتعاون إقليمي مستدام. ولتمكين هذا التحول وترجمته إلى واقع عملي، تم التأكيد كذلك على ضرورة قيام الدول بوضع مؤشرات أداء واضحة، وأطر للرصد والمتابعة، وآليات تقييم دورية لقياس فعالية حلول الذكاء الاصطناعي في قطاع المياه، وقابليتها للتوسع، وآثارها على المدى الطويل، بما يضمن الشفافية، والمساءلة، والتحسين المستمر.

الاستنتاجات الشاملة والمسارات الاستراتيجية المستقبلية

حددت عروض الورشة مجتمعةً مساراً واضحاً ومتماسكاً لقطاع المياه في دول مجلس التعاون الخليجي يمكّنه من الاستفادة الفاعلة من إمكانات التقنيات الناشئة وتطبيقات الذكاء الاصطناعي المتقدمة في قطاع المياه، استناداً إلى البحث التطبيقي، ودراسات الحالة، والرؤى القائمة على الأدلة، وذلك بما يعزز استدامة الموارد المائية وأمنها على مستوى المنطقة على النحو التالي:

1. **من المبادرات التجريبية إلى النظم المتكاملة:** الانتقال من المشاريع التجريبية المنفصلة والمجزأة إلى أنظمة حوكمة مائية متكاملة مدعومة بالذكاء الاصطناعي، تتسم بالقدرة على التنبؤ، والطابع الاستباقي، والمرونة في مواجهة التحديات المائية المعقدة.
2. **الموازنة بين الفرص والحكمة:** الإدارة الاستباقية للمخاطر المرتبطة بتطبيقات الذكاء الاصطناعي، بما في ذلك تحيز البيانات، والثغرات في الأمن

السيبراني، وانحراف النماذج، والآثار البيئية (البصمة الطاقية والمائية لمراكز البيانات)، ومخاطر الاعتماد المفرط على الذكاء الاصطناعي على حساب الخبرات الهيدرولوجية الأساسية.

3. **إعطاء الأولوية للسيادة الرقمية:** بناء القدرات الوطنية وتعزيز التعاون الإقليمي لتطوير حلول مصممة خصيصاً لتلائم الخصوصية البيئية للمناطق الجافة في دول مجلس التعاون الخليجي، بما يقلل الاعتماد على الأنظمة الاحتكارية الأجنبية، ويضمن السيطرة طويلة الأمد على البنية التحتية الرقمية الحرجة وأصول البيانات.
4. **تعزيز التعاون الإقليمي:** الاستفادة من التحديات والفرص المشتركة بين دول مجلس التعاون الخليجي من خلال تشجيع الجهود التعاونية، بما يشمل إنشاء منصات بيانات مشتركة، ومواءمة السياسات، والتطوير المشترك للأدوات مفتوحة المصدر، واستدامة تبادل المعرفة عبر المنصات الإقليمية، مثل جمعية علوم وتقنية المياه الخليجية (WSTA).

ختاماً، تجدر الإشارة إلى أن تحقيق هذه المسارات الاستراتيجية يتطلب التزاماً سياسياً مستداماً، وتنسيقاً مؤسسياً فعالاً، واستثمارات طويلة الأجل في أطر الحوكمة، وتنمية رأس المال البشري، وآليات التعاون الإقليمي، مدعومةً بمؤشرات أداء واضحة، وأنظمة رصد ومتابعة مستمرة لتتبع التقدم المحرز ودعم اتخاذ القرار التكيفي.

الخلاصة

لقد تجاوز دمج تقنيات الذكاء الاصطناعي في إدارة الموارد المائية كونه خياراً مستقبلياً لدول مجلس التعاون الخليجي، ليصبح ضرورة ملحّة في الوقت الراهن. ومن خلال التوظيف الاستراتيجي لهذه التقنيات، المستند إلى الممارسات القائمة على الأدلة، ضمن إطار يقوم على هياكل حوكمة قوية، وبنية تحتية مرنة، واستثمار مستدام في رأس المال البشري، وتعاون إقليمي فعّال، تمتلك دول مجلس التعاون الخليجي القدرة على تحويل تحدياتها المائية إلى نموذج رائد عالمياً للإدارة المستدامة والذكية للموارد المائية في المناطق الجافة.

الخطوات القادمة

سيعمل منظمو الورشة (معهد الكويت للأبحاث العلمية، وجمعية علوم وتقنية المياه الخليجية، والأمانة العامة لمجلس التعاون لدول الخليج العربية) على البناء على مخرجاتها لمواصلة دفع وتعزيز تنفيذ التقنيات الناشئة وتطبيقات الذكاء الاصطناعي المتقدمة في قطاع المياه بدول مجلس التعاون الخليجي. وتحقيقاً لهذه الغاية، تم الاتفاق على المبادرات التالية:

1. إعداد «موجز سياسات» (Policy Brief) حول تطبيقات الذكاء الاصطناعي في قطاع المياه بدول مجلس التعاون الخليجي بهدف رفع مستوى الوعي بإمكانات الذكاء الاصطناعي، ومتطلبات تبنيه، والتحديات المرتبطة به. وسيستهدف هذا الموجز صناع السياسات والمتخصصين في قطاع المياه، على أن تتولى اللجنة العلمية لجمعية علوم وتقنية المياه الخليجية قيادة عملية الإعداد، مع إسهامات من جميع المتحدثين في الورشة، على أن يكون العنوان المقترح للموجز «الذكاء الاصطناعي من أجل الإدارة المستدامة للموارد المائية في دول مجلس التعاون الخليجي: الأولويات والسياسات والمسار المستقبلي».
2. إعداد قائمة مرجعية (Bibliography) شاملة تضم جميع التقنيات الناشئة وتطبيقات الذكاء الاصطناعي في قطاع المياه، وكافة المبادرات المعنية بدمج الذكاء الاصطناعي في إدارة المياه، بما يشمل دول مجلس التعاون الخليجي، مع إمكانية التوسع لتشمل الدول العربية ومناطق أخرى. وسيتولى معهد الكويت للأبحاث العلمية قيادة عملية إعداد هذه القائمة.
3. متابعة مخرجات الورشة خلال المؤتمر الخليجي السادس عشر للمياه الذي تنظمه جمعية علوم وتقنية المياه الخليجية بسلطنة عُمان في أبريل 2026، وذلك عبر صيغ مناسبة (مثل عقد جلسة خاصة حضورية أو افتراضية، أو حلقة نقاشية، أو أنشطة ذات صلة)، على أن تتولى اللجنة العلمية للجمعية التنسيق بهذا الشأن.
4. رفع استنتاجات وتوصيات الورشة إلى الأمانة العامة لمجلس التعاون لدول الخليج العربية، على أن يقوم معهد الكويت للأبحاث العلمية بالتنسيق مع جمعية علوم وتقنية المياه الخليجية بإرسال هذه المخرجات إلى الأمانة العامة (الدكتور محمد الرشيدي).
5. تعزيز التنسيق المشترك بين معهد الكويت للأبحاث العلمية وجمعية علوم وتقنية المياه الخليجية مع الأمانة العامة لمجلس التعاون لدول الخليج العربية لاستكشاف فرص الدعم للمبادرات القائمة والجديدة الهادفة إلى تعزيز تبني الذكاء الاصطناعي وغيره من التقنيات الناشئة في قطاع المياه، على أن تتولى اللجنة العلمية للجمعية إعداد المقترحات اللازمة بهذا الشأن.

الشكر والتقدير

يتقدم منظمو الورشة، وأعضاء اللجنتين التنظيمية والعلمية، بخالص الشكر والتقدير إلى الجهات الراعية لهذه الورشة على دعمهم الكريم الذي كان له الأثر البالغ في إنجاح هذا الحدث الهام. فقد أسهمت رعايتهم الكريمة في تحقيق أهداف الورشة وضمان جودة مخرجاتها، بما يعكس التزامهم الواضح بدعم المبادرات العلمية والمعرفية ذات الأثر الاستراتيجي. وبفضل هذا الدعم، تمكّن منظمو الورشة من تقديم تجربة متميزة وناجحة ذات قيمة علمية وتطبيقية ملموسة لجميع المشاركين. وإذ نعتز بهذه الشراكة المثمرة، فإننا نتطلع إلى تعزيز أواصر التعاون مع هذه الجهات مستقبلاً، واستكشاف فرص جديدة للعمل المشترك في مبادرات مماثلة.

الجهات الراعية:

- مؤسسة البترول الكويتية والشركات التابعة لها
- مؤسسة الكويت للتقدم العلمي
- اتحاد مجالس البحث العلمي العربية
- شركة الكويت المتحدة للدواجن

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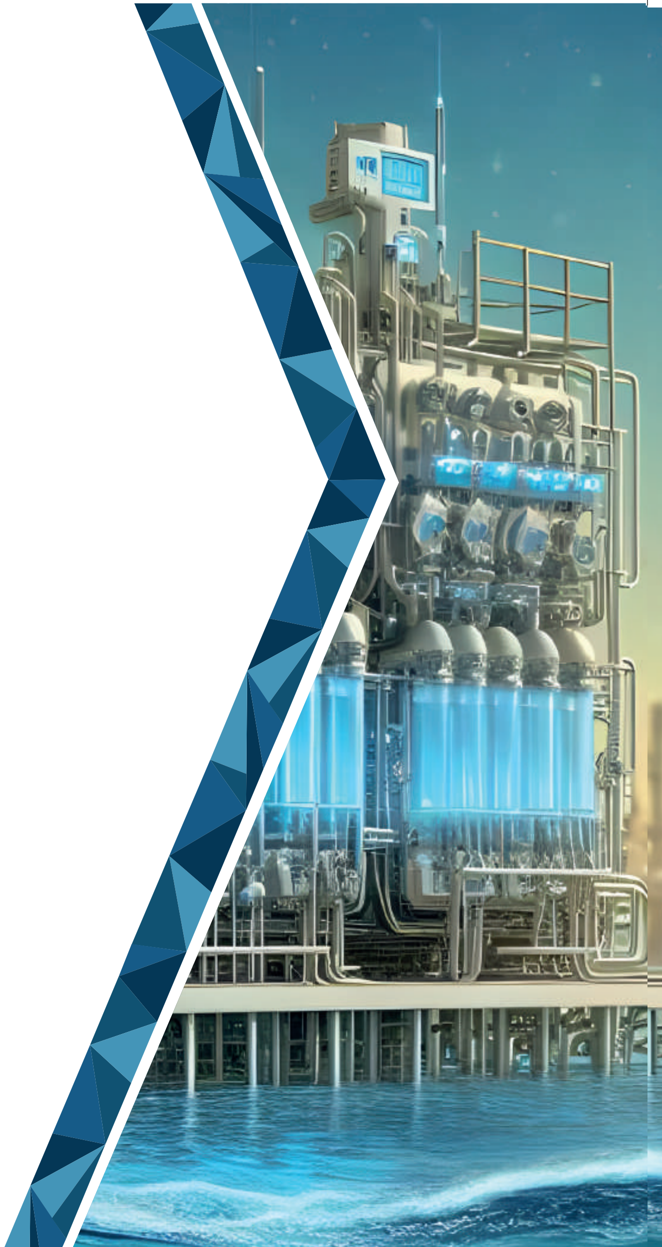

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