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A lighthouse to future opportunities for sustainable water provided by intelligent water hackathons in the Arabsphere

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Complex water-related challenges hunger, poverty, climate change, biodiversity, land-use change, desertification agriculture, industrialization, urbanization, human population, and hygiene, need wise and urgent actions to overcome them. Globally, many drivers such as the U.S.-Chinese competition, the Russo–Ukrainian war, food security, pandemics, and human overpopulation, have water-related impacts. Freshwater is a truly complex interdisciplinary topic that requires innovative intelligent-inclusive ideas to reconcile limited water resources with expanding water demands. The article explores how artificial intelligence (AI) could rethink human-water interactions, remake water practices, humanize water science, and enhance daily water life. The Global Goals could be viewed as an integrated framework of human effort to face pressing today's issues and to formulate a more sustainable and better world. Goal 6 (SDG 6 "sustaining water") devoted to sustaining water and related actions for all humans is the skeleton of global goals (GGs). The Arabsphere faces severe water quality, quantity, and practice challenges to ensure the smooth achievement of global goals (GGs). Compared with the whole world and its main regions, the overall water stress indicator in the Arabsphere is greater than 100% (critical). This article explores how applied intelligence could be strengthened to achieve Goal 6, focuses on the "water stress" indicator, and how to ensure a sustainable water future (SWF) in the Arabsphere. The Intelligent Water Hackathon is a collaborative open science event. The hackathon was designed to mitigate water stress (WS) in the Arabsphere. The hackathon process involves four main phases: problem identification, team building, solution proposing, and presentation. The paper concludes hackathons could be a valuable process for the water researchers' community to generate new and creative ideas and collective knowledge. Hackathon events could mitigate water stress, strengthen community engagement, and improve water resources outcomes. In closing, artificial intelligence (AI) methodologies are efficient providers to mitigate water stress, scarcity, and related risks. A future-driven Arab water vision based on artificial intelligence (AI) and intelligent water systems (IWSs) should be prioritized.

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Introduction

In the last decades, many models that use AI techniques, including knowledge-based systems, neural networks, evolutionary systems, fuzzy logic, genetic algorithms, adaptive agents, and expert systems, were created and described in the water engineering literature. Effective water use for a local community, country, or river basin depends on managing both the supply and demand for water using intelligent techniques. Smart water (SW) has embraced AI, water knowledge (WK), and a wide variety of search techniques. Intelligent water, in this context, is a subset both of WK and AI. Smart water (SW) technologies and software for operational monitoring of critical water crisis and problems is a must. The issue is to transform into a more rational and effective one while integrating operational and smart water monitoring, thereby providing objective, accurate, and sufficiently comprehensive data to serve as a basis for reliable evaluations, projections, and forecasts. The advantages that are expected from applying a smart water approach to the water industry might be realized. The specific objectives of this paper are to shed light on applied intelligence and how to be employed in all topics of water-related SDGs, to show the reasons for applied intelligence techniques' success when optimization models fail, to suggest using these techniques in situations where optimal or exact results are either too expensive or not possible.

The study aims to explore how artificial intelligence (AI) could enhance the wise use of freshwater in all development actions related to global goals, The focus would be on conceptual work. As water resources are the core component in everyday life in any community, the broad scope is interdisciplinary and includes all global goals.

The research questions are as follows:

1. How the intelligent water applications could be implemented, and what are its components?
2. What are the features of intelligent water systems (IWSs), their contributions, and future opportunities that could be provided by intelligent water hackathons in the Arabsphere?

Literature review

Coronaviruses (CoV) pandemic. The coronavirus pandemic has triggered a crisis in food, health, and water security and severely impacted the Water-Climate-Food Nexus across the Arab Societies. In the Covid-19 era, many different approaches and attempts are being made to understand how the pandemic progresses. Many researchers have addressed the COVID-19 epidemic and its related challenges that occur in various application domains. Due to economic contraction, air and water quality were improved across the globe (Saadat et al. 2020). Others have addressed the COV pandemic from an environmental perspective. During the COVID-19 pandemic, the future control and forecasting of air pollutants in megacities are displayed in; China (Yuan et al. 2021), Korea (Ju et al. 2021), Spain (Martorell-Marugán et al. 2021), and California, USA (Liu et al. 2021). According to the Food and Agriculture Organization (FAO) (FAO 2020), sanitation, hygiene, and food safety practices may intensify and threaten the food supply. Alternatively, the COV pandemic may urge food production (Rowan and Galanakis 2020).

Forecasting models for the COV pandemic were used to make reasonable control measures. The CoV pandemic outbreak in Italy, China, and France was reported (Fanelli and Piazza 2020). Forecasting of the COV pandemic spread in Russia, India, USA, Peru, and Brazil was modeled (Hazarika and Gupta 2020). Based on time series, the death rate of the COV pandemic was modeled (Maleki et al. 2020). Machine Learning (ML) as a significant method for forecasting the CoV epidemic was reviewed (Lalmuanawma et al. 2020). Intelligent computing systems include both deep learning (DL) and machine learning (ML) techniques. These advanced computing techniques were applied in the forecasting of COVID-19. ML techniques include [Random Forest algorithm (RF), Support Vector Machine (SVM), XGBoost machine, K-means, neural network, logistic regression, Multi-Layered Perception (MLP), Adaptive Network-based Fuzzy Inference System (ANFIS)]. DL techniques include [Convolutional Neural Network (CNN), Tailored CNN Models, Deep CNN (DCNN), Improved Inception Recurrent Residual Neural Network (IRRCNN), Modified CNN, Generative Adversarial Networks (GAN), 3D DCNN, Residual Neural network, and Autoencoder]. The advanced intelligent computing methods for prognosis were reviewed (Swapnarekha et al. 2020). Forecasting of the COVID-19 outbreak in Canada using AI and Deep Learning was developed (Chimmula and Zhang 2020). The Self-organizing maps (SOM) applied to cluster classify the spatial spread of the coronavirus pandemic (Melin et al. 2020). Genetic programming (GP) [Genetic Evolutionary Programming (GEP)] was applied to assess the confirmed cases and death cases of the coronavirus pandemic in India (Salgotra et al. 2020).

Water stress (WS) indicator. The water stress indicator was displayed by FAO. In the context of human efforts to combat the world's freshwater crisis, the United Nations (UN) addresses this core challenge to facilitate satisfying global goals and needs. Goal 6 of the global goals is to sustain water for all humans. The target 6.4 of Goal 6 is to reduce water scarcity by increasing water-use efficiency. The indicator "6.4.2" assesses the level of water stress. This indicator shows the degree to which WRs are exploited to meet a country's water demand. It measures a country's pressure on its water resources and therefore the challenge on the sustainability of its water use. It tracks progress regarding "withdrawals and supply of water resources to mitigate water scarcity".

Methods

Arabsphere. The Arabsphere consists of twenty-two countries. In Arabsphere, sustainable development is particularly related to Water-Food-Climate Nexus. Water and food are exposed to high vulnerability and external shocks which causes significant challenges to achieving SDGs. Climate change happens in different ways, in particular, gradual changes in precipitation and/or temperature patterns, and increased both variability and frequency of extreme events. Global warming is the fundamental aspect of climate change. Climate change could be detected by studying patterns of climate variability and means. Climate change could affect all dimensions of the water security of vulnerable groups and different elements of food systems. Unconventional water is a strategic option to face water challenges. The promising unconventional waters for the Arab water future are desalination, agricultural drainage water reuse, treated greywater, treated wastewater, brackish groundwater use, and water, rain, dew, and fog harvesting.

Water stress (WS). FAO is the data provider of the SDG6 indicator metadata, through AQUASTAT. Total renewable freshwater resources (TRWR), Environmental flow requirements (EFR), and Total freshwater withdrawal (TFWW) were defined by FAO. The definition implies all economic activities need water resources or water flow requirements to maintain environmental and ecosystem health. *By defining* TFWW, TRWR, and EFR, the "water stress" indicator could be straightforwardly computed using the Eq. (1):

$$\text{Waterstress}\,(\%) = \frac{\text{Total freshwater withdrawn (TFWW)}}{\text{Total renewable water resources (TRWR)} - \text{Environmental flow requirements (EFR)}}$$

$$\text{Water stress}\,(\%) = TFWW/(TRWR - EFR) \times 100 \quad (1)$$

TFWW, *TRWR*, and *EFR* are expressed in 10^9 m^3/year (km^3/year).

Water stress indicators and data were issued by (FAO and UN Water 2021), for the Year 2020. Data for the Arab water were defined by the score (0–100), [Units = %].

Classes of water stress were displayed in Table 1 to elaborate the data. Water stress indicators in the Arabsphere are provided in Table 2. The last column was added to elaborate the class of water stress according to Table 1. Water stress indicators in the main regions and the world were displayed in Table 3 to elaborate on the severity of water stress in the Arabsphere, compared with the main regions and the world.

The thresholds of 25%, 50%, and 75% were identified to classify the limits for water stress. Classes of water stress were identified as follows: no stress <25%, low 25–50%, medium 50–75%, high 75–100%, and critical >100%.

Data validation was done according to the FAO (AQUASTAT) rules. The validation tools included cross-variable comparison, time-series coherency, and metadata verification. The last step is a statistical working system, with many validation rules.Missing values could be treated and imputed by linear imputation, carry forward, and vertical imputation. Data could be interpolated to continue the time series. After revision and validation, the data quality should be ensured by FAO. The quality management, quality assessments, quality assurance, and compliance monitoring of the statistical processes were the responsibility of FAO.

Smart water systems (SWSs). Various types and sources of data are needed to conduct SWS. Some of these can be summarized as follows:

- Meteorological data. These data are needed to define the climate of the region, and they are used to analyze the water availability for both planning and operational water supply management. Examples of meteorological data are precipitation, evaporation, temperature, wind direction, and velocity.
- Hydrologic data. Hydrologic data consists of in situ precipitation gauge data, stream gauge readings, discharge measurements, and reservoir elevations. Water quality measurements and evaporation data are needed to establish the water balance. An adequate hydrologic network is required to manage water resources.
- Remotely sensed data. The satellite used to derive large volumes of meteorological and hydrological products is advancing at a very high rate. Satellites can now provide estimates of precipitation rates, vegetation, evapotranspiration, soil moisture, and flood inundation coverage.

Integrative smart water knowledge system. The knowledge system that will serve SWS will have to take advantage of the existing data, information, and science on all critical water industry assets. The main features of the Smart Water System are depicted in Fig. 1. Identification, integration, behavior, characterization, and performance systems of the Smart Water System Components that maintain complex, dynamic, and non-stationary interactions were displayed. Integrating knowledge systems is envisioned to serve as the cement for new and objective data. Information could be retrieved from relevant components throughout the critical location of the water system, and with a fine spatial distribution. Such knowledge systems would acquire and provide, on-demand, real-time data to administrators, engineers, researchers, operators, enforcement officials, and the public.

Integrative knowledge systems would help provide online access to data. The integration and synchronization of data, graphical interfaces, and application software could facilitate the analysis, design, and interpretation of the SWS. Most importantly, an integrative knowledge system would further be integrated with a heuristic knowledge base and possess a certain level of intelligence. Then, data streaming from many nodes of a large network could be processed, and operators could be alerted if incidents or anomalies requiring human intervention are diagnosed. Otherwise, it is not realistic to expect even well-trained human operators to successfully recognize all critical incidents and events promptly.

Knowledge acquisition and interpretation. Knowledge integration (fusion) in water monitoring is critical for the reliable interpretation of data and information. Knowledge integration is closely dependent on how data is transformed into knowledge. The general platform for smarter water applications is illustrated in Fig. 2.

Smart water system identification process. Strategies, methods, and tools that may enable reliable observations, experimental measurements, conceptualization, and characterizations of climate, environment, and behavior of complex water systems should be carefully investigated. The complexity of measuring, processing, and integrating data coming from such a spectrum of space, time, and frequency modality characteristics is a challenge that has yet to be fully recognized and appreciated in water knowledge.

Before various data sets from anywhere within the data space may be processed, structured, archived, correlated, displayed, and interpreted, they should be accurately synchronized concerning time and space, and their variability and confidence intervals must be established.

Table 1 Classes of water stress.

	Overall water stress (2020) %				
%	<25%	25% - 50%	50% - 75%	75-100%	>100%
Class	NO STRESS	LOW	MEDIUM	HIGH	CRITICAL
Legend "Color"					

Table 2 Water stress indicators in the Arabsphere.

Country	Overall (2020)	Renewable water resources	Water withdrawal	Environmental flow requirements	Stress severity
	%	10^9m^3/year	10^9m^3/year	10^9m^3/year	Class
Algeria	137.92	11.67	10.46	4.56	CRITICAL
Bahrain	133.71	0.12	0.43		CRITICAL
Comoros	0.83	1.2	0.01		NO STRESS
Djibouti	6.33	0.3	0.02		NO STRESS
Egypt	141.17	57.5	77.5	2.6	CRITICAL
Iraq	79.51	89.86	56.62	18.66	HIGH
Jordan	104.31	0.94	1.1	0.03	CRITICAL
Kuwait	3850.5	0.02	1.25		CRITICAL
Lebanon	58.79	4.5	1.84	1.42	MEDIUM
Libya	817.14	0.7	5.83		CRITICAL
Mauritania	13.25	11.4	1.35	1.22	NO STRESS
Morocco	50.75	29	10.43	8.17	MEDIUM
Oman	116.71	1.4	1.92		CRITICAL
Qatar	431.03	0.06	0.88		CRITICAL
Saudi Arabia	974.17	2.4	25.99		CRITICAL
Somalia	24.53	14.7	3.3	1.25	NO STRESS
State of Palestine	47.01	1.67	0.9	0.14	LOW
Sudan	118.66	37.8	26.94	15.1	CRITICAL
Syria	124.36	16.8	16.76	5.57	CRITICAL
Tunisia	96	4.62	3.59	0.68	HIGH
United Arab Emirates	1630.67	0.15	4.98		CRITICAL
Yemen	169.76	2.1	3.56		CRITICAL
Arabsphere	**111.39**	**288.91**	**255.66**	**59.4**	**CRITICAL**

The bold values show that the numbers in the Arabsphere cell represent the summation of all countries-related cells.

Intelligent water hackathons. Smart water hackathon could be supported by multidisciplinary teams involving many academic disciplines, scientific disciplines, humanities, and social sciences. Community engagement including experts, specialists, generalists, and citizens could be involved. Hackathon is a powerful process to connect government agencies, academia, industry, and representatives for rural, urban, luxurious, and marginalized areas, and other water stakeholders' communities. Participants include experts "water professionals, practitioners, scholars, engineers, designers, programmers, administrators, public health specialists, and environmentalists, …", and non-experts, "consumers, users, …". Based on collaboration and community engagement, and through scheduled sessions, hackathons could facilitate community engagement, and balanced team building.

Results

Significant applied intelligence techniques for smart water system. Applied intelligence methodologies aim to achieve robustness, tractability, and low solution cost, although partial truth, uncertainty, and imprecision could be generated. The focus was to highlight the significant soft computing methodologies to solve real water problems. Examples of applied intelligence methodologies are Neural Networks, Evolutionary Computing, Fuzzy Logic, and Rough Sets. Examples of significant applied intelligence techniques for SWSs are shown in Table 4.

Successful implementation of smart water system. Implementing SWS involves linking various techniques, models, procedures, and data that could be easily learned and applied to existing water management programs. Success occurs when costs and efforts are expended to establish a modernized water management program that brings positive economic, health, social, and environmental returns.

The success of SWS could be assessed by the subsequent questions: Are water stakeholders involved to ensure fair and equitable allocation of water among users and to protect the environment? Are the data readily accessible? How are water-use planning and allocation carried out? Is the current data network

Table 3 Water stress indicators in the main regions and world.

Region / World	Overall (2020)	Renewable water resources	Environmental flow requirements	Stress severity
	%	10^9m^3/year	10^9m^3/year	Class
Australia and New Zealand	5.39	819	458.29	NO STRESS
Central and Southern Asia	70.39	4155.71	1691.54	MEDIUM
Eastern and South-Eastern Asia	30.97	9847.02	5281.82	LOW
Europe and Northern America	12.47	13758.84	6845.87	NO STRESS
Latin America and the Caribbean	6.82	19203.52	10773.06	NO STRESS
Northern Africa and Western Asia	84.07	580.4	108.91	HIGH
Sub-Saharan Africa	6.1	5488.56	3025.05	NO STRESS
World	**18.55**	**42825.6**	**20556.29**	**NO STRESS**

The bold values show that the numbers in the World cell represent the summation of all regions-related cells.

sufficient to accurately depict the water balance and water quality for the river basin and country? Is the present hydrologic prediction capability adequate to meet the needs of the various water users? The main water users are agriculture (irrigation), drinking and municipal water supply, industry, hydropower, and river transport. The water users could be interested in specific water quality, pollution mitigation, or flood response. How are decisions arrived at to optimize water resources and/or flood control? How conflict among water users is resolved at the local, national, regional (Arab), and international levels? Can users point to improvements in actions and behavior from implementing an intelligent approach? To be successful, every player in the process must benefit. Some potential areas of SW applications include Selection between alternatives; Estimation and classification; Diagnostic problems; Dynamic modeling; Optimization tasks; and Real-time applications and time-dependent changes. Hopefully, several extensions to the described Smart Water applications could be quickly developed.

SWF opportunities provided by artificial intelligence. SWF opportunities mainly included agriculture, domestic purposes, and industry. The challenges for SWF include water governance, water scarcity, water-related disasters, river flow forecasting, surface, and/or groundwater flow, ensuring water quality, contaminant transport, water planning, smart metering, leakage detection in pipelines and water networks, analyzing environmental data, climate change, weather forecasting, climate-smart agriculture, rain-fed land, irrigated land, optimal land use, rising populations, access to fresh and clean water, adequate sanitation, water-related diseases, stakeholder engagement, socio-economic aspects, economic growth, and building an efficient circular water economy. Brief SWF opportunities provided by AI systems are offered in Table 5.

Discussion

The Arabsphere population is 5% of the world, and its share is 1% of available global water (IFAD 2009). The Arabsphere faces water stress, scarcity, and crises. By 2035 the Arabsphere will face acute water stress. The shortage of water needs is vastly growing. The Arabic world should introduce innovative methods for adapting to water shortage. Arabic world peoples, political leaders, water professionals, scientists, governmental officials, NGOs, private businesses, civil associations, development organizations, and financing agencies must identify wise solutions and commitments to face the water challenges. Food security, and water security, are fundamental and vital for human and national stability. The main option available is to achieve more goods with less water, i.e. Increase water use productivity for the reason that new water development in the Arabic world is both limited and costly. Complex challenges and interactions related to water-food-energy nexus could be developed in a well-rounded equitable sustainable manner (Zhang et al. 2019).

This article has attempted to define the innovation in water knowledge from optimization to AI research and application. Numerical optimization for solving water issues has focused researchers' interest on well-defined, isolated problems, often of limited scope that proved to be solvable. Accepting satisfaction instead of optimality of solutions, one need not restrict oneself to addressing only narrowly tailored problems and instead can look at broader problems to start with. AI techniques in water engineering are modest, compared to domains like transportation, and energy (Doorn 2021). The emerging risks and limitations of existing mechanisms in adopting AI for sustainability fields were identified (Galaz et al. 2021). AI could be incomprehensible and/or opaque. So, Innovative AI techniques are humanly explainable. Explainable AI was discussed from an engineering perspective (Naser 2021). Responsible AI pathways were suggested to face poor clearness and responsiveness (Buhmann and Fieseler 2021).

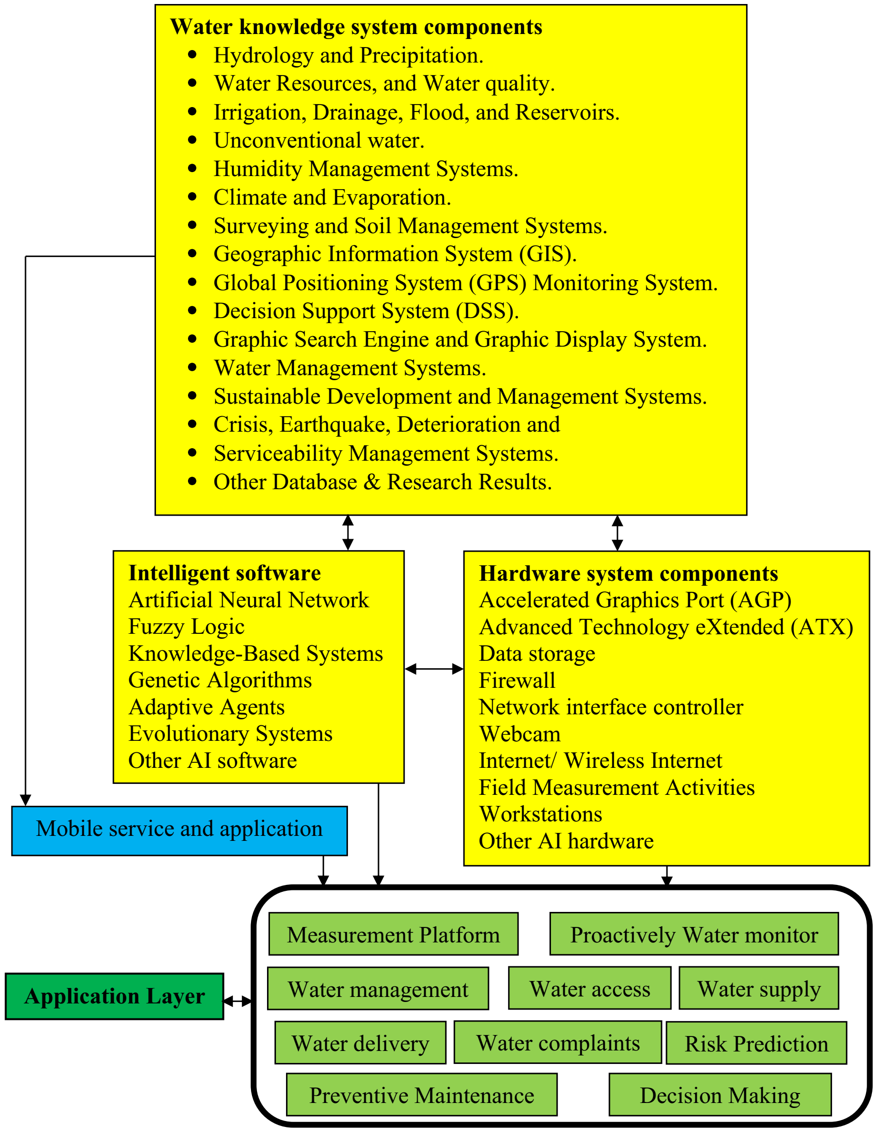

Fig. 1 Smart water system components. The diagram shows the main components of the smart water system; the colors stand for the main components (yellow color = water knowledge system components including software and hardware components, blue color = modern mobile service and application components, and pistachio color = application layer components).

Climate Change (CC). CC and food security are particularly closely linked in Arab societies due to their high vulnerability to water-related "external shocks." Arab societies are exposed to CC, WS, and negative impacts on water resources security, safety, and peace. CC has significant implications for water security, creating new crises, risks, problems, and challenges and exacerbating existing vulnerabilities. The Arabsphere's climate became warmer and drier. Climate changes cause uncertainty in water-related decisions. Water investments should offer the best strategies to adapt to CC. Facing climate change challenges requires applications of science, technology, innovations, knowledge systems, wise water investments, and improving agricultural water productivity. CC impacts should be included in water master plans in all economic sectors. Broad-based water service interventions in water supply and energy utilities, water and sanitation, irrigation services, and CC are a must. This ensures a basket of benefits for improved sustainable livelihoods.

Unconventional water. The AI techniques applied in hydrology were reviewed. Examples included forecasting of hydrological streamflow (Ibrahim et al. 2022). The decision-making activities in the public sector by AI, data intelligence, and big data were discussed (Di Vaio et al. 2022). The overpopulation, increasing consumption, Quality of life (QOL), and CC put more pressure on the limited available water, especially in arid (Arab) regions. There improvements in the efficiency of exploiting water resources have a ceiling (World Bank, 2017). Some researchers have studied unconventional water. Examples of unconventional water are atmospheric water (water-from-air extraction), reclaimed gray/wastewater, desalinated water, *offshore groundwater*, and *water* transportation. There is much fresh water available in the air. Atmospheric water capture (humidity harvesting, fog harvesting, dew harvesting, cloud seeding …) is a promising technology for harvesting water from the air. Reclaimed water is a reliable unconventional water resource alternative to address CC impacts (WWAP 2017). Seawater and/or brackish water desalination are productive water resources. Worldwide, 95 million m^3/day of desalinated water was produced from about 16,000 desalination plants, approximately 50% of which is produced in the MENA region (Jones et al. 2019). In

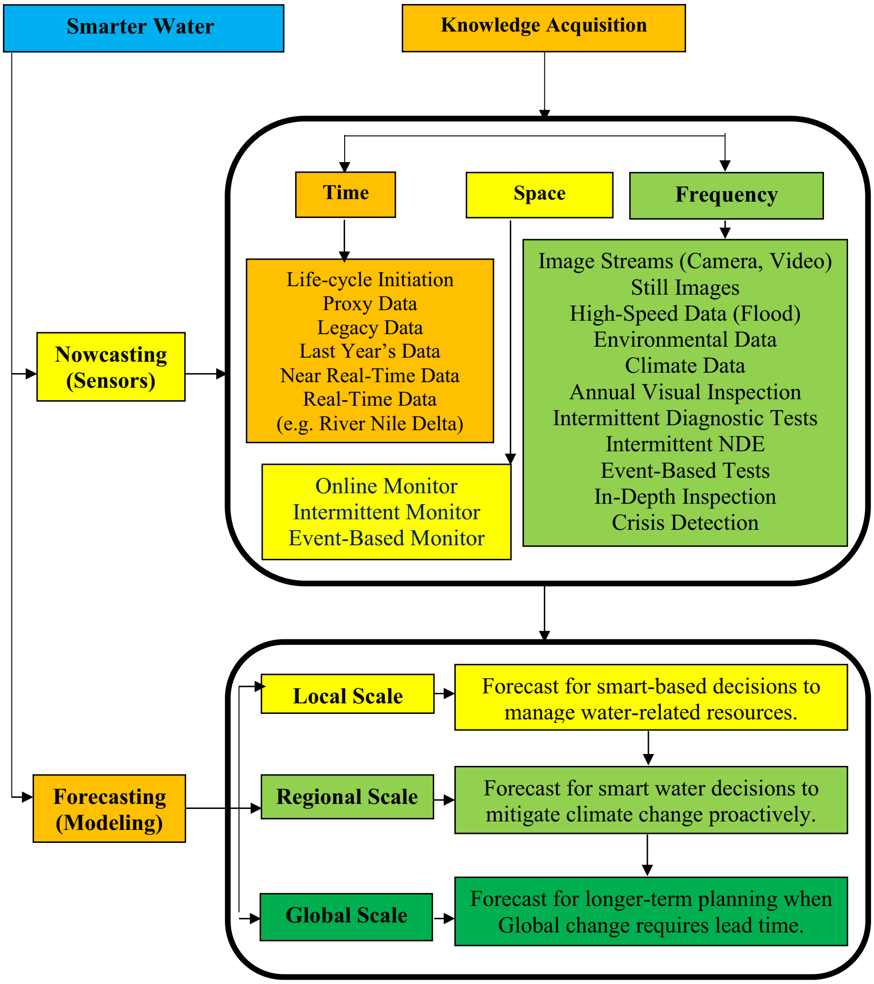

Fig. 2 The general platform for smarter water applications. The diagram shows the two main phases of the smarter water applications; the colors stand for the two phases (yellow = Nowcasting (Sensors) phase, and orange = Forecasting (Modeling) phase). The nowcasting (Sensors) phase has three main components (yellow color = space component, orange color = time component, and pistachio color = frequency component). The forecasting (Modeling) phase has three main scales (yellow color = local scale, pistachio color = regional scale, and green color = globals cale).

2022, the Arab League estimated Arab region has a 46.7% share of global desalination capacity, 7-9 % annual growth, 78 desalination projects operating or planned for construction, and an expansion totaling 1.16 million m^3/day. Offshore groundwater could be a practicable water resource alternative in the future. Fundamental metrics of offshore groundwater occurrences such as Locations, Offshore distances, Minimum total dissolved solids (TDS), and Water depths are reported (Post et al. 2013). Optimum coastal fresh groundwater resources could be estimated by Submarine Groundwater Discharge (SGD) (George et al. 2018). Greater volumes of water will be needed. Transportation of water and Towing icebergs technologies can be suitable future options to provide fresh water. Unconventional water (e.g., reclaimed water, desalination, fog collection, cloud seeding, and atmospheric water harvesting) is vital in future planning for the next generations (UNESCO, UN-Water 2020).

Hackathons development. Although hackathons were recognized in engineering disciplines, lately, hackathons have been implemented as a collaborative process in some scientific domains. Recent hackathon topics included health, healthcare, medicine, biotechnology, and social innovation. Recent examples included Pediatrics (Sajid et al. 2021), clinical trials (Tan et al. 2022), healthcare "genomics" (Leonard et al. 2023), healthcare "biomedical research" (Ramadi et al. 2022), healthcare (Park et al. 2023), digital biotechnology (Jenkins et al. 2022), and social innovation (Wu et al. 2023).

Globally, the Hajj hackathon was a notable, valuable, and huge event. Approximately, three thousand participants attended the Hajj hackathon. The participants were mainly software developers from a hundred countries. The Hajj pilgrimage is one of the largest religious gatherings in the world. Annually, Millions of Muslim pilgrims head to the Holy City of Makkah "Mecca" and the Holy Sites, seven circling the Kaaba -Islam's holiest site- for the Hajj pilgrimage. Also, the Muslim pilgrims "Guests of the Merciful" converge on tent camps at the Mina location in the near desert for days. The Hajj hackathon aimed to serve millions of pilgrims (Muslims), and provide the opportunity for the largest possible number of Muslims to perform the Hajj to the fullest extent. The Hajj hackathon worked to enrich and deepen pilgrims' experience, by preparing the Grand Mosque, the spiritual and holy sites, and religious Mecca city to receive them during the days of Hajj and mitigating the obstacles that they may face. The Hajj hackathon competition included important Hajj services such as capacity increase, the holy sites development, the longest pedestrian globally road, which starts from Jabal al-Rahma in Arafat "Arafah", passing through Muzdalifah, and ends at Mina, travel and accommodation, food and beverages, crowd management, transportation, traffic control, public health, waste management, communication, and financial solutions.

Table 4 Significant applied intelligence techniques for smart water systems.

Feature	Smart water
Time Series Prediction	Hydro-meteorological data / Water bodies / Water supply / Water distribution system (WDS) / Water treatment plant (WTP) / Irrigation system / Water pollution / Water footprint / Watering timing.
Real-time monitoring	Hydro-meteorological data / Water bodies / Water infrastructure / Water supply / Water monitoring / Watering timing / Water quality / Water flow / Water pressure / Water moisture / Oxygen content / Water pollution / Water footprint / Water loss.
Natural calamities predictions	Water bodies / Flood / Water infrastructure.
Planning	Water infrastructure / Water bodies / Water supply / WDS / WTP / Irrigation system / Water footprint / Watering timing.
Scheduling	Water supply / WDS / WTP / Irrigation system / Watering timing / Pump scheduling.
Design analysis	Water infrastructure / WDS / WTP / Irrigation system.
Dynamic modeling	Water infrastructure / WDS / WTP /Irrigation system.
Quality prediction	Water infrastructure / Water monitoring / WDS / WTP / Irrigation system /Pipeline accidents.
Quality inspection	Water infrastructure / Water monitoring / WDS / WTP / Irrigation system / Pipeline accidents.
Signal identification	Water infrastructure / Water monitoring / Water pollution / Water supply / Water bodies / Pipeline accidents / Leakage detection.
System diagnosis	Water infrastructure / Water monitoring / Water pollution / Water footprint / Water supply / Pipeline accidents / WDS / Leakage detection / Water loss.
Fault detection	Water infrastructure / Water supply / Water monitoring / WDS / WTP / Irrigation system / Leakage detection / Water loss / Pipeline accidents.
Failure analysis	Water infrastructure / Water monitoring / WDS / Water supply / WTP / Irrigation system / Water loss / Leakage detection / Pipeline accidents.
Maintenance analysis	Water infrastructure / Water monitoring / WDS / WTP / Irrigation system / Leakage detection / Water loss / Pipeline accidents.
Pattern Recognition	Water infrastructure / Water monitoring / Water supply / Water pollution / Water footprint / Water loss / Water contamination / Water scarcity / Leakage detection / Pipeline accidents.
Image identification	Water bodies / Water infrastructure / Water monitoring / Water pollution / Water loss / Water contamination / Water stress / Leakage detection / Pipeline accidents.
Anomaly Detection	Water supply / Water infrastructure / Water monitoring / Water pollution / Water footprint / Water loss / Water contamination / non-revenue water losses / Irrigation system / Leakage detection / Pipeline accidents.
Management	Water bodies / Water supply / Water infrastructure / Water Resources / Water pollution / Water footprint / Water footprint / Water loss / Water monitoring / Irrigation system.
Target tracking	Water bodies / Water supply / Water monitoring / Water pollution / Water footprint / Water loss.
Guidance system	Water monitoring / Water supply.
Routing systems	Water bodies / Water monitoring.
Value prediction	Water bodies / Water supply / Water pollution / Watering timing / Leakage assessment / Water loss.
Telecommunications	Hydro-meteorological data / Water bodies / Water infrastructure / Water supply / Water monitoring /Water loss / WDS / Irrigation system / Data exchange between water authorities / Data security / Data reliability / Pipeline accidents.

Table 5 SWF opportunities provided by artificial intelligence.

Items	Key SWF opportunities
Minimizing and Facing Water Scarcity	On a timely basis, in a particular location, and a particular situation, AI could foster water knowledge, maximize the sustainable revenue of water, minimize the water loss in the various economic systems, and equitably maximize the water benefits. Water Scarcity could be expressed as a mathematical function of future variables, water demand, water resources, unconventional water, water consumption, climate change, rising populations, water awareness, desertification, COVID-19 impact, water management, irrigation system (open field, sprinkler, drip, protected drip, ..etc.) irrigation efficiency, water efficiency use, overall water use efficiency (WUE), water vulnerability, and economic welfare.
The water footprint	AI could assess the water needs of domestic, agricultural, and industrial sectors. Assess the water footprints. Assess the local and actual water footprint for different products such as one cup of orange juice, tea, and coffee, one kg of meat, wheat, and vegetables, and one suit of cotton, linen, and jeans.
Machine-to-Machine (M2M) in Smart Water	AI could improve cost-effective opportunities in M2M. Applications in SWSs include semantic sensors, smart pipes, smart metering, …

Smart water hackathon in Arabsphere. The smart water model is established on the smart platform Data Collection & Analysis M2M Transactions. The main components of the SW model are water management, water security, water economy, ecology, environment, and energy. Water management focuses on modernizing water administration through AI solutions to better allocate water resources, prioritize investments to a comprehensive water view, and empathize E-Government, smart meter/grid, cloud, virtual hosting, remote control, automated solutions, minimizing water loss, smart computing, and maintenance. Water Security focuses on pollution prevention and water quality and efficiency, through AI solutions to enhance reservoir Capacity Tracking, water Emergency Management, leak detection, and optimizing water service routes. The water economy focused on modernizing how water is performing and enabling World growth. Ecology, environment, and sustainability focused on reducing water consumption, improving World growth

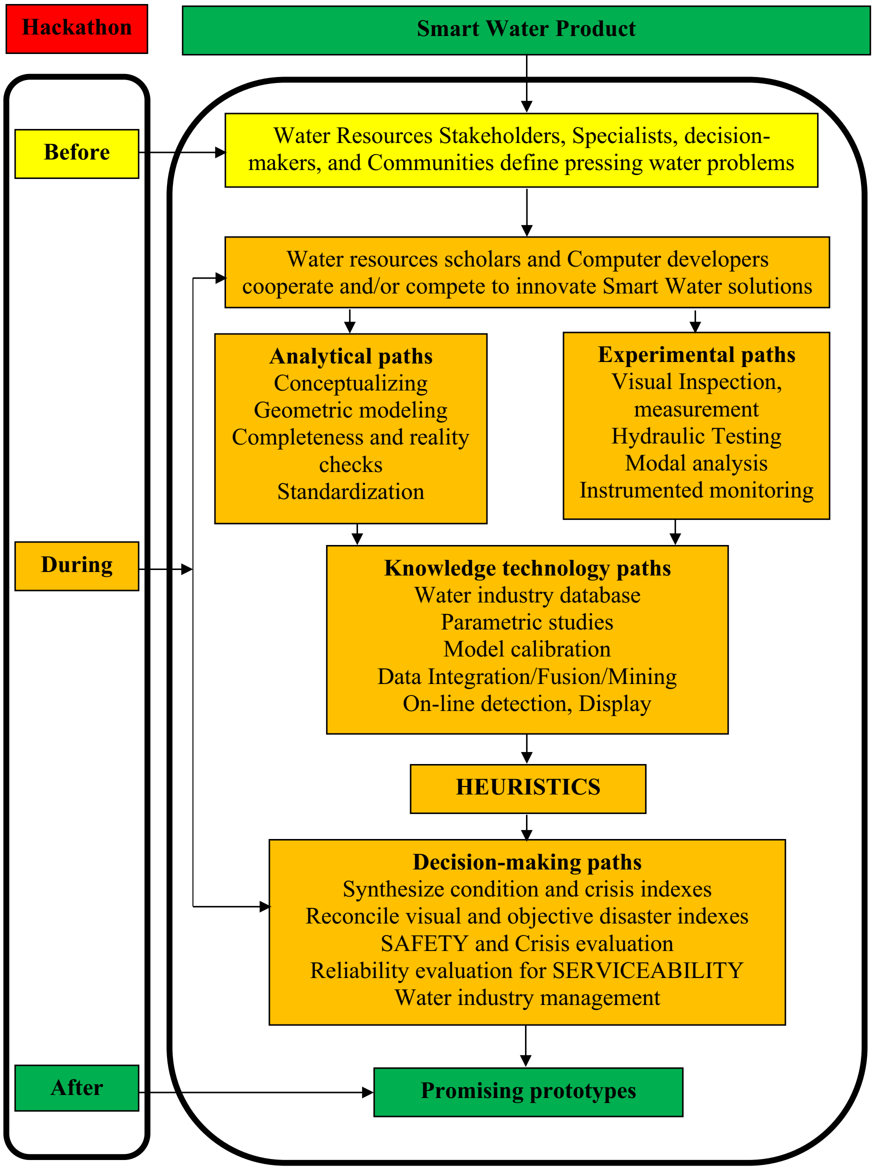

Fig. 3 Flow diagram of the successful implementation of smart water hackathon. The flow diagram shows the three main phases of the smart water hackathon; the colors stand for the three phases (yellow = before the hackathon phase, orange = during hackathon phase, and green = after the hackathon phase).

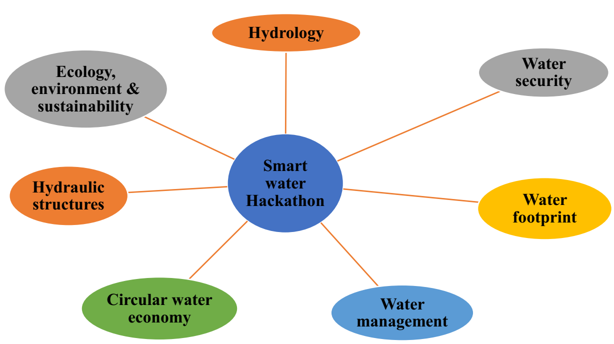

Fig. 4 The smart water hackathon in Arabsphere. The diagram shows the critical components of the intelligent water hackathon (e.g., hydrology, water security, water footprint, circular water economy, hydraulic structures, etc.). The colors highlight the idea of diversity.

and environment indicators by managing wastewater, and sustainability measures as part of national strategy. Figure 3 presents a Flow diagram of the Successful implementation of the Smart Water Hackathon. Smart Water Management (SWM) could improve hydrological responses, water quality, and water management by using proactive strategies based on real-time data (Du Plessis 2021). Global exemplary SWM case studies in both emerging and developed locations and their smart solutions were reported (K-WATER AND IWRA 2018).

Smart solutions include smart sensors, real-time monitoring, flood, drought, water quality, leak detection, community satisfaction, integrated network, drinking water, groundwater, sanitation, efficient irrigation, soil monitors, energy optimization, rainwater collection, and stormwater management. The application of smart water-based fluid containing a magnetic suspension (ferrofluid) in anionic dye removal to prevent wastewater treatment pollution was reported (Chen et al. 2021). A smart irrigation water system to achieve related SDGs was implemented (Barkhordari and Hashemy Shahdany 2021). Also, an intelligent irrigation system

Table 6 Artificial intelligence' SMART criteria for sustainable water future.

Item	Description
Vision	Adopt effective policies, smart standards, and best water practices for SWF through the applications of AI to optimize overall WUE and water footprints.
Foresight	Encourage the integration of AI into water policies (health, water, food, agriculture, industry, environment, energy, AI experts, and policymakers)
Global agenda	Integrate AI policies in the international dialog on SWF in organizations such as UN-Water, the United Nations Environment Programme (UNEP), the Food and Agricultural Organization (FAO), the World Meteorological Organization (WMO), the Arab Water Council, and others.
Cooperation	Reinforce partnerships at the international, continental, and regional levels, among developed countries, developing countries, international organizations, governments, academic research institutes, and the civil World, on the use of AI practices for SWF. Mobilize know-how, best practices, skills, and expertise to explore significant work in this influential area. Foster business models to encourage partnerships among stakeholders through win-win practices.
Innovation and knowledge	Foster innovation in the water cycle and ecosystem. Improve water knowledge, in particular, water efficiency, water resilience, water availability, water demand management, water consumption, and CC impacts.
Water awareness and education	Develop water training, education, and building capacity of water professionals to enhance skills and expertise in different water applications. Foster awareness about AI in the water industry among beneficiaries and farmers.
Standardization	The impact of AI on ensuring SWF; the AI applications for SWF to ensure computer systems and software interoperability and benefit from economies of scale; ensure AI systems, technologies, and software interoperability. For intelligent decision-making for SWF; and use of AI technologies to enable interoperability of SWF solutions. Shape the situation benchmarking in different regions and countries.
Feasibility and success	Implement pilot demonstration projects to show AI solutions for SWF in agriculture, domestic and industrial practices. Utilizing AI for SWF. Identify opportunities, strengths, challenges, and weaknesses of implementation of AI technologies, and report best practices and success stories.
Circular water economy	Promote circular water opportunities and technologies. Enhance green services, products, and economic activities. Develop water footprints for different services, products, and economic activities.
Evaluation	Assess performance indicators for different industries, regions, and countries, for SWF through the application of AI and support countries to optimize their water resources.

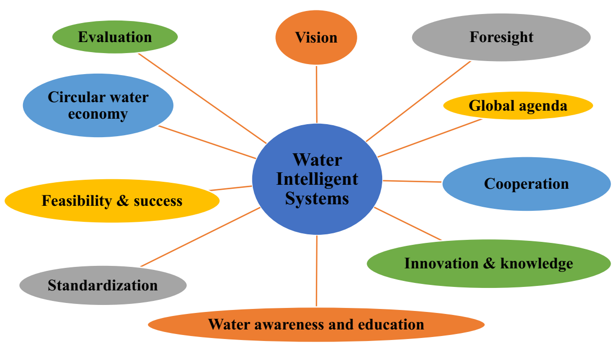

Fig. 5 The framework of water intelligent systems for sustainable water future. The diagram shows the critical components of the water intelligent systems for a sustainable water future (e.g., Vision, Foresight, Global Agenda, etc.). The colors highlight the idea of multifariousness.

that utilizes the Internet of Things (IoT) and fuzzy logic controller (FLC) has better irrigation performance by using the indicators of energy and water consumption (Benyezza et al. 2021).

Intelligent water metering (IWM) was applied to alleviate drought and water crises, and be efficient in water conservation and sustainable cities (Visser et al. 2021). Smart irrigation was proposed to optimize water use and improve crop yield (Shi et al. 2021). Smart water using soft computing techniques was proposed to ensure accurate incentives, water-wise usage, and sustainability of water resources (Thakur et al. 2021). In the governmental sector, AI could be used in the adoption phase, implementation phase, and decision-making phase (W. Zhang et al. 2021). The impact of AI on employees and worker welfare regarding health, stress, freedom, monitoring, insecurity, and satisfaction was studied (Nazareno and Schiff 2021). Unified Theory of Acceptance and Use of Technology (UTAUT2) was used to investigate the user behavior and behavioral intention of the common products and segments equipped with AI technologies (Gansser and Reich 2021).

The main issues of the intelligent water hackathon were expressed concerning hydrology, water security, water footprint, water management, circular water economy, hydraulic structures and ecology, environment & and sustainability. The intelligent water hackathon for the Arabsphere is displayed in Fig. 4. Hydrology topics included watersheds, flows, sediment transport, flooded areas, evaporation, seepage, hydropower generation… etc. Virtual water is an indicator to evaluate the significance of water for development or production. Water footprint is a numerical tool to value the relation between water consumption and water-related products. Water footprints (blue, green, and gray) are used to assess rainwater evaporated, surface or groundwater evaporated, and polluted water, respectively. Hydraulic structures could be constructed for irrigation, drinking water, agriculture, energy, and other purposes. When analyzing hydraulic structures and infrastructure, the realized benefits, alternatives, possible impacts, feasible alternatives, location, size, cost, and cost-effectiveness should be determined.

Characteristics of intelligent water system. Water intelligent systems imply the intensive use of AI concepts to optimize current and future water rural and urban requirements and services and enable safe and fresh water for new generations. The value opportunities of Smart water (Water Intelligent Systems) include but are not limited to cost reduction, increased income, water efficiency, optimal water planning, and governance, and paving the road for sustainability and quality of life. The framework of SWF based on AI is displayed in Table 6. The significant characteristics of an intelligent water system (IWS) could be outlined as:

- SWS is fault tolerant. Since memory is distributed, failure of some processing elements will slightly alter the overall behavior of the system. Unlike traditional computing systems, the failure of any smaller part will stop its performance. This characteristic is very well suited to applications where reliable systems need to be developed from less reliable components like the case of the water industry.

- SWS could represent uncertainty; a measure of "belief" could be incorporated by modifying the problem pattern.
- SWS has associative memory. The SWS responds to noisy, incompetent, or previously unseen data.
- SWS extracts classification characteristics from many input examples.
- SWS needs small computer time for learning and could achieve fast responses.
- SWS are particularly suited for pattern recognition tasks.
- SWS learns by example. These examples could be elicited from experts without asking how and why they came to those conclusions.

The water intelligent systems. The framework of Water Intelligent Systems for SWF is displayed in Fig. 5. The Water Intelligent System was expressed in terms of Vision, Foresight, Global Agenda, Cooperation, Innovation and knowledge, Water awareness and education, Standardization, Feasibility and success, Circular water economy, and Evaluation.

The contributions of smart water to water knowledge & and industries are:

First, large amounts of knowledge or data are typically made available in SW systems or databases linked to SW systems. These may be encoded as knowledge bases, classifying crises that appear on water industry sites, or detailed descriptions of water industry projects. Describing a crisis by using natural language such as English instead of cryptic variables makes SW systems easier to browse and understand even by novice users. Moreover, knowledge can include details that are quite domain-specific. Together with a sound classification system and fast query routines, such knowledge-intensive systems then make crisis-solving easier and produce tailored solutions.

Second, SW systems typically articulate individual objects and constraints between objects and constructively assemble solutions, much like people do. This enables them to reason about which objects to select and constraints to apply, relax, or ignore, and when to take applied constraints into account. If the SW system were developed to do so, it could even generate constraints to proceed with problem-solving. Decision-makers, initially using trial-and-error for selecting objects and constraints, eventually learn which choices are more likely to succeed than others, and develop strategies for problem-solving. Strategic knowledge can also make SW systems more effective in finding solutions.

The smart water influence. Finally, SW systems generally rely on one of two methods to somehow guarantee the quality of their solutions. Developers of SWSs may assume that their programmed strategy is a good one, and consequently, that the generated solution is a good one as well, even if that is difficult to prove. In addition, they may implement evaluation functions to compare intermediate solutions.

Conclusions

Artificial and applied intelligence methodologies are applied in a growing number of practices and research related to the fields of hydrology, and water resources. This paper reveals a young and promising field of study whose primary concern is finding an effective way to apply Smart Water problem-solving, and skills to a wide range of practical problems. Research and demonstrations of smart water require adequate resources, integrated multidisciplinary teams, and a true partnership of academe, government, and industry. Recruiting motivating and educating a new breed of researcher-engineers who can meet the intellectual and physical challenges of meaningful scientific explorations on operating SWSs was a most daunting challenge. Also, of note is the significance of the proper application of knowledge tools and methods within the scope of integrated water industry management. Knowledge fusion in smart water monitoring is critical for the reliable interpretation of data for management, governance, and decision-making. SWSs utilize current water data and future stream-flow forecasts to provide knowledge to water managers on how to optimize water usage, minimize the impact of both droughts and floods and maintain environmental quality. The smart water approach opened new ways of building computer models while bringing models and practice closer together. Model developers could make computers mimic water managers' actions, and add flexibility and functionality to existing models, to develop programs that are potentially easier to understand and use. Smart water modeling techniques fill a gap among other modeling tools available today. Artificial intelligence could shape future policies to recover from the COVID-19 pandemic while preserving livable Arab societies. The author hopes that this paper provides some feel for the Arabsphere to face its water future benefiting from artificial intelligence. By highlighting challenges and encouraging competition, hackathons could develop applicable solutions or valuable wild, creative, or promising ideas. The hackathon encouraged diverse participation to generate innovative ideas and creative water solutions to complex water stress problems. The hackathon revealed the urgent need for mitigating the stress on freshwater resources in the Arabsphere.

Data availability

The datasets used and/or analyzed are available from the author upon reasonable request.

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References

Barkhordari S, & Hashemy Shahdany SM (2021) Developing a smart operating system for fair distribution of irrigation water, based on social, economic, and environmental considerations. Agric Water Manag, 250. https://doi.org/10.1016/j.agwat.2021.106833

Benyezza H, Bouhedda M, Rebouh S (2021) Zoning irrigation smart system based on fuzzy control technology and IoT for water and energy saving. J Cleaner Prod, 302, https://doi.org/10.1016/j.jclepro.2021.127001

Buhmann A, Fieseler C (2021) Towards a deliberative framework for responsible innovation in artificial intelligence. Technol Soc, 64. https://doi.org/10.1016/j.techsoc.2020.101475

Chen J, Cao Q, Han X (2021) Smart water-based ferrofluid with stable state transition property: preparation and its application in anionic dye removal. J Clean Prod, 287. https://doi.org/10.1016/j.jclepro.2020.125003

Chimmula VKR, Zhang L (2020) Time series forecasting of COVID-19 transmission in Canada using LSTM networks. Chaos Solitons Fract, 135. https://doi.org/10.1016/j.chaos.2020.109864

Di Vaio A, Hassan R, Alavoine C (2022) Data intelligence and analytics: a bibliometric analysis of human–Artificial intelligence in public sector decision-making effectiveness. Technol Forecast Soc Change, 174. https://doi.org/10.1016/j.techfore.2021.121201

Doorn N (2021) Artificial intelligence in the water domain: opportunities for responsible use. Sci Total Environ, 755. https://doi.org/10.1016/j.scitotenv.2020.142561

du Plessis A (2021) The necessity of making water-smart for proactive informed decisive actions: a case study of the upper vaal catchment, South Africa. Environ Chall, 4. https://doi.org/10.1016/j.envc.2021.100100

Fanelli D, Piazza F (2020) Analysis and forecast of COVID-19 spreading in China, Italy and France. Chaos Solitons Fract, 134. https://doi.org/10.1016/j.chaos.2020.109761

FAO (2020) Food Safety in the time of COVID-19. FAO, Rome, https://doi.org/10.4060/ca8623en

FAO and UN Water (2021) Progress on the level of water stress: global status and acceleration needs for SDG indicator 6.4.2, 2021. FAO and UN Water, Rome, https://doi.org/10.4060/cb6241en

Galaz V, Centeno MA, Callahan PW, Causevic A, Patterson T, Brass I, Baum S, Farber D, Fischer J, Garcia D, McPhearson T, Jimenez D, King B, Larcey P, Levy K (2021) Artificial intelligence, systemic risks, and sustainability. Technol Soc, 67. https://doi.org/10.1016/j.techsoc.2021.101741

Gansser OA, Reich CS (2021) A new acceptance model for artificial intelligence with extensions to UTAUT2: An empirical study in three segments of application. Technol Soc, 65. https://doi.org/10.1016/j.techsoc.2021.101535

George ME, Babu DSS, Akhil T, Rafeeque MK (2018) Investigation on submarine groundwater discharge at Kozhikkode Coastal Aquifer, SW Western Ghats. J Geological Soc India, 92 (5). https://doi.org/10.1007/s12594-018-1077-5

Hazarika BB, Gupta D (2020) Modelling and forecasting of COVID-19 spread using wavelet-coupled random vector functional link networks. Appl Soft Comput J, 96. https://doi.org/10.1016/j.asoc.2020.106626

Ibrahim KSMH, Huang YF, Ahmed AN, Koo CH, El-Shafie A (2022) A review of the hybrid artificial intelligence and optimization modelling of hydrological streamflow forecasting. Alexandria Eng J 61(1). https://doi.org/10.1016/j.aej.2021.04.100

IFAD (International Fund for Agricultural Development) (2009) Fighting water scarcity in the Arab countries. Jordan, Sudan

Jenkins TP, Lopez Carranza N, Bray A, Beguir K, Laustsen AH (2022) Can hackathons unlock a new talent pool from the developing world? Nat Biotechnol 40(8). https://doi.org/10.1038/s41587-022-01415-x

Jones E, Qadir M, van Vliet MTH, Smakhtin V, Kang SM (2019) The state of desalination and brine production: a global outlook. Sci Total Envir 657. https://doi.org/10.1016/j.scitotenv.2018.12.076

Ju MJ, Oh J, Choi YH (2021) Changes in air pollution levels after COVID-19 outbreak in Korea. Sci Total Environ, 750. https://doi.org/10.1016/j.scitotenv.2020.141521

K-Water (Korea Water Resources Corporation) and IWRA (International Water Resources Association) Report (2018). Smart Water Management Case Study Report. https://www.iwra.org/swmreport/

Lalmuanawma S, Hussain J, Chhakchhuak L (2020) Applications of machine learning and artificial intelligence for Covid-19 (SARS-CoV-2) pandemic: a review. Chaos Solitons Fract, 139. https://doi.org/10.1016/j.chaos.2020.110059

Leonard HL, Murtadha R, Martinez-Carrasco A, Jama A, Müller-Nedebock AC, Gil-Martinez AL, Illarionova A, Moore A, Bustos BI, Jadhav B, Huxford B, Storm C, Towns C, Vitale D, Chetty D, Yu E, Grenn FP, Salazar G, Rateau G, … Noyce AJ (2023) The IPDGC/GP2 Hackathon - an open science event for training in data science, genomics, and collaboration using Parkinson's disease data. Npj Parkinson's Dis 9 (1). https://doi.org/10.1038/s41531-023-00472-6

Liu Q, Harris JT, Chiu LS, Sun D, Houser PR, Yu M, Duffy DQ, Little MM, Yang C (2021) Spatiotemporal impacts of COVID-19 on air pollution in California, USA. Sci Total Environ, 750. https://doi.org/10.1016/j.scitotenv.2020.141592

Maleki M, Mahmoudi MR, Heydari MH, Pho KH (2020) Modeling and forecasting the spread and death rate of coronavirus (COVID-19) in the world using time series models. Chaos Solitons Fract, 140. https://doi.org/10.1016/j.chaos.2020.110151

Martorell-Marugán J, Villatoro-García JA, García-Moreno A, López-Domínguez R, Requena F, Merelo JJ, Lacasaña M, de Dios Luna J, Díaz-Mochón JJ, Lorente JA, Carmona-Sáez P (2021) DatAC: a visual analytics platform to explore climate and air quality indicators associated with the COVID-19 pandemic in Spain. Sci Total Environ, 750. https://doi.org/10.1016/j.scitotenv.2020.141424

Melin P, Monica JC, Sanchez D, Castillo O (2020) Analysis of spatial spread relationships of coronavirus (COVID-19) pandemic in the world using self organizing maps. Chaos Solitons Fract, 138. https://doi.org/10.1016/j.chaos.2020.109917

Naser MZ (2021) An engineer's guide to eXplainable Artificial Intelligence and Interpretable Machine Learning: Navigating causality, forced goodness, and the false perception of inference. Autom Constr, 129. https://doi.org/10.1016/j.autcon.2021.103821

Nazareno L, Schiff DS (2021) The impact of automation and artificial intelligence on worker well-being. Technol Soc, 67. https://doi.org/10.1016/j.techsoc.2021.101679

Park CH, von Krogh G, Stadtfeld C, Meboldt M, Shrestha YR (2023) Healthcare hackathons as open innovation. Nat Rev Bioeng. https://doi.org/10.1038/s44222-023-00070-4

Post VEA, Groen J, Kooi H, Person M, Ge S, Edmunds WM (2013) Offshore fresh groundwater reserves as a global phenomenon. Nature 504, 7478. https://doi.org/10.1038/nature12858

Ramadi KB, Mehta R, He D, Chao S, Chu Z, Atun R, Nguyen FT (2022) Grass-roots entrepreneurship complements traditional top-down innovation in lung and breast cancer. Npj Digital Med, 5 (1). https://doi.org/10.1038/s41746-021-00545-x

Rowan NJ, Galanakis CM (2020) Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis? Sci Total Environ, 748. https://doi.org/10.1016/j.scitotenv.2020.141362

Saadat S, Rawtani D, Hussain CM (2020) Environmental perspective of COVID-19. Sci Total Environ, 728. https://doi.org/10.1016/j.scitotenv.2020.138870

Sajid MI, Ahmed AS, Baig MA, Nasir N, Mian AI (2021) A low-cost low-tech solution to lessen the fear of needles in children. Pediatric Res 89(3). https://doi.org/10.1038/s41390-020-01178-8

Salgotra R, Gandomi M, Gandomi AH (2020) Time series analysis and forecast of the COVID-19 pandemic in India using genetic programming. Chaos Solitons Fract, 138. https://doi.org/10.1016/j.chaos.2020.109945

Shi J, Wu X, Zhang M, Wang X, Zuo Q, Wu X, Zhang H, Ben-Gal A (2021) Numerically scheduling plant water deficit index-based smart irrigation to optimize crop yield and water use efficiency. Agric Water Manag, 248. https://doi.org/10.1016/j.agwat.2021.106774

Swapnarekha H, Behera HS, Nayak J, Naik B (2020) Role of intelligent computing in COVID-19 prognosis: a state-of-the-art review. Chaos Solitons Fract 138. https://doi.org/10.1016/j.chaos.2020.109947

Tan RKJ, Wu D, Day S, Zhao Y, Larson HJ, Sylvia S, Tang W, Tucker JD (2022) Digital approaches to enhancing community engagement in clinical trials. npj Digital Med 5, 1. https://doi.org/10.1038/s41746-022-00581-1

Thakur T, Mehra A, Hassija V, Chamola V, Srinivas R, Gupta KK, Singh AP (2021) Smart water conservation through a machine learning and blockchain-enabled decentralized edge computing network. Appl Soft Comput, 106, https://doi.org/10.1016/j.asoc.2021.107274

UNESCO, UN-Water (2020) United Nations World Water Development Report 2020: Water and Climate Change. UNESCO, Paris

Visser M, Booysen MJ, Brühl JM, Berger KJ (2021) Saving water at Cape Town schools by using smart metering and behavioral change. Water Resour Econ 34, https://doi.org/10.1016/j.wre.2020.100175

World Bank (2017) Beyond scarcity: water security in the Middle East and North Africa. World Bank, https://doi.org/10.1596/978-1-4648-1144-9

Wu YJ, Goh M, Mai Y (2023) Social innovation and higher education: evolution and future promise. Hum Soc Sci Commun 10, 1. https://doi.org/10.1057/s41599-023-01759-y

WWAP (United Nations World Water Assessment Programme) (2017) The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. UNESCO, Paris

Yuan Q, Qi B, Hu D, Wang J, Zhang J, Yang H, Zhang S, Liu L, Xu L, Li W (2021) Spatiotemporal variations and reduction of air pollutants during the COVID-19 pandemic in a megacity of Yangtze River Delta in China. Sci Total Environ, 751. https://doi.org/10.1016/j.scitotenv.2020.141820

Zhang P, Zhang L, Chang Y, Xu M, Hao Y, Liang S, Liu G, Yang Z, Wang C (2019) Food-energy-water (FEW) nexus for urban sustainability: a comprehensive review. Resour Conserv Recycl. 142. https://doi.org/10.1016/j.resconrec.2018.11.018

Zhang W, Zuo N, He W, Li S, Yu L (2021) Factors influencing the use of artificial intelligence in government: evidence from China. Technol Soc 66. https://doi.org/10.1016/j.techsoc.2021.101675

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Competing interests

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Ethical approval

This article does not contain any studies with human participants performed by the author.

Informed consent

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Additional information

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