جمعية علوم وتقنية المياه الخليجية
Gulf Water Sciences and Technology Association

جامعة الخليج العربي
Arabian Gulf University

# The Smart Water Revolution

## *Harnessing Emerging Technologies for Sustainable Water Management in the GCC Countries*

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# Overview

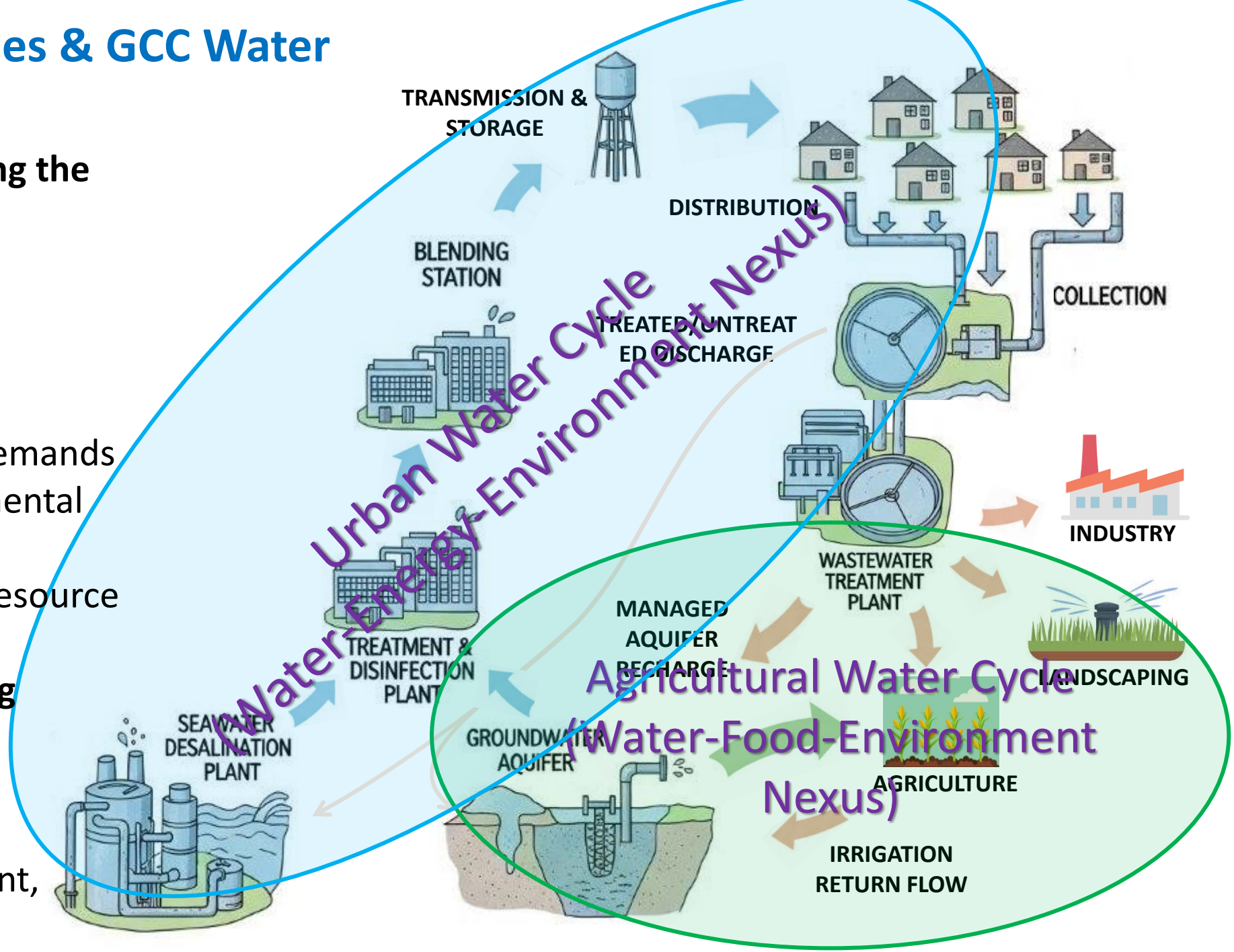
- From Reactive to Predictive
- Emerging Technologies & GCC Water Supply Chain
- Major GCC Water Sector Challenges
  - **Challenge 1:** Agricultural & Groundwater
  - **Challenge 2:** Desalination, Municipal Demands & Associated Costs
  - **Challenge 3:** Inadequate Utilization of Municipal Wastewater
  - **Challenge 4:** Vulnerability of Municipal Water Supply System
  - **Challenge 5:** Impact of Climate Change: Urban Water Flooding
- **Conclusion 1:** Transformative Power of ET in Water Management in GCC
- **Conclusion 2:** Water Education in the 4IR
- **Recommendations:** Embedding 4IR in Water Education & Training

## **From Reactive to Predictive** (Old vs. New Paradigm)

- Emerging technologies (i.e., *Artificial Intelligence, Geo AI, Internet of Things, Blockchain, Big Data Analytics, Robotics/Drones, Quantum Technologies*, ..**)** are transforming entire systems of production, management, and governance of all sectors, **including the water sector**
- Provide powerful enabling tools for effective water management: **Diagnostic/Analysis, Optimization/Improvement, and Prediction**
- **The Old Paradigm**: Siloed data, periodic reports, reactive decision-making will be outdated and replaced
- **The New Paradigm (4IR):** Integrated, real-time data systems powered by AI for forecasting and optimization

# Emerging Technologies & GCC Water Supply Chain

- **Integrating & Optimizing the Water Supply Chain** to
  - Maximize Efficiency
  - Minimizing losses
  - Reducing costs
  - Ensuring reliability
  - Meeting customer demands
  - Minimizing environmental impacts
  - Ensuring long-term resource availability
- **Implementing Emerging Technologies** (AI, IoT, Blockchain, Quantum Computing, ..) in
  - Analysis, Improvement, and Prediction



# Challenge 1: Extensive Agricultural Consumption incompatible with Available Water Resources (mainly from fossil)

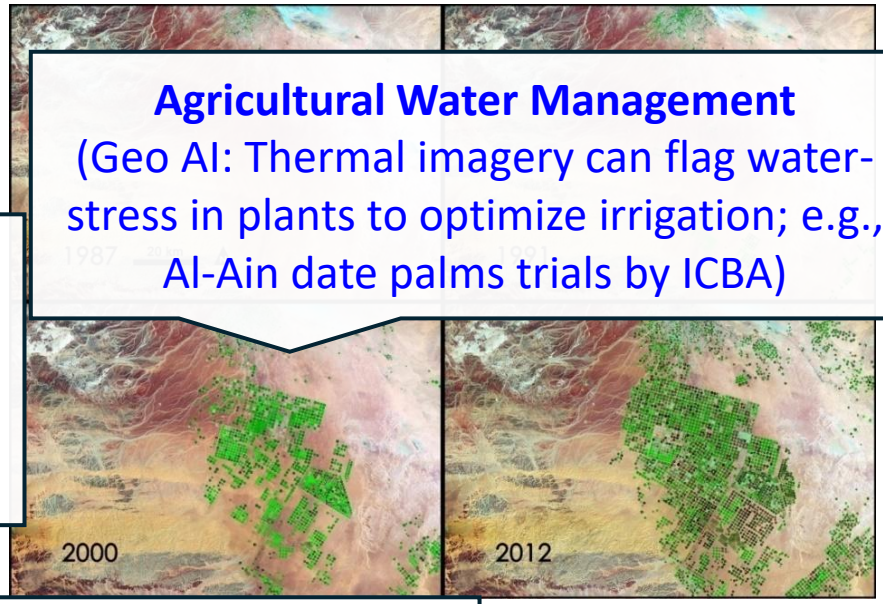
- **Drivers:** food demand/security and/or socio-economic policies, major subsidies (including water) & incentives programs for agricultural expansion and food production
- Exaggerated Agricultural consumption by:
  - Inefficient irrigation methods (low Irrigation efficiencies: 25-40%);
  - Cultivation of high-water consuming crops (e.g. alfalfa as a cash crop);
  - Privately owned groundwater rights (unlimited abstraction)
  - Absence of well metering/monitoring and groundwater tariffs for agricultural water use

**Crop-specific Algorithms**
(AI-recommended drought resistant crops using market trade data)

**Precision/Smart Agriculture**
(using soil moisture, IoT weather data, and crop water requirement to apply irrigation volumes (30-50% saving))

**Monitoring Groundwater consumption**
(Geo AI: Satellite imagery with automated NDVI analysis and thermal water-stress detection )

**Expansion in agriculture, e.g., Wadi Al-Sarhan, KSA**

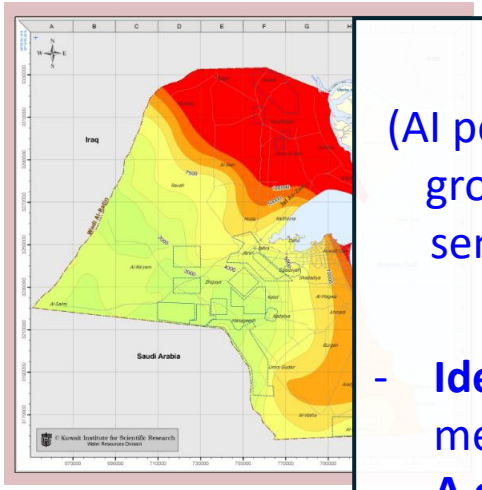



**Agricultural Water Management**
(Geo AI: Thermal imagery can flag water-stress in plants to optimize irrigation; e.g., Al-Ain date palms trials by ICBA)

**IoT guided groundwater extraction**
(sensors monitor aquifer salinity and levels and trigger alerts for over-pumping)

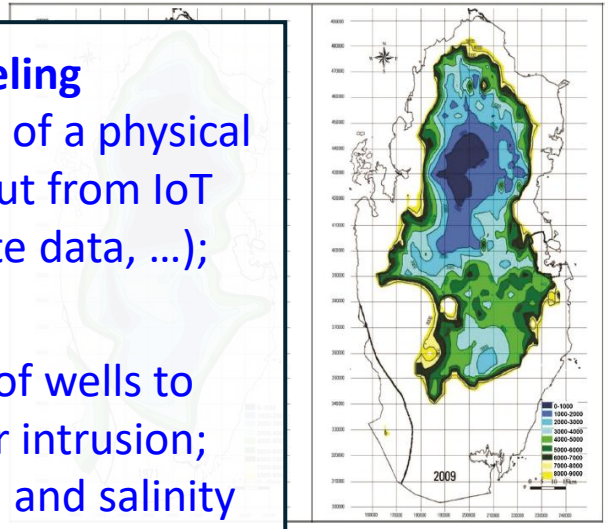
**Traditional Irrigation Methods**

## Saltwater Intrusion to GW in Kuwait (KISR,2000)




## GW level decline in Bahrain (Zubari 2017)

## Depletion of fresh GW lens in Qatar, 1971-2009 (Baaloush, 2009)

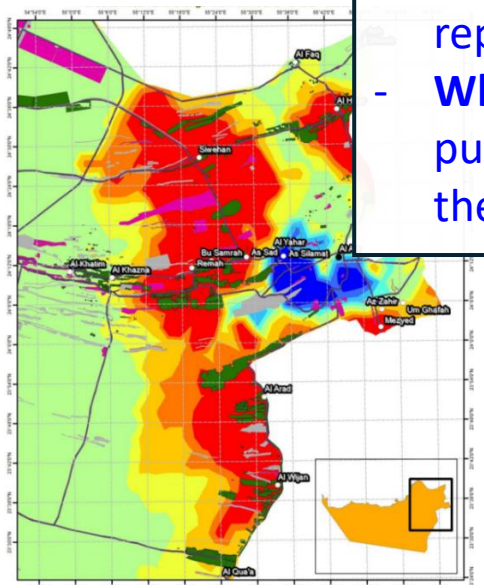


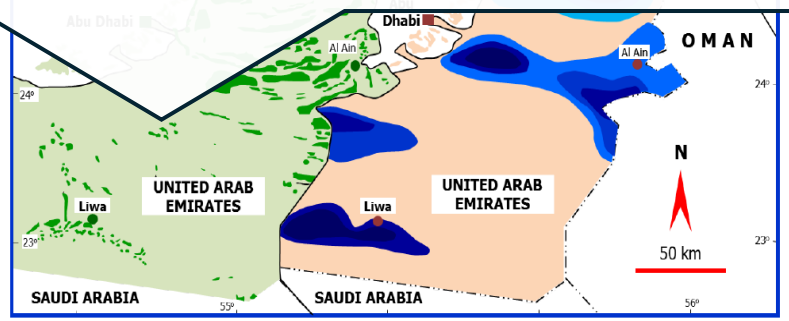

## Digital Twin for Groundwater Monitoring & Modeling

(AI powered virtual, dynamic, and interactive digital replica of a physical groundwater system, with continuous, real time data input from IoT sensors (water levels, salinity, and extraction rate, satellite data, …); various applications:

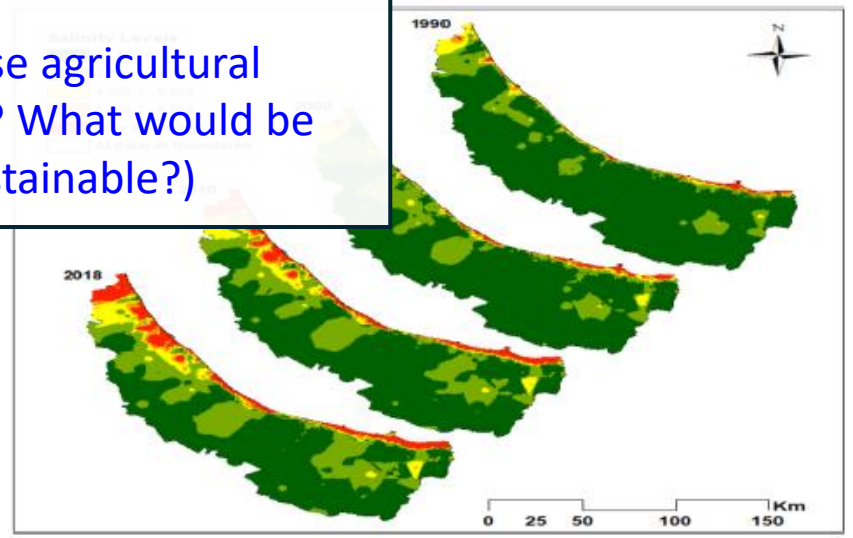
- **Identifying optimal pumping schedule** across hundreds of wells to meet demand while minimizing drawdown and saltwater intrusion;
- **A dashboard** shows the current groundwater water level and salinity at every monitoring well and provide alerts for set extraction rules
- **Finding optimal location** for a new recharge dam to maximize natural replenishment
- **What if?** scenarios analysis (e.g., what if we increase agricultural pumping by 20% in this region for the next 5 years? What would be the response of the aquifer in terms of salinity? sustainable?)

## Groundwater level decline in AD UAE, 2008-2010 (EA



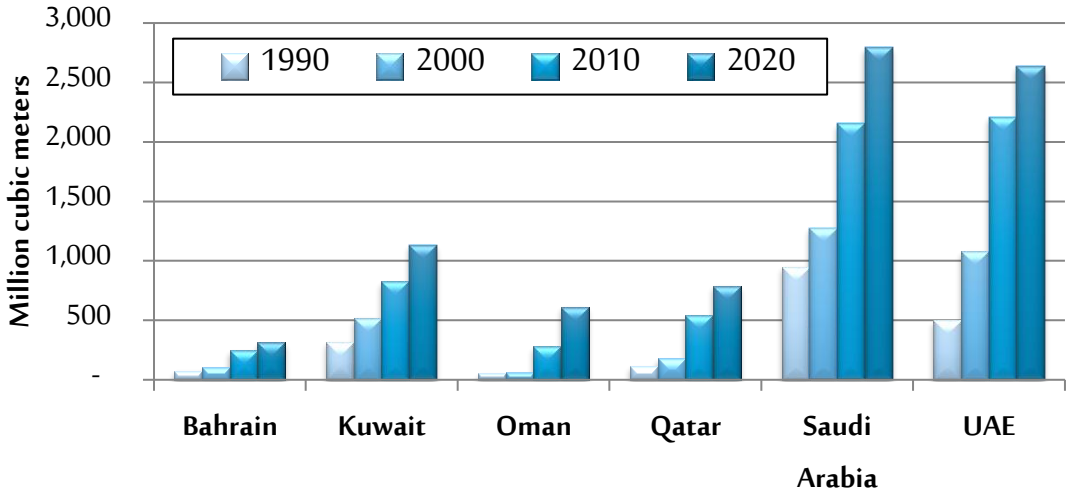

## …n in Albatinah region …libdeh, et al. 2021)



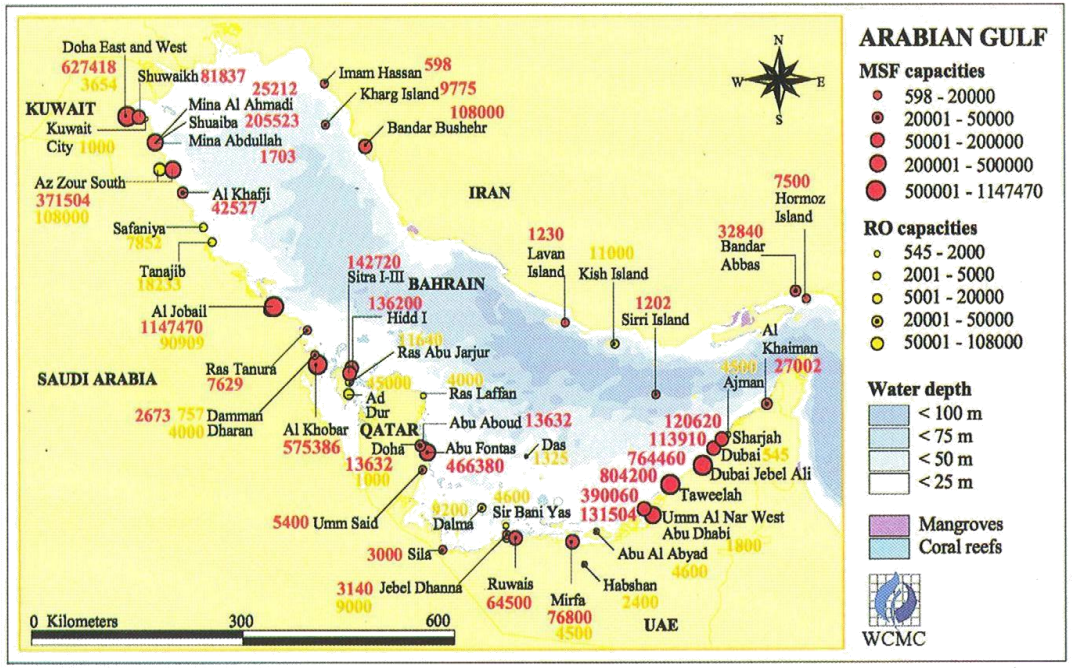
# Challenge 2: Massive Desalination Expansion, Meeting Municipal Demands & Associated Costs

- Heavy investment in desalination; >45% of world's desalination capacity, rate to continue
- Trends toward production privatization (to reduce cost) and membrane technology (to reduce cost and diversify energy input)

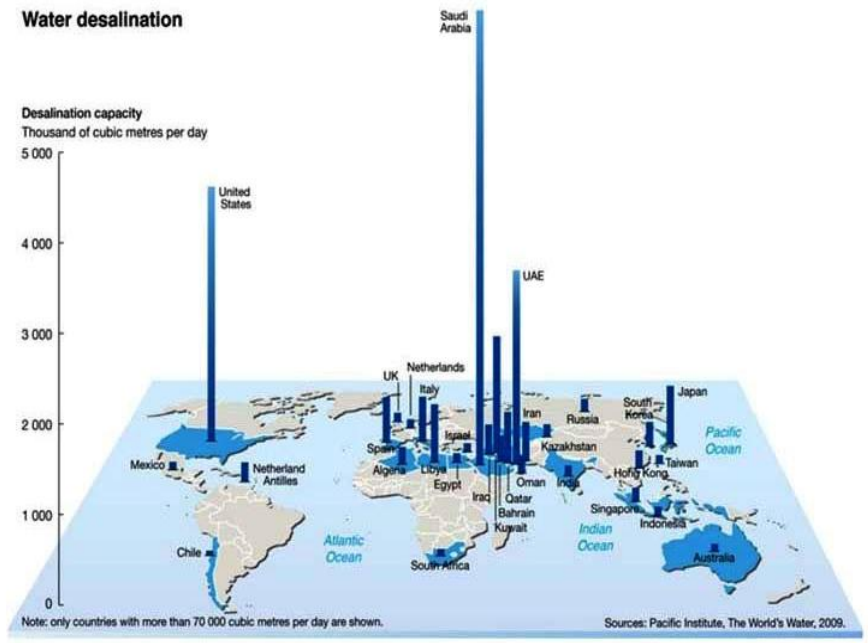
## Trends in Desalination Capacity in GCC, 1990-2020




## Desalination Plants in Arabian Gulf



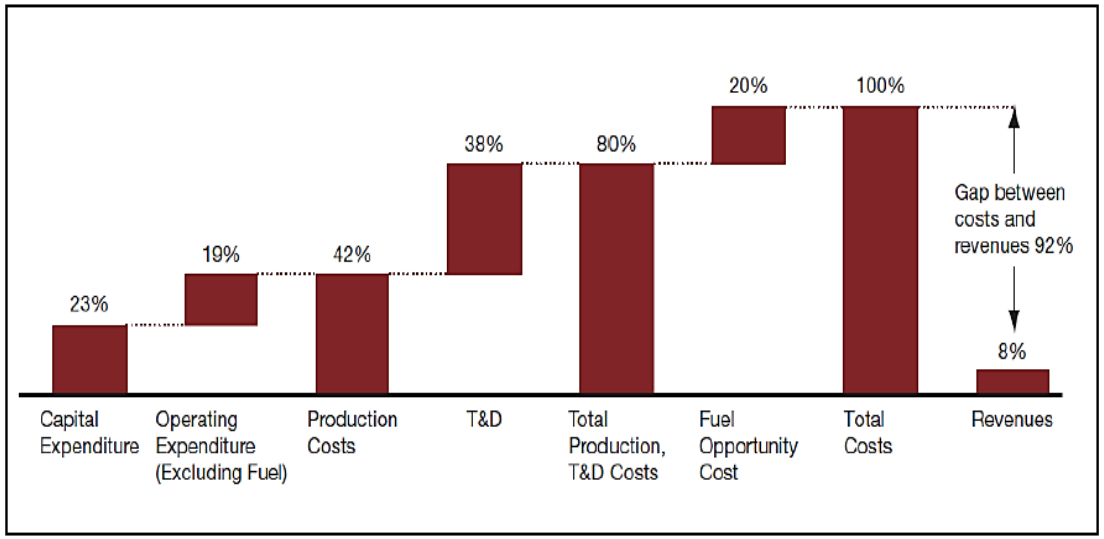

## Global Desalination Capacity by Country



# Cost of Municipal Water Supply

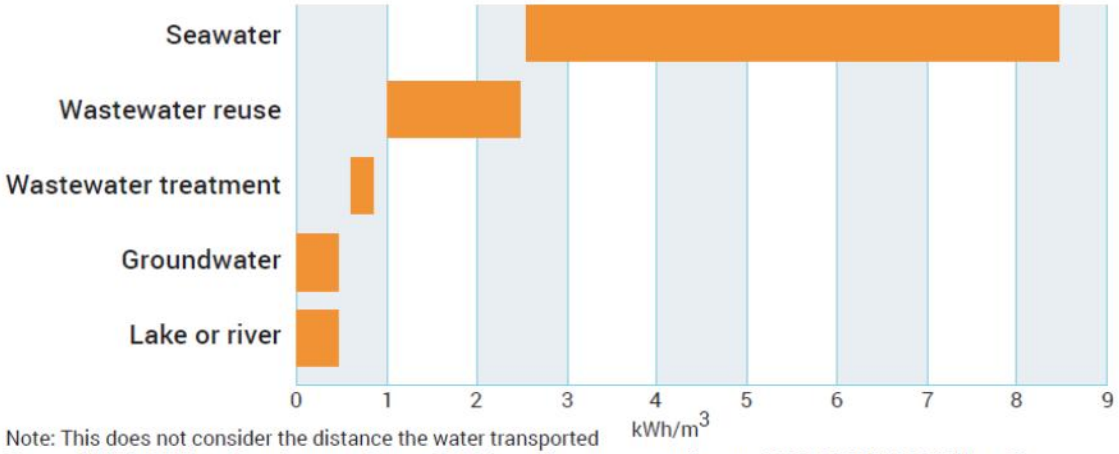
- **Financial** (high O&M, subsidies, low-cost recovery impacting financial sustainability of water utilities
- **Economic** (energy-intensive, high fuel opportunity cost)
- **Environmental** (GHGs emissions & brine and chemicals discharge to the marine environment)
- **Very limited added value to GCC economy** (imported technology, consumables, etc.)

## Average Cost of Water Supply and Subsidies in GCC




(Strategy&, 2014)

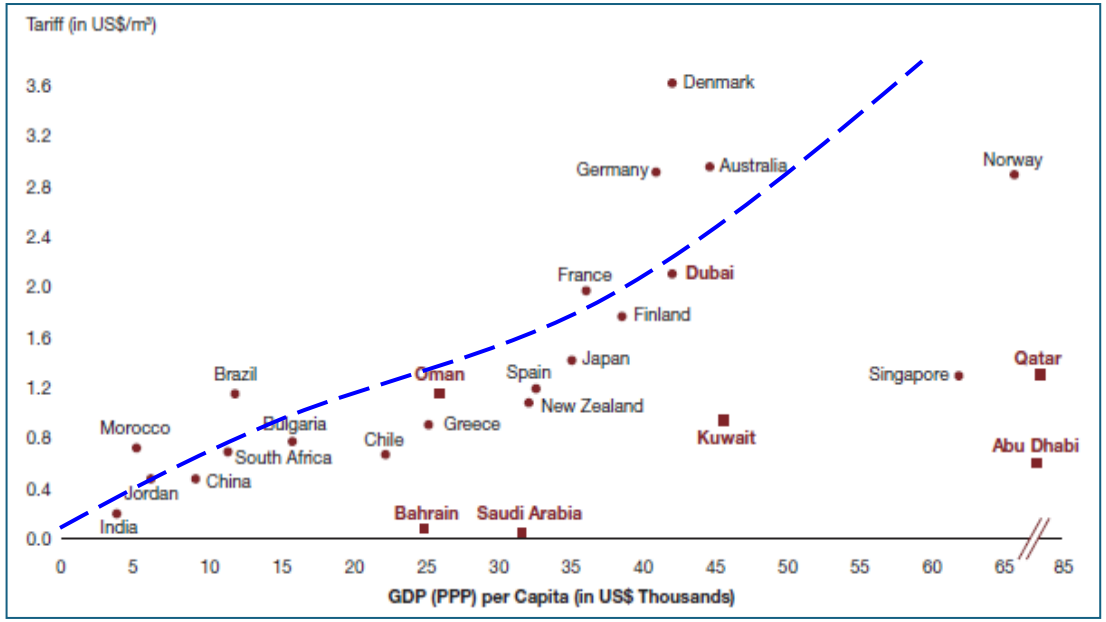
## Amount of Energy required to provide one cubic meter of water safe for human consumption from various water sources




Note: This does not consider the distance the water transported
Source: UN World Water Development Report, 2014 (unesdoc.unesco.org/images/0022/002257/225741e.pdf)

(UN Water, 2014)

## Water Tariff vs. GDP per capita



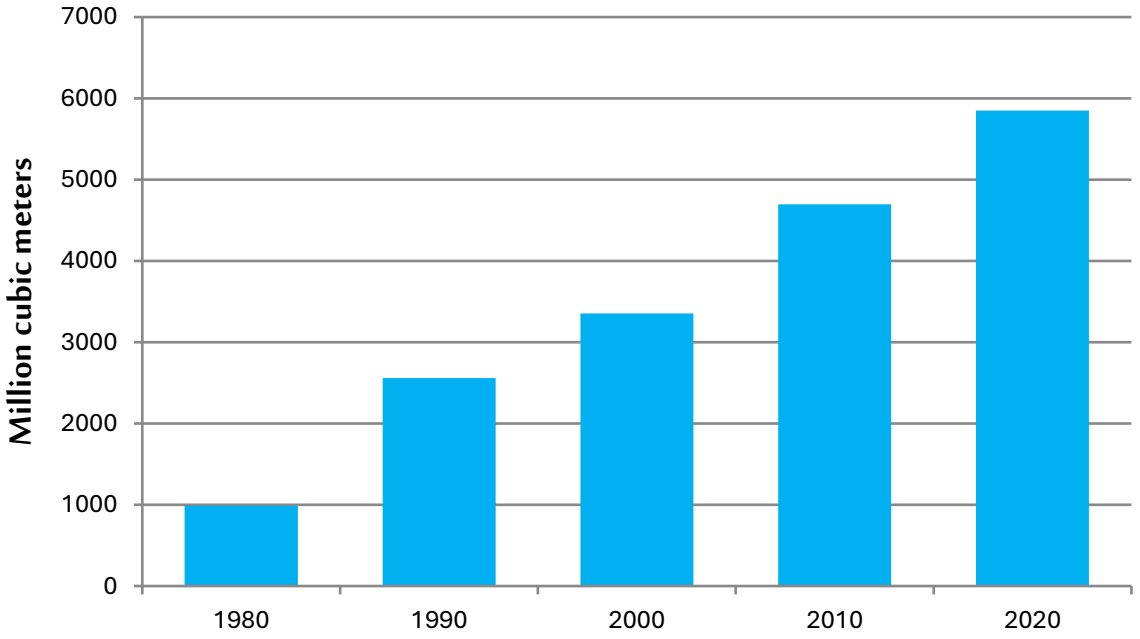

(Strategy&, 2014)

**ML Demand Forecast**
(predicting water demands more precisely using population, temperature, humidity, … e.g., by ANN)

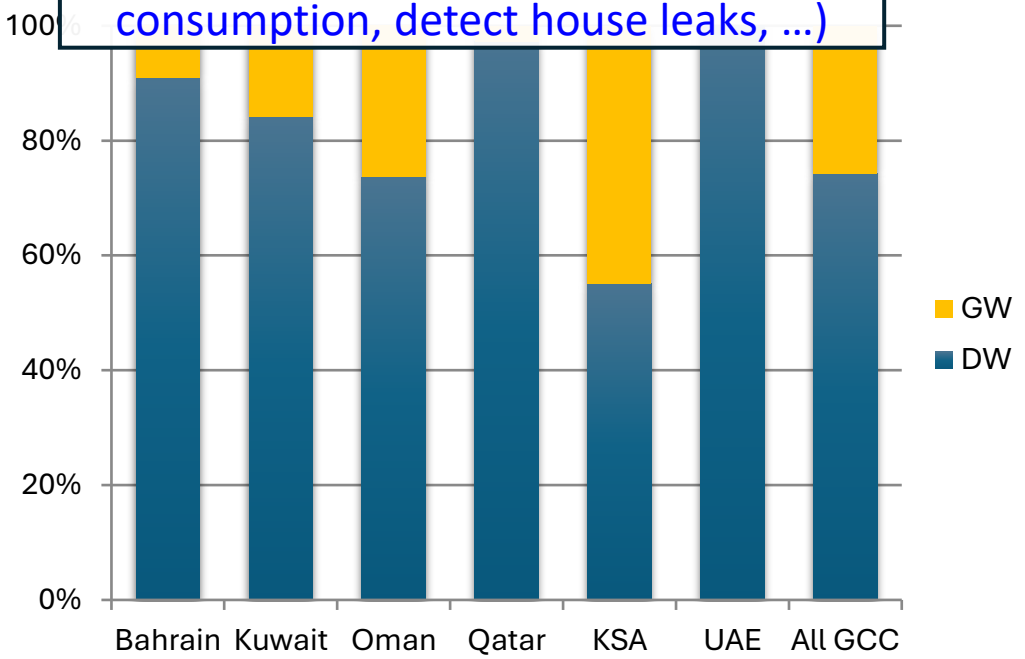
**Distribution Network O&M**
(space-time analysis of pressure/flow sensors to flag probable leaks and prioritize field inspections; e.g., DEWA smart water utility real-time monitoring of 13K distribution network with predictive analytics optimizing water distribution, reduced losses to 6%)

- Reliance mainly on desalination; GCC achieved almost 100% coverage for safely managed drinking water services (SDG6.1)
- Escalating municipal water demands due to rapid population and urbanization
- Exaggerated by water inefficiency on the supply side (network physical losses)
- Exaggerated by inefficient water use on the demand side (high per capita water use; >500 L/d in many countries)

**Municipal water consumption in GCC, MCM (1980-2020)**

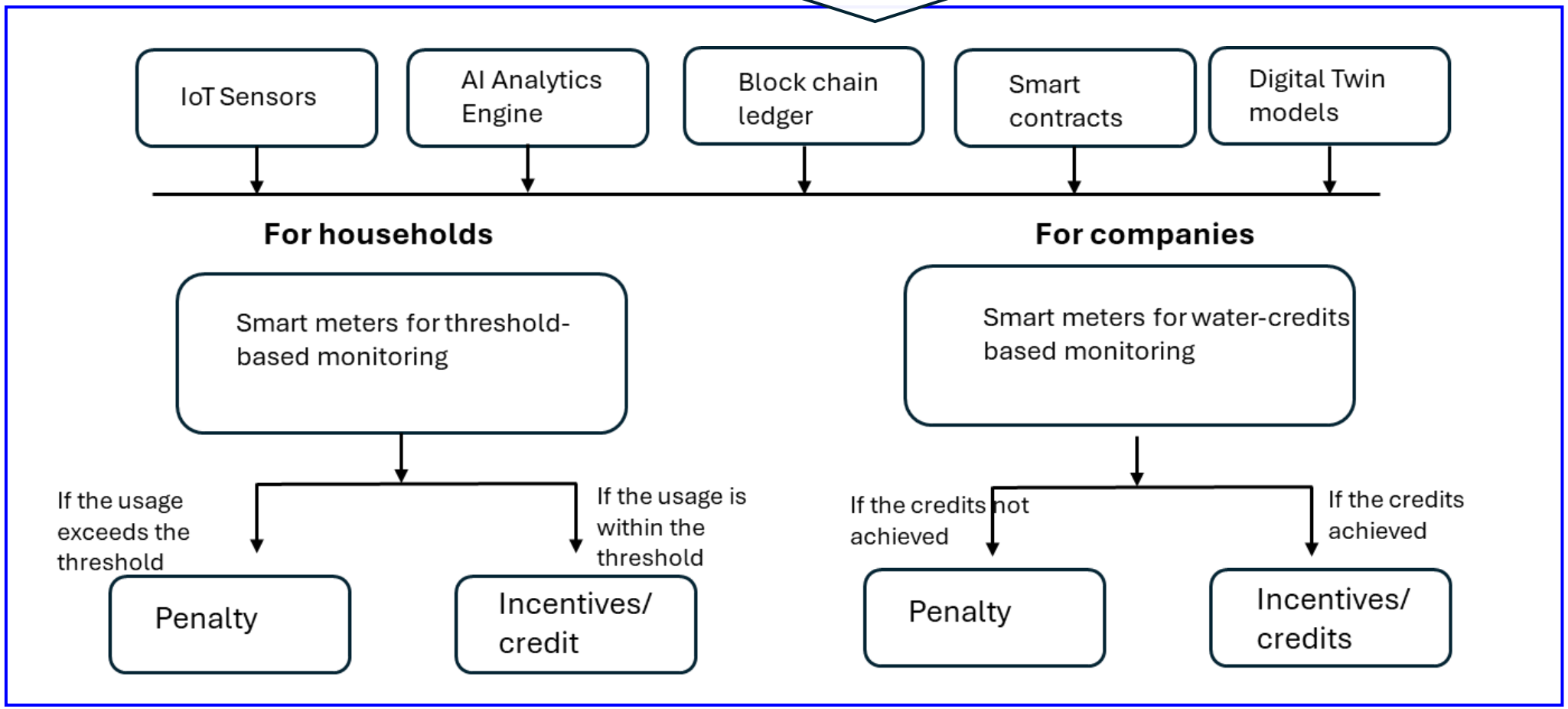



**Online Smart Meters**
(making users aware of their consumption, detect house leaks, …)



# Smart Water Contract

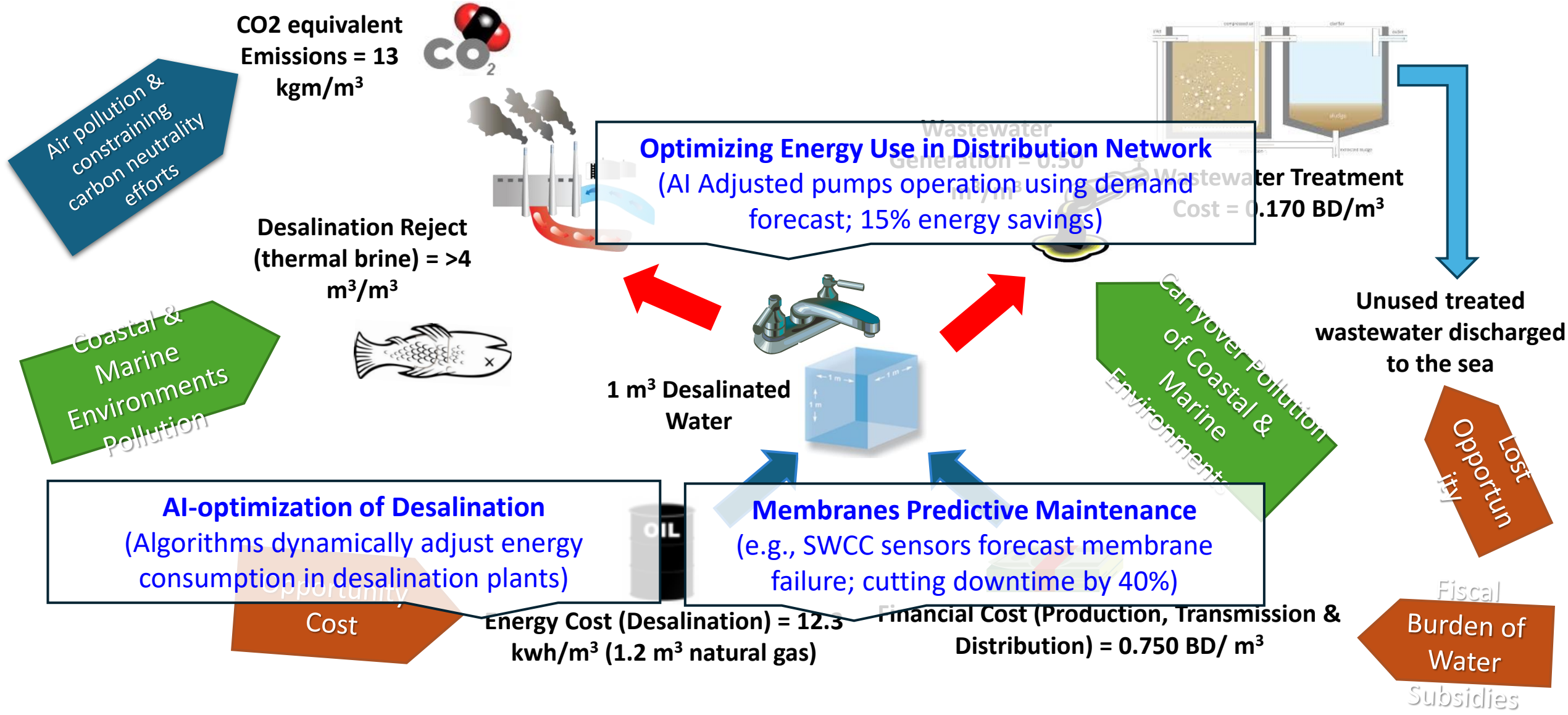
**AI-Driven Penalty and Credit Enforcement System**
(IoT sensors continuously track water use across households, feeding it into AI engines, with block chain ensure integrity and transparency of water use records, smart contracts impose penalties on households exceeding predefined consumption thresholds)




Jaykumar, Bouhoula, and Al-Zubari, in progress

# The Wider Cost of Municipal Water Supply Chain in the GCC

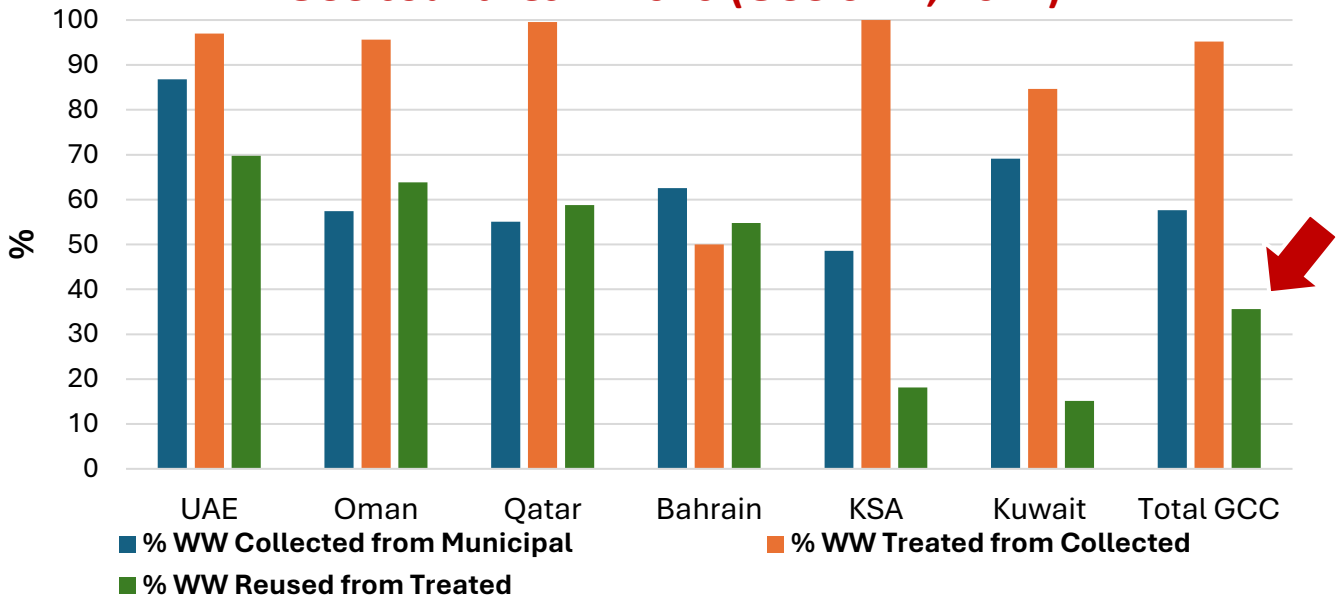
## Case Study: Kingdom of Bahrain



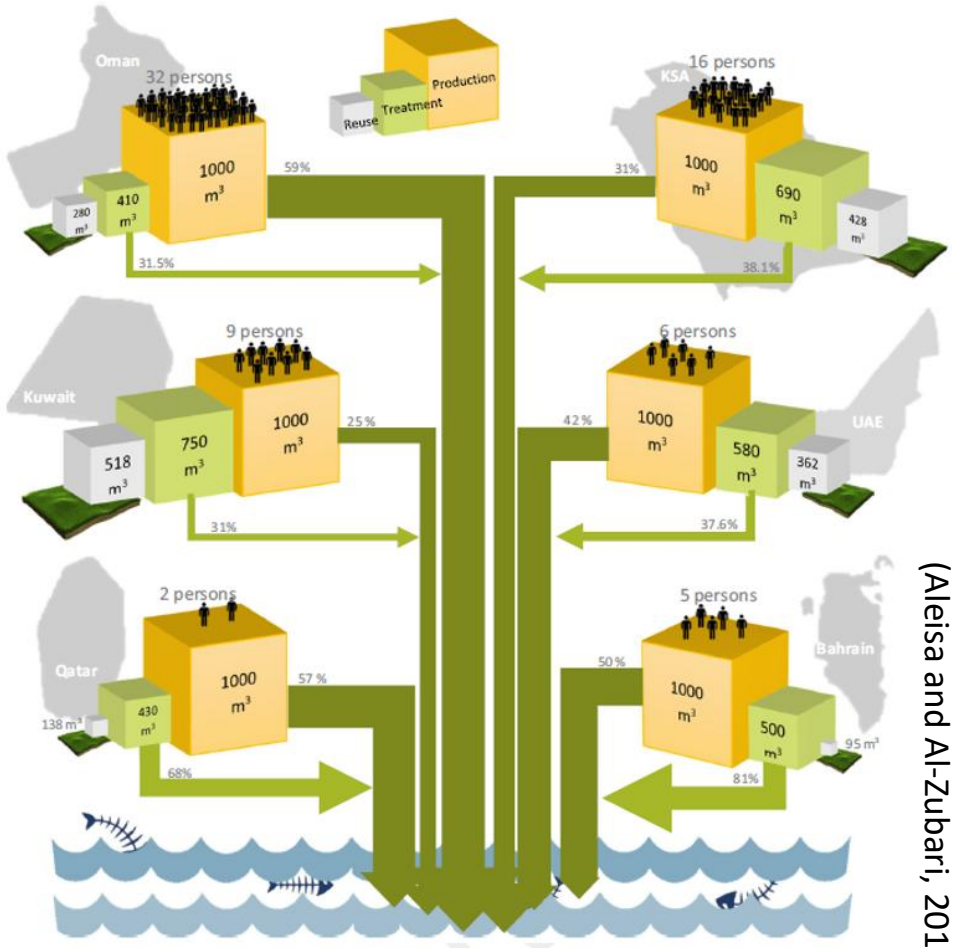
# Challenge 3: A Major Lost Opportunities: Inadequate Utilization of Municipal Wastewater

- **Reuse potential** of generated wastewater & sludge is **not fully developed** in many countries
- **Frequent Hydraulic loading** (lack of integrated planning with water supply), impacting environment (carryover) and quality of treated wastewater & reuse

**Percentages of collected wastewater, treated, and reused in GCC countries in 2020 (GCC-STAT, 2022)**




**Generation, Treatment and Reuse of 1000 $m^3$ of wastewater in GCC**



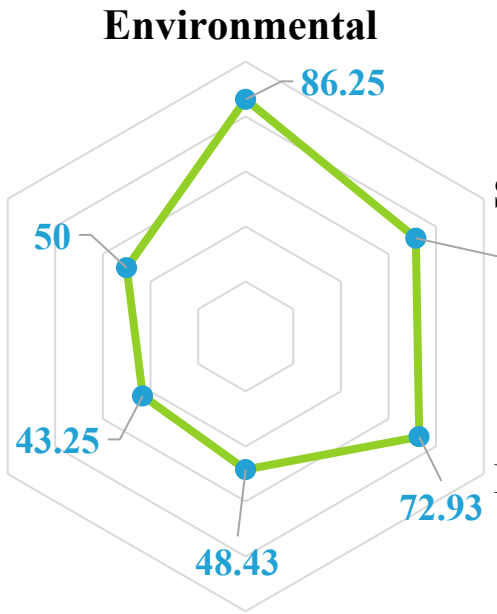

(Aleisa and Al-Zubari, 2017)

# Scores of the Dimensions of the Wastewater Sustainability Framework in the Kingdom of Bahrain

**Blockchain Traceability for Quality Control & Compliance**
(monitoring TWW quality from plant to farm to ensure compliance and confidence)

**Non-existence of stakeholders institutional structure for reuse**

**Wastewater Sustainability Framework**




**Public awareness & acceptance**

**Infrastructure Management, Collection Network O&M**
(Using ML analysis of historical data on infrastructure and infiltration/exfiltration (age, materials, etc..) to schedule maintenance)

**Infiltration and exfiltration to collection network**

**Public Health & Epidemiological Surveillance**
(AI use in analyzing viral loads in sewage providing early warning of outbreaks)

**Cost recovery & resources recovery**

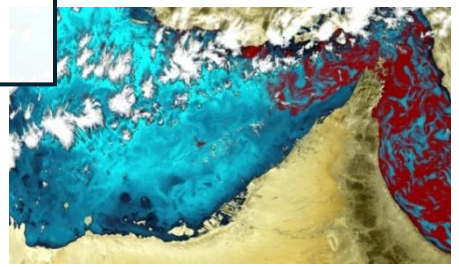
(Tashtoush, 2025)

## Challenge 4: High Vulnerability of Municipal Water Supply System

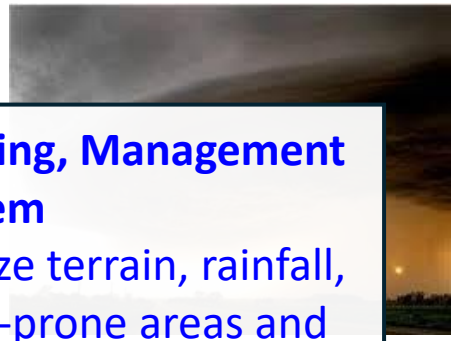
- **Threats to Desalination Plants:** Maritime pollution (e.g., nuclear, wastewater, oil and chemical spills, radiation); Natural disasters (e.g., hurricane, seawater flooding); Actual combat (e.g., targeting desalination facilities)
- **Threats to Water Supply System:** Power outage; Hacking of SCADA system; Intentional contamination of the domestic water supply
- Pandemics (e.g., COVID-19 human resources, spare parts and consumables)

**Emergency Response Plan AI-Optimization**
(AI generate and simulate thousands of potential emergency scenarios and response variations to identify the most robust and effective emergency plans and policies)

Oil Spills



HABs



Cyclones

**AI-Powered Urban Flash Flood Forecasting, Management & Dynamic Control System**
(Geo AI: Machine learning models analyze terrain, rainfall, and infrastructure data to predict flood-prone areas and optimize drainage systems, as well as issuing warning and direction to population for evacuation before impact)

## Challenge 5: Impact of Climate Change: Urban Water Flooding

- Increased frequency of intense rainfall events causing flooding in many GCC cities

# Conclusion 1

## Transformative Power of Emerging Technologies to Water Management in GCC

- The water sector in the GCC countries faces major challenges (resources depletion, high supply costs, and vulnerability), which demand a **transformative approach** to water management
- Emerging Technologies (AI, IoT, BC, QC, CS, …) has the potential to transform water supply chain system from a "**reactive**" to an "**optimized, predictive, and integrated**" system
- Emerging technologies and cutting-edge AI can be used effectively in water resources planning and management in "**diagnostic/Analysis, optimization/ Improvement, and Prediction**"
- To unlock the emerging technologies potential in the water sector, we need to **link water professionals and ICT professionals**

# Conclusion 2

## Water Education in the 4IR (Redefining the Water Scientist/Engineer)

- The skills required for water management have fundamentally changed; current education and traditionally acquired skills must keep pace
- **The 4IR Skill Set** (The **"Water Data Scientist"**):
  - **Data Literacy**: Understanding IoT, Application Programming Interfaces (APIs), and big data
  - **Computational Skills:** Python, machine learning, ANN, …
  - **Cyber-Physical Systems:** Managing digital twins and AI models
  - **Systems Thinking:** Integrating technology in the Water Supply Chain with policy and economics
- **The Gap:** except for few, current university curricula are lagging behind these needs

# Recommendations

## Embedding 4IR in Water Education & Training

- **Curriculum Modernization**: Integrating modules on AI, Geo AI, IoT, and data analytics into water engineering and science degrees
- **The "Living Lab" University**: Using the GCC's own water infrastructure (dams, desalination plants, networks, …) as real-time data sources for student projects and research (or providing data for case studies)
- **Immersive Learning with Digital Twins**: Using groundwater and urban water models as advanced teaching simulators. Students can test management strategies in a risk-free virtual environment
- **Professional Upskilling**: Short courses/micro-credentials for current water professionals on the application of emerging technologies and managing smart water systems

# Thank You!