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Smart Water Networks and IoT Integration in Saudi Urban Water Distribution

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Abstract: Saudi Arabia faces acute water scarcity, with virtually no natural surface water and one of the world's highest per-capita water use rates (≈263 L/person·day in 2019). To meet demand, the Kingdom relies heavily on desalination (60% of supply) and non-renewable groundwater, making efficient water management both an economic and environmental imperative. Saudi Vision 2030 explicitly calls for "promoting the optimal use of our water resources by reducing consumption and utilizing treated and renewable water". Smart Water Networks (SWNs) – water distribution systems instrumented with IoT sensors, communication links, and data analytics – offer a key solution. By enabling real-time monitoring, leak detection, demand forecasting, and automated control, SWNs can dramatically reduce non-revenue water and energy use, supporting Vision 2030 goals. For example, smart metering pilots have halved water theft in some cities and can reduce the carbon footprint of supply through conservation . This review surveys state-of-the-art SWN architecture, environmental impacts, and Saudi deployments. It covers sensors and communication technologies (pressure, flow, quality sensors; LoRaWAN, NB-IoT, satellite, etc.), data platforms and protocols (cloud analytics, MQTT, OPC-UA), and links these to Saudi initiatives (smart metering by the National Water Company, pilot leak-detection projects, NEOM's water strategy, etc.). Emphasis is placed on conservation, energy efficiency, and sustainability in line with Vision 2030.

Keywords: Smart sensors; Water networks; IoT; Water distribution; Saudi Vision 2030

1. Smart Water Networks: Overview and Motivation

A Smart Water Network integrates physical water infrastructure with digital monitoring and control. In practice, SWNs combine devices such as smart water meters, pressure and flow sensors, and actuators (valves, pumps) with IoT communications and data analytics. This enables continuous monitoring of flow, pressure, and quality, automated detection of leaks or anomalies, and demand-side management. The benefits are well-documented: large water losses (often 30% or more of supply) can be quickly identified and mitigated, operational efficiency is improved, and resource use is optimized. For instance, installation of smart meters in Alicante, Spain, led to an 80% drop in illegal consumption over four years. Moreover, by saving water, SWNs indirectly reduce energy and emissions: Monks et al. note that each liter saved also cuts the carbon footprint of treatment and distribution. In an era of growing urbanization and climate stress, such resilience is vital. Smart networks are now core to many modern water utilities. They represent a shift from conventional periodic manual readings and reactive fixes toward continuous, data-driven management. This can include consumer engagement (apps showing usage), predictive maintenance (forecasting pipe failures), and integrated management of urban water demand and supply (even coupling water-energy grids).[1-8]

Key Drivers: High non-revenue water (leakage/theft), aging infrastructure, regulatory mandates, and consumer demand for transparency all drive SWN adoption. Saudi Arabia's aggressive urban growth and energy-water nexus (desalination is energy-intensive) create strong incentives.[9-12] As of 2016 Saudi Arabia (via the National Water Company) was the first in the region to pursue large-scale smart metering.[13]

2. Technical Architecture of Smart Water Networks

A SWN consists of (a) sensor/actuator devices in the field, (b) communication layers linking them, (c) data management platforms, and (d) integration protocols tying it all together. Figure 1 (below) schematically shows common components: field sensors and meters collect data, which is transmitted via IoT networks (LPWAN, cellular, fiber, etc.) to cloud or SCADA platforms where analytics run, and actionable insights or controls are relayed back.[14-16]

3. Sensors and Field Devices

The measurement layer of a SWN comprises diverse sensors and smart devices. Flow meters (typically ultrasonic or magnetic) measure volumetric flow in pipes. Pressure sensors are critical: abrupt pressure changes often indicate leaks or bursts . For example, high-frequency pressure and acoustic sensors have been extensively studied to detect and locate leaks. Water quality sensors (for pH, turbidity, dissolved oxygen, chlorine residual, conductivity, etc.) monitor potability and catch contamination; advanced systems even include sensors for pollutants or microbiological parameters. Level sensors in reservoirs and tanks ensure storage is optimally used. Smart valves and actuators allow remote control (e.g. closing a valve on detection of a leak). At consumers' premises, smart water meters (often ultrasonic) continually register usage and send readings; these have replaced mechanical meters in Saudi projects. As described by the Saudi National Water Company (NWC), its smart meters "read water consumption by ultrasonic waves or electromagnetic waves" and automatically send readings every 15 seconds to data hubsnwc.com.sa. Such granular data enables near real-time monitoring of the network.[17-22]

Data from sensors is typically digitized by a small controller (microprocessor) at the device and then forwarded. A recent review notes that IoT water applications use microcontrollers, embedded languages, sensors, and communication modules as building blocks. In practice, sensors are chosen for low power and durability.[23-24] Many modern water sensors are low-cost, low-power MEMS devices suitable for battery operation. For example, pressure and flow sensors can now run on micro-watt levels, enabling multi-year battery life for remote wireless nodes.[25-26] As Okoli et al. summarize, sensors in SWNs range from "flow rate, pressure, temperature, residual chlorine, water pH, water conductivity, [to] turbidity" and more . In Saudi Arabia's arid climate, robust sensors (e.g. with corrosion-resistant housing) are needed; many reported deployments use industrial-grade meters meeting international standards, as certified by NWC. Table 1 summarizes key sensor types and purposes.[27-30]

Device / Sensor	**Measurement**	**Typical Use**
Smart Water Meter	Water volume/flow	Household/residential consumption; frequent readings (e.g. every 15s)[31]
Pressure Sensor	Pipe pressure	Leak/burst detection; zone monitoring (installed at strategic nodes)[32]
Flow Meter	Flow rate	Bulk flow measurement; network balancing; leak detection (flow drops)[33]
Valve Actuator	Flow control (open/close)	Automated shutoff on leak or block; remote control of flows[34]
Level Sensor	Reservoir/tank level	Storage management; detect overflows or

Device / Sensor	Measurement	Typical Use
		drying; process control[35]
Quality Sensor	pH, turbidity, chlorine, DO, conductivity, etc.	Water quality monitoring; compliance, contamination detection[36]
Telemetry Node	Multi-sensor hub	Aggregates and transmits data from multiple sensors to network[37]

4. Communication Technologies

- Connecting field devices to data platforms requires a mix of communication technologies. SWNs span both urban (dense) and rural (sparse) areas, so solutions vary. Common wireless IoT networks include:
- LoRaWAN (Low-Power Wide-Area Network): Many studies highlight LoRaWAN for SWNs due to its long range (2–15+ km) and low power. LoRaWAN uses a star topology: sensor nodes send uplink packets to gateways, which forward to cloud servers . In one case study, LoRaWAN was shown to reliably transmit pressure and flow data for leak detection in a housing complex. LoRaWAN supports battery-powered sensors with years of life. Its range (urban ≈2–5 km, rural up to 15–45 km) makes it suitable for dispersed networks.[38-40] NB-IoT and LTE-M are alternatives; NB-IoT (a cellular LPWAN) offers higher data rates and native support in phone networks, but typically higher power use and subscription fees. Utility choice depends on coverage and cost.[41-42]
- Cellular (3G/4G/5G): In urban networks, existing cellular networks (NB-IoT, LTE-M) can carry IoT data. The 5G era brings potential for ultra-reliable low-latency communication, but deployments in water are still nascent. Notably, a survey found that none of the existing SWN projects in literature used 5G yet . However, cellular provides ubiquitous coverage and high data rates (useful for video or large data), at the expense of power and cost.[43-45]
- Wi-Fi and Mesh: In local zones (e.g., inside a treatment plant or near office buildings), Wi-Fi or ZigBee mesh networks may connect sensors to a local gateway. These can support short-range, high-bandwidth links but are uncommon for large outdoor pipes.[46]
- Satellite IoT: For remote areas with no ground network (e.g. desert sites or far-flung villages), satellite LPWAN is emerging. A notable Saudi pilot used Myriota's ultra-low-power satellite network to connect smart meters in remote locations. Since satellites have global coverage, this enables monitoring of isolated pipelines or tanks. The cost and data rates are limited (narrowband messages), but for infrequent meter readings or alarms it is feasible.[47]
- Wired (Fiber/PLC): Many large utilities also use wired links. Fiber-optic backbones connect major reservoirs and treatment plants. Power-line communication (PLC) can send data over the power grid to remote nodes. Traditional SCADA systems often rely on hardwired links (RS-485, ethernet). In hybrid setups, wireless IoT often coexists with legacy wired infrastructure: e.g., flowmeters might send data via fiber to a central server.[48]

Comparison of IoT Links: Table 2 summarizes typical IoT comms for water networks.

Table 2: Communication Technologies for Smart Water IoT

Technology	Range	Data Rate	Power Use	Notes

Technology	Range	Data Rate	Power Use	Notes
LoRaWAN	Kilometers (5–15 km)	Low (kbps)	Very low	Long-range, low-power, good for battery sensors; used in housing complexes.
NB-IoT	Cellular coverage (km)	Low (kbps)	Low to moderate	Licensed LPWAN; robust connectivity in cities; higher cost.
LTE-M/5G	Cellular (wide)	High (Mbps)	Higher	High bandwidth, low latency; emerging use (not yet in many water projects).
Wi-Fi/ZigBee	Tens of meters	Moderate (Mbps)	Moderate	Short range; used inside plants or offices.
Satellite (e.g. Myriota)	Global (km)	Very low (bps)	Low-power nodal	Connects remote sites (no cellular); demonstrated by NRIW project.
Ethernet/Fiber	Tens of km+	Very High (Gbps)	High (infrastructure)	For backbone networks; provides reliable links for SCADA and cloud connectivity.

Modern SWN designs often use a mix: dense urban areas may use LoRaWAN plus fiber, while remote branches use NB-IoT or satellite. For example, García-Baigorri et al. describe an architecture with nodes using LoRaWAN to reach a local gateway, which then connects via LEO satellite to the cloud. This hybrid ensures connectivity even over wide areas.[49]

5. Data Platforms and Analytics

Collected sensor data must be aggregated, stored, and analyzed. Today's SWNs leverage cloud or edge-computing platforms running advanced analytics. Data flows from IoT gateways (via internet or private networks) to central databases. Commonly, utilities extend or replace legacy SCADA (Supervisory Control And Data Acquisition) systems with IoT-enabled platforms. Modern platforms ingest high-frequency readings, apply machine learning or statistical models, and visualize status for operators.[35,48]

Key functionalities include:

- ***Real-time Monitoring and Visualization:*** Dashboards show live flows, pressures, and quality indices across the network. Outliers trigger immediate alerts (e.g. leak detected).
- ***Leak Detection Algorithms:*** High-frequency data enables automated leak detection. Techniques range from simple thresholding (pressure drop) to complex model-based methods. Recent reviews note many ML methods (ANN, SVM, decision trees) are used for leak classification. Data-driven ML models can learn normal patterns and flag anomalies.[24]
- ***Demand Forecasting:*** By analyzing usage data, platforms forecast future water demand by zone. This aids pump scheduling and reservoir management.[49]
- ***Energy Optimization:*** Some analytics calculate pump schedules to minimize energy cost or use of desalinated water when electricity prices are high.[33]
- ***Digital Twin / Simulation:*** A digital twin is a live hydraulic model of the network. Sensor data continually updates the model, enabling "what-if" analysis (e.g. simulating a valve closure or demand surge). Studies highlight the use of EPANET or custom simulators integrated with IoT data.[50]
- ***Decision Support:*** Outage management, pipe replacement planning, and resource allocation can be optimized using analytics on the collected data.[26,39]

Integration with GIS (geographic information systems) is also common: data points (meters, sensors) are mapped onto spatial layouts, aiding geo-visualization and analysis. Automated billing and customer portals are enabled by linking meter data to customer accounts.

Platforms often use open IoT protocols. Commonly, sensors push data via MQTT or HTTP to a message broker or REST API. Standard MQTT brokers and RESTful web services allow scalable ingestion. Interoperability protocols like OGC's SensorThings API or OPC-UA (for industrial devices) can be used for standardized data exchange. As an example, the reviewed layered meter architecture uses a web service API to link the smart meter's communication layer to cloud databases and user interfaces. In practice, many SWN projects use cloud platforms (e.g. AWS IoT, Azure IoT) combined with custom SCADA front-ends.[15]

In summary, the technical architecture of SWNs in Saudi cities typically comprises:

- ***Sensing layer:*** Field sensors (metering, pressure, flow, quality) plus smart actuators.
- ***Communication layer:*** Mixed IoT networks (LoRa, NB-IoT, cellular, satellite, etc.) to transport data.
- ***Data/Platform layer:*** Cloud or on-premises IoT platforms for storage, analytics, ML, and dashboards.
- ***Integration layer:*** APIs and protocols (REST/MQTT, OPC-UA, etc.) connecting sensors, analytics, and end-user applications.

6. Environmental Impact and Sustainability

Smart water networks yield significant environmental benefits in three main areas:

Water Conservation and Reduced Non-Revenue Water

A central goal is water conservation. By detecting leaks and unauthorized use quickly, SWNs drastically cut losses. Worldwide, leaks can waste 20–30% of supply (even 50–70% in poorly maintained systems). Smart sensing mitigates this. In Saudi pilots, advanced leak-detection tech was deployed to target non-revenue water (NRW) in Buraydah. Globally, utilities report 15–25% reductions in NRW after smart meter rollouts and leak programs. For example, an Alicante study reported water theft down 80% following smart meter installation and monitoring . Decreasing NRW conserves precious treated water and extends supply sources; each cubic meter saved is a direct gain toward Vision 2030's target of reduced consumption.[32,39]

Energy Efficiency and Carbon Footprint

Water pumping and treatment consume large amounts of energy. In Saudi Arabia, 97% of the population has potable water, largely from desalination. Desalination is energy-intensive; historically SWCC's thermal plants used ~15 kWh/m^3. The Kingdom is transitioning to more efficient processes (e.g. RO) to cut desal energy by ~80%, but distribution and pumping remain significant energy draws. By saving water (via leak reduction and demand management), SWNs indirectly save energy. Monks et al. highlight that smart metering's water savings translate into lower carbon footprint for the water supply . Additionally, optimized pumping schedules (e.g. pumping at off-peak hours or when renewable electricity is available) are possible with smart controls. Ultimately, SWNs contribute to the Vision 2030 sustainability goals by minimizing wasted water and the associated energy per m^3 delivered.[9,16]

Sustainability and Vision 2030 Alignment

Smart networks directly support Saudi Vision 2030's environmental sustainability pillar. Vision 2030 explicitly aims to "safeguard water security" and "conserve natural resources through optimal utilization". SWNs embody optimal utilization by ensuring water reaches users with minimal loss. Moreover, programs like the SWCC's decarbonization plan (net-zero by 2060) envision coupling digital water and energy management. For example, NEOM's water strategy (a Vision 2030 flagship) targets 100% wastewater reuse and smart sensors to achieve a "water-positive" utility. In sum, IoT-driven water networks are enablers of green urban growth: they reduce extraction pressure on scarce aquifers, limit desalination demands, and enhance resilience against drought. As Lamrini et al. note, integrated sensors and analytics in SWNs "enhance water conservation, lower energy costs, and boost the water supply's resilience".[28]

Key Environmental Outcomes (Illustrative):

- ***Leakage reduction:*** Smart meters and sensors can cut NRW by ~10–20% or more.
- ***Water savings:*** End-use monitoring and consumer feedback often reduce per-capita use by ~10% .
- ***Energy/cost savings:*** Each percent saved in water can proportionally reduce pumping costs; for desalination plants, efficiency gains like SWCC's RO conversion (15→3 kWh/m^3) complement these savings.[11]

7. Real-World Deployments in Saudi Arabia

While SWN concepts are global, we focus on Saudi-specific cases:

While SWN concepts are global, we focus on Saudi-specific cases:

- ***National Smart Metering (NWC):*** The Saudi National Water Company (NWC) has rolled out smart water meters nationwide. As of [circa 2023], ~2 million smart ultrasonic meters are installed and integrated into billing systems, covering 94.6% of targeted customers. These meters send 15-second consumption readings via proprietary wireless networksnwc.com.sanwc.com.sa. NWC reports that ~1.3 million of these are communicating via fixed wireless hub. The smart meter deployment alone is one of the largest in the region, enabling near-real-time usage tracking for consumers and operators. It provides the data backbone for analytics (e.g. nightly demand curves, anomaly detection).[17,42]
- ***Leak-Detection Pilots:*** Localized projects demonstrate SWN tech in action. For example, in September 2024 the city of Buraydah (Qassim region) ran a pilot with WI.Plat's advanced acoustic leak sensors. Over a week, field teams (with local partner IAC) used the IoT-enabled leak detectors to survey ~3,800 meters, identifying and mapping leaks in the distribution system. The project trained local staff in the technology, aiming to reduce Buraydah's non-revenue water. Though a private press piece, this case illustrates Saudi utilities' interest in AI/IoT leak management. Similarly, Xylem and other vendors offer field leak-detection services for Saudi utilities (screening pressure zones, inserting smart sensors), though academic details are scant.[44]
- ***Satellite IoT in Remote Areas:*** To serve rural or difficult-to-reach zones, Saudi agencies trialed satellite connectivity. Myriota (an Australian IoT-satellite firm) reports partnering with the Saudi telecom regulator (CST), STC, and local integrator Giza Systems to install satellite-connected smart meters in

remote locations for the Ministry of Water (MEWA). These meters, fitted with Myriota's ultra-low-power modules, send hourly readings via Low Earth Orbit (LEO) satellites to the cloud . This case (late 2023) shows innovation: even in areas with no cell signal, meter data can be reliably gathered. The proof-of-concept remains active, and further scale-up is planned.[47]

- ***Smart City Projects:*** Ambitious developments are embedding SWNs from the start. NEOM, the futuristic megacity, is designing its water system with full IoT integration. Plans call for "smart sensors to reduce water losses" across NEOM, along with 100% treatment/reuse and renewable desalination. While NEOM is still under construction, its strategy (as stated by Itron's Chief Engineer) highlights IoT as key to achieving a "circular economy" for water. Other Saudi smart-city zones (e.g. King Salman Park in Riyadh) also plan IoT-managed water supply networks, though details are emerging.[50]

- ***Agriculture and Irrigation:*** Water management in agriculture is critical in Saudi Arabia. IoT systems (soil moisture sensors, automated valves) for irrigation indirectly affect urban supply by reducing agricultural abstraction. Projects at KAUST and elsewhere have developed IoT irrigation controllers that cut farm water use, aligning with resource sustainability. While outside strict "urban distribution", these efforts relieve overall demand pressures.[27]

Table 3 summarizes notable Saudi smart water initiatives:

Table 3: Examples of Smart Water Deployments in Saudi Arabia

Project/Location	Focus/Tech	Description/Outcome	Source
National Smart Meter Rollout (Saudi)	Ultrasonic smart meters, fixed wireless networks	~2 million meters installed since 2016; ~94.6% coverage of customers; automatic 15s reading updatesnwc.com.sanwc.com.sa; enables remote billing and monitoring.	NWC/official
Buraydah Leak-Detection Pilot	Acoustic IoT leak sensors	Pilot (Sept 2024) in Qassim region using WI.Plat sensors and AI; trained local teams; aimed at reducing non-revenue water_. Result: identified multiple leaks, demonstrating tech viability.	WI.Plat case study
Myriota Satellite Smart Meters	Satellite IoT (LEO, ULPM)	Cohort of smart water meters in remote areas using low-power satellite connectivity. Live meters transmit usage where cellular is absent_. Demonstrates connectivity in rural zones.	Myriota (press)
NEOM Smart Water System	IoT sensors, circular design	Fully integrated planning: renewable desalination, 100% reuse, and IoT sensors to minimize losses. Strategy	NEOM interview

Project/Location	Focus/Tech	Description/Outcome	Source
		expects high efficiency and net-positive water supply.	
Xylem Leak Detection	Mobile leak detection teams	Xylem (and others) offer condition assessment and temporary IoT deployments to screen networks for leaks (e.g. ground microphones, AQUALAB® monitors) across Saudi utilities. Achieved reductions in targeted test areas.	Industry (Xylem)

These real-world examples show Saudi Arabia’s commitment to smart water technology, from national-scale metering to focused pilots. They align with the Kingdom’s National Water Strategy, which emphasizes innovation and efficiency to meet Vision 2030 objectives.

8. Challenges and Future Directions

Despite progress, implementing SWNs faces challenges: high capital costs (smart meter devices, network infrastructure), interoperability among vendors, data management complexity, and cybersecurity risks. Skilled workforce training is needed (e.g., leak-detection pilots included local training). Desert climate and vast geography pose harsh conditions for devices and networks. However, Saudi initiatives are investing heavily. Research directions include machine-learning enhancements for leak prediction, digital twins for proactive management, and integration of renewable energy (smart pumping aligned with solar power).[21,35]

Vision 2030 also drives a circular economy perspective: blending SWNs with wastewater reuse and stormwater capture. IoT sensors now monitor reclaimed water systems. The emerging Saudi Center for Global Water (announced in 2023) will likely incubate advanced IoT solutions for desalination, distribution, and reuse.

In summary, smart water networks, powered by IoT, are key to Saudi Arabia’s urban water future. They offer end-to-end visibility and control that can stretch scarce water resources and meet sustainability targets. Ongoing projects and research (in both academia and industry) continue to expand the technology frontier, adapting it to Saudi needs. By combining cutting-edge sensors, robust communication (including novel satellite IoT), and big-data analytics, Saudi cities can build more resilient and efficient water distribution systems that serve Vision 2030’s goals.[37]

9. Conclusions

Smart water networks, underpinned by IoT, represent a transformative approach to urban water distribution. Technical architectures typically involve diverse sensor arrays (flow, pressure, quality) coupled via LPWAN (LoRaWAN, NB-IoT, satellite) to data platforms running advanced analytics. These networks directly address Saudi Arabia’s water scarcity and sustainability challenges by reducing losses (e.g. via smart meters that cut theft by 80%) and improving energy efficiency in pumping/desalination. They also align with Vision 2030’s mandate for optimized resource use and environmental stewardship.

Recent deployments—from the NWC’s national smart metering to pilot leak-detection projects in Buraydah, and satellite-based monitoring in remote zones—demonstrate practical progress. Emerging applications in new developments like NEOM further highlight the potential of integrated smart water grids. While challenges remain (integration with legacy SCADA, cybersecurity, etc.), the trajectory is clear: Saudi Arabia is leveraging IoT in water distribution as a cornerstone of its urban infrastructure modernization. The reviewed literature and case studies suggest that continued innovation—particularly in data analytics and system integration—will yield even greater gains in conservation and efficiency, helping the Kingdom achieve its ambitious sustainability targets.

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