RURAL WATER SUPPLY

Smart, scalable, and ready for the field: A digital operator for rural water plants

In many parts of South Africa, the challenge of delivering safe drinking water is not a matter of availability – it is a matter of operational control. Rural water treatment plants often face equipment failures, poor-quality monitoring, and limited oversight. These weaknesses are exacerbated by financial constraints, staff shortages, and an increasing compliance burden. A project funded by the Water Research Commission aims to change that. Article by Kim Trollip.

The Smart Water Operations Platform (SWOP) is a frontier-technology solution supporting rural and decentralised water treatment systems. Developed by a multidisciplinary team of engineers and researchers, it acts as a low-cost, autonomous digital 'operator', a plug-and-play supervisory system that can monitor key water quality parameters, automate basic responses, and enable remote oversight. SWOP is especially relevant to rural water treatment plants because it directly addresses the unique operational, financial, and human resource challenges these plants face, challenges that differ markedly from those in urban or well-resourced settings.

The platform can either be retrofitted to existing treatment facilities or supplied as part of new water treatment systems. Its primary function is to autonomously bridge the technical skills deficit and logistical challenges associated with deploying a human plant operator (process controller) to remote sites on a routine basis. As the authors note, "Technological advancements in microprocessors, low-cost sensors, wireless communication, cloud storage, machine learning and artificial intelligence (AI), which are driving the broader adoption of Internet of Things (IoT) is increasingly being explored to provide disruptive solutions for smart water quality monitoring."

Smarter responses to rural water challenges

South Africa's water crisis is deepening. As a water-scarce country, it faces growing pressure on limited resources due to climate change, erratic rainfall, and prolonged droughts. Rural and underserved areas feel the impact most, often forced to rely on unreliable or absent municipal supply. Many communities depend on groundwater from boreholes, which often produce low volumes and suffer from pollution. Government programmes have installed small-scale treatment plants, typically filtration and chlorination, but many fail within months.

One key reason is the assumption that short-term training equips community members to operate and maintain such infrastructure. Sustained support, technical oversight, and routine maintenance are essential but rarely available. Consequently, plants fall into disrepair or deliver untreated water due to inadequate disinfection; some are vandalised for parts.

Rural plants treating 10 to 100 m^3 daily are too small for full-time staff yet too complex to operate without skilled oversight. Staff shortages, budget constraints, and remoteness reduce servicing and compliance.

Smart, connected technologies offer a practical alternative. By integrating low-cost automation, real-time data capture, and remote oversight, these tools reduce municipalities' operational load while improving plant reliability. Frontier technologies such as IoT, analytics, and solar-powered automation enable a shift from reactive crisis management to proactive, data-driven resilience.

Digital control for decentralised systems

Traditional plant management relies on manual inspections and delayed interventions. SWOP, however, uses IoT, cloud analytics, and sensor-integrated microcontrollers to enable real-time decision-making. It continuously tracks pH, turbidity, electrical conductivity (EC), oxidation-reduction potential (ORP), flow rate, and pressure, providing early warnings when systems begin to fail.

The test platform integrates widely available hardware, ESP32 microcontrollers and Arduino boards, to keep costs low. Data is transmitted wirelessly via Wi-Fi to the Blynk IoT cloud, where users visualise system performance, detect anomalies, and initiate proactive maintenance.

Blynk was chosen for its real-time monitoring and control capabilities critical for maintaining optimal water treatment conditions. Its user-friendly interface allows operators to respond quickly to anomalies, enabling timely interventions.

Future developments will enhance alert functionality, optimise long-term data analytics, and expand real-time control capabilities for fully autonomous water treatment plant operations.

How SWOP works

The system is based on a low-cost microprocessor backbone, such as Arduino or Industruino, and integrates cost-effective physical sensors to enable real-time monitoring and operational control of rural water treatment plants.

The data collection subsystem comprises a range of sensors with either direct or indirect measurements of the parameters required, which are either wired to or wirelessly connected to the controller to transfer the information from the sensor. The data transmission subsystem receives information from the data collection system and transmits this data to the data storage cloud. Finally, the data management subsystem allows remote access by the end user to the data through an application on their mobile device or desktop computer.

The data management subsystem together with the application may or may not include data analytics, machine learning and artificial intelligence functionality.

The researchers carefully evaluated the choice of sensors, controllers, processors, hardware and software for each module to ensure that they make right choice for the platform and its intended application. The aim was to ensure that each module is stable and accurate and aligns with the operational requirements of rural water treatment systems, particularly in terms of real-time monitoring, data-driven decision-making, and system scalability.

A step toward safer, smarter water

To assess hardware and software performance, the team tested the system's ability to accurately measure, convert, and interpret analogue signals from various sensors. These tests were conducted using both synthetic and actual groundwater samples sourced from a diverse range of locations to ensure robustness and adaptability.

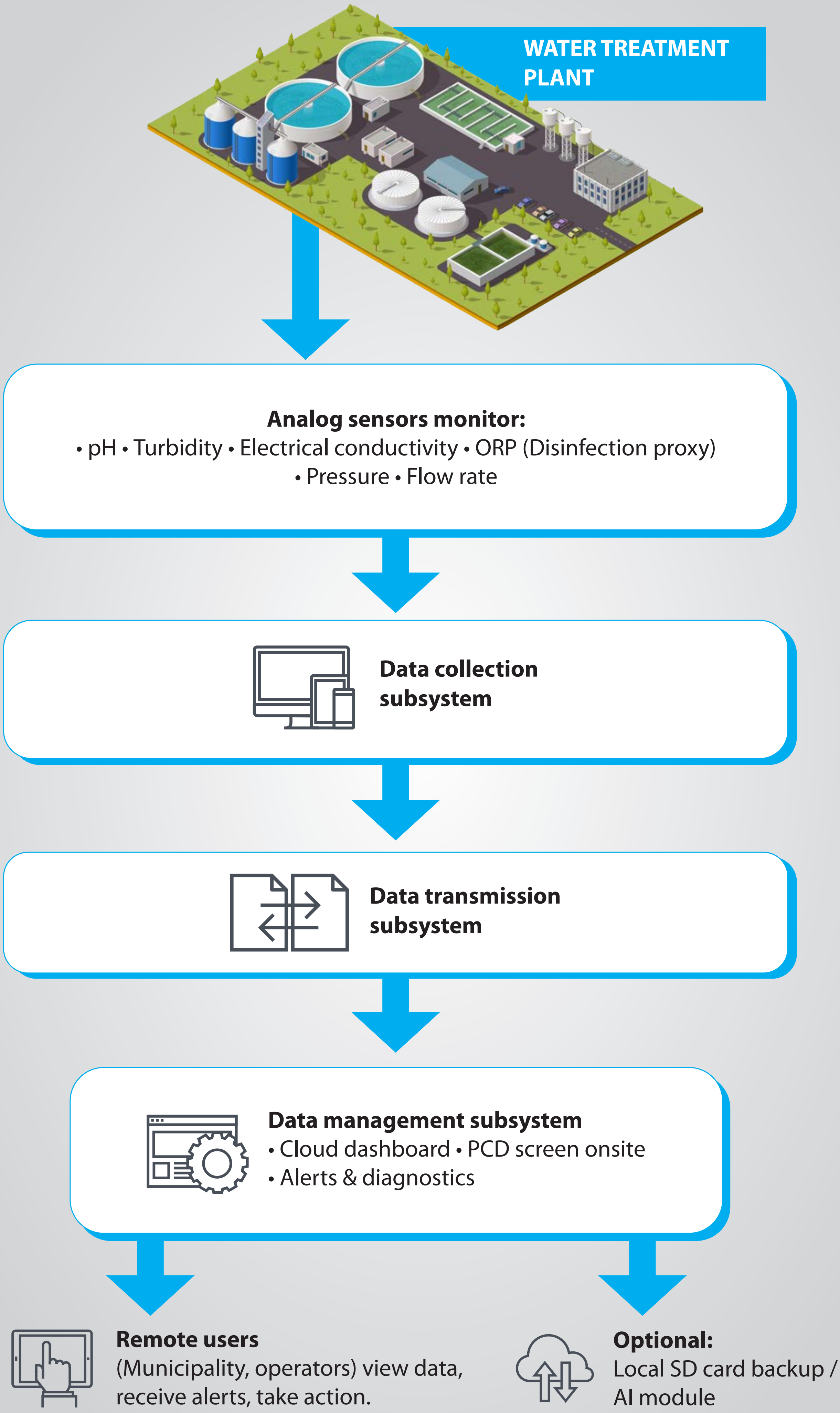
In controlled lab tests simulating diverse groundwater conditions, SWOP's sensor suite demonstrated strong correlation with commercial-grade reference meters. The pH sensor showed near-zero deviation; EC and ORP readings stayed within industry-accepted thresholds. While some calibration challenges remain—especially with flow and pressure under variable conditions—researchers are confident that these can be addressed through site-specific calibration during field deployment.

Critically, SWOP is designed with resilience and modularity in mind. It can be powered by off-grid sources such as solar panels, and its architecture allows it to be retrofitted into existing package plants without major modifications.

Proving the potential: Pilots and practical pathways

While the preceding sections outline the comprehensive range of potential features for the final SWOP system, the deliverables for this study were limited to the aspects of prototype development defined by the approved funding, focusing on specific prototype functionalities rather than full-scale system implementation.

These constraints shaped the development of the SWOP



A block flow diagram of the system.

prototype, guiding decisions on component selection, system architecture, and functional capabilities.

Despite these limitations, the prototype still successfully demonstrated the core principles and objectives outlined in this chapter, laying the groundwork for future iterations and enhancements.

The development team now seeks extended field trials to validate performance in real-world conditions across diverse plant configurations. Future upgrades may include LED status indicators, enhanced enclosures, and additional sensors (e.g., for dissolved oxygen or total organic carbon). A more advanced version could incorporate AI-based analytics to support predictive maintenance and automatic calibration, further reducing the need for hands-on operator input.

SWOP's promise lies in reducing health risks linked to poor water treatment, especially in underserved communities. By automating routine monitoring and enabling early intervention, it tackles inconsistent water quality caused by a lack of timely, actionable data.

The platform is designed to be cost-effective enough to justify keeping a spare unit on-site, enabling quick replacement in the event of a system failure. Its plug-and-play functionality allows a relatively unskilled person to easily remove and replace a faulty unit without the need to dispatch a skilled technician to a remote location for troubleshooting or servicing.

Laying the foundation for digital water resilience

While technology cannot replace skilled operators or long-term infrastructure investment, SWOP offers a compelling support tool for rural water systems. It combines affordability, digital innovation, and practical application, aligning with national goals for water security and public health.

As the report concludes: "This study establishes a solid foundation for future research and development, providing a pathway towards smarter, more sustainable, and data-driven water treatment solutions. By addressing current limitations and incorporating advanced predictive analytics, the SWOP has the potential to revolutionise rural water management, ensuring safe drinking water access for underserved communities."

With further development, this digital operator could help municipalities move from reactive crisis management to data-driven operational resilience, one rural plant at a time.

While technology cannot replace skilled operators or long-term infrastructure investment, SWOP offers a compelling support tool for rural water systems.