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Article

Development and Field Evaluation of a Mobile Water-Quality Sensing System for Environmental Monitoring in Tainan, Taiwan

Yi-Lin Zhou * and Wen-Hui Wu

Environmental Protection Bureau of Tainan City Government, Tainan 701044, Taiwan; u8714416@mail.tnepb.gov.tw
* Correspondence: flysky5108@gmail.com

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Abstract: This study presents the design, deployment, and field performance of a city-scale mobile water-quality sensing network developed to complement regulatory inspections and citizen-complaint investigations in Tainan, Taiwan. Six IP68-rated mobile sensor units measuring pH, electrical conductivity (EC), dissolved oxygen (DO), and temperature were deployed at two regulatory inspection sites and four complaint hotspots within the Yanshui River, Liuchong Creek, and Liucuo Drain systems. The network operated from 7 April to 31 August 2025, with temporary retrievals during typhoon events and one theft incident followed by successful recovery and redeployment. High-frequency measurements revealed recurrent pH excursions beyond the effluent standard range (6.0–9.0) at three sites, as well as persistent hypoxia (DO $\leq$ 1 mg/L on average) across multiple reaches, findings that are consistent with suspected industrial and livestock pollution sources. Overall, the results demonstrate that compact, rapidly deployable, solar-assisted sensing units can effectively capture short-lived water-quality violations and delineate spatiotemporal pollution hotspots that are often missed by conventional low-frequency grab sampling, while also underscoring operational considerations such as antifouling maintenance, security, and storm-response protocols.

Keywords: Mobile water-quality sensing, Dissolved oxygen, Effluent compliance, Citizen-science hotspots

1. Introduction

Timely and fine-scale water-quality information is essential for protecting public health and aquatic ecosystems, yet traditional grab sampling is labor-intensive and often fails to capture short-duration discharges or rapidly evolving pollution episodes [1–3]. Recent advances in Internet-of-Things (IoT) sensing and continuous monitoring technologies have enabled high-resolution observations that improve the detection of episodic disturbances and strengthen adaptive enforcement and watershed-management strategies [4–6]. Core regulatory parameters such as pH and dissolved oxygen (DO) have well-established measurement standards, calibration procedures, and data-handling protocols that ensure consistency and comparability across monitoring programs [7]. In parallel, water-quality assessment frameworks and watershed models provide the conceptual basis for interpreting these measurements, identifying cumulative stressors, and linking observed conditions to management responses in urban aquatic systems [2,3,8].

Within this broader context, Tainan City has experienced recurring complaints of odor, discoloration, and fish kills across several drains and river reaches, conditions that are often associated with sudden pollutant inputs, rapid biogeochemical shifts, or tidal-driven variability. Such episodic disturbances are difficult to characterize with conventional low-frequency sampling alone, creating a monitoring gap for both routine inspections and emergency response. To help address this gap, we deployed a mobile, solar-assisted water-quality sensing network across six locations spanning the Yanshui River, Liuchong Creek, and the Liucuo Drain system between April and August 2025. The system was designed to capture high-frequency fluctuations in pH, DO, electrical conductivity, and temperature, thereby improving the ability to detect short-lived anomalies linked to potential industrial, livestock, or domestic discharges.

This study describes the sensor platform and field procedures, presents the resulting high-frequency datasets, and evaluates how these continuous measurements informed targeted enforcement, event-triggered grab sampling, maintenance planning, and storm-season operational decisions. By integrating mobile sensing with regulatory workflows, the project illustrates a practical pathway for enhancing investigative monitoring and for directing limited enforcement resources to the right locations and times in subtropical urban watersheds.

2. Materials and Methods

Each mobile sensing unit housed probes for pH (0–14), EC (~0.07–50,000 µS/cm), DO (0–100 mg/L), and temperature (−40 to 125 °C) within an IP68-rated enclosure designed for continuous submersion (Figure 1). The units operated autonomously for roughly two days on internal batteries, and at selected sites solar panels or external battery packs were added to support extended operation under variable hydrological and meteorological conditions. Their compact size and modular power configuration allowed rapid installation, retrieval, and redeployment—an essential feature for investigative monitoring in highly dynamic urban drainage systems.

Six units were deployed at locations selected to represent two major environmental-management contexts: regulatory inspection sites and reaches repeatedly associated with citizen-reported odor, discoloration, or fish-kill incidents. The monitoring network spanned three systems—Yanshui River (Mujialiuwan Blvd Bridge), Liuchong Creek (Xingxiang Bridge), and the Liucuo Drain system, which included Liucuo Bridge, a bridge adjacent to a water-treatment facility, the Xigang branch, and the Qing'an Bridge reach. These sites were chosen based on prior evidence of episodic pollutant pulses, documented nuisance events, and practical accessibility for routine servicing, thereby capturing hydrological and anthropogenic gradients characteristic of mixed industrial–agricultural watersheds in southern Taiwan.

Units were secured to bridge railings or nearby structures following coordination with landowners. Installations were configured to maintain probe submergence across approximately 1 m of water-level variability while avoiding sediment interference, which can bias readings in shallow, tidally influenced channels. At solar-assisted sites, panel orientation and cable reinforcement were adjusted to ensure power stability during high winds, intense sunlight, and storm-related debris impacts.

All probes were calibrated prior to deployment using established regulatory procedures. Upon activation, data transmission, alarm functions, and sensor stability were verified, and initial measurements were cross-checked against handheld instruments until ten consecutive readings met agreement thresholds. Monthly maintenance visits focused on mitigating biofouling and sediment accumulation—both common causes of signal drift in subtropical drainage waters—and handheld comparisons were again performed to evaluate drift. Recalibration was conducted whenever deviations exceeded recommended tolerances [7]. These procedures were essential for preserving data comparability and ensuring that anomaly detection reflected environmental conditions rather than instrument artifacts.

Monitoring was conducted from 7 April to 31 August 2025. During this period, the units were temporarily retrieved ahead of typhoon landfalls to avoid loss or damage, and one unit was stolen on 14 May but later recovered and redeployed on 23 May. All operational interruptions were logged in the metadata and incorporated into the interpretation of temporal coverage and data continuity.

Time-series data were processed to characterize parameter distributions and their monthly variability. Anomalies were identified when pH values deviated from the 6.0–9.0 effluent-standard range or when DO values remained persistently low. These conditions are commonly associated with organic overloading, intermittent wastewater discharges, or altered biogeochemical processes in tidally affected channels. Each anomalous event was time-stamped to support source-tracing analyses and regulatory follow-up. The 6.0–9.0 pH threshold corresponds to the applicable effluent standard referenced in the field documentation, providing a consistent regulatory benchmark for interpreting the high-frequency records.

Fig. 1. External view of the second-generation mobile water quality sensing device.

3. Results and Discussion

Continuous monitoring from April to August revealed pronounced spatial and temporal variability across the six sampling locations in the Yanshui River and Liucuo Drain systems. At the Yanshui River site (Mujialiuwan Blvd Bridge), extreme pH excursions (3.3–11.1) were recorded, with frequent departures beyond the regulatory 6.0–9.0 band. These excursions coincided with persistently low dissolved oxygen (mean ≈ 1.5 mg/L), a condition consistent with short-duration discharge events and episodic pollutant inputs (Figure 2a). Such rapid fluctuations align with field reports of odor and discoloration in this reach, suggesting acute disturbances that could trigger localized hypoxia and fish-kill events. In contrast, the agricultural tributary at Liuchong Creek (Xingxiang Bridge) exhibited relatively stable conditions following temporary interruptions associated with typhoons and a theft incident. pH remained within 7.1–8.8, DO averaged 4.3 mg/L, and no major anomalies were detected (Figure 2b), underscoring differences in hydrological buffering capacity and anthropogenic pressures between riverine and drainage environments.

The Liucuo Drain system displayed persistent signs of degradation throughout the monitoring period. At Liucuo Bridge, repeated alkaline exceedances (pH up to 10.5) occurred alongside chronically depressed DO (mean ≈ 0.4 mg/L) and unusually high electrical conductivity (up to 15,524 µS/cm), indicating combined influences of tidal mixing, industrial discharges, and livestock effluent inputs. Downstream at the unnamed bridge near the water treatment facility, DO remained near anoxic levels (~0.5 mg/L) despite moderate pH variation, suggesting sustained organic and nutrient loading that overwhelmed reaeration processes. The Xigang branch displayed similarly low DO but lacked major pH excursions (Figure 2c), implying that oxygen depletion was driven more by biochemical oxygen demand than by caustic or acidic inputs. At Qing'an Bridge, distinct alkaline surges (pH > 9.0) during June–July and large DO oscillations (up to 17 mg/L) pointed toward episodic discharge pulses, likely tied to upstream food-processing operations (Figure 3d). These episodic signatures are consistent with citizen complaints of intermittent odor and color changes in this drainage system.

Overall, the network captured both short-lived pH excursions and chronic hypoxia across multiple reaches, revealing clear contrasts between complaint-driven drainage sites and the comparatively stable agricultural creek. The fine temporal resolution of the dataset—anchored by precise timestamps—enabled reconstruction of event timing and duration, providing actionable information for synchronized grab sampling, targeted inspections, and enforcement follow-up. These findings also illuminate the distinct hydrological and anthropogenic drivers shaping water quality in urban drainage networks, including the influence of tidal backflow, industrial flushing cycles, and livestock effluent patterns. Routine antifouling maintenance proved effective in preserving data quality, though enhanced security measures and storm-resilient mounting strategies are recommended for long-term operation in subtropical urban watersheds. Collectively, this integrated mobile sensing approach demonstrates strong potential as an investigative monitoring layer, allowing limited regulatory resources to be directed toward the right place and time for timely, evidence-based water-quality management.

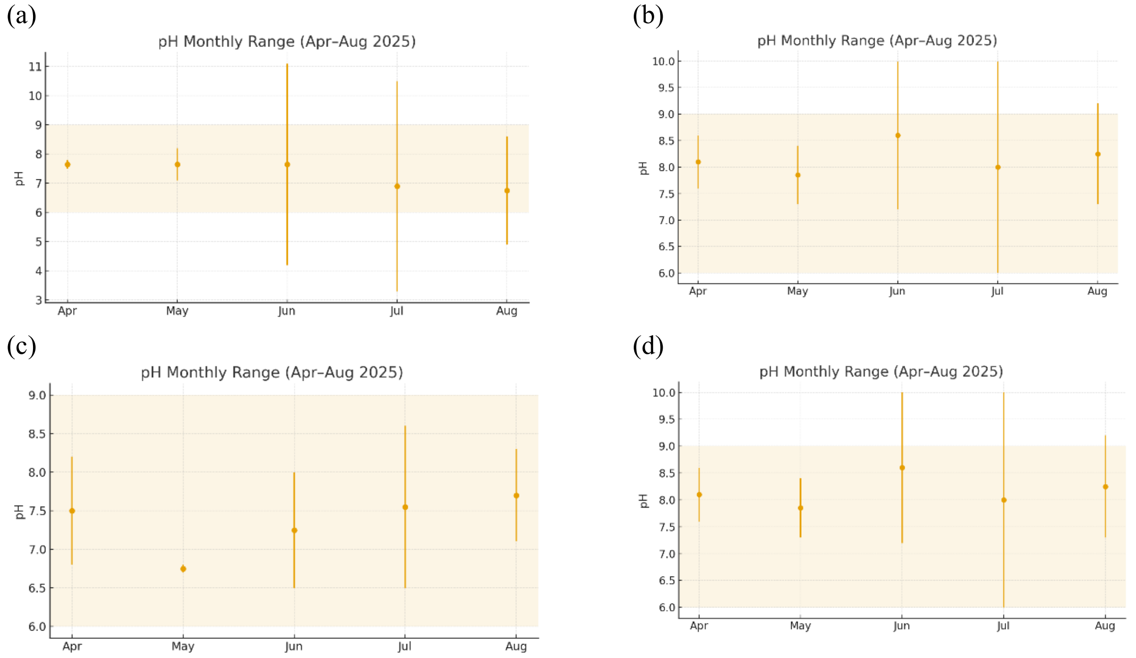

Fig. 2 (**a**)Yanshui River at Mujialiuwan Blvd bridge (**b**) Liuchong Creek at Xingxiang Bridge. (**c**) Xigang branch, Unnamed Bridge. (**d**) Liucuo Drain at Qing'an Bridge.

4. Conclusions

The compact, solar-assisted network of mobile water-quality sensors generated actionable, high-frequency evidence of both short-lived pH excursions and sustained hypoxia in several complaint-prone drains in Tainan, while simultaneously confirming the relative stability of the comparison reach. By enabling rapid deployment, maintaining stable performance with routine antifouling maintenance, and integrating effectively with existing inspection workflows, the system demonstrated clear value as an investigative monitoring layer that complements conventional grab sampling and regulatory patrols.

Nonetheless, the present configuration has limitations, particularly in its reliance on core physicochemical parameters, partial vulnerability to storm-season disruptions, and the absence of nutrient measurements critical for source attribution. Future work should incorporate ammonium or nutrient probes to better differentiate industrial, livestock, and domestic inputs; integrate rainfall and tide data to improve the prediction of episodic events; and automate site-specific alert thresholds to support real-time enforcement response. Additional improvements in hardware security, mounting stability, and power resilience will be essential for sustained operation in subtropical urban watersheds, especially during typhoon seasons. Together, these enhancements would further strengthen the role of mobile sensing networks as a practical and scalable tool for evidence-based water-quality management.

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