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ENVIRONMENTAL FACTORS MONITORING SYSTEMS: HISTORY, TRENDS AND THE D.R.E.A.M. HYBRID MODEL

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Abstract: *This article develops a deep, practice-oriented narrative on Environmental Factors Monitoring Systems (EFMS), tracing a fifty-year arc from reference-grade fixed networks to AI-native, mobile, hybrid deployments that integrate air and water sensing. The D.R.E.A.M. Project on the Danube is positioned as a transferable blueprint for large rivers and port approaches, demonstrating a crewed vessel with a vessel-mounted multi-parameter water probe, planned laboratory sampling, and supervised UAV vertical air profiles. A comparison of stationary versus mobile modalities is presented; architecture, operations patterns, and codification of QA/QC are proposed; and a 2025–2035 research and policy agenda is set. The historical evolution, trade-offs, mission planning, and D.R.E.A.M. architecture is summarized in tables.*

Keywords: *EFMS, air quality, water quality, UAV, vessel-mounted probe, laboratory sampling, D.R.E.A.M., QA/QC, Danube River*

INTRODUCTION

Environmental monitoring underpins policy compliance, public-health protection, incident response, and strategic planning (LibreTexts, n.d.). Classical EFMS architectures relied on fixed, highly accurate stations and laboratory pipelines. While these remain essential for trend comparability and legal defensibility, they cannot alone resolve the micro-scale heterogeneity and transient events that characterize urban airsheds and dynamic river systems.

A new generation of EFMS leverages miniaturized sensors, low-power electronics, robust communications, and autonomous mission software. Mobile systems—specifically unmanned aerial vehicles (UAVs) and a crewed vessel carrying a mounted water-quality probe—augment stationary networks with vertical and longitudinal intelligence, accelerating time-to-insight and enabling targeted, adaptive missions under human supervision (Danube River Environmental Assessment and Monitoring - D.R.E.A.M. Project, n.d.; Puig & Darbra, 2024).

EXPOSITION

Background and Literature Synthesis

The recent literature emphasizes AI/IoT integration, edge-to-cloud pipelines, and interoperable data models. Studies report gains in anomaly detection, adaptive path planning, and fused forecasting for both air and water domains (Rajesh et al., 2019). Port-area syntheses highlight multi-domain monitoring (air, water, sediment, noise and energy) and the rapid uptake of drones and remote sensing. Industrial and civic deployments show the need for rigorous siting, calibration transfer, and governance.

Low-cost sensors have expanded spatial reach but introduce drift, cross-sensitivity and environmental dependencies; successful programs pair them with reference anchors, continuous QA, and field co-locations (Clarity, 2024). In water, multi-parameter sondes and fluorometric probes enable spatial transects and vertical profiles, while river advection necessitates longitudinal mapping beyond bankside stations.

Table 1 represents the historical evolution of environmental monitoring from its birth as an idea to the possible near future (EarthyB, n.d.). A comparison between Drivers and Policy, Methods and Platforms, and Limitations to be Addressed Next is made.

Table 1. Historical evolution of environmental monitoring

Era / Decade	Drivers & Policy	Dominant Methods & Platforms	Limitations to be Addressed Next
Pre-1970	Early conservation; local ordinances	Manual sampling; lab assays	No comparability; sparse coverage
1970s	Clean air/water acts; Earth Day; national agencies	Reference stations; gravimetric PM; wet chemistry	Sparse spatial sampling; lagging feedback
1980s	Instrumentation advances; QA/QC standardization	Continuous analyzers, automated data loggers	Vertical profiles; plume mapping
1990s	GIS/EO expansion; integrated assessments	Bankside analyzers, buoys, first satellite products	Data silos; metadata gaps
2000s	Digitalization; early web portals	Network densification; community outreach	Hyperlocal inequities hidden
2010 – 2013	Low-cost sensors; maker movement	Electrochemical/optical nodes; pilot deployments	Calibration & drift; siting biases
2014 – 2017	UAV pilots; mobile labs	Transects, vertical profiling, incident response	Endurance; airspace rules
2018 – 2020	Edge computing, 4G/5G, cloud lakes	Real-time QA; streaming analytics	Interoperability; governance
2021 – 2024	AI mainstream; digital twins	Adaptive missions; ML forecasting	Resilience, cybersecurity, equity
2025 – 2035	Open, resilient, low-power fleets	Hybrid swarms; autonomous retasking (where permitted)	Sustainable O&M; workforce upskilling

Methods and Architecture

As seen in Table 1, the methods and architecture of the systems evolved with the extent of the environmental monitoring and care. To be accurate, the new methods did not replace the old ones; instead, they layered them by anchoring the data with references and enhancing it with mobile sensing supported by laboratory confirmations.

Table 2 presents a comparison between stationary and mobile monitoring systems for air and water quality.

Table 2. Comparative Assessment of Fixed-Site and Mobile Monitoring for Air and Water Domains

Domain	Modality	Strengths	Limitations	Best-use scenarios
Air	Stationary (reference)	Traceable accuracy; trends; regulation	Sparse spatial/vertical detail	Baselines; compliance; calibration anchor
Air	Dense, low-cost nodes	Hyperlocal coverage; community engagement	Drift; siting/metadata gaps	Inequity mapping; school corridors
Air	Mobile (UAV/vehicle)	Hotspots, vertical profiles, incidents	Payload/endurance; permissions	Near-source plumes; road canyons
Water	Stationary (buoy/bankside)	Continuous time series; early warning	Single-point view; fouling	Intakes, confluences, boundaries
Water	Mobile (AUV*/ROV*/ vessel) + laboratory sampling	Continuous transects; targeted grab samples; rapid anomaly verification	Fouling/maintenance; crew scheduling; operational range for AUV/ROV	River monitoring intake protection incident follow-up and evidence packages
Both	Remote sensing (EO/UAV imagery)	Regional context; targeting	Cloud cover; revisit times	Mission planning; model constraints
Both	Edge+Cloud fusion	Real-time QA; forecasting; twins	Standards, governance, security	24/7 ops; public dashboards

**AUV-Autonomous Underwater Vehicle*
**ROV-Remotely Operated Vehicle (Underwater drone)*

As seen by the table, fixed-site networks secure comparability and legal defensibility but offer limited spatial/vertical resolution. Mobile platforms—balloons/vehicles (incl. UAVs) for air and vessels/AUVs/ROVs with lab sampling for water—recover fine-scale patterns and transport pathways (Kapoor, S. 2025). Low-cost nodes extend footprint but heighten QA demands, while remote sensing enriches regional context with near-surface gaps. Edge-to-cloud fusion and AI make these heterogeneous streams operational (Popescu et al., 2024); in practice, the most decision-ready view is a hybrid stack that balances accuracy–coverage and responsiveness–repeatability trade-offs (Mazur, B., Ignitec (2025).

The D.R.E.A.M. Project as a Flagship Hybrid Model

System concept. D.R.E.A.M. deploys a crewed research vessel with a vessel-mounted multi-parameter water-quality probe to produce continuous water-quality transects along the Danube. In parallel, UAVs fly supervised vertical and lateral profiles to map air gradients. All streams are time-synchronized, georeferenced (RTK for UAV), and fused into maps and simple indices for decision-makers.

At predefined stations, water samples are collected for accredited laboratory analysis to extend the parameter set beyond in-situ instrumentation.

Operational posture. UAV missions use high automation for repeatable profiles but remain human-supervised under current aviation rules. The vessel is crewed; no autonomous water robots are used. The priority is defensible data within the current regulatory framework.

Regulatory note. All UAV flights are conducted with a remote pilot in command and applicable authorizations. Water-sample collection follows a written sampling plan and chain-of-custody protocol (sample IDs, preservatives, storage, and transport to accredited labs).

Operations, Ethics, and Governance

Lifecycle costing balances reference-site capital with field O&M; modular payloads safeguard investments. Risk management covers airspace permissions, waterway procedures, weather windows, and cyber-hardening. Equity and inclusion are supported via open dashboards and multilingual labeling.

Not less important is the capacity building (Sustainability Directory, 2025). Hybrid systems thrive when contracts value uptime, QA/QC, and data use—not only hardware delivery. Upskill field teams on EFMS operations, calibration and custody; upskill analysts on data fusion.

Trends and 2025–2035 Agenda

Wider adoption of AI-assisted, human-supervised operations with a trend towards reducing human oversight and transitioning towards AI-native operations. E.g., onboard anomaly detection and autonomous retasking (where permitted) (ApolloTechnical, 2024).

Sensor miniaturization and stability: toward multi-parameter, low-drift probes with environmental compensation and self-diagnostics.

Interoperability and reproducibility: OGC/ISO profiles, FAIR data*, and automated QA/QC checklists baked into pipelines.

Resilience and sustainability: solar/hydrogen range extenders, ruggedized enclosures, and repairable designs.

Decision integration: health-risk indices, compliance dashboards, and scenario simulation for spills, heatwaves, and combined sewer events.

CONCLUSION

The concept of accessible, quality-assured, quality-controlled, real-time environmental data is not new! But what this concept lacks nowadays is reliability. Reliability is born in the publicity and is built on transparency. Public data invites scrutiny, which helps the errors to surface, and as a result, trust grows and the innovation adoption risk drops. The question is how to make it matter and leverage it to provoke decisions and actions? To to encourage the development and implementation of preventive measures, rather than solely focusing on reactive ones.

The DREAM Project's answer is to empower communities with timely and accurate information while sharing knowledge and raising awareness. This approach lays the foundations for the development of an informed and ecologically conscious community.

The EFMS's core purpose, embedded in the very idea of the DREAM Project, is to serve as a bridge between science, policy, community, and business.

The hybrid model—supervised UAVs for air, a river vessel with a mounted probe for water, and regular sampling for laboratory testing—balances speed, coverage, and credibility of the EFMS within the current legal framework. The D.R.E.A.M. Project is proof of concept at real-world scale: public-facing, quality-assured intelligence built from tools that can legally and safely operate today. Over the next decade, progress will not hinge on one miracle gadget but on systems that are honest about uncertainty, open about methods, and useful to the people who live with the results.

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