

IoT Frameworks for Real-Time Water Quality Monitoring in Coral Atolls: A Systematic Review for Lakshadweep Islands

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Abstract

Groundwater lenses in thin coral atolls are highly susceptible to anthropogenic contamination and saltwater intrusion. This review synthesizes global Internet of Things (IoT) water quality architectures and maps their viability to the specific hydro-geological constraints of Kavaratti Island, Lakshadweep, India. We examine sensor arrays, micro-controller choices, edge computation of the Water Quality Index (WQI), and telemetry constraints unique to isolated island geographies. Finally, we review critical deployment challenges—including bio-fouling, hyper-salinity corrosion, and monsoon power limits—and outline engineering mitigation required for robust coastal operations.

1. Introduction

Coral atoll environments possess a distinct hydro-geological framework where fresh groundwater exists solely as a fragile lens floating above denser marine saltwater. On Kavaratti Island, the capital of the Lakshadweep archipelago, this lens is shallow, typically sitting just 1.5 to 3 meters below the surface. With rapid urbanization, increasing tourism, and dependence on localized household dug wells, these vital lenses face two major vectors of degradation: anthropogenic pollution (nitrates and fecal coliforms from septic infrastructure) and induced saltwater intrusion driven by climate variations and excessive pumping.

2. Telemetry and System Architecture

A critical choice in adapting IoT platforms for isolated environments like Lakshadweep is the communication topology. The table below presents an evaluation matrix of core telemetry frameworks mapped against island constraints:

Telemetry Architecture	Range & Pen.	Power Efficiency	Infrastructure Dependence	Lakshadweep Viability Summary
LoRaWAN (868 MHz)	High (up to 5km)	Excellent (Years on battery)	Low (Requires local gateway)	Highly Recommended. Allows independent data network infrastructure without carrier fees.
Cellular (4G LTE / GSM)	Medium	Poor (High active current)	High (Dependent on local uptime)	Moderate. Subject to localized outages during monsoons and high power draws.
NB-IoT (Narrowband)	High	Excellent (Optimized sleep)	High (Requires specific carrier band)	Experimental. Dependent on mainland carrier rollouts across the territory.

3. Analytical Processing: Mathematical WQI Formulation

To parse the incoming multi-sensor streams into an interpretable metric for municipal action, edge nodes or centralized cloud systems compute the Water Quality Index (WQI) based on parameters regulated by the Bureau of Indian Standards (BIS):

- pH (Permissible: 6.5–8.5)
- Electrical Conductivity (Permissible: 1500 $\mu\text{S}/\text{cm}$)
- Turbidity (Permissible: 5 NTU)

Using the weighted arithmetic index strategy, quality ratings for each parameter are aggregated against assigned weights, where conductivity is given maximum scaling to instantly reflect saltwater upwelling. Indexes exceeding a score of 100 trigger an immediate structural alert via local edge nodes.

4. Island Environmental Challenges & Mitigations

Deploying long-term hardware frameworks in Lakshadweep requires addressing three coastal challenges:

1. Marine Biofouling & Humid Oxidation: Shallow groundwater lenses exhibit high organic activity. Sensors require localized copper-mesh shielding and periodic cleanings to prevent structural biofilm bias.
2. High Salinity Atmospheric Corrosion: Enclosures must be strictly IP67/IP68 rated with marine-grade poly carbonate materials to withstand pervasive salt spray.
3. Monsoon Power Limitations: Solar charging infrastructure drops significantly during extended monsoon covers. Micro-controllers must utilize strict deep-sleep intervals (e.g., waking for 10 seconds every 30 minutes) to operate reliably on small battery capacities.

5. Conclusion & Strategic Roadmap

Deploying automated, low-cost IoT networks tailored for thin atoll environments bridges a critical operational gap in Lakshadweep's water safety planning. Combining low-power LoRaWAN hardware topologies with edge-computed WQI frameworks facilitates rapid, democratic access to localized environmental intelligence, protecting the community's primary lifeline.

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