ICA2025OSLO
14th IWA Specialised Conference on
Instrumentation, Control and Automation

# Sensor Fault Characteristics and Fault Detection in Wastewater Treatment Plants: Current Status and Trend Analysis

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**Abstract:** Sensor faults in wastewater treatment plants (WWTPs) significantly compromise monitoring reliability and operational efficiency. These faults are inextricably linked to the complexities of environmental factors, system characteristics, and data properties, making fault identification and diagnosis increasingly challenging. Recent developments in machine learning and artificial intelligence (AI) provide promising technological opportunities for detecting and diagnosing water-quality instrument faults. In this review, CiteSpace was used to retrieve and analyze relevant literature from 2008 to 2024. This work centers on the current state and future developments of applying machine learning and AI to early fault diagnosis—particularly in addressing bias, drift, and accuracy degradation. The findings reveal that contemporary research primarily focuses on the development of robust fault detection and diagnosis methods, along with their applications in environments characterized by high-dimensional, multi-temporal datasets. Furthermore, this review evaluates the mathematical approaches employed in developing sensor fault detection and diagnosis techniques, with special attention to their evolution, advantages, and limitations. While wastewater treatment plants provide a clear context for illustrating these issues and solutions, the insights gleaned here are broadly applicable to other domains featuring similarly complex, high-volume data.

**Keywords**: sensor fault; fault detection; fault diagnosis; wastewater treatment; machine learning

## 1 Introduction

Precise sensor monitoring is essential for correctly assessing process performance and enhancing both process efficiency and effluent quality (Vanrolleghem and Lee, 2003; Yang, 2023). However, However, the reliability of sensors in WWTPs is often compromised by their complex, dynamic, and harsh operating environments (Sweeney & Kabouris, 2020). Advances in machine learning and artificial intelligence (AI) present promising opportunities to enhance the robustness of monitoring networks in WWTPs. This review employs CiteSpace to analyze literature from 2008 to 2024, focusing on the applications and development trends of machine learning and AI in early fault diagnosis. Serving as a technical guide for WWTP engineers, this paper offers valuable insights into the opportunities and challenges posed by the digital and intelligent transformation of wastewater treatment processes.

## 2 Literature analysis method

Literature was searched using TS= ((("sensor fault*" OR "fault detection" OR "fault diagnosis" OR "fault identification" OR "anomaly detection" OR "sensor failure" OR "fault tolerance" OR "fault compensation") AND ("wastewater" OR "WWTP" OR "wastewater treatment plant*" OR "sewage treatment" OR "water monitoring"))) through Web of Science to identify the topic research trend. The search yielded a total of 225 results, including 212 research papers, 9 review papers and 4 conference papers.

## 3 Article keyword analysis and current trend analysis

Figure 3.1 visualizes research trends in sensor fault detection and diagnosis, showing a rapid increase in publications after 2018, peaking in 2024. Keyword co-occurrence analysis (Figure 3.1b) identifies "fault detection" and "fault diagnosis" as central terms, with 73 and 50 occurrences, respectively, highlighting their importance in both theoretical methodologies (e.g., PCA, data modeling, algorithm development) and practical applications (e.g., wastewater treatment, system optimization). A timeline (Figure 3.1c) traces the evolution of related research, with "fault

detection" and "fault diagnosis" first appearing in 2009 and 2008. Before 2016, traditional statistical methods and early machine learning dominated, focusing on fault identification and differentiation. Post-2016, advanced techniques like "machine learning," "deep learning," and "dynamic kernel principal component analysis" gained prominence, addressing high-dimensional, multi-temporal data challenges. The focus shifted from single fault detection to optimizing large-scale sensor networks, emphasizing system-level integration and holistic solutions.

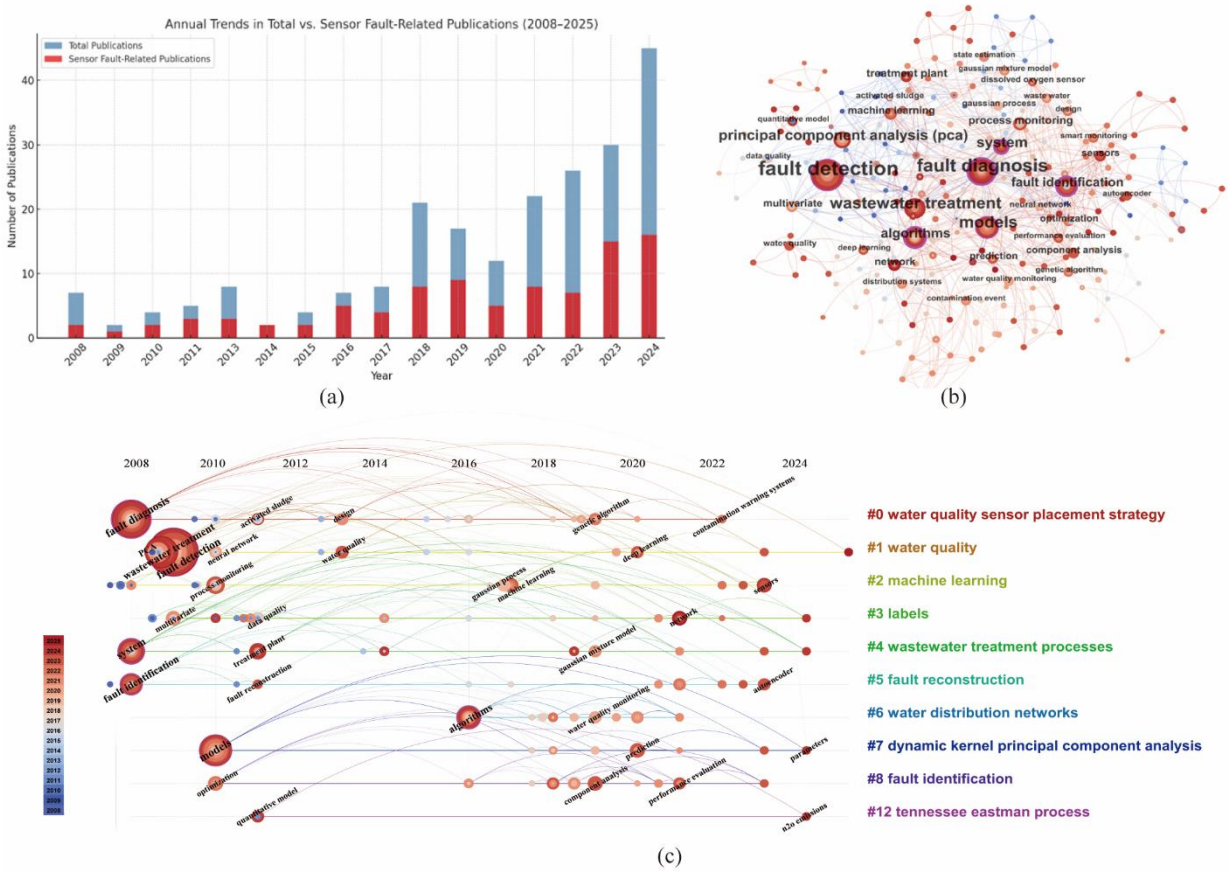


**Figure 3.1** Visualization of Research Trends in Sensor Fault Detection and Diagnosis Using CiteSpace. (a) Annual Trends in Total vs. Sensor Fault-Related Publications (2008–2024). (b) Keyword Co-occurrence Network for Sensor Fault Detection and Diagnosis. (c) Keyword Timeline of Research Evolution and Keyword Clustering of Research Directions

## 4 From Redundancy to AI: The Evolution of Fault Detection Approaches

Figure 4.1 illustrates the overall framework for sensor fault management in wastewater treatment plants. The comprehensive process typically consists of three components: fault detection and isolation, fault diagnosis, and fault handling and recovery (Liu et al., 2023). First, fault detection and isolation involve determining whether the sensor is operating within its normal measurement range and identifying the specific source and location of the fault, i.e., pinpointing which sensor or system component has failed. Second, fault diagnosis focuses on identifying the type, severity, and possible causes of the fault. Finally, fault handling and recovery refer to the measures taken after identifying and diagnosing the fault to minimize or eliminate its impact on the system.

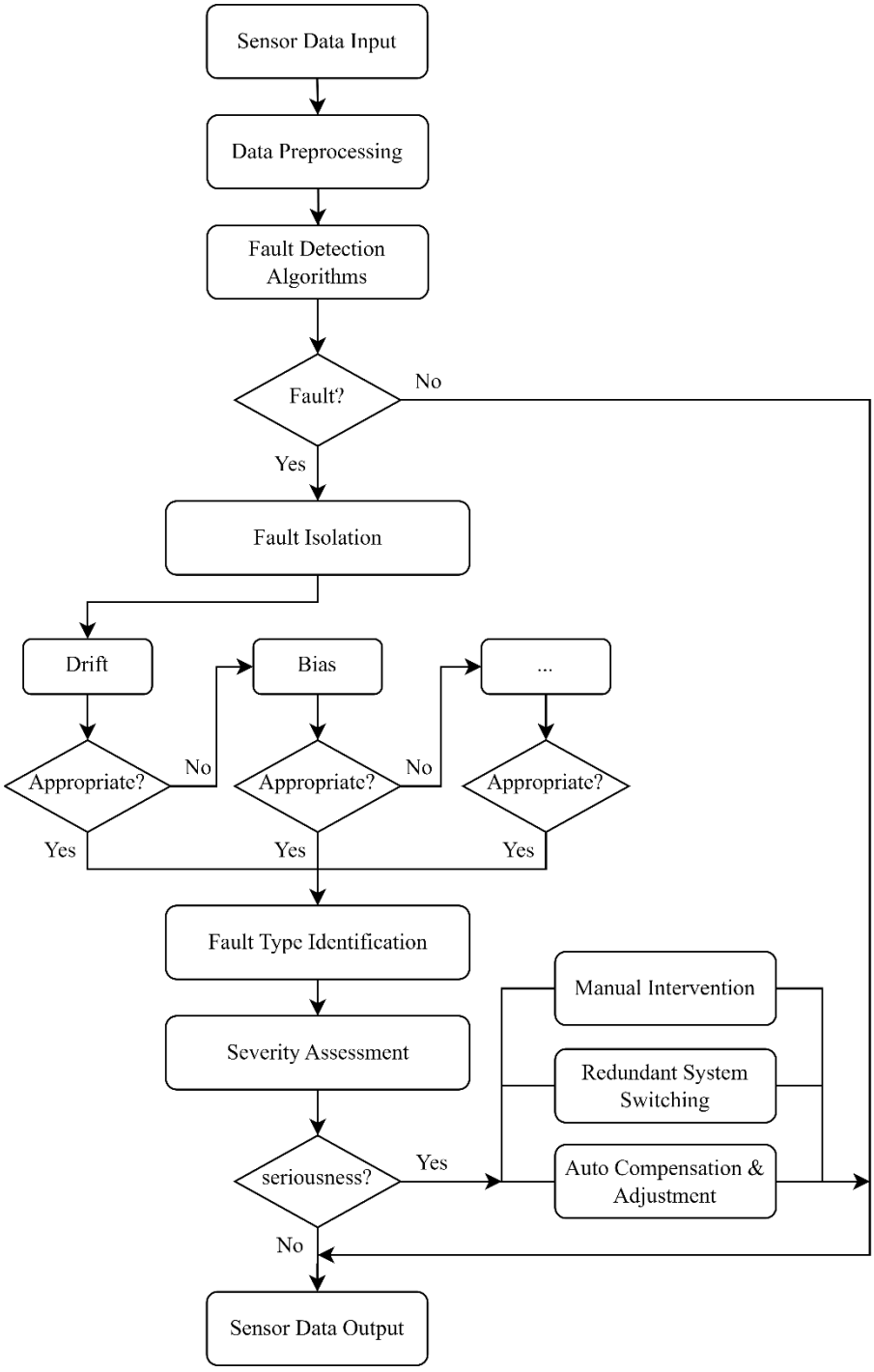


**Figure 4.1** A process framework for sensor fault management

Fault detection and diagnosis, the cornerstone of fault management, has evolved from experience-based approaches and basic redundancy analysis to automated methods integrating mathematical models and signal processing, and now to data-driven and AI-based system management. This progression reflects advancements in technology and shifting application demands. As smart water management advances and wastewater treatment becomes more intelligent and integrated, the need for comprehensive fault management systems grows. Future systems must combine real-time data fusion, advanced predictive analytics, and automated response mechanisms to meet these demands.

**REFERENCES**

Liu, Y., Ramin, P., Flores-Alsina, X., & Gernaey, K. V. 2023 Transforming data into actionable knowledge for fault detection, diagnosis and prognosis in urban wastewater systems with AI techniques: A mini-review. *Process Safety and Environmental Protection.* **172,** 501–512.

Sweeney, M., & Kabouris, J. 2020 Modeling, instrumentation, automation, and optimization of water resource recovery facilities. *Water Environment Research.* **92(10)**, 1618–1624.

Vanrolleghem, P. A., & Lee, D. S. 2003 On-line monitoring equipment for wastewater treatment processes: State of the art. *Water Science and Technology.* **47(2)**, 1–34.

Yang, Z. 2023 Low-cost and rapid sensors for wastewater surveillance at low-resource settings. *Nature Water.* **1(5)**, 405–407.