

# Wireless Sensor Network for Environmental Monitoring

**T. Bhaira Vardhan Reddy<sup>1</sup>, S. Jyothika<sup>2</sup>, B. Lakshmi Subbamma<sup>3</sup>,  
G. Hari Krishna<sup>4</sup>, B. V. Hari Pratap Reddy<sup>5</sup>**

<sup>1,2,3,4,5</sup>Department Of ECE, Tadipatri Engineering College, Tadipatri.

## **ABSTRACT:**

This paper presents the design and implementation of a wireless sensor network (WSN) for real-time environmental monitoring using a compact and energy-efficient architecture. The proposed system integrates multiple sensing units, including temperature and humidity (DHT11), carbon dioxide (CO<sub>2</sub>), methane gas, and pressure sensors, to continuously observe critical environmental parameters. These sensors are interfaced with a NodeMCU microcontroller, which serves as the central processing and communication unit. The NodeMCU collects data from all sensors, processes the readings, and transmits the information wirelessly for monitoring and analysis. The system is capable of generating alert messages when the sensed parameters exceed predefined safety thresholds, thereby enabling early warning and preventive action. Additionally, the measured values are displayed locally for quick reference and verification. The proposed solution is cost-effective, scalable, and suitable for deployment in various environments such as industrial zones, agricultural fields, and urban areas. Its wireless capability reduces the need for complex wiring and enhances flexibility in installation. The system ensures continuous monitoring with minimal human intervention, improving reliability and response time. Overall, this work demonstrates an efficient approach to environmental monitoring by combining multiple sensors with wireless communication for accurate and timely data acquisition.

**KEYWORDS:** Wireless Sensor Network, Environmental Monitoring, NodeMCU, DHT11 Sensor, CO<sub>2</sub> Sensor, Methane Sensor, Pressure Sensor.

## **INTRODUCTION:**

Current surface water monitoring systems often operate in isolation, relying on fragmented data sources, limited sampling strategies, and inconsistent sensor placement, which restricts accurate environmental assessment and timely decision-making. Growing pressures from human activities, climate variability, and wastewater discharge demand a more unified and reliable monitoring approach. This work is motivated by the need to overcome these limitations through better integration of monitoring techniques and data sources. The main contribution lies in emphasizing a structured framework that combines sensing, modeling, and data fusion to enhance system performance, improve prediction accuracy, and support sustainable watershed management through informed and standardized practices [1]. Existing smart water network solutions largely focus on isolated physical or cyber components, often overlooking the dynamic interactions between environmental conditions and social factors, which limits their ability to respond effectively to complex challenges such as contamination events and climate impacts. This gap motivates



the need for a holistic framework that captures the interdependencies among sensing infrastructure, data-driven control systems, human decision-making, and environmental dynamics. The key contribution of this work is the emphasis on a Cyber-Physical-Socio-Environmental Systems approach, enabling integrated monitoring, adaptive response, and improved resilience, thereby supporting sustainable and secure water management through coordinated feedback and intelligent system design [9]. Current IoT-based environmental monitoring systems often lack robust information security mechanisms, making them vulnerable to data breaches, unauthorized access, and system manipulation, especially in large-scale, data-intensive environments. This challenge is amplified by the rapid growth of interconnected devices and real-time data exchange. The motivation of this work is to address the urgent need for a structured and reliable security monitoring framework that ensures data integrity and system reliability. The key contribution lies in proposing an integrated security monitoring and evaluation approach, combining big data techniques, multi-layer architectures, and systematic assessment models to enhance protection, support decision-making, and ensure secure and efficient IoT-based environmental management [7]. Conventional environmental monitoring systems rely on fixed sensors, which often result in delayed anomaly detection, limited spatial coverage, and reduced adaptability in dynamic and critical environments such as space habitats. This limitation motivates the need for intelligent and autonomous monitoring approaches capable of improving detection accuracy and response time. The main contribution of this work is the introduction of an active sensing framework based on Markov Decision Process, where mobile sensors dynamically adjust their positions to optimize monitoring performance. This approach significantly enhances anomaly detection speed, reduces uncertainty in source localization, and improves overall system reliability in complex and evolving environments [3]. Traditional bio-environmental monitoring systems often lack the capability for continuous, autonomous, and multimodal data collection, particularly in remote or harsh environments, leading to incomplete analysis of microbial activity and environmental conditions. This limitation motivates the development of compact and energy-efficient platforms that can integrate multiple sensing modalities while operating over extended periods with minimal human intervention. The key contribution of this work is the design of an autonomous sensor platform that combines microbiological monitoring with environmental sensing, supported by low-power electronics and wireless communication, enabling reliable long-term data acquisition and improving the understanding of bio-environmental dynamics in challenging habitats [5]. Conventional monitoring of building cooling systems often depends on intrusive sensors and dedicated instrumentation, which increases cost and complexity while limiting scalability across large facilities. Moreover, faults in variable speed drive components can remain undetected, reducing expected energy efficiency gains. This motivates the need for a nonintrusive and data-driven approach that can accurately assess system performance using existing infrastructure. The main contribution of this work is the development of a nonintrusive load monitoring framework that disaggregates cooling system power consumption from aggregate electrical data and estimates thermal performance, enabling efficient fault detection, improved energy management, and enhanced operational reliability without additional hardware installation [13].

## LITERATURE SURVEY:

Recent studies such as Yuli Sudriani et al. (2022) reviewed integrated surface water monitoring approaches and emphasized combining multiple data sources, yet highlighted limited optimization of sampling and sensor placement strategies. Similarly, Viktor Sebestyén et al. (2021) discussed sustainability-focused monitoring frameworks but lacked real-time data fusion mechanisms. János Abonyi et al. (2020) explored



model-based monitoring, though integration with diverse sensing techniques remained insufficient. Despite these contributions, existing works reveal gaps in unified frameworks that simultaneously address data integration, predictive modeling, and efficient sensor deployment for comprehensive and standardized watershed management [1]. Recent studies such as Muhammad Zakir Shaikh et al. (2023) presented a comprehensive review of wayside condition monitoring systems for railway wheels, highlighting the use of sensors like strain gauges and vision systems for fault detection, yet identified limitations in real-time adaptability and onboard integration. Zeeshan Ahmed et al. (2022) explored sensor-based diagnostic techniques but lacked advanced predictive capabilities. Similarly, Bhawani Shankar Chowdhry et al. (2021) discussed monitoring frameworks, though challenges remain in data fusion and intelligent analysis. These works reveal gaps in developing robust, AI-driven, and fully integrated onboard monitoring systems for improved railway safety [2]. Recent work by Yanjie Guo et al. (2023) introduced an active environmental monitoring framework using mobile sensors and Markov decision processes, significantly improving anomaly detection efficiency compared to fixed sensing systems, yet challenges remain in handling environmental uncertainties and scalability. Zhaoyi Xu et al. (2022) explored reinforcement learning-based sensing strategies but lacked comprehensive evaluation across diverse real-world conditions. Similarly, Joseph Homer Saleh et al. (2021) examined reliability aspects of autonomous monitoring, though integration with adaptive sensing architectures is still limited. These studies highlight gaps in developing fully adaptive, robust, and scalable monitoring systems for complex environments [3]. Recent studies such as D. M. G. Preethichandra et al. (2024) reviewed robotic systems for environmental monitoring, highlighting the integration of diverse sensors and platforms like drones and wheeled robots, yet indicating limitations in system coordination and real-time adaptability. Lasitha Piyathilaka et al. (2023) examined sensor networking strategies but lacked efficient data fusion and autonomous decision-making. Similarly, Umer Izhar et al. (2022) discussed hybrid robotic monitoring approaches, though scalability and energy efficiency remain challenges. These works reveal gaps in developing fully autonomous, energy-efficient, and intelligent robotic monitoring systems for complex environments [4]. Recent work by P. Sarati Das et al. (2020) introduced an autonomous multimodal sensor platform for bio-environmental monitoring, integrating microbial sensing with environmental parameters, yet limitations exist in scalability and real-time remote accessibility. G. Gagnon-Turcotte et al. (2019) focused on low-power system design but lacked advanced data analytics for predictive insights. Similarly, K. Ouazaa et al. (2018) explored wireless data transmission techniques, though continuous real-time streaming and adaptive control remain underdeveloped. These studies reveal gaps in achieving fully scalable, intelligent, and real-time bio-environmental monitoring systems [5]. Recent work by Yunpeng Liu et al. (2021) proposed an intelligent residential monitoring system integrating cloud computing and IoT, enabling data collection and centralized management, yet it shows limitations in handling real-time adaptability and large-scale deployment. Fei Xiao et al. (2020) focused on data fusion techniques for improving monitoring accuracy but lacked advanced predictive analytics and autonomous decision-making. Despite these contributions, existing studies reveal gaps in developing scalable, intelligent, and fully automated environmental monitoring systems capable of dynamic response and efficient resource management in diverse residential settings [6]. Recent studies such as Wuchao Liang et al. (2021) proposed a big data-driven information security monitoring framework for IoT environments, integrating multi-layer architectures and evaluation models, yet limitations exist in real-time threat detection and adaptive response mechanisms. Wenning Li et al. (2020) explored security evaluation using structured index systems but lacked dynamic risk assessment capabilities. Similarly, Lili Feng et al. (2019) focused

on monitoring strategies, though scalability and intelligent automation remain underdeveloped. These works highlight gaps in developing robust, scalable, and self-adaptive IoT security monitoring systems [7]. Recent work by Agustin Zuniga et al. (2024) highlighted the potential of low-cost sensing for improving environmental sustainability through increased spatial coverage and pollutant monitoring, yet challenges remain in data accuracy and calibration. Mayowa Olapade et al. (2023) explored scalable sensing solutions but lacked robust data validation mechanisms. Similarly, Naser Hossein Motlagh et al. (2022) investigated pervasive sensing applications, though issues in long-term reliability and integration persist. These studies reveal gaps in developing cost-effective, accurate, and fully reliable environmental sensing systems for large-scale deployment [12].

## PROPOSED METHODOLOGY:

The proposed system adopts a distributed wireless sensor network architecture for continuous environmental monitoring. At the sensing layer, multiple sensors including temperature and humidity (DHT11), gas sensors for CO<sub>2</sub> and methane, and a pressure sensor are deployed to capture real-time environmental parameters. Each sensor node is interfaced with a NodeMCU microcontroller, which performs initial signal conditioning, analog-to-digital conversion, and local preprocessing to reduce noise and improve data reliability. The processed data is transmitted wirelessly through the built-in Wi-Fi module of the NodeMCU to a centralized monitoring unit or cloud platform. A lightweight communication protocol is used to ensure efficient data transfer with minimal power consumption. At the receiver side, the collected data is stored, visualized, and analysed to identify abnormal environmental conditions. Threshold-based logic is implemented to trigger alerts when any parameter exceeds safe limits. To enhance system performance, periodic calibration and synchronization among sensor nodes are maintained. The modular design allows scalability by adding additional nodes without affecting system stability. This approach ensures low-cost deployment, real-time monitoring, and reliable data acquisition suitable for diverse environmental applications.

## BLOCK DIAGRAM:

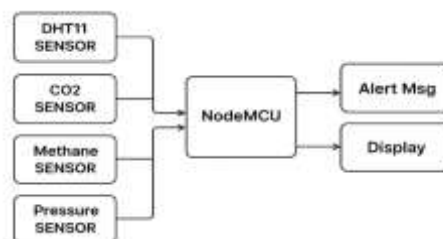


FIG 1: BLOCK DIAGRAM

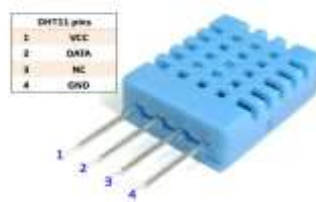
## HARDWARE WORKFLOW: NODEMCU



FIG 2: NODEMCU

The NodeMCU based on the ESP8266 acts as the central control unit of the system, integrating data acquisition, processing, and wireless communication within a single platform. It interfaces with multiple environmental sensors through its GPIO pins and performs analog-to-digital conversion where required. The onboard Wi-Fi capability enables seamless transmission of sensor data to remote servers or monitoring platforms without the need for external communication modules. Its low power consumption and compact design make it suitable for distributed sensor networks. Additionally, it supports flexible programming, allowing implementation of data filtering, threshold analysis, and alert generation.

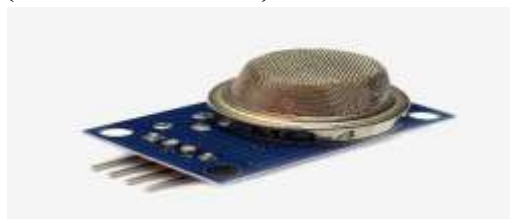
## DHT11 TEMPERATURE AND HUMIDITY SENSOR



**FIG 3: DHT11 TEMPERATURE AND HUMIDITY SENSOR**

The DHT11 sensor is used to measure ambient temperature and relative humidity in the environment. It operates using a capacitive humidity sensing element and a thermistor for temperature detection, providing calibrated digital output directly to the microcontroller. The sensor communicates through a single-wire protocol, simplifying interfacing and reducing wiring complexity. Although it offers moderate accuracy, it is sufficient for general environmental monitoring applications. Its low cost and stable performance make it suitable for continuous data acquisition. The sensor contributes to assessing environmental comfort and detecting variations that may indicate abnormal or unsafe conditions.

## MQ SERIES GAS SENSORS (CO<sub>2</sub> / METHANE)



**FIG 4: MQ SERIES GAS SENSORS**

MQ series gas sensors are employed to detect the presence and concentration of harmful gases such as carbon dioxide and methane. These sensors operate based on a change in resistance of a sensing material when exposed to target gases. The output is typically analog, which is processed by the microcontroller to estimate gas concentration levels. They require a preheating phase to stabilize readings and ensure accuracy. These sensors play a critical role in identifying hazardous environmental conditions, especially in industrial or confined spaces. Their sensitivity and affordability make them widely used in environmental monitoring and safety applications.

## PRESSURE SENSOR



**FIG 6: PRESSURE SENSOR**

The pressure sensor is utilized to measure atmospheric pressure variations within the monitored environment. It typically operates using piezoresistive or capacitive sensing principles, converting pressure changes into electrical signals. These signals are then digitized and processed by the microcontroller. Monitoring pressure is essential for understanding environmental dynamics, weather variations, and altitude-related changes. The sensor provides stable and precise readings, enabling integration with other environmental parameters for comprehensive analysis. Its compact size and digital interface simplify implementation in wireless sensor nodes, making it an important component for multi-parameter environmental monitoring systems.

## DISPLAY UNIT (LCD/OLED)



**FIG 7: DISPLAY UNIT**

The display unit, typically an LCD or OLED module, provides real-time visualization of sensor readings at the local level. It is interfaced with the microcontroller using parallel or I2C communication protocols, depending on the model. The display presents key environmental parameters such as temperature, humidity, gas concentration, and pressure, allowing immediate observation without requiring external devices. This feature is particularly useful during system setup, calibration, and maintenance. The display enhances usability by offering a simple and direct method of monitoring system performance, ensuring that users can quickly interpret environmental conditions.

## POWER SUPPLY UNIT



**FIG 8: POWER SUPPLY UNIT**



The power supply unit provides the necessary electrical energy required for the operation of all system components. It typically consists of a regulated DC supply, ensuring stable voltage levels for the microcontroller and sensors. Voltage regulators are used to prevent fluctuations that may affect sensor accuracy or system reliability. Depending on the application, the system can be powered using batteries or external adapters, supporting both portable and fixed installations. Efficient power management is crucial for long-term deployment, especially in remote locations. The design ensures minimal power loss while maintaining consistent system performance.

## RESULTS AND DISCUSSION:

The developed wireless sensor network demonstrated reliable performance in monitoring multiple environmental parameters under real-time conditions. The system successfully acquired temperature, humidity, gas concentration, and pressure data with consistent accuracy over extended operation. The NodeMCU ensured stable wireless communication, enabling continuous data transmission without significant packet loss. Sensor readings showed expected variations corresponding to environmental changes, validating proper system functionality. Gas sensors effectively detected fluctuations in air quality, while the pressure sensor provided stable atmospheric readings. The implemented threshold-based alert mechanism responded promptly when parameters exceeded predefined limits, indicating the system's capability for early warning applications. Minor deviations in sensor outputs were observed due to environmental noise and calibration limitations, but these did not significantly impact overall system performance. The integration of multiple sensors provided a comprehensive understanding of environmental conditions. Overall, the system proved to be cost-effective, scalable, and suitable for real-time environmental monitoring, with potential for further enhancement through advanced data analytics and calibration techniques.

## CONCLUSION:

The proposed wireless sensor network demonstrates an efficient and practical solution for real-time environmental monitoring by integrating multiple sensors with a low-power communication platform. The system provides reliable data acquisition, timely alert generation, and flexible deployment, making it suitable for diverse applications such as industrial safety and smart environments. Despite its effectiveness, further improvements can enhance accuracy and scalability. Future work may focus on advanced calibration techniques, integration of machine learning for predictive analysis, energy optimization for long-term deployment, and incorporation of additional sensors to support more comprehensive environmental assessment in dynamic conditions.

## REFERENCES:

1. Y. Sudriani, V. Sebestyén and J. Abonyi, "Surface Water Monitoring Systems—The Importance of Integrating Information Sources for Sustainable Watershed Management," in *IEEE Access*, vol. 11, pp. 36421-36451, 2023, doi: 10.1109/ACCESS.2023.3263802.
2. M. Z. Shaikh *et al.*, "State-of-the-Art Wayside Condition Monitoring Systems for Railway Wheels: A Comprehensive Review," in *IEEE Access*, vol. 11, pp. 13257-13279, 2023, doi: 10.1109/ACCESS.2023.3240167.



3. Y. Guo, Z. Xu and J. H. Saleh, "Active Environmental Monitoring and Anomaly Search System for Space Habitat with Markov Decision Process and Active Sensing," in *IEEE Access*, vol. 9, pp. 49683-49696, 2021, doi: 10.1109/ACCESS.2021.3068950.
4. D. M. G. Preethichandra, L. Piyathilaka and U. Izhar, "Review on Robotic Systems for Environmental Monitoring," in *IEEE Open Journal of Instrumentation and Measurement*, vol. 4, pp. 1-17, 2025, Art no. 9500317, doi: 10.1109/OJIM.2024.3493875.
5. P. S. Das *et al.*, "The EcoChip 2: An Autonomous Sensor Platform for Multimodal Bio-environmental Monitoring of the Northern Habitat," *2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, Montreal, QC, Canada, 2020, pp. 4101-4104, doi: 10.1109/EMBC44109.2020.9176335.
6. Y. Liu and F. Xiao, "Intelligent Monitoring System of Residential Environment Based on Cloud Computing and Internet of Things," in *IEEE Access*, vol. 9, pp. 58378-58389, 2021, doi: 10.1109/ACCESS.2021.3070344.
7. W. Liang, W. Li and L. Feng, "Information Security Monitoring and Management Method Based on Big Data in the Internet of Things Environment," in *IEEE Access*, vol. 9, pp. 39798-39812, 2021, doi: 10.1109/ACCESS.2021.3064350.
8. Y. -J. Yang *et al.*, "Applying Reliability Centered Maintenance (RCM) to Sampling Subsystem in Continuous Emission Monitoring System," in *IEEE Access*, vol. 8, pp. 55054-55062, 2020, doi: 10.1109/ACCESS.2020.2980630.
9. D. G. Eliades, K. Malialis, S. Vrachimis and M. M. Polycarpou, "Smart Water Networks as Cyber-Physical-Socio-Environmental Systems," in *IEEE Transactions on Industrial Cyber-Physical Systems*, vol. 3, pp. 95-105, 2025, doi: 10.1109/TICPS.2024.3520558.
10. Y. Sun, J. Zhou, Z. Sun and Z. Wei, "Selective Maintenance for a Multistate System Considering Energy Loss and Environmental Effect," in *IEEE Access*, vol. 12, pp. 77079-77091, 2024, doi: 10.1109/ACCESS.2024.3405329.
11. M. Sharone and A. Muhtaroglu, "Patient-Centered Design Method for Self-Powered and Cost-Optimized Health Monitors," in *IEEE Access*, vol. 11, pp. 125055-125063, 2023, doi: 10.1109/ACCESS.2023.3329935.
12. Zuniga *et al.*, "Low-Cost Sensing for Environmental Sustainability," in *IEEE Pervasive Computing*, vol. 23, no. 4, pp. 76-86, Oct.-Dec. 2024, doi: 10.1109/MPRV.2024.3448199.
13. P. A. Lindahl *et al.*, "Nonintrusive Load Monitoring of Variable Speed Drive Cooling Systems," in *IEEE Access*, vol. 8, pp. 211451-211463, 2020, doi: 10.1109/ACCESS.2020.3039408.