International Journal of Research Publication and Reviews, Vol 6, Issue 5, pp 16783-16786 May 2025

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

AI and IOT For Environmental Monitoring, Applications and Challenges : A Review

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Abstract

Environmental monitoring is a systematic process that assesses ecosystem health, promoting sustainable development and public health globally, by collecting, analyzing, and interpreting data over time.The Internet of Things (IoT) is a revolutionary technology with diverse applications, including environmental monitoring.IoT technologies revolutionize environmental data collection, analysis, and utilization by integrating sensors with existing monitoring frameworks. The data, combined with advanced analytics and machine learning algorithms, provides real-time insights for environmental management, enhancing prediction and response to changes.The study aims to enhance resilience and sustainable environmental practices by providing practical insights on the use of the Internet of Things (IoT) for real-time environmental data collection and analysis. The study aims to address the gap in IoT use for environmental monitoring by investigating advanced applications that enhance real-time data collection and analysis, benefiting stakeholders like communities, policymakers, and environmental agencies.It aims to bridge the gap between theoretical developments and practical implementation, equipping decision-makers with effective strategies.

Keywords: AI, Internet of Things (IoT), Environmental Monitoring

INTRODUCTION:

In order to evaluate the health and quality of ecosystems, which are vital for both public health and sustainable development worldwide, environmental monitoring is vital. To monitor changes in environmental parameters over time, it entails the methodical collection, analysis, and interpretation of data. Effective environmental management techniques and evidence-based policymaking are greatly aided by accurate monitoring data.A paradigm shift in device connectivity is represented by the Internet of Things (IoT), in which commonplace items are outfitted with sensors, actuators, and communication capabilities to gather and share data on their own. Through smooth integration with digital systems, this network of interconnected devices enables real-time monitoring and control of physical environments1. With its many uses, including environmental protection, the Internet of Things (IoT) has become a game-changing technology. Every IoT device, from consumer electronics to industrial machinery, adds to the vast network of interconnected devices that shapes today's technological environments. IoT devices come with a variety of sensors designed to keep an eye on particular environmental factors that are essential for resource management and sustainability. These sensors include, among others, water quality sensors, air quality analyzers, temperature gauges, and humidity detectors.2To ensure regulatory compliance and protect public health, environmental monitoring stations, for instance, IoT-enabled sensors track changes in air pollutant levels.3 Global environmental monitoring capabilities are being revolutionized by recent developments in monitoring technologies, including satellite remote sensing, Internet of Things sensors, and big data analytics. At first, monitoring efforts were crude, using simple instruments and observational methods. Air quality monitoring has been completely transformed by the Internet of Things, which allows for real-time data collection and analysis via networked sensors and devices. In order to detect dangerous gases like NO2, CO, NH3, and benzene, modern systems a range of sensors, including MQ135, MQ6, MQ7, and MQ2 are used. These sensors then transmit the data to microcontrollers and online servers for ongoing monitoring and alerting. IoT technology transforms environmental monitoring by offering scalable, reasonably priced solutions for a variety of applications. IoT sensors placed on building facades and streetlights in urban settings track air quality parameters like nitrogen dioxide (NO2), particulate matter (PM2.5), and ozone (O3) in real time. Cities can use these sensors to implement specific pollution control measures. Simpler and less expensive monitoring systems that are based on USEPA concepts have been modified to local conditions in developing nations, guaranteeing greater usability and accessibility. Stationary monitoring stations that measure different pollutants like CO2, NO2, NH3, and benzene are usually used in traditional air quality monitoring methods. Although these stations offer trustworthy data and are very accurate, they have a lot of drawbacks. One significant disadvantage is the high cost of installation and upkeep, which limits their use to more affluent areas and larger cities, leaving less coverage for smaller cities and less developed areas.4Furthermore, these conventional systems frequently call for laboratory analysis, which impairs real-time monitoring's sensitivity and precision . One significant drawback is the absence of real-time data, which makes it impossible to react quickly to abrupt changes in air quality, which may be harmful to the general public's health.9

Furthermore, it is challenging to predict trends in air quality and take preventative action because traditional methods lack predictive capabilities. For example, although HVAC systems are capable of regulating indoor air quality, their operation frequently depends on a large amount of historical data, which can be expensive and may not be able to adjust well to changing circumstances.5 Although they have drawbacks like poor accuracy and issues with data quality, IoT-based air quality monitoring systems have emerged as a promising solution to these limitations by offering real-time data with a higher spatiotemporal resolution.6 More accessible and extensive monitoring is made possible by these IoT systems, which use inexpensive sensors and cloud-based platforms for data storage and visualization.8

IoT technologies have transformed data collection and analysis across multiple ecosystems, greatly improving environmental management practices. Real-time data on agriculture, wildlife habitats, urban green spaces, and air and water quality was effectively collected by integrating IoT sensors with pre-existing monitoring frameworks. Proactive decision-making, early environmental risk detection, and the development of evidence-based policies to address the issues of climate change, biodiversity conservation, and sustainable resource management were made easier by this data. Using sensors to measure temperature, humidity, CO2, VOCs, and particulate matter, systemsends data to a microcontroller and notifies users through the Telegram app.7 To monitor toxic compounds in a melting furnace setting, for example, a distributed sensing system employing commercial sensors was implemented, successfully identifying hazardous conditions for employees and improving safety protocols.10The hybrid sensor network, which combines inexpensive devices for air quality monitoring with public monitoring stations, is another noteworthy implementation. It has shown increased cost-effectiveness and calibration accuracy, making large-scale deployments possible.11

Applications of IoT

IoT in air quality monitoring: IoT sensors are installed throughout several cities, carefully positioned in high-pollution zones to detect the effects of air quality on public health and legal compliance in urban settings. Real-time measurements of ozone, NO_2, PM2.5, and other pollutants are made by sensors. When compared to conventional monitoring techniques, the IoT-enabled monitoring systems greatly improved the temporal and spatial resolution of air quality data. More precise identification of pollution hotspots and real-time modifications to urban air quality management plans made it possible by the high-resolution data. In order to lessen the negative effects of air pollution on populations that are already at risk, the study suggest incorporating IoT data streams into public health programs and urban planning frameworks.

IoT for water quality: IoT sensors with probes to measure conductivity, turbidity, dissolved oxygen, and pH are placed in lakes, reservoirs, and rivers in a variety of geographical locationsto track freshwater ecosystems to improve water resource management and ecosystem health.Early detection of pollution events and ecosystem disturbances, made it possible by the continuous, real-time data on water quality parameters byIoT-based monitoring systems. Better comprehension of seasonal variations and human impacts on freshwater ecosystems was made possible by the data granularity. In order to cover vulnerable and distant water bodies that are not sufficiently covered by conventional monitoring techniques, the researchers suggest extending IoT sensor networks. They underlined that in order to facilitate cross-border cooperation in the management of water quality, standardized protocols and data sharing platforms are required.[12]

IoT in agriculture: IoT devices with nutrient analyzers, weather stations, and soil moisture sensors are placed in agricultural fields in various climate zones for monitoring, to maximize agricultural productivity and environmental sustainability, as well as for sustainable land use and resource management.Through data-driven decision-making, IoT-enabled agricultural monitoring systems enhanced crop yield forecasts and maximized the use of fertilizer and water. Additionally, the systems made it easier to identify pest infestations and soil degradation early on, encouraging proactive farm management techniques. The study promotes the use of IoT data in conjunction with precision farming methods like crop rotation planning and variable rate irrigation.[13]

Iot in forest fire detection and management: Enhancing early warning systems and minimizing environmental harm are the goals of forest fire detection and management. In order to track forest conditions, identify heat anomalies, and forecast fire spread patterns, IoT sensors are integrated with satellite data and geographic information systems (GIS). IoT-enabled forest fire detection systems showed improved precision in locating fire outbreaks' early stages and ignition points. Rapid deployment of firefighting resources and mitigation techniques are made possible by real-time data integration and analysis. In remote and environmentally delicate forested areas, the researchers suggest extending the reach of IoT sensor networks. Additionally, they proposed combining artificial intelligence (AI) algorithms with advanced analytics to enhance fire behavior prediction modelling.[13]

IoT in the marine environment: To keep an eye on climate parameters, marine biodiversity, and water quality, IoT sensors with underwater cameras, hydrophones, and environmental probes are placed along coastal areas to monitor for sustainable fisheries, biodiversity conservation, and coastal management.Comprehensive and high-resolution data on coastal ecosystems are made available by IoT-enabled marine monitoring systems, facilitating sustainable fishing methods and efficient management of marine protected areas. The information made it easier to identify dangerous algal blooms and instances of marine pollution early on. For comprehensive marine conservation strategies, the study suggests integrating data from various sources (such as satellite imagery and citizen science) and expanding IoT deployments to cover larger coastal areas. The necessity of international collaboration in the management of transboundary marine resources are also emphasized.[14]

IoT in wildlife conservation: In wildlife habitats like national parks and wildlife reserves, Internet of Things devices with motion sensors, GPS trackers, and environmental monitors were installedto monitor habitats to safeguard biodiversity hotspots and endangered species. Real-time information on animal movements, habitat fragmentation, and climate impacts was made available by IoT-based wildlife monitoring systems. In remote and rugged environments, where conventional monitoring techniques are frequently impractical, the researchers argued for improving IoT sensor capabilities as how crucial ethical issues and data privacy are to wildlife monitoring.

In urban green spaces: To improve community well-being and public health through sustainable urban planning ,IoT sensors are placed in parks, gardens, and green belts to track visitor trends (such as foot traffic and leisure activities) and environmental factors (such as temperature, noise levels, and air quality). By giving visitors real-time notifications of environmental changes and crowding, IoT-enabled urban green space monitoring systems increased visitor satisfaction and maintenance efficiency. When it came to developing urban green infrastructure, the data backed evidence-based decision-making. In order to improve green space management and design for increased livability and resilience to the effects of climate change, the study suggest combining IoT data with urban planning procedures.[15]

CHALLENGES

A number of obstacles and restrictions still exist in spite of these achievements. The accuracy of sensors is still a major technical problem, especially for inexpensive sensors that are prone to mistakes and deterioration over time. Another technical challenge is data integration because accurate analysis and pollution level forecasting depend on complex models that process high-dimensional, spatiotemporal data from multiple IoT devices. The cost and scalability of implementing these systems are practical obstacles. Although inexpensive sensors are more cost-effective, they can be logistically challenging to maintain and calibrate, particularly when used in large quantities. Even though IoT and AI-based air quality monitoring systems have advanced significantly, there is still a noticeable lack of use of these technologies in actual industrial settings. Environmental monitoring still faces difficulties despite technology breakthroughs, which affects the precision of data and the efficacy of policies. Funding limitations for long-term monitoring programs, data interoperability across monitoring networks, and sensor calibration and maintenance expenses are among the problems.
These difficulties impair coordinated efforts to address global environmental issues and have an impact on the accuracy of monitoring results.[16] The study should offers a novel solution that permits prompt interventions and proactive pollution management by resolving the drawbacks of conventional techniques and bridging the current knowledge gap. In order to ensure that the systems are reliable, scalable, and able to produce precise and useful data, closing this gap will offer useful insights into the requirements and difficulties of implementing IoT and AI technologies in industrial settings.

Conclusion

Governments and organizations can improve the long-term sustainability and resilience of IoT-driven environmental monitoring projects by making investments in the development of human capital.In order to innovate and enhance IoT technologies for environmental monitoring, studies on scalable data analytics platforms, energy-efficient IoT gadgets, and novel sensor technologies are need to be developed. Researchers can overcome present constraints like battery life, sensor accuracy, and data transmission reliability by developing technological capabilities. This will open up new possibilities for IoT applications in environmental sustainability. The results of this study will be essential in forming laws and procedures that promote environmental stewardship and sustainable development globally as IoT develops.

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