World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Implementation of an IoT-Based Temperature Monitoring System for Pharmaceutical Storage: A Qualitative Case Study at the District Pharmaceutical Installation of Kendari City

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World Journal of Advanced Research and Reviews, 2025, 28(03), 890-896

Publication history: Received on 06 November 2025; revised on 10 December 2025; accepted on 13 December 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.3.4151

Abstract

Background: This study aimed to describe the implementation of an Internet of Things (IoT)–based automated temperature monitoring system for pharmaceutical storage at the District Pharmaceutical Installation (UPTD Instalasi Farmasi) of Kendari City.

Method: A qualitative study with a case study approach was conducted, involving four pharmacy staff members as primary informants and one key informant from the District Health Office selected through purposive sampling. Data were collected using semi-structured in-depth interviews covering manual temperature monitoring practices, IoT implementation, human resource and technical constraints, as well as perceptions of system effectiveness and sustainability, and were then analyzed thematically.

Results: Four main themes were identified: (1) manual temperature monitoring prior to IoT implementation, which relied on periodic recording, was prone to omission, and lacked an early warning system; (2) implementation of the IoT system, which enabled real-time temperature monitoring and continuous data logging to support reporting and pharmaceutical planning; (3) human resource and technical challenges, including limited training, restricted Bluetooth range, unstable network quality, and inconsistent power supply; and (4) positive perceptions of pharmacy staff and policymakers regarding the effectiveness of the IoT system, including its potential for replication in other health care facilities. The study concludes that the IoT-based system contributes to improved work efficiency and accountability of temperature monitoring data; however, its success and sustainability largely depend on strengthening human resource capacity, ensuring adequate infrastructure support, and integrating the system into policies and standard operating procedures of pharmaceutical installations.

Keywords: Internet of Things; Temperature monitoring; Pharmaceutical storage; Pharmacy installation

1. Introduction

The quality and stability of medicines are strongly influenced by storage conditions, particularly temperature and humidity, making rigorous temperature monitoring a critical component of pharmaceutical management and vaccine cold chain systems (Kartoglu & Ames, 2022). Global studies have shown that storage outside the recommended temperature range increases the risk of medicine degradation and loss of vaccine effectiveness, ultimately affecting patient safety and the success of public health programs (Hodel et al., 2024).

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In many health care facilities, including those in middle-income countries, temperature monitoring is still performed manually through periodic entries on paper logs, which are vulnerable to omission, delayed recording, and the absence of early warning systems when temperature excursions occur(Jayatilleke, 2020). The development of the Internet of Things (IoT) offers an opportunity to deploy networked sensors and real-time monitoring with automated notifications for medicine and vaccine storage, thereby strengthening quality assurance and supporting data driven managerial decision-making (Polenghi et al., 2023).

Several studies have developed IoT-based prototype systems to monitor temperature and humidity in pharmaceutical storage areas, including warehouse environments and refrigerators, with a primary focus on technical design and sensor performance (Ali-Dinar et al., 2021). However, there is still limited qualitative research exploring the experiences, perceptions, and challenges faced by pharmacy personnel in adopting IoT systems in public sector pharmacy services in low and middle income settings (Doreen Mureyi, 2021). This study addresses this gap by examining the implementation of an IoT-based automated temperature monitoring system at the District Pharmaceutical Installation (UPTD Instalasi Farmasi) of Kendari City, Indonesia (Buzuleeva, 2025a).

The aim of this study is to provide a detailed description of manual temperature monitoring practices prior to the implementation of the IoT system at the UPTD Instalasi Farmasi Kota Kendari; to describe the process and configuration of the IoT-based automated temperature monitoring system for pharmaceutical storage; to identify human resource and technical challenges arising during system implementation; and to analyze the perceptions of pharmacy staff and policymakers regarding the effectiveness and sustainability of IoT use within the pharmaceutical installation(Ghozali, 2023)

1.1. Internet of Things (IoT) in health care and pharmacy

In health care, IoT is defined as a network of interconnected physical devices equipped with sensors and communication capabilities that enable real time data collection and exchange to support health services and both clinical and managerial decision making (Islam et al., 2023). In the pharmaceutical context, IoT has been applied to monitor environmental conditions in medicine and medical device storage, including temperature, humidity, and air quality, to maintain product stability and prevent damage during storage and distribution (Kumar et al., 2024).

A number of studies have developed IoT-based multi-sensor platforms to monitor medicine storage beyond hospital settings using combinations of communication modules such as LoRa and Bluetooth Low Energy, enabling near real time monitoring and tracking of product conservation across locations (Frontera-Bergas et al., 2025). Other research has designed smart control systems that integrate temperature–humidity sensors with fuzzy logic to maintain optimal environmental conditions in pharmaceutical storage rooms. Overall, this body of evidence suggests that IoT can improve monitoring accuracy, provide historical data, and reduce reliance on manual recording (Abdulmalek et al., 2022).

1.2. IoT and vaccine cold-chain management

Within vaccine cold chains, the use of IoT for temperature monitoring has been identified as a key pillar for reducing vaccine damage due to exposure to extreme temperatures during transport and storage (Jiang et al., 2024). IoT-enabled cold chain frameworks allow 24/7 monitoring of temperature and humidity, location tracking, and alarm systems when temperatures fall outside the safe range, thereby preventing events such as large scale vaccine spoilage caused by power outages or operational errors. Implementations of such frameworks have been reported to reduce vaccine incident rates and improve the efficiency of cold-chain management (Ashok et al., 2017).

1.3. IoT adoption and human resource factors

Despite the clear technical benefits of IoT, its adoption in health care remains relatively limited and faces challenges related to organizational and human resource readiness (Ghaleb et al., 2021). Systematic reviews have identified key barriers including insufficient training, resistance to change, limited network infrastructure, and concerns about data security. Studies in Indonesian hospitals further indicate that successful IoT integration is influenced by business innovation, operational efficiency, availability of dedicated IT staff, and the costs of training and maintenance. These findings are highly relevant for analyzing IoT implementation in public pharmaceutical installations such as the UPTD Instalasi Farmasi Kota Kendari

2. Material and methods

This study employed a qualitative design with an intrinsic case study approach to explore in depth the implementation of an IoT-based automated temperature monitoring system at the District Pharmaceutical Installation (UPTD Instalasi

Farmasi) of Kendari City (Tran et al., 2022). The study site was selected purposively because it served as a pilot project for IoT implementation in medicine storage temperature monitoring, with plans for subsequent replication in primary health centers (puskesmas) across the city (Lin et al., 2021).

The study informants consisted of four pharmacy staff members directly involved in monitoring the temperature of medicine and vaccine storage areas, and one key informant from the District Health Office who was responsible for planning, procurement, and policy related to the IoT system. Informants were selected using purposive sampling based on the following criteria: having worked at the installation for at least several months, being involved in temperature monitoring before and after IoT implementation, or holding policy-level authority at the district health office (D'Oca et al., 2018).

Primary data were collected through semi-structured in-depth interviews guided by an interview protocol covering four domains: (1) manual temperature monitoring practices; (2) IoT implementation; (3) human resource and technical constraints; and (4) perceptions of system effectiveness and sustainability. With participants' consent, interviews were audio-recorded, transcribed verbatim, and subjected to thematic analysis through open coding, categorization, and identification of main themes and subthemes. Data trustworthiness was ensured through source triangulation (pharmacy staff and key informant), peer debriefing, and member checking of key findings with selected informants (Nduka et al., 2024).

2.1. Sampling Techniques

The study informants consisted of four pharmacy staff members directly involved in monitoring the temperature of medicine and vaccine storage areas, and one key informant from the District Health Office who was responsible for planning, procurement, and policy related to the IoT system. Informants were selected using purposive sampling based on the following criteria: having worked at the installation for at least several months, being involved in temperature monitoring before and after IoT implementation, or holding policy-level authority at the district health office (D'Oca et al., 2018).

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2.2. Data Collection

Data trustworthiness was ensured through source triangulation (pharmacy staff and key informant), peer debriefing, and member checking of key findings with selected informants (Nduka et al., 2024).

3. Results

Four main themes were identified: (1) manual temperature monitoring practices prior to IoT implementation; (2) implementation of the IoT-based automated temperature monitoring system; (3) human resource and technical challenges; and (4) perceptions of the effectiveness and sustainability of the IoT system

Table 1 Implementation of an IoT-Based Temperature Monitoring System for Pharmaceutical Storage at the District Pharmaceutical Installation of Kendari City

Main theme	Subtheme	Summary of key findings
Manual temperature monitoring prior to IoT	Pattern and frequency of monitoring	Temperature monitoring was performed manually 1–2 times per day at fixed times, mainly at midday when ambient temperature was highest, by designated staff responsible for recording .
	Limitations of the manual system	The system was perceived as sufficiently effective when performed routinely but was often constrained by workload, staff absence, and lack of alarms, leading to missed or delayed entries and incomplete reflection of actual temperature fluctuations .

IoT-based automated temperature monitoring	System deployment and configuration	The IoT system was introduced approximately 2–3 months before data collection, with sensors installed at several points in storage rooms and refrigerators, connected to applications on computers or mobile devices .
	Role as a pilot project	The implementation formed part of efforts to meet pharmaceutical installation standards and was positioned as a pilot project to be replicated in 15 primary health centers, while generating continuous temperature records for reporting and planning of medicines and medical supplies .
Human resource and technical challenges	Readiness and capacity of staff	Most staff had not received specific training on IoT use, resulting in initial confusion about application features and data interpretation, and uneven dissemination of standard operating procedures (SOPs) .
	Infrastructure and technical constraints	Key challenges included limited Bluetooth range, unstable network quality, and frequent power drops, which reduced monitoring reliability and required continued reliance on manual procedures under certain conditions .
Perceptions of effectiveness and sustainability	Perceived impact on work processes	Staff perceived the IoT system as more effective than manual monitoring because it reduced repetitive workload, saved time, and enabled more frequent temperature checks without walking between rooms .
	Managerial benefits and scalability	Data from the IoT system were considered crucial for ensuring medicine storage quality, supporting planning of medicines and medical supplies, and providing an objective basis in the event of disputes over product quality, with most informants supporting replication to other health care facilities .

Source: Primary Data (October 2025 - December 2025)

4. Discussion

The findings of this study highlight structural weaknesses inherent in manual temperature monitoring practices, particularly the risk of missed or delayed recordings, the absence of temperature alarms, and a high dependence on room conditions and staff compliance (Yi et al., 2016). Spot check, non-continuous measurements make it difficult to detect short duration temperature excursions, even though evidence indicates that brief and repeated deviations can compromise medicine stability and necessitate comprehensive quality risk assessment. In this context, practices at the District Pharmaceutical Installation of Kendari City reflect a common challenge in health care facilities, namely a mismatch between regulatory requirements for temperature control and the limitations of available manual monitoring systems (Filip et al., 2022).

The implementation of an IoT-based automated temperature monitoring system at this installation represents an important shift from reactive to more proactive and data driven monitoring (Valinejadshoubi et al., 2021). The availability of real-time temperature data, continuous historical records, and access via mobile devices is consistent with the evolution of IoT multisensor platforms for medicine and vaccine storage, which have been reported to improve transparency of environmental conditions and strengthen cold chain control. With a traceable data trail, the IoT system functions not only as a technical monitoring tool but also as an accountability instrument that supports quality audits, investigation of temperature incidents, and decision-making on product usability following excursions (Sarkar, 2022).

Nevertheless, the study also shows that technological benefits do not materialize automatically in the absence of sufficient organizational capacity. The lack of structured training, limited SOP dissemination, and dependence on unstable network and power infrastructure illustrate a spectrum of human resource and infrastructural barriers widely reported in the literature on IoT and digital health adoption, including insufficient protected time for learning, uneven digital competence, and underdeveloped connectivity (Mwamkinga & Barongo, 2025). These conditions place staff in an ambivalent position: on the one hand, they recognize the effectiveness and convenience of IoT, yet on the other hand they must retain manual procedures as a backup in the event of technical disruptions, thereby preventing the realization of full efficiency gains.

Conceptually, the findings from the Kendari City Pharmaceutical Installation reinforce the notion that successful IoT implementation in pharmaceutical supply chains and storage is determined not only by the sophistication of devices but also by the integration of technology with governance, resources, and organizational culture. Positive perceptions among staff and policymakers regarding the ability of IoT to reduce workload, increase monitoring frequency, and provide an objective basis for medicine planning and dispute resolution constitute important social capital that should be promptly leveraged through investments in training, SOP refinement, and reinforcement of network and power infrastructure. Without these measures, the IoT system risks becoming an "expensive ornament" that does not fully address fundamental temperature control issues, despite global evidence that robust temperature monitoring can prevent high-value medicine losses and significantly protect patient safety (Buzuleeva, 2025b).

5. Conclusion

This study demonstrates that transitioning from manual temperature monitoring to an IoT-based automated system in a public pharmaceutical installation in Indonesia yields tangible benefits in terms of staff work efficiency, monitoring frequency, and accountability of medicine storage data. However, the success and sustainability of implementation are highly dependent on human resource readiness, network and power infrastructure support, and integration of the system into standard operating procedures and medicine management policies at the health authority level.

In practical terms, local governments and pharmaceutical managers are advised to: (1) develop ongoing training programs and systematic SOP dissemination for IoT use; (2) strengthen network and electrical infrastructure in strategically important pharmaceutical facilities; and (3) leverage IoT data not only for daily operational monitoring but also for medicine planning, cold-chain evaluation, and broader quality improvement in pharmacy services. Future research could combine qualitative and quantitative approaches to assess the impact of IoT on medicine quality indicators, cost efficiency, and clinical outcomes more comprehensively.

Compliance with ethical standards

Acknowledgments

The authors would like to express their sincere appreciation to the Head of the Kendari City Health Office and the management of the District Pharmaceutical Installation (UPTD Instalasi Farmasi) of Kendari City for granting permission, support, and facilitation throughout the conduct of this study. Special thanks are extended to all informants, particularly the pharmacy staff and the key informant, who generously devoted their time and shared their experiences and valuable insights. The authors also wish to thank colleagues and all other individuals who cannot be mentioned individually for their scientific input and support, which contributed to the refinement of this study and the preparation of the manuscript.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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