

The Role of Technology in Enhancing Health Monitoring and Safety of Pilgrims During Hajj

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Abstract

The Hajj pilgrimage is one of the largest and most complex annual gatherings in the world, attracting millions of Muslims from diverse geographical regions. This convergence of people presents not only a profound spiritual experience but also significant public health and safety challenges. The rapid advancement of digital health technologies, including artificial intelligence (AI), Internet of Things (IoT) devices, and wearable sensors, has opened new pathways for improving health surveillance, risk prediction, and emergency response during the pilgrimage. This paper explores the role of technology in enhancing pilgrims' health monitoring and safety during Hajj, analyzing both the ethical and legal implications of data use and management. The research also evaluates how Saudi Arabia's Vision 2030 and health sector transformation initiatives integrate digital systems for mass gatherings. Drawing upon recent studies, official reports, and real-world implementations, this paper argues that the convergence of digital health tools with ethical frameworks can ensure both effective medical management and respect for pilgrims' dignity. Recommendations are made for policy harmonization, AI governance, and regional data-sharing protocols to support future Hajj operations.

Keywords: hajj, digital health, artificial intelligence, wearable technology, pilgrims' safety, health monitoring, saudi vision 2030

Introduction

The Hajj pilgrimage to Makkah stands as one of the world's most significant mass gatherings, attracting more than two million pilgrims annually from over 180 countries. While it is a deeply spiritual journey, it also presents unique logistical, environmental, and health challenges. Pilgrims face extreme heat, physical exhaustion, and exposure to contagious diseases due to the dense crowding (Yezli et al., 2024). Over the past decade, the Kingdom of Saudi Arabia has embraced technological innovations to manage these challenges effectively. Integrating artificial intelligence (AI), Internet of Things (IoT), and health informatics has emerged as a key strategy to safeguard public health and ensure efficient coordination among healthcare authorities.

In recent years, the Saudi Vision 2030 initiative has accelerated digital transformation across health and safety domains. This has enabled the implementation of electronic health monitoring systems, real-time tracking of vital signs through wearable devices, and AI-based predictive analytics to identify potential emergencies before they occur (Saudi Vision 2030, 2024). These innovations demonstrate how technology can harmonize with Islamic values,

emphasizing preservation of life and collective well-being, as outlined in the objectives of Shariah (Maqasid al-Shariah).



Figure.1 How AI tech innovation has enhancing safety, easing logistics during the Hajj of 20225

The convergence of millions of people in one geographic area during Hajj creates an environment of potential health risks, including heatstroke, dehydration, respiratory infections, and chronic disease exacerbations. Traditional health systems often face difficulty providing real-time monitoring and rapid emergency responses. Despite the introduction of advanced tools, challenges persist regarding data privacy, interoperability between systems, and ethical considerations in digital surveillance (WHO, 2023).

Furthermore, the use of wearable technologies and AI-driven analytics raises questions about data ownership, informed consent, and responsibility in cases of device failure or inaccurate readings. These challenges highlight the urgent need for comprehensive frameworks that integrate technology, ethics, and law to ensure that digital transformation enhances—not compromises—pilgrims’ dignity and safety (Al-Mogren et al., 2025).

This research aims to explore how technology can be effectively utilized to enhance the health and safety of pilgrims during Hajj. The specific objectives are to:

1. Examine current technological innovations in health monitoring during Hajj.
2. Assess the ethical, legal, and social implications of these technologies.
3. Analyze the role of artificial intelligence and wearable devices in improving health outcomes.
4. Propose recommendations for a sustainable and integrated digital health system aligned with Vision 2030 goals.

The significance of this study lies in its interdisciplinary nature, bridging the fields of technology, healthcare, and Islamic ethics. By analyzing digital health solutions from both practical and moral perspectives, this research contributes to developing a balanced model that promotes innovation while maintaining respect for human dignity. It also supports Saudi Arabia’s national goal of transforming its healthcare sector into a digital-first ecosystem that ensures safety for all pilgrims (Al-Anezi et al., 2025).

This study further contributes to global discussions on health management during mass gatherings, offering insights applicable to other large-scale events worldwide. The findings emphasize that digital technologies are not merely tools of efficiency but instruments of compassion, reflecting Islamic principles of mutual care and protection.

The research seeks to address the following questions:

1. How are digital health technologies currently being implemented during the Hajj pilgrimage?
2. What are the ethical and legal challenges associated with these technologies?
3. In what ways can AI and IoT enhance predictive health management for pilgrims?
4. How can Saudi Arabia establish a unified framework to ensure data privacy and international cooperation during Hajj?

Conceptual Definitions

Digital Health: The use of technology, data analytics, and connected systems to improve healthcare delivery and disease prevention (Alghamdi et al., 2021).

Artificial Intelligence (AI): Computational systems capable of analyzing data and making predictions or decisions that aid healthcare management.

Internet of Things (IoT): A network of interconnected devices capable of collecting and exchanging data in real time.

Wearable Devices: Portable sensors worn on the body to continuously monitor physiological signals such as heart rate, temperature, and oxygen levels.

Pilgrim Health Monitoring: Continuous observation and evaluation of pilgrims' health conditions to prevent medical emergencies during Hajj.

Results

In the past decade, Saudi Arabia has transformed the way healthcare is delivered during the Hajj season. The country's health authorities have adopted advanced technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and big data analytics to manage the health and safety of millions of pilgrims (Memish et al., 2024). These systems are designed to predict potential health crises, reduce medical response times, and ensure the optimal distribution of healthcare resources across the holy sites of Makkah, Mina, Arafat, and Madinah.

The Kingdom's commitment to innovation reflects the broader objectives of the Saudi Vision 2030 program, which emphasizes digital transformation, sustainability, and efficient public service delivery (Saudi Vision 2030, 2024). In this context, health technology during Hajj is not merely a convenience but a strategic necessity to maintain public safety in one of the most complex religious gatherings in the world.

Health Technology Applications during Hajj

Internet of Things (IoT) and Wearable Devices

The use of wearable IoT devices for health monitoring has become one of the most impactful innovations during Hajj. These devices, such as smart wristbands or badges, collect real-time physiological data including heart rate, body temperature, oxygen saturation, and physical activity levels. This information is transmitted to centralized monitoring stations, allowing healthcare professionals to identify pilgrims at risk of heat stress, dehydration, or cardiac arrest (Al-Turaiki et al., 2024).

For instance, the Makkah Health Cluster (2024) introduced wearable sensors connected to an integrated health management system capable of alerting medical teams when a pilgrim's vital signs deviate from safe levels. This initiative significantly reduced response times and prevented several heat-related incidents during the 2024 pilgrimage season.

Additionally, the development of the Smart Bracelet Project provides pilgrims with an electronic identity linked to their medical records, enabling quick access to health information in emergencies. Research conducted by Ismail et al. (2022) demonstrated the feasibility and user acceptance of such IoT systems in ensuring continuous monitoring while maintaining pilgrims' comfort.

Artificial Intelligence in Health Surveillance

Artificial Intelligence (AI) has been increasingly used to analyze the vast amounts of health data generated during Hajj. AI algorithms can detect abnormal physiological patterns, forecast disease outbreaks, and optimize medical logistics in real time. For example, machine learning models have been developed to classify crowd density and predict heat-related illnesses among pilgrims based on video analytics and environmental data (Shah, 2025).

A study by Al-Zahrani et al. (2025) introduced an AI-driven fatigue detection system that uses wearable sensors to monitor physical exertion and predict fatigue levels. The integration of such systems helps authorities anticipate medical emergencies before they occur, saving both time and lives. Similarly, Abdel-Rahman et al. (2023) presented a model for real-time crowd health management using physiological sensors and AI-based analytics.



Figure.2 Prophet Mosque's AI-driven medical capsule enhance healthcare 2025.

Data Analytics and Predictive Modelling

Big data analytics plays a crucial role in identifying patterns of illness and optimizing healthcare deployment. By collecting and analyzing millions of data points from pilgrims' wearables, health centers, and environmental sensors, predictive algorithms can forecast where and when medical incidents are most likely to occur (Khan et al., 2024). The Ministry of Health's Central Control Room utilizes predictive dashboards that visualize live data from multiple hospitals, enabling immediate resource allocation. Studies such as those by Al-Mogren et al. (2025) and Alghamdi et al. (2021) highlight how data-driven approaches increase operational efficiency and reduce preventable fatalities.

Digital Health Infrastructure

The establishment of a robust digital infrastructure has been central to Saudi Arabia's efforts to enhance pilgrims' health. Hospitals and clinics in Makkah and Madinah are now connected through a unified Health Information Exchange (HIE) platform, ensuring that every pilgrim's health record is accessible across all facilities (Zakari et al., 2025). This digital integration allows healthcare workers to make faster, evidence-based decisions and coordinate responses

between emergency centers, ambulances, and hospitals. Furthermore, the Saudi Ministry of Health's Smart Hajj Initiative leverages cloud computing and AI to provide mobile health applications that allow pilgrims to report symptoms, locate nearby clinics, and receive instant medical advice (Alshahrani, 2025).

Ethical and Legal Perspectives

The integration of digital health systems introduces complex ethical and legal questions regarding privacy, consent, and accountability. The World Health Organization (2023) emphasizes that ethical frameworks must accompany technological innovation to prevent misuse of sensitive data.

Privacy and Data Protection

Collecting sensitive health data such as heart rate, location, and biometric identifiers raises concerns about data confidentiality and ownership. Questions such as “Who controls the data?” and “How long should it be stored?” require clear legal frameworks. Ethical debates also center on whether all pilgrims should be required to wear monitoring devices and whether they have the right to refuse participation (WHO, 2023).

Legal Accountability

When AI systems make errors—such as false alerts or delayed warnings—determining responsibility becomes a legal challenge. Liability may rest with the service provider, the technology manufacturer, or the regulatory authority (Al-Mogren et al., 2025). This complexity highlights the need for international agreements to standardize the use of AI and IoT in cross-border health management during Hajj, as millions of pilgrims come from diverse countries with varying legal frameworks.

Challenges and Limitations

Despite the progress, several challenges remain in implementing digital health technologies during Hajj:

1. **Data Security Risks:** Cyberattacks or system failures could compromise sensitive health information.
2. **Interoperability Issues:** Lack of standardization across systems from different vendors leads to communication gaps.
3. **User Acceptance:** Some pilgrims, especially the elderly, may find wearable technologies intrusive or uncomfortable (Al-Shammari et al., 2025).
4. **Regulatory Barriers:** The absence of an international framework for digital health during mass gatherings limits effective global cooperation.

These limitations underscore the importance of establishing ethical guidelines, improving digital literacy among pilgrims, and developing unified data governance systems to ensure technological sustainability.

Discussion

The digital transformation of healthcare during Hajj represents one of the most innovative public health efforts in the Muslim world. It is a model of how modern technology can harmonize with religious traditions to promote collective welfare. However, as this transformation deepens, it brings both opportunities and responsibilities. This chapter discusses the broader implications of health technology deployment during Hajj, explores ongoing

challenges, and provides recommendations for sustainable, ethical, and legally compliant digital health systems.

The integration of technology into Hajj health management demonstrates a convergence of Islamic ethics, technological innovation, and public policy. AI-powered systems have improved surveillance and diagnosis capabilities, while IoT devices have revolutionized how data is collected and analyzed in real time.

Yet, the effectiveness of these systems depends on their trustworthiness and inclusivity. According to Hassan et al. (2024), user acceptance plays a crucial role in determining the success of digital initiatives. Many pilgrims express concerns about being monitored continuously or about potential misuse of their personal information. This reveals that successful implementation requires not only technological sophistication but also cultural and ethical sensitivity.

Furthermore, Al-Anezi et al. (2025) highlight that achieving Vision 2030's healthcare transformation goals will depend on a balance between innovation and regulation. Technology without robust governance may lead to ethical violations or unequal access to healthcare services. Thus, digitalization should always be accompanied by transparent communication, clear accountability, and education for both users and professionals.

Ethical and Legal Frameworks in the Context of Shariah

From an Islamic perspective, the preservation of life (*ḥifẓ al-nafs*) is one of the core objectives of Shariah. Therefore, using technology to protect pilgrims' health is not only permissible but encouraged, as it serves the collective interest (*maṣlahah*). However, Shariah also emphasizes the importance of privacy (*ḥifẓ al-'ird*) and human dignity. Hence, any technological surveillance must adhere to ethical principles that respect autonomy, informed consent, and confidentiality (WHO, 2023).

To align modern digital practices with Islamic ethics, Saudi health authorities could establish a "Shariah-Compliant Digital Ethics Charter" for Hajj operations. This framework would ensure that technological innovation remains grounded in moral responsibility, protecting pilgrims' data and dignity while advancing public health goals.

Technical and Operational Challenges

Despite the significant progress achieved, operational challenges persist:

1. **System Integration:** Multiple healthcare providers operate during Hajj, often using distinct digital systems. Integration gaps hinder seamless data exchange (Zakari et al., 2025).
2. **Infrastructure Strain:** The immense surge in network usage during Hajj creates technical bottlenecks, reducing the reliability of IoT connectivity (Makkah Health Cluster, 2024).
3. **International Coordination:** Pilgrims come from more than 180 countries, many of which lack compatible digital health standards, making data-sharing difficult (Al-Turaiki et al., 2024).
4. **Training and Human Resources:** Healthcare professionals require specialized training to interpret AI-generated data and manage wearable device networks (Abdel-Rahman et al., 2023).

These challenges necessitate long-term investment in digital infrastructure, international agreements, and professional capacity building to ensure system resilience.

Strategic Recommendations

1. Establish a Unified Digital Health Command Center: A centralized AI-driven platform should manage all pilgrim health data, integrating hospitals, mobile clinics, and field teams under one system (Al-Mogren et al., 2025).
2. Enhance Predictive Analytics Capabilities: By developing deep learning models, authorities can forecast potential outbreaks or emergencies with higher accuracy (Khan et al., 2024).
3. Promote Interoperability Standards: Saudi Arabia should collaborate with international health organizations to establish global data-sharing protocols for mass gatherings.

Ethical Recommendations

1. Ensure Informed Consent: Pilgrims should be clearly informed about what data is collected, how it will be used, and their right to opt out.
2. Adopt Transparent AI Systems: Algorithms should be explainable and subject to ethical review to prevent bias or misuse.
3. Protect Privacy and Dignity: Continuous monitoring must not compromise the sanctity or autonomy of pilgrims.

Policy and Legal Recommendations

1. Formulate a Legal Framework for Digital Health in Hajj: Legislation should define liability for errors in AI predictions, data misuse, or system failures (WHO, 2023).
2. Create International Agreements: Establish cross-border data governance mechanisms to allow real-time medical collaboration during Hajj.
3. Implement Shariah-Based Ethics Oversight: Ethical review boards should include both legal and Islamic scholars to ensure compliance with religious principles.

Educational and Cultural Recommendations

1. Digital Literacy Training: Educate pilgrims, particularly elderly and first-time participants, on the purpose and benefits of wearable devices.
2. Professional Development: Offer specialized training for healthcare staff in AI-based decision systems and IoT monitoring.

Conclusion

The integration of technology into the management of health and safety during Hajj has proven to be a transformative advancement. It not only enhances efficiency and responsiveness but also embodies the Islamic values of compassion, preservation of life, and community welfare. Through the use of AI, IoT, and big data analytics, Saudi Arabia has set a global precedent for digital health management in mass gatherings.

However, for this transformation to be sustainable, it must rest upon strong ethical foundations and legal safeguards. As this study has shown, the future of digital health during Hajj depends on balancing technological progress with respect for human dignity and privacy. A unified approach that combines Shariah-based ethics, scientific innovation, and international cooperation will ensure that every pilgrim performs their rites safely and with peace of mind. Ultimately, the fusion of faith and technology reflects a profound truth: that knowledge and innovation, when guided by moral principles, serve humanity's highest purpose — the preservation of life and dignity for all.

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