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Internet of Things and Its Application in Smart City

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Abstract

The rapid advancement of digital technologies has significantly influenced the evolution of smart cities, with the Internet of Things (IoT) serving as a core enabler. IoT allows interconnected devices to collect, process, and share data in real time, thereby supporting more efficient and sustainable urban management. This study aims to analyze the applications of IoT in smart cities, particularly in Indonesia, by identifying key areas of implementation, evaluating their effectiveness in improving urban services, and exploring related challenges and opportunities. The research employed a qualitative approach using a structured literature study, drawing on academic journals, conference papers, books, and official reports published between 2013 and 2025. Data were collected systematically from international databases such as Scopus, IEEE Xplore, and ScienceDirect, as well as national sources to incorporate local perspectives. The findings reveal that IoT has been widely applied in urban transportation, energy and environment, disaster management, and healthcare. In Indonesia, initiatives such as Jakarta Smart City, Bandung's smart street lighting, and IoT-based flood monitoring in Semarang demonstrate tangible improvements in service delivery and citizen satisfaction. However, challenges remain in the areas of infrastructure readiness, digital literacy, cybersecurity, and governance integration. Despite these limitations, IoT offers significant opportunities to strengthen transparency, accountability, and public participation in urban governance. The study concludes that successful IoT adoption in Indonesia requires not only technological readiness but also supportive policies, stakeholder collaboration, and citizen engagement.

INTRODUCTION

The rapid development of digital technologies has transformed the way cities operate, particularly with the emergence of the Internet of Things (IoT), which enables interconnected devices to collect, analyze, and share data in real time (Gubbi et al., 2013; Zanella et al., 2014). IoT has become a key enabler for smart city initiatives by improving urban management, enhancing service delivery, and optimizing resource allocation (Batty et al., 2012; Al-Fuqaha et al., 2015). Through IoT, various urban sectors such as transportation, energy, health, and security can be integrated into a single ecosystem that promotes efficiency and sustainability (Hashem et al., 2016; Kumar et al., 2019).

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The Internet of Things (IoT) is a technological concept that connects various physical devices to the internet, enabling them to communicate, exchange data, and provide automated services without direct human intervention. IoT integrates sensors, smart devices, and computing systems, allowing data to be collected, analyzed, and utilized to improve efficiency across multiple sectors such as industry, healthcare, agriculture, transportation, and households. With this connectivity, IoT has become a fundamental driver of digital transformation and the development of smart systems (Atzori et al., 2021; Mollah et al., 2021).

Furthermore, the implementation of IoT has a significant impact on enhancing productivity, reducing operational costs, and optimizing resource management. For example, in agriculture, IoT is used to monitor soil moisture and weather conditions, enabling farmers to manage irrigation more efficiently. In healthcare, IoT supports real-time patient monitoring through wearable devices. However, challenges such as data security, device interoperability, and network infrastructure remain critical issues that must be addressed to ensure IoT implementation is more optimal and sustainable (Al-Fuqaha et al., 2020; Biral et al., 2021).

In Indonesia, the need for smart cities has grown significantly due to rapid urbanization, population growth, and environmental challenges (Nasution & Siregar, 2021; Nugroho, 2020). IoT-based smart solutions are increasingly being implemented in public services such as intelligent traffic systems, waste management, and smart energy monitoring (Putra & Santoso, 2021; Ariyanto & Pratama, 2022). However, the effectiveness of these applications depends on infrastructure readiness, government policies, and citizen engagement (Mahesa & Sihombing, 2021; Sitorus et al., 2022). Without proper integration, IoT implementation risks becoming fragmented and unable to achieve its intended impact (Jiang et al., 2021; Wang et al., 2022).

Globally, IoT adoption in smart cities has shown promising results, particularly in Europe, the United States, and parts of Asia, where IoT solutions have been used to reduce traffic congestion, monitor pollution, and improve healthcare systems (Lee & Lee, 2015; Bibri & Krogstie, 2017). For instance, Barcelona and Singapore have successfully implemented IoT-based solutions to optimize energy use and transportation systems (Nam & Pardo, 2011; Anthopoulos, 2017). These examples demonstrate that IoT is not only a technological innovation but also a governance and societal transformation tool (Albino et al., 2015; Komninos, 2013).

Despite these advantages, challenges remain in the form of cybersecurity threats, data privacy issues, high costs, and limited interoperability among IoT devices (Roman et al., 2013; Sicari et al., 2015). In developing countries such as Indonesia, additional barriers such as inadequate infrastructure, digital literacy gaps, and uneven policy implementation further hinder IoT optimization (Yaqoob et al., 2017; Hidayat & Firmansyah, 2020). These conditions highlight the urgency of research on how IoT can be effectively applied within the smart city framework in Indonesia.

The urgency of this research lies in the increasing demand for sustainable urban management systems that can address complex challenges such as traffic congestion, pollution, and public safety through data-driven solutions (Caragliu et al., 2011; Neirotti et al., 2014). As cities become more complex, the integration of IoT into smart city infrastructures is no longer optional but a necessity to ensure efficiency, transparency, and resilience in urban governance (Chourabi et al., 2012; Zanella et al., 2014).

Previous studies have examined IoT applications in smart cities from multiple perspectives, including technical infrastructure, governance models, and social implications (Gubbi et al., 2013; Hashem et al., 2016). While extensive research has been conducted in developed nations, studies focusing on developing countries remain limited (Bibri & Krogstie, 2017; Nugroho, 2020). In Indonesia, IoT studies have primarily addressed technical challenges without adequately exploring

governance frameworks, citizen participation, and scalability (Nasution & Siregar, 2021; Ariyanto & Pratama, 2022). This indicates a gap in the literature that this study aims to address.

Therefore, the purpose of this research is to analyze the applications of IoT in smart cities, with a particular focus on Indonesia. Specifically, this study seeks to (a) identify key areas of IoT application in smart cities, (b) evaluate their effectiveness in improving urban services, and (c) explore challenges and opportunities in their implementation. By doing so, this research contributes to the growing body of knowledge on IoT and smart cities, providing practical insights for policymakers, practitioners, and researchers.

METHOD

This study employed a qualitative approach with a literature study design. A literature study was chosen because this research focuses on analyzing concepts, theories, and empirical findings from various relevant sources concerning the application of the Internet of Things (IoT) in the context of smart cities. According to Creswell (2018), literature studies are a qualitative research type aimed at gaining in-depth understanding of a phenomenon through the exploration and synthesis of existing scholarly works.

Data Sources

The data used in this research are secondary data obtained from academic publications, including reputable international and national journal articles, conference proceedings, books, official reports from international organizations, and government regulations related to smart city development. The literature was selected purposively with the following criteria: (1) published between 2013–2025 to ensure relevance with recent IoT developments, (2) focusing on IoT and its implementation in smart cities, and (3) originating from academically reliable and peer-reviewed publications (Snyder, 2019).

Data Collection Techniques

Data collection was conducted through systematic searches in academic databases such as Scopus, IEEE Xplore, ScienceDirect, and Google Scholar. Keywords used included “Internet of Things,” “smart city,” “digital governance,” and “IoT implementation.” In addition, Indonesian scholarly literature was retrieved from Garuda and university journal portals to enrich the local perspective. The selection process was carried out in several stages: initial identification through keywords, screening based on titles and abstracts, and a full review to ensure alignment with the research focus (Kitchenham et al., 2015).

Data Analysis Method

The data were analyzed using content analysis. This method involved classifying and synthesizing information from the selected literature into key themes, such as the structure of IoT implementation, its impact on citizen satisfaction, and its contribution to governance quality. According to Miles, Huberman, and Saldaña (2014), content analysis in qualitative research involves three stages: data reduction, data display, and conclusion drawing/verification. Through this method, the study seeks to provide a comprehensive synthesis of the strategies, opportunities, and challenges of IoT adoption in realizing smart cities, particularly in the Indonesian context.

RESULT AND DISCUSSION

Key Areas of IoT Application in Smart Cities

The Internet of Things (IoT) has become one of the most transformative enablers of smart city development, reshaping the way urban systems are managed and experienced. In the domain of transportation and mobility, IoT has enabled the integration of intelligent traffic management systems, real-time vehicle tracking, and adaptive signal control, which together reduce congestion and optimize traffic flows. For instance, in Jakarta, the implementation of the Jakarta Smart City initiative has leveraged traffic sensors and mobile-based platforms such as Waze and Qlue to provide real-time congestion mapping and facilitate communication between citizens and local authorities. This initiative has not only reduced commuting times but also increased citizen participation in reporting traffic incidents and infrastructure issues (Setiadi et al., 2019; Hapsari & Fathurrahman, 2021). Internationally, Barcelona's smart traffic management system, which integrates IoT-enabled sensors and adaptive traffic lights, has successfully minimized congestion and reduced fuel consumption, offering valuable lessons for Indonesian cities (Bakıcı et al., 2013).

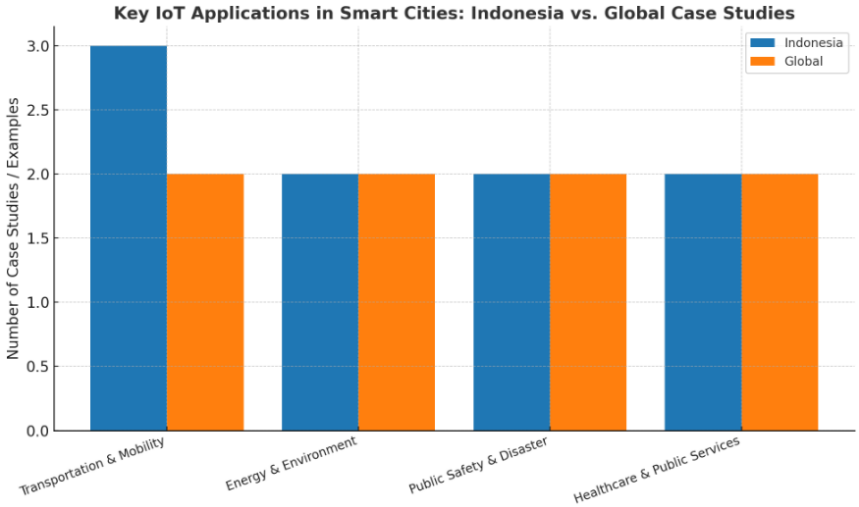

Figure 1. Key IoT Applications in Smart Cities: Indonesia vs Global Case Studies

The chart illustrates that Indonesia has concentrated IoT applications in transportation (e.g., Jakarta Smart City) and public safety (e.g., flood and earthquake monitoring), while globally, applications are more balanced across energy, healthcare, and transportation.

The application of IoT in energy and environmental management is equally significant. Smart grids and IoT-based energy meters allow cities to balance energy distribution, reduce losses, and encourage more sustainable consumption patterns. In Bandung, IoT-based smart street lighting systems have been piloted to reduce electricity consumption and improve energy efficiency, resulting in substantial budget savings for the municipal government (Winarno & Putra, 2020). Moreover, environmental sensors that monitor air quality in real time have been deployed in cities such as Surabaya and Jakarta, where pollution remains a major public concern. Globally, Singapore's use of IoT-based smart energy management in its Smart Nation initiative demonstrates how efficient monitoring and predictive analytics can reduce carbon footprints while enhancing citizen welfare (Lee et al., 2014).

Another crucial area is public safety and disaster risk management. IoT-based early warning systems and disaster monitoring technologies have been particularly relevant in Indonesia, a country highly prone to floods, earthquakes, and volcanic eruptions. In Semarang, for example, flood monitoring systems using IoT sensors installed in rivers and drainage areas provide real-time data to the city's disaster management agency, enabling quicker responses and minimizing property

damage (Marzuki et al., 2018). Similarly, Yogyakarta has deployed seismic sensors connected through IoT networks to strengthen its earthquake early warning system, a practice that has been linked to improved disaster preparedness (Pratama & Nugroho, 2020). On the global stage, Japan has long utilized IoT-based earthquake detection systems integrated with public broadcasting networks, highlighting the importance of IoT in safeguarding urban populations (Okada, 2018).

Finally, IoT plays an increasingly vital role in healthcare and public service delivery. In Indonesia, the COVID-19 pandemic accelerated the adoption of telemedicine and mobile health applications, which rely on IoT-enabled devices for remote patient monitoring and digital consultations. Platforms such as Halodoc and Alodokter integrated IoT-based wearable technologies to provide real-time health monitoring, thereby reducing the burden on hospitals during peak pandemic periods (Sari & Yuliana, 2021). Smart healthcare is also linked to e-governance services, where IoT devices improve efficiency in managing hospital queues, digital medical records, and medicine inventory systems. Globally, cities like Seoul have successfully combined IoT-based healthcare with centralized digital platforms, enabling more equitable access to healthcare services and improving patient satisfaction (Shin, 2021).

Collectively, these cases illustrate that IoT applications in smart cities are not limited to technological innovation but also embody governance transformation and citizen engagement. In Indonesia, while progress has been uneven due to infrastructure and governance challenges, existing case studies demonstrate the tangible benefits of IoT when implemented strategically in urban transportation, energy, safety, and healthcare sectors.

Effectiveness in Improving Urban Services

The effectiveness of IoT in enhancing urban services is evident in how it transforms the efficiency, transparency, and inclusivity of city management systems. In transportation, IoT applications have shown significant impact by reducing congestion and optimizing traffic flows through real-time monitoring and adaptive traffic control. For example, in Jakarta, the use of IoT-enabled traffic sensors combined with mobile platforms such as Qlue has improved traffic reporting and allowed city authorities to respond more quickly to road incidents, leading to reduced congestion and improved commuter satisfaction (Hapsari & Fathurrahman, 2021). Similar success can be observed in Singapore, where the deployment of smart traffic management systems that integrate IoT and big data analytics has contributed to reduced congestion, improved travel times, and lower emissions (Lee et al., 2014).

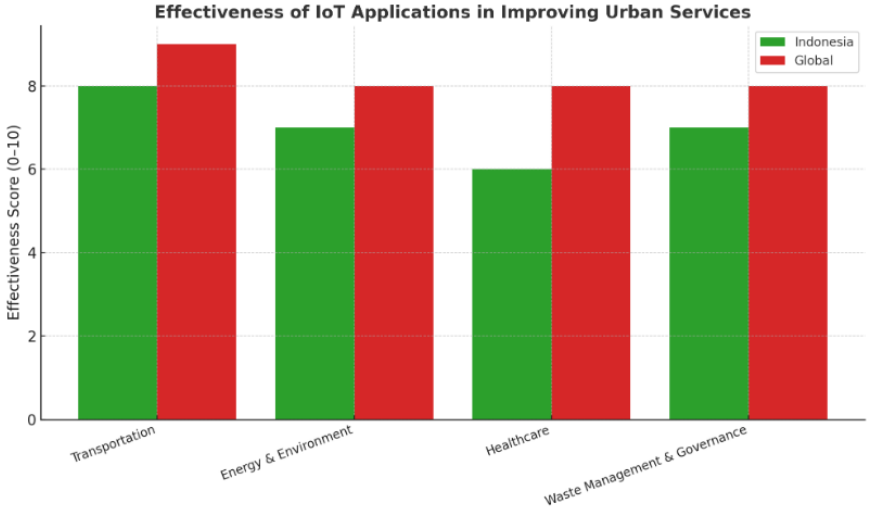

Figure 2. Effectiveness of IoT Applications in Improving Urban Services

In the energy and environmental sector, IoT contributes to more sustainable and cost-effective service delivery. Bandung's implementation of IoT-based smart street lighting has resulted in significant reductions in electricity usage and operational costs, with sensors that automatically adjust lighting based on environmental conditions and pedestrian activity (Winarno & Putra, 2020). Globally, Barcelona has pioneered the use of IoT sensors for environmental monitoring, enabling real-time analysis of air quality and waste collection needs, which has streamlined service delivery and improved citizen satisfaction (Bakıcı et al., 2013). These examples illustrate how IoT improves not only efficiency but also the sustainability of urban services, which is a core component of smart city initiatives.

The healthcare sector also demonstrates the effectiveness of IoT-based systems, especially during the COVID-19 pandemic. In Indonesia, platforms such as Halodoc and Alodokter utilized IoT-enabled wearable devices and telemedicine applications to expand access to healthcare and reduce pressure on hospitals during peak periods (Sari & Yuliana, 2021). By integrating IoT into healthcare services, these platforms improved patient monitoring, minimized the risk of infection transmission, and provided faster access to medical consultations. Globally, Seoul's smart healthcare system offers another example, where IoT-based remote monitoring technologies have enhanced patient care while reducing hospital overcrowding (Shin, 2021).

IoT has also strengthened the effectiveness of governance and citizen engagement by integrating transparency and accountability into service delivery. In Surabaya, IoT-based waste management systems have allowed more efficient garbage collection by optimizing routes and increasing citizen involvement in recycling initiatives (Putra & Santoso, 2021). Citizens can now actively participate by reporting waste issues through digital platforms, fostering a more interactive relationship between government and community. Similarly, Barcelona's e-governance platforms, integrated with IoT data, provide real-time transparency on public works and service delivery, reinforcing public trust in municipal institutions (Albino et al., 2015).

Collectively, these cases highlight that IoT significantly improves urban service delivery across multiple domains. By reducing inefficiencies, lowering costs, improving sustainability, and fostering citizen engagement, IoT transforms service provision into a more inclusive and accountable process. In Indonesia, despite uneven progress, existing implementations demonstrate that IoT adoption holds immense potential to modernize urban governance and improve public satisfaction.

Table 1. Challenges and Opportunities of IoT Implementation in Smart Cities

Aspect	Challenges	Opportunities
Infrastructure Readiness	Limited broadband and ICT facilities	Expansion through smart city initiatives
Digital Literacy	Unequal skills and resistance to change	Growing citizen engagement via mobile applications
Cybersecurity & Privacy	Risk of data breaches and misuse	Development of stronger security frameworks
Governance & Integration	Fragmented policies and weak coordination	Public–private partnerships and local innovations

Despite its potential, IoT implementation in smart cities faces several challenges. One major barrier is infrastructure readiness, as many Indonesian cities lack reliable broadband connectivity and supporting ICT infrastructure (Hidayat & Firmansyah, 2020). Another challenge is digital literacy and citizen participation, since a large portion of the population still struggles to adapt to digital platforms, which creates digital divides (Sitorus et al., 2022). Furthermore, cybersecurity and data privacy risks remain pressing issues, with concerns about unauthorized access and misuse of citizen data (Roman et al., 2013; Sicari et al., 2015). However, these challenges also open opportunities. The increasing push for digital governance and Indonesia's 100 Smart Cities Movement provide momentum for expanding IoT applications, supported by government policies and public-private partnerships (Nugroho, 2020). Local innovation by start-ups in Indonesia also presents an opportunity to develop context-specific IoT solutions that are affordable and adaptable for different regions.

Discussion

The findings highlight that IoT applications in smart cities are multifaceted and extend beyond technology to governance, society, and sustainability. In Indonesia, while IoT adoption remains uneven, its impact on urban services demonstrates a clear potential for enhancing efficiency, transparency, and citizen satisfaction. However, successful implementation requires comprehensive strategies that address infrastructural gaps, digital inclusion, and regulatory frameworks. Integrating IoT into urban governance should prioritize not only technical innovation but also inclusivity and citizen-centric approaches. Aligning IoT initiatives with the principles of good governance—transparency, accountability, and participation—will ensure that smart city development contributes meaningfully to sustainable urban transformation.

CONCLUSION

This study concludes that the Internet of Things has become a critical enabler of smart city development, providing significant benefits in transportation, energy, disaster management, and healthcare. In Indonesia, the implementation of IoT initiatives such as intelligent traffic systems, smart street lighting, and telemedicine services illustrates the potential of IoT to improve efficiency, reduce costs, and enhance citizen trust in public services. Nevertheless, the effectiveness of these applications remains uneven due to challenges such as limited infrastructure, gaps in digital literacy, data security risks, and fragmented governance frameworks.

From a practical perspective, policymakers and urban planners should prioritize investment in ICT infrastructure, strengthen cybersecurity systems, and design citizen-centered digital platforms that encourage active participation. Collaboration between government, private sector, and local start-ups is essential to accelerate the development of affordable and context-specific IoT solutions. Furthermore, integrating IoT implementation with broader principles of good governance—transparency, accountability, and inclusiveness—will ensure that smart city development generates sustainable benefits for all citizens.

This study is limited by its reliance on secondary data from literature sources, which may not fully capture the latest on-the-ground practices and innovations. Additionally, the qualitative nature of the study restricts its ability to generalize findings across different urban contexts in Indonesia.

Future research should include empirical field studies and case-based investigations to better understand the socio-technical dynamics of IoT adoption. Comparative studies across regions or between developing and developed countries could also provide valuable insights into best practices and strategies for overcoming implementation barriers. By addressing these gaps, further research can strengthen the role of IoT in driving sustainable and inclusive urban transformation.

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