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| RESEARCH ARTICLE

Exploring the Multifaceted Impact of Artificial Intelligence and the Internet of Things on Smart City Management

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| ABSTRACT

The evolution of cities into sustainable and intelligent entities is undergoing a significant transformation with the integration of Artificial Intelligence (AI) and the Internet of Things (IoT). This study systematically examines 133 papers published between 2014 and 2021, predominantly sourced from Scopus (90%) and WoS (70%). Focusing on key smart city domains such as healthcare, education, environment, waste management, mobility, agriculture, risk management, and security, the analysis explores the applications of AI. As cities increasingly embrace AI for operational automation, data-driven decision-making, and environmental improvements, regulatory challenges surface, spanning concerns related to privacy, service delivery discrimination, and ethical considerations. The impact of AI adoption, especially in healthcare following the 2019 global health crisis, is underscored, emphasizing the pivotal role of AI algorithms, including ANN, RNN/LSTM, CNN/R-CNN, DNN, and SVM/LS-SVM, in shaping urban development trajectories. This research provides insights into the multifaceted implications of AI in smart cities, offering a comprehensive overview of the benefits, challenges, and transformative potential of these technologies across diverse urban sectors.

| KEYWORDS

Artificial Intelligence (AI), Internet of Things (IoT), Urban Development, Security

| ARTICLE INFORMATION

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1. Introduction

The dynamic evolution of cities into sustainable and intelligent entities has been significantly influenced by the transformative integration of Artificial Intelligence (AI) and the Internet of Things (IoT). In response to the burgeoning importance of these technologies in shaping modern urban environments, this study undertook a meticulous examination of 133 papers published between 2014 and 2021, with a predominant focus on Scopus (90%) and WoS (70%). The comprehensive analysis delves into the diverse applications of AI across key domains that define smart cities, including healthcare, education, environment and waste management, mobility, agriculture, risk management, and security. As cities strive to leverage AI for operational automation, data-driven decision-making, and environmental enhancements, regulatory challenges and identified barriers emerge, spanning concerns related to service delivery discrimination, privacy, and ethical considerations. Unraveling the multifaceted impact of AI adoption in smart cities, particularly accentuated in the healthcare sector since the onset of the global health crisis in 2019, this research underscores the pivotal role of AI algorithms, including ANN, RNN/LSTM, CNN/R-CNN, DNN, and SVM/LS-SVM, in shaping the trajectory of urban development. This introduction sets the stage for an in-depth exploration of how AI is steering the metamorphosis of cities into intelligent, sustainable, and efficient hubs of innovation.

A city, defined as a densely populated area with officially designated limits and a predominantly non-agricultural workforce (Goodall, 1987), stands as a permanent and heavily inhabited region characterized by high concentrations of human developments such as residences, commercial properties, roadways, bridges, and railroads. According to the United Nations Department of Economic and Social Affairs, urban areas currently accommodate 55% of the global population, a figure projected to surge to 68% by 2050. In 2016, there were 512 urban areas with populations exceeding one million and 31 megacities boasting over ten million inhabitants. This number is expected to grow to approximately 662 urban areas and 41 megacities by 2030, with a notable concentration in emerging regions (United Nations, 2018). This rapid urbanization trend is poised to exert profound impacts on the environment, management, healthcare, energy, education, and security of cities. The ascendancy of smart cities is anticipated to become the norm in major urban centers globally. Embracing various technologies and innovations, modern smart cities are at the forefront of achieving long-term socioeconomic goals. Diverse smart-city initiatives are currently underway across various geographical locations, as evidenced by extensive studies, creating a diverse and dynamic tapestry of urban visions (Cowley et al., 2018; Dowling et al., 2019; Fernandez-Anez et al., 2018; Pinna et al., 2017).

2. Literature Review

IBM defines a smart city as one that maximizes the utilization of linked data available today to enhance its understanding and regulation of operations while optimizing the use of limited resources. According to Chourabi et al. (2012), a smart city leverages collective intelligence by integrating the city's physical infrastructure, information technology infrastructure, social infrastructure, and commercial infrastructure. Aguilera et al. (2013) emphasize that a smart city is a comprehensive concept encompassing physical infrastructure as well as human and social issues. Khan et al. (2013) describe a smart city as one that engages in ICT-enhanced governance and participatory procedures to define suitable public service and transportation investments, aiming to improve the quality of life, enable intelligent resource management, and foster sustainable socio-economic growth. Sterbenz (2017) characterizes the term "Smart City" as referring to new industries that leverage ICT, influencing urban functions and environments. Mustafa & Kar (2017) highlight the emergence of the "Smart City" concept from "Intelligent Cities," emphasizing the core idea of using existing resources more smartly.

3. Research Methodology

The absence of a comprehensive review paper on the adoption of artificial intelligence (AI) in smart cities prompted our study to fill this critical gap in the existing literature. Considering this, we meticulously examined relevant sources and identified a dearth of viable reviews on this subject. To address this knowledge gap, our research endeavors to explore the diverse applications of AI in modern smart cities. In this section, we elucidate our methodology, presenting a conceptual framework that delineates the various uses of AI in smart urban environments. Figure 1 provides a visual representation of this conceptual framework, depicting the selected common smart city applications that form the focal points of our investigation.

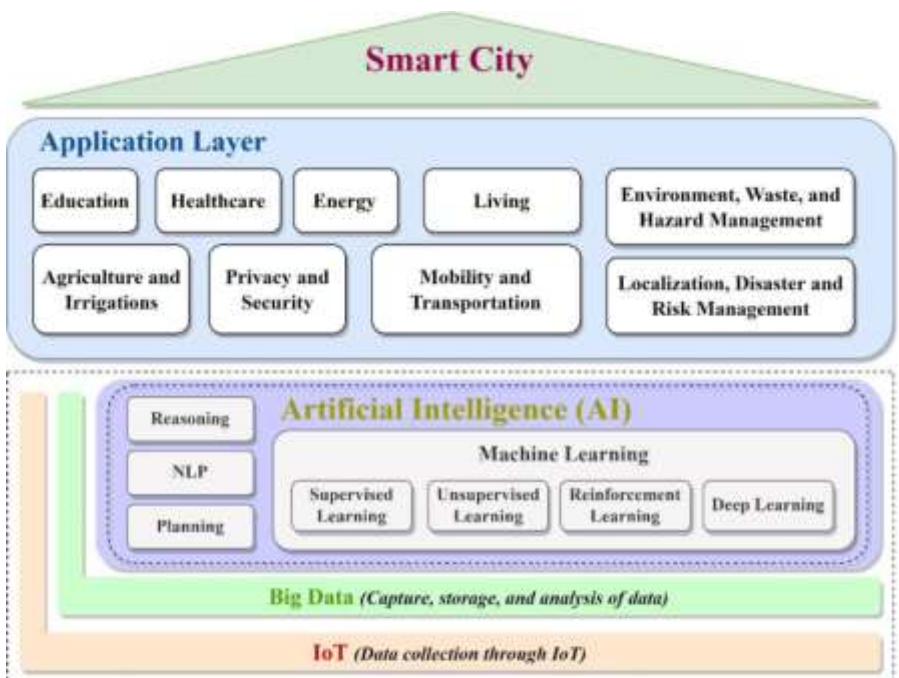

Figure 1 illustrates a conceptual framework that outlines the interrelation between smart cities and artificial intelligence (AI).

To identify pertinent literature for our study, we employed a comprehensive search strategy utilizing keywords and keyword combinations related to Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), Smart Healthcare, Smart City/Smart Cities, Smart Education, Smart Infrastructure, Smart Living, Smart Security, and Smart Governance. The search was conducted across various electronic bibliographical sources such as Web of Science (WoS) and Scopus, targeting peer-reviewed journals, international conferences, and books. The initial search, employing the specified keywords, yielded 440 publications. Subsequently, we scrutinized all 240 relevant main content entries, ultimately selecting 133 publications (with a distribution of 96% from Scopus and 70% from WoS) that exhibited exceptional relevance to our study. The chosen publications, spanning the period between 2014 and 2021, encompassed a variety of computational and analytical approaches, conceptual models, design science, and case studies.

3.1 Evaluation of the Integration of Artificial Intelligence in Smart Urban Environments

Despite the inception of smart cities over two decades ago, rapid iterations and advancements have introduced numerous challenges. The essence of cities is evolving towards affluence, healthier populations, heightened social mobility, robust community interconnectivity, and positive overall growth, as articulated by Radu in 2020. This section delves into the identification and analysis of contributing factors, drawing insights from an extensive review of published papers and studies. Our primary focus centered on the adoption of AI in various domains, including education, mobility, smart transportation, agriculture, healthcare, environment and waste management, as well as privacy, security, and risk management.

A notable study by Allam and Dhunny in 2019 explored the urban potential of AI, proposing a novel system that intertwines AI with cities. This approach ensures the integration of essential aspects such as governance, metabolism, and culture, recognized as crucial for the effective incorporation of smart cities in alignment with sustainable development goals (SDGs) and the new urban agenda. According to PwC research on the application of Blockchain (BC) in smart cities, combining BC with ML, IoT, and AI holds the promise of significantly enhancing urban administration. Various subfields of AI, including robotics, natural language processing (NLP), speech recognition, vision systems, and expert systems, contribute to this integration. Big Data technologies facilitate the collection of massive data sets from diverse networks, enabling AI-based technologies to conduct advanced analyses on the recorded information, as highlighted by Kushwaha et al. in 2021. The integration of Big Data and IoT, particularly with the advent of 5G technology, is expected to yield more valuable information for citizens.

The automotive industry serves as a noteworthy example of a sector reaping substantial benefits from the progress of AI and IoT. Monitoring, analyzing, and predicting environmental phenomena, particularly air pollution levels, has gained increased importance for public institutions. Continuous efforts by researchers to enhance air quality (AQ) prediction tools aim to provide consumers and governments with more accurate information about their surrounding air quality. Artificial intelligence plays a pivotal role in enabling smart cities to detect and address air quality concerns, with the ongoing development of AI-based algorithms for anticipating and monitoring environmental hazards such as floods and wildfires.

3.2 AI in smart education and smart Energy

Artificial Intelligence (AI) is reshaping the landscapes of both smart education and smart energy, ushering in unprecedented advancements and opportunities. In the realm of smart education, AI applications have become integral to fostering innovative learning environments and personalized educational experiences. The convergence of AI with technologies such as Deep Learning (DL), Big Data, and the Internet of Things (IoT) is evident in initiatives like UbeHealth, which addresses next-generation healthcare challenges by combining edge computing, DL, Big Data, and IoT. AI-driven educational tools, as proposed by Bajaj & Sharma (2018), are designed to assess and accommodate diverse learning styles, providing scalable solutions within cloud settings. This transformative integration facilitates not only enhanced learning outcomes but also the development of smart classrooms and smart learning frameworks.

Simultaneously, in the domain of smart energy, AI is playing a pivotal role in optimizing energy efficiency and sustainability. The inclusion of AI in traditional energy industries has given rise to smart energy models, revolutionizing the way societies consume and manage energy. Studies by Ahmad et al. (2014), Selim et al. (2021), and Bourhnane et al. (2020) explore various facets of AI applications in energy, ranging from predicting electrical demand and optimizing energy consumption to utilizing AI-based Blockchain for smart grids. The predictive capabilities of AI, coupled with technologies like Deep Neural Networks (DNNs) and Bayesian Deep Learning (BDL), are leveraged to forecast energy consumption, assess uncertainties, and enhance building energy performance.

In essence, the incorporation of AI into smart education and smart energy is driving transformative change, offering tailored learning experiences and sustainable energy solutions. As these technologies continue to evolve, the synergy between AI, education, and energy holds immense promise for creating smarter, more efficient, and sustainable societies.

In recent years, the education sector has undergone significant transformations fueled by the widespread adoption of Artificial Intelligence (AI) applications, particularly within the realm of smart cities. The integration of AI and Information Technology (IT) has played a pivotal role in shaping the landscape of smart education, ushering in a multitude of developments. This section provides an overview of the AI-based advancements in the field of education within smart cities.

The exploration of smart education initiatives across different countries reveals the global momentum in this domain. Malaysia initiated its smart school implementation plan in 1997, introducing the smart education project as a pioneering effort to fortify the educational system against the challenges of the 21st century (Chan, 2002). Singapore followed suit in 2006 with its smart country master plan, incorporating cutting-edge technologies such as the Internet of Things (IoT) and AI into smart schooling initiatives focused on creating diverse learning environments (Pipe, 2010; Hua, 2012). Finland's 2011 smart education initiative, known as SysTech, aimed at continuous learning through user-driven motivating learning solutions, emphasizing education enhancement for the twenty-first century (Mäkelä et al., 2018). Australia collaborated with IBM in 2012 to develop a smart, multidisciplinary education system connecting all educational institutions nationwide (IBM, 2012). South Korea, in 2014, initiated the smart school program in the United States, integrating the latest IT technologies into classrooms (New York Smart Schools Commission, 2014).

Further insights into the adoption of AI in smart education emerge from the examination of specific studies. Researchers such as Ahmad et al. (2021), Alshmrany (2021), Bajaj & Sharma (2018), Jemni & Khribi (2017), Juanatey et al. (2021), Kim et al. (2018), Pacheco et al. (2018), and Salem & Nikitaeva (2019) have delved into the use of AI and computational intelligence to enhance the quality of education. Ahmad et al. (2021) specifically investigated the role of Artificial Intelligence Applications (AIA) in smart education. Other studies, such as those by Jemni & Khribi (2017) and Salem & Nikitaeva (2019), explored computational intelligence, knowledge engineering paradigms, and AI-based smart learning frameworks to advance smart education systems.

The advent of intelligent technologies has given rise to smart learning through devices. Juanatey et al. (2021) engaged in long-term robotics AI education, presenting the Robobo SmartCity educational framework centered around a smartphone-controlled robot (Robobo) and a real-life smart city model. Pacheco et al. (2018) introduced a Deep Learning (DL) and Osmotic IoT computing-based smart classroom paradigm, while Kim et al. (2018) developed an emotionally aware AI smart classroom paradigm.

Recognizing the importance of individual learning styles in any educational environment, Bajaj & Sharma (2018) proposed a framework for an education tool that considers various learning models and AI approaches to assess students' learning styles. The suggested tool aims to offer a scalable approach for determining learning styles quickly and effectively within a cloud setting.

In the domain of smart energy, the integration of AI into traditional energy systems has given rise to smart energy models. The increasing global demand for energy, coupled with the imperative to reduce CO_2 emissions, has prompted numerous studies on AI developments in energy efficiency within sustainable smart cities. Ahmad et al. (2014), Bourhnane et al. (2020), Daut et al. (2017), Dong et al. (2016), ElHusseini et al. (2020), Hernández-Ocaña et al. (2019), Kumar et al. (2020), Lilliu et al. (2019), Lu et al. (2020), Sadeghi et al. (2020), Selim et al. (2021), Şerban & Lytras (2020), and Zhong et al. (2019) have investigated various aspects, including energy forecasting, cost optimization, Blockchain for smart grid, energy optimization, and renewable energy solutions, all facilitated by AI.

For instance, Selim et al. (2021) introduced Bayesian Deep Learning (BDL) and gradient tree boosting models for assessing uncertainty in short-term electrical demand estimates. Sadeghi et al. (2020) employed Deep Neural Networks (DNNs) to predict heating load (HL) and cooling load (CL) for structures, while Dong et al. (2016) applied multiple machine learning algorithms for electricity consumption forecasting using smart meters. Ahmad et al. (2014) reviewed AI approaches such as Support Vector Machines (SVM) and Artificial Neural Networks (ANN) in creating electrical energy forecasts. Other studies explored energy consumption prediction models, with Bourhnane et al. (2020) integrating ANN with genetic algorithms (GA) for enhanced accuracy.

In summary, the intersection of AI and education in smart cities has witnessed significant global initiatives, while the application of AI in smart energy has led to innovative models for improving efficiency and sustainability. These developments underscore the transformative impact of AI across diverse domains within the context of smart cities.

3.3 AI in Smart Healthcare

Artificial Intelligence (AI) has emerged as a transformative force in the realm of smart healthcare, catalyzing innovative solutions to enhance medical processes, patient care, and overall healthcare outcomes. The integration of AI technologies into smart healthcare systems is redefining traditional approaches and fostering a new era of medical advancements. One notable facet of this integration is the utilization of AI-integrated Internet of Things (IoT) frameworks, which significantly contribute to the efficient management and analysis of medical data. The responsive, reliable, low-latency, and scalable healthcare systems proposed by researchers like Rathi et al. (2021) exemplify the potential of AI-enabled IoT and edge computing in overcoming challenges such as network latency and bandwidth limitations. Additionally, the amalgamation of AI with healthcare, as depicted in Figure 2, underscores the pivotal role of Machine Learning (ML) in predicting and detecting diseases, infections, injuries, immunological responses, and drug discoveries. As researchers continue to explore and develop AI-based models, the synergy between AI and smart healthcare is poised to revolutionize the medical landscape, offering personalized, efficient, and data-driven healthcare solutions for the benefit of both healthcare providers and patients alike.

Numerous conventional cities are striving to emulate the concept of smart city healthcare by integrating conventional technologies and devices, amalgamating medical resources with AI-infused solutions. The nexus between smart health and the Information and Communication Technology (ICT) infrastructure of the smart city positions it as a subset within the realm of e-health. The incorporation of AI-integrated Internet of Things (IoT) has proven to be highly advantageous for healthcare systems. Challenges such as reliability, network latency, and bandwidth have impeded the realization of next-generation healthcare. Addressing these concerns, Rathi et al. (2021) proposed a responsive, reliable, low-latency, and scalable AI-enabled healthcare system based on IoT and edge computing. They employed a neural network to estimate transmission latency and assess system performance in real-world scenarios. Additionally, Muhammed et al. (2018) introduced UbeHealth, a ubiquitous healthcare system that tackles next-generation healthcare challenges through the integration of edge computing, Deep Learning (DL), Big Data, high-performance computing, and IoT.

The incorporation of AI into the healthcare sector is succinctly illustrated in Figure 2. Machine Learning (ML), a branch of AI utilizing statistical approaches for learning with or without explicit programming, has played a pivotal role in this integration. With the adoption of AI in smart city healthcare systems, researchers have made notable advancements. Various studies, including those by Alotaibi et al. (2020), Juyal et al. (2021), Mansour et al. (2021), Massaro et al. (2019), Muhammad & Alhussein (2021), Singh et al. (2021), and Tuli et al. (2020), delve into AI-based models for predicting or detecting diseases, infections, and injuries. Immunology is explored in studies such as those by Andrés-Rodríguez et al. (2019) and Zhang et al. (2017), while drug discovery is addressed in Ngiam & Khor's (2019) work. Patient health status prediction is the focus of studies by Massaro et al. (2019), and hospital readmissions are predicted in works by Chaki et al. (2020), Raj et al. (2020), and Uddin & Syed-Abdul (2020).

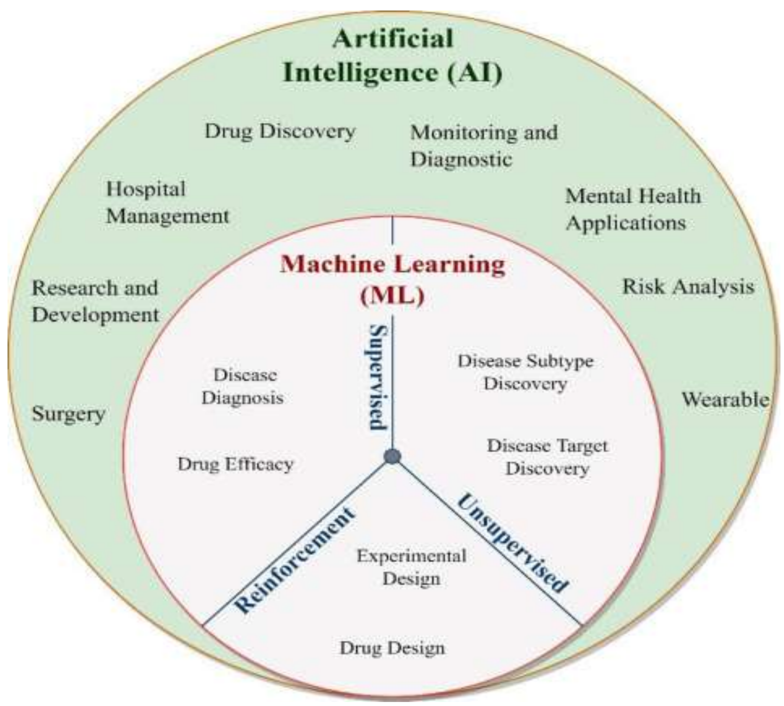

Fig 2: Overview of AI in Healthcare

4. Discussion of AI Application

In the landscape of modern cities, the energy industry has undergone significant growth to meet the escalating demand driven by urbanization. Artificial Intelligence (AI) applications have proven instrumental in providing precise estimations for developing energy maps, facilitating energy modeling, and aiding in strategic planning. The influence of AI is evident, with 27% of Support Vector Machine (SVM)/Least Squares Support Vector Machine (LS-SVM) and 28% of Artificial Neural Network (ANN)-based developments significantly impacting the energy sector. In the realm of education, AI's role extends to intelligent methods for tutoring, communication, analysis, and assessment, with AI-based systems increasingly performing tasks traditionally handled by teachers and students. The implementation of smart education systems in cities, particularly high-populated ones, is anticipated to rise post-2018, with the global pandemic further driving the adoption of AI in remote education systems.

The Massive Open Online Courses (MOOCs) concept, born from open educational materials and e-learning, has become a prominent trend in online learning, with various AI methodologies such as ANN, RNN/LSTM, CNN/R-CNN, DNN, and MLP addressing education challenges in smart cities. Since 2019, the COVID-19 pandemic has posed new challenges to cities, leading to a heightened focus on smart health, logistics, population monitoring, and crisis management. AI technologies, especially machine vision applications, have played a crucial role in smart city applications during the pandemic. Traffic management systems, smart security, and risk management in smart cities also heavily rely on AI, addressing challenges in mobility, privacy, and security. However, alongside its advantages, AI in smart cities presents challenges related to data collection, ethical frameworks, algorithm complexity, and security concerns, underscoring the importance of informed citizenry and responsible use of Information and Communication Technology (ICT) in urban development.

The integration of AI technology has become a cornerstone in the development of smart cities, aiming to alleviate local resource strain and enhance governance and services. The educational landscape has also undergone a notable shift towards e-learning platforms, enabling widespread access to education through the Internet. Ongoing research in mobility and transportation systems seeks innovative solutions for managing urban traffic efficiently. The security sector is witnessing the infusion of AI into IoT-based systems, enhancing the safety measures implemented to protect citizens. The recent global health crisis has prompted countries to explore the potential of artificial intelligence in addressing complex challenges associated with the pandemic, facilitating measures to counteract the spread of COVID-19 and navigate the transition from lockdowns. Notably, AI, Blockchain, Virtual Reality/Augmented Reality, IoT, and 3D printing are identified as major disruptive technologies propelling the evolution of smart cities. In practical terms, AI-based smart city initiatives offer governments and service providers valuable tools for optimizing data exchanges, enhancing information flow, monitoring real-time co-creation, and increasing service effectiveness through the integration of Big Data, IoT, and ICTs in smart systems.

Looking ahead, future endeavors will delve into the adoption of AI in traditional cities, exploring how traditional urban plans can transform into sustainable smart city models through collaboration with AI and Big Data. Subsequent research will continue to explore disruptive technologies beyond those covered in this article, including gamification, virtual and augmented reality, wearable tech, 3D printing, social robots, and more. These evolving technologies are expected to shape the trajectory of smart city development, offering new avenues for innovation and sustainable urban living.

5. Conclusion

The transformation of cities has been profound, marked by the adoption of concepts like resilient cities, sustainable cities, and inclusive cities. Among the technologies driving this evolution, Artificial Intelligence (AI) and the Internet of Things (IoT) stand out as pivotal forces capable of shaping cities into sustainable smart entities. This study comprehensively analyzed 133 papers published between 2014 and 2021, with a predominant presence in Scopus (97%) and WoS (73%). The examination focused on AI adoptions across key domains of smart cities, encompassing healthcare, education, environment and waste management, mobility and smart transportation, agriculture, risk management, and security. The study concludes that the integration of AI into smart cities brings manifold benefits, including operational automation, error reduction, data-driven decision-making, environmental enhancements, new commercial opportunities, and streamlined urban management. However, this technological advancement also introduces regulatory challenges, including concerns related to service delivery discrimination, privacy issues, and legal and ethical considerations.

Additionally, identified risks and barriers to AI implementation in smart cities encompass factors such as data availability, the shortage of qualified professionals, the cost and duration of AI initiatives, and high unemployment rates. Our findings indicate that the healthcare sector holds a significant impact on AI adoption in smart cities, with a notable surge in AI-based breakthroughs since the outbreak in 2019. AI algorithms, including ANN, RNN/LSTM, CNN/R-CNN, DNN, and SVM/LS-SVM, play a prominent role across various smart city sectors, shaping the trajectory of urban development through intelligent technological interventions.

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