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Project Management Strategies for Smart City Initiatives: A Framework for Sustainable Urban Development

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Abstract

Rapid advances in artificial intelligence (AI), the Internet of Things (IoT), and digital government platforms are accelerating the transformation of urban systems toward smart and sustainable cities, creating new challenges for managing complex urban development projects. This study proposes an integrated project management framework that aligns digital transformation technologies with sustainability principles to enhance smart city implementation in emerging economies. A qualitative research design combining systematic literature analysis and comparative case study evaluation was employed, examining smart city initiatives in Aqkol, Nur-Sultan (Astana), and Almaty, Kazakhstan. The analysis investigates how technological integration, governance mechanisms, stakeholder collaboration, and sustainability objectives interact within adaptive project management environments. Results indicate that successful smart city development depends on coordinated alignment across these four dimensions, supported by flexible governance models and data-driven decision processes. The findings further demonstrate that AI-enabled digital twin technologies and participatory digital governance significantly improve infrastructure optimization, urban decision-making efficiency, and resilience outcomes. The proposed framework contributes a structured evaluation and implementation model that bridges project management theory with smart city digitalization practices. The novelty of this research lies in integrating sustainability-driven project governance with emerging digital technologies into a unified operational framework, providing practical guidance for policymakers, urban planners, and project managers seeking scalable and resilient smart city solutions in rapidly evolving technological contexts.

Keywords: Urban Resilience; Smart Cities; Sustainability; Urban Planning; E-Governance; Project Management; Smart Sustainable Cities.

1. Introduction

In the context of increasing global environmental and urban challenges, sustainable urban development is becoming a strategic priority of national policies, especially for countries undergoing intensive urbanization and infrastructure modernization. Kazakhstan, as the largest state in Central Asia, is faced with the need to strike a balance between rapid economic growth, improving the quality of the urban environment, and preserving natural resources. Approaches to sustainable urban development based on international standards and assessment practices are becoming particularly relevant. Reputable systems for assessing the environmental and social sustainability of buildings and districts have developed in world practice, such as LEED (Leadership in Energy and Environmental Design), BREEAM (Building

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Research Establishment Environmental Assessment Method), CASBEE (Comprehensive Assessment System for Built Environment Efficiency), Green Star, and GB Tool, as well as the Green Building Index (GBI). These systems allow for a comprehensive analysis of design decisions, urban planning policy, and operational characteristics of urban development, focusing on sustainability and energy efficiency.

However, the direct implementation of these standards in the Kazakh context, without considering climatic, infrastructural, regulatory, and socio-economic characteristics, cannot be considered effective. In view of this, there is a need to adapt international approaches to the assessment of sustainable development to national realities. Among the key factors are extreme climatic conditions (for example, temperature fluctuations in the northern regions), spatial dispersion of settlements, peculiarities of local building materials, and priorities of state policy in the field of the "green" economy.

In the context of Kazakhstan, and particularly the city of Almaty, the application of international experience in the development of project management strategies for smart city initiatives represents a significant opportunity to improve the efficiency of urban governance and improve the quality of life of citizens. Studying successful practices and adapting them to local conditions can contribute to the creation of a sustainable and innovative urban environment.

The purpose of this research paper is to present a framework for analyzing sustainable development in Kazakhstan, with the goal of improving sustainable practices in urban development. The sustainability index for urban development will be developed based on important elements critical to the success of long-term urban expansion in Kazakhstan, considering the country's specific socioeconomic, environmental, and infrastructure context. Furthermore, the framework will incorporate insights from established grading systems used in industrialized nations, modifying them to correspond with Kazakhstan's urban development objectives, climate circumstances, and national sustainability goals.

In recent decades, the concept of a "Smart City" has gained considerable popularity, representing the integration of modern information and communication technologies (ICT) into urban infrastructure to improve the quality of life of citizens, optimize urban services, and ensure sustainable development [1]. According to Statista, the global smart cities market is showing steady growth, with revenue expected to reach 79.94 billion US dollars in 2025, with a projected average annual growth rate (CAGR) of 9.59% between 2025 and 2029, leading to a market volume of 115.30 billion US dollars by 2029 [2].

An analysis of the regional distribution of smart city initiatives shows that Europe is leading with 170 projects aimed at developing smart cities. However, North America holds the largest share of the smart cities market, accounting for 32.14% in 2023. At the same time, Asia, with its multibillion-dollar population, demonstrates high rates of connected devices in cities, which underlines the global nature of the introduction of smart city technologies [3, 4].

The success of smart city initiatives largely depends on effective project management strategies that consider the complexity and interdisciplinary nature of such projects. According to the UN-Habitat report "World Smart Cities Outlook 2024", 55% of cities have formalized action plans for the development of smart cities, and 57% of them consider maintenance costs at the planning stage. However, only 57% of municipalities monitor the impact of their smart city initiatives, which indicates the need to strengthen assessment and monitoring mechanisms [5]. A common and modern objective of many urban development policies across different nations is sustainable development [6].

Understanding urban development policies is necessary for the housing sector's development. In the current setting, the housing development aligns with both the Habitat Agenda's objective and Agenda 21's tenets. At the 1992 Rio de Janeiro, Brazil, United Nations Conference on Environment and Development (UNCED), 178 nations endorsed Agenda 21, a comprehensive action plan. It is a UN action plan for sustainable development that is optional and non-binding. The 21st century is referred to as "Agenda 21," which emphasizes the necessity for the globe to embrace sustainable development methods to meet current demands without compromising the ability of future generations to support themselves.

Agenda 21 emphasizes the need for sustainable development, which balances economic, social, and environmental issues. It pushes nations to work toward development that satisfies current demands without jeopardizing the capacity of future generations to satisfy their own. The agenda promotes an integrated approach to planning and decision-making, highlighting the connections between a few challenges, including economic development, population expansion, poverty, and environmental degradation. Agenda 21 acknowledges that local implementation is the most effective way to carry out sustainable development efforts. It enables local communities to create plans and strategies for sustainable development that are specific to their needs and challenges.

According to the Brundtland Commission (1987), sustainable development is growth that satisfies current demands without endangering the capacity of future generations to satisfy their own. The idea of sustainability as a long-term development for nations is further developed by Blackburn (2007). The endeavors of sustainability practices include the prudent use of limited natural resources through sound economic implementation, while keeping social and environmental considerations in mind. Achieving sustainability through performance integration of the economic, environmental, and social spheres is the focus of the sustainability philosophy. The environment may be significantly

impacted by a number of construction, design, use, and demolition-related factors [7]. Ecological, economic, technological, cultural, and social sustainability are all a part of sustainable urban development. Regarding urban housing, Edwards & Turrent proposed that housing is sustainable if everyone has the chance to live in a suitable home that fosters self-reliance, social cohesiveness, and well-being [8].

Many countries throughout the world have created measures for measuring sustainability for various forms of development. For instance, Japan's Comprehensive Assessment System for Building Environmental Efficiency established standards and norms for sustainable urbanization and building [9]. These system tools refer to CASBEE for building size and CASBEE for urban development. LEED for Neighborhood Development Rating Systems is the name of the rating system used in the United States [10]. By incorporating LEED for building scale evaluation for sustainable building, it assesses urban development for sustainability. As a result, sustainable urban development refers to the process of developing an area based on sustainability criteria, such as the environment, social factors, economics, site/land uses, communication, transportation, and the evaluation of building forms for housing performance [11]. Houses constructed within the last ten years did not satisfy the fundamental requirements of sustainability, according to Bakar & Cheen [12]. The following are the specifics of the issue:

Green affordable housing and energy efficiency were not considered in the building's design. Specialized designs that outline the intended use of building installations, building structure requirements, and the estimated energy consumption of proposed buildings are necessary for the construction of green housing. According to Nkurikiye & Ma [13], building professionals needed to have "a lot of residential construction experience, drafting experience, building science backgrounds, indoor air quality investigation training, mechanical ventilation training, and other related skills" to construct greenhouses [14].

Sustainability in home development prioritizes social, economic, and environmental concerns. Because of the materials used, design, construction techniques, locations and layout, physical structure, and the use of buildings, construction itself causes several environmental issues, including greenhouse gas emissions and pollution [15]. Groups of buildings that together impact environmental performance are also included in the development of the housing sectors in urban areas. Most developing nations have not yet introduced a tool for assessing sustainable housing development in both urban and suburban areas, even though CASBEE for Urban Development has developed one for this aim.

Even though organized evaluation frameworks are offered by worldwide sustainability assessment systems like LEED, BREEAM, and CASBEE, most research to date has concentrated on applications in industrialized nations with stable regulatory frameworks and temperate climates. Prior studies have focused on building-scale sustainability and environmental performance evaluation, but there hasn't been much focus on combining these frameworks with smart city project management techniques, especially in developing nations. Additionally, a lot of research treats digital urban transformation and sustainability evaluation as distinct fields, which leads to disjointed implementation strategies.

There are still several unanswered questions in the expanding corpus of research on smart cities and sustainable urban development. First, adaptive project management techniques and sustainability evaluation methods are not sufficiently integrated for smart city projects. Second, regional specificities, including Central Asian countries' harsh climates, government transitions, and infrastructure discrepancies, are rarely taken into consideration by current frameworks. Third, there are still few empirical studies on how sustainability concepts are operationalized in Kazakhstani smart city government.

This study fills these gaps by creating an integrated framework for smart city deployment that blends adaptive project management techniques with sustainability evaluation concepts. The suggested framework, in contrast to current methods, integrates sustainability performance, governance practices, stakeholder engagement, and technology innovation into a single analytical model that is suited to developing urban situations. The study makes theoretical contributions by connecting the literature on smart cities and sustainability assessments, and it makes practical contributions by offering a framework for decision-making that is relevant to Kazakhstan and other developing nations.

The remainder of this paper is structured as follows. Section 2 presents the research methodology and reviews the relevant literature on smart cities, sustainability assessment systems, and project management approaches. Section 3 examines the role of digital government in smart city planning and implementation. Section 4 discusses stakeholder involvement in Kazakhstan's smart city development. Section 5 analyzes project management challenges in smart city development, focusing on the case of Kazakhstan. Finally, Section 6 concludes the paper by outlining key implications, limitations, and directions for future research.

- How can digital transformation technologies and sustainability principles be aligned in an integrated project management framework for Kazakhstan's smart city development?
- What measures and indicators may be applied to Kazakhstan's urban development to create a context-sensitive sustainability index?
- In what ways do the case studies of Aqkol, Nur-Sultan, and Almaty highlight the difficulties and real-world applications of implementing smart cities within this framework?

To focus on the study and clearly guide the research, the following research questions are posed. These questions structure the analysis, linking the development of an integrated project management framework with the assessment of sustainability performance and the evaluation of practical case studies in Kazakhstan."

2. Research Methodology

This study examines the existing sustainable rating systems used around the world to determine their best practices and relevance to Kazakhstan. Primary information sources for evaluating sustainability benchmarks within urban development are the CASBEE, LEED, BREEAM, GB Tool, Green Star, and GBI. These globally recognized systems serve not only as evaluation tools but also as strategic policy instruments that guide sustainable construction and urban development across various socio-economic and climatic contexts.

The six main dimensions of sustainable urban development - environmental, social, economic, building morphology, site or land usage, and communication and transportation will all be consideration the formulation of the sustainability assessment framework [16]. These dimensions are reflective of the holistic nature of sustainable development, where environmental stewardship must align with societal well-being and economic resilience. The integration of these elements ensures that the evaluation of sustainability is not fragmented, but rather systemic, capturing interdependencies that are critical in urban environments.

As shown in Figure 1, the proposed framework includes 30 design indicators that are pertinent to neighborhood development, building performance, and urban planning, and that are consistently identified in current green assessment systems. These indicators span a wide array of themes, such as energy and water efficiency, carbon footprint reduction, land use optimization, biodiversity preservation, accessibility, waste management, thermal comfort, and public transportation connectivity. Collectively, they offer a robust basis for developing context-sensitive sustainability metrics.

The selection of the final 30 indicators followed a multi-stage filtering process. An initial pool of more than 130 considerations was compiled through comparative analysis of international sustainability assessment systems. These considerations were first consolidated through thematic grouping to eliminate overlap and redundancy. A qualitative screening was then conducted based on four criteria: relevance to sustainable urban development objectives, contextual applicability to Kazakhstan, measurability using available urban data, and practical feasibility within existing governance and infrastructure conditions. Indicators demonstrating consistent expert agreement across these criteria were retained and refined to form the final framework. Given the exploratory nature of the study, prioritization relied on expert consensus rather than quantitative weighting.

However, these international standards must undergo careful contextualization to be effectively applied within Kazakhstan. In particular, the framework must be adapted to reflect national policies and priorities (such as those outlined in Kazakhstan's Green Economy Concept); regional climatic conditions ranging from sharply continental to arid zones; and persistent infrastructural challenges, especially in rapidly growing urban areas like Almaty, Nur-Sultan, and Shymkent. Kazakhstan's urban development must strike a careful balance between rapid modernization, driven by economic and demographic trends, and the imperative for long-term environmental and socio-economic sustainability.

A pilot study will be conducted to confirm the inclusion and relevance of more than 130 shortlisted considerations within the proposed sustainability assessment model. These considerations have been preliminarily identified through a comparative analysis of existing rating systems and their performance in different global regions. The pilot phase will engage local urban planners, architects, policymakers, and sustainability experts to validate the indicators' applicability, ensuring that they are both technically sound and locally feasible.

To ensure methodological rigor, the pilot study employed purposive expert sampling. Participants were selected based on demonstrated professional experience in urban planning, sustainable construction, smart city technologies, or public policy related to urban development. Experts represented academia, municipal governance, professional practice, and sustainability consulting sectors, each possessing a minimum of five years of relevant experience. Selection emphasized familiarity with Kazakhstan's urban development context to ensure contextual applicability of the proposed indicators.

Indicator validation followed a multi-criteria qualitative assessment approach. Each indicator was evaluated against four validation dimensions: (1) relevance to sustainable urban development objectives, (2) contextual applicability to Kazakhstan's climatic and institutional conditions, (3) measurability based on available or obtainable urban data, and (4) practical feasibility within existing governance and infrastructure capacities. Indicators demonstrating consistent expert agreement across these criteria were retained or refined within the final framework.

The verification process is a critical component in establishing the model's validity and reliability, thereby enhancing its suitability for integration within regional urban development norms and legal frameworks. This process will also support the institutionalization of sustainability benchmarks within national construction codes, urban master plans, and investment appraisal guidelines. Furthermore, it will facilitate alignment with international sustainability commitments,

such as the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement, thus positioning Kazakhstan as a proactive actor in global environmental governance.

Ultimately, the localized sustainability assessment framework aims to serve as both a diagnostic and a planning tool, enabling decision-makers to evaluate urban development projects against comprehensive sustainability metrics. It will also promote best practices across the public and private sectors, encourage innovation in green building technologies, and contribute to the creation of resilient, inclusive, and future-ready urban environments throughout Kazakhstan.

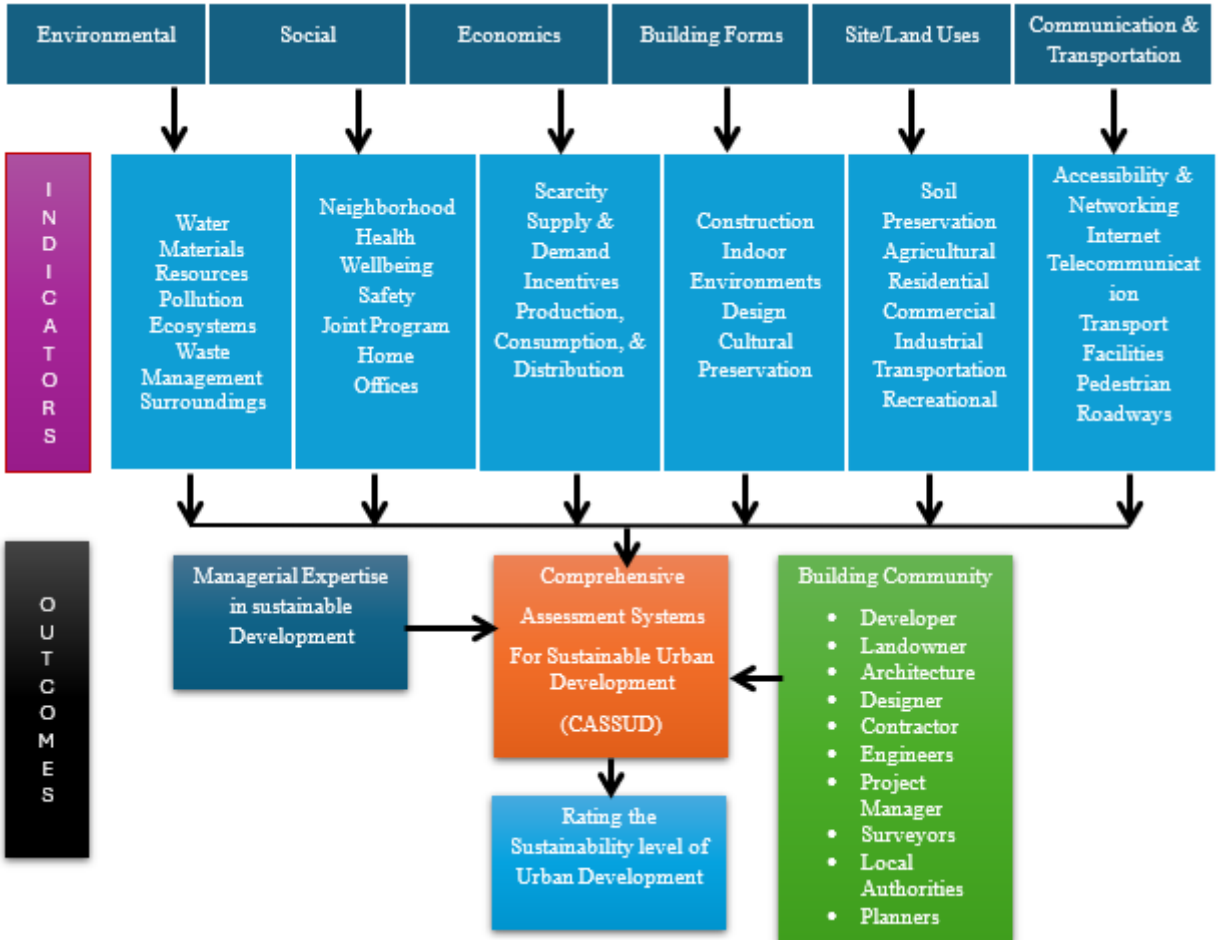

Figure 1. Conceptual Framework for a Holistic Sustainable Urban Development Assessment System [17]

2.1. Current Landscape of Smart City Initiatives in Kazakhstan

The national "Digital Kazakhstan" program, which has been providing the financial channels and strategic framework for digitizing public services, constructing digital infrastructure, and promoting urban innovation since 2017, serves as the cornerstone of Kazakhstan's smart-city strategy [18]. Major urban centers (Astana/Nur-Sultan, Almaty, Shymkent, and other significant cities) are the focus of implementation. There, local authorities have approved national standards for "Smart City" systems and started implementing pilots in utilities, public safety, e-government, and traffic management. To standardize local initiatives throughout the five biggest cities, the government released an official concept and set of guidelines [19].

Due to visible deployments like the CITY PASS platform, expanded e-services, and partnerships to integrate AI and video analytics into city operations, Astana has become the national leader in smart city rankings, according to recent government evaluations and media coverage [20]. Smart Data "Ukimet," a noteworthy national initiative, aims to combine agency datasets and enable shared digital services and AI-assisted decision-making; this backbone is speeding up initiatives that need cross-agency data (emergency response, transportation, and utilities) [21]. Astana's recent procurement and cooperation activity includes AI vendors and specialized platform providers implementing real-time traffic optimization, incident detection, and unified city dashboards, demonstrating the growing trend of private-public collaboration. Even while there has been noticeable improvement in major areas, there are still issues that need to be addressed by legislators, such as uneven broadband and IoT coverage outside of major cities, gaps in digital inclusion, and data governance and privacy concerns [22]. Scaling to regional and rural areas will determine whether the smart-city transition becomes truly nationwide, but overall, Kazakhstan's landscape combines a strong national strategy, concentrated city-level deployments (with Astana leading), expanding AI and platform partnerships, and an active policy dialogue on standards and data sharing.

2.2. Kazakhstan's Ideal Environment for the Development of Smart Cities

Kazakhstan has made significant strides in improving urban living conditions over the past 20 years, as seen by the data on the percentage of the urban population living in slums. This puts the nation in a favorable position for the development of smart cities. About 24.46% of Kazakhstan's urban population resided in slums in 2000. Since then, the nation has had a steady and severe decrease, which peaked in 2018 at 0.79% and stayed steady throughout 2020 and 2022. The almost complete eradication of slum conditions indicates that better housing, dependable utilities, better transportation systems, and stronger governance procedures are beneficial to Kazakhstan's cities. These circumstances lessen fundamental urban shortfalls and free up policymakers to concentrate on more sophisticated Smart City projects, like data-driven urban services, intelligent transportation systems, digital governance, and smart energy management, as opposed to simple housing rehabilitation [23, 24].

On the other hand, neighboring Central Asian nations made less steady and slower progress. Although Kyrgyzstan's slum population decreased from 47.16% in 2000 to 2.44% in 2022, it is still more than three times larger than Kazakhstan's. Uzbekistan experienced a similar decline, but in 2022 it stayed at 7.1%, indicating ongoing difficulties in controlling housing quality and growing urbanization. Slum proportions in Turkmenistan were comparatively high and stable, declining somewhat from 10.5% in 2000 to 8.38% in 2022, indicating no structural change in urban living circumstances [25].

Kazakhstan's performance is comparable and has been beneficial in recent years when compared to Russia, which has already maintained relatively low slum levels. The percentage of people living in slums in Russia decreased steadily from 3.65% in 2000 to 2.62% in 2022, but Kazakhstan had a quicker and more thorough decrease. Overall, Kazakhstan's solid urban basis is demonstrated by its continuously lower slum frequency across the analyzed nations. The nation can move past basic urban issues and concentrate on more complex Smart City projects, such digital infrastructure, intelligent mobility, and data-driven urban management, because to its success in tackling basic housing and infrastructure deficiencies. Kazakhstan is positioned as a regional leader in intelligent and sustainable urban development because to this comparative advantage.

In conclusion, Kazakhstan's urban resilience and preparedness for Smart City transformation are highlighted by the continually low percentage of urban residents living in slums [26]. The nation's achievements in tackling basic urban issues offer a solid foundation for putting creative, technologically advanced ideas into practice that can further improve urban sustainability, efficiency, and quality of life.

The trends in the percentage of urban dwellers in Kazakhstan and a few adjacent countries that live in slums between 2000 and 2022 are shown in Figure 2. The percentage of Kazakhstan's urban population living in slums dropped from very high levels in the early 2000s to less than 1% after 2018, demonstrating a dramatic and ongoing decline. Kyrgyzstan and Uzbekistan, on the other hand, show declining tendencies as well, albeit more slowly, with larger shares throughout the course of the period. While Russia displays consistently low levels with gradual improvement, Turkmenistan shows only slight change, with slum incidence remaining largely stable over time. Overall, the graph shows how well Kazakhstan has performed in enhancing urban living standards, highlighting its advantageous basis for intelligent and sustainable urban development.

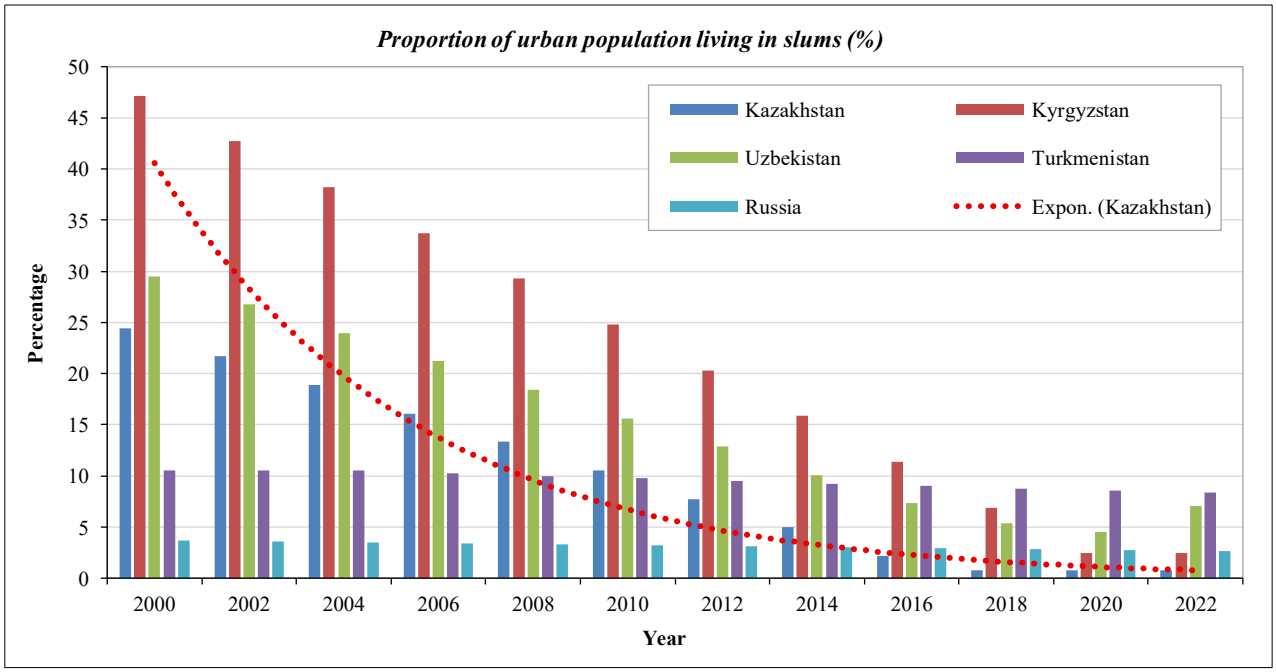

Figure 2. Trends in Kazakhstan's and a few neighboring countries' percentages of urban residents living in slums (2000–2022) [24]

2.3. Aqkol Becomes First Smart City in Kazakhstan

Through the Smart Aqkol initiative, Aqkol, a tiny city with a population of little over 13,000 and located around 100 kilometers north of Astana, was formally named Kazakhstan's first smart city in January 2019. Aqkol lacked even the most basic infrastructure, such as public lighting, before the effort. But in just six months, digital technology completely changed the city into a contemporary urban hub that prioritizes efficiency, comfort, and safety [27]. By combining systems for traffic, public safety, ecological monitoring, utilities, and education into a single situational center, the Smart Aqkol project completely digitalized consumer and public services. By gathering real-time data from GPS units, Internet of Things sensors, and road and security cameras, this center enables analysts to keep an eye on and react swiftly to urban problems and emergencies. From a project management perspective, the integrated situational center improved response coordination by centralizing real-time data flows across municipal services. Automated detection of incidents through video analytics reduced reliance on manual monitoring and enabled faster response initiation, thereby improving service efficiency and urban safety management. Although detailed response-time statistics are not publicly disclosed, operational integration represents a measurable improvement in decision-making speed and inter-agency coordination capacity. After the 2018 Kerch attack, advanced video analytics greatly improved public security by automatically identifying traffic infractions, crowds, unattended objects, and possible weapons. High-resolution and thermal imaging cameras, smart energy and water meters that eliminate manual readings, and intelligent traffic and street lighting systems that have reduced electricity expenditures by about two-thirds are just a few examples of the city's technological advancements. Warm bus stops with device chargers, free public Wi-Fi, better paved roads, and increased public lighting are just a few of the new amenities available to residents.

These outcomes indicate measurable operational benefits associated with smart infrastructure deployment. The reported reduction in electricity expenditures demonstrates improved energy efficiency and lifecycle cost optimization, while automated metering reduced administrative workload and minimized human error in utility management. Such results suggest that even small-scale smart city implementations can generate quantifiable efficiency gains when supported by integrated digital monitoring systems.

The change has garnered national attention; in January 2019, then-President Nursultan Nazarbayev visited Aqkol and commended the project for being in line with more general objectives to modernize Kazakhstan's towns. He emphasized the significance of centrally planned data-driven urban administration for improving economic performance and quality of life [28]. Residents describe significant advances in safety, services, and daily convenience, even if the smart city is still developing and there are still some technological faults and vandalism problems. Since then, numerous smart city initiatives in Kazakhstan have cited Aqkol's path as an early example of urban digitalization [29]. The architectural framework of the SmartAqkol program, which is a trailblazing example of integrated service delivery and urban digitalization in Kazakhstan's smart city landscape, is depicted in Figure 3. Each of the framework's five interconnected basic components addresses a crucial aspect of contemporary urban administration.

The five main elements of Aqkol's smart city plan are based on the SmartAqkol program mentioned above:

- ***City Command Center (Integrated Situational Center):*** A centralized digital platform that compiles data in real time from all throughout the city. As the foundation of smart city governance, it permits monitoring, analysis, and quick action for traffic, utilities, public safety, and emergency situations [30].
- ***Intelligent Public Safety and Monitoring System*:** Installation of infrared, high-resolution, and video analytics-capable cameras around the city. These devices greatly increase urban safety by automatically identifying potentially dangerous situations, suspicious activity, unattended objects, and traffic infractions [31].
- ***Energy Management and Intelligent Utilities*:** Installation of smart heat, water, and electricity meters to increase efficiency and do away with manual readings. By automatically controlling energy use, smart street lighting systems cut electricity consumption by around two thirds [32].
- ***Urban Mobility and Smart Transportation*:** To maximize vehicle flow, enhance road safety, and assist public transportation operations, GPS tracking, traffic monitoring cameras, and intelligent traffic management are used [33].
- ***Urban Amenities and Digital Public Services*:** Digitization of consumer and government services, backed by connectivity throughout the city. Warm smart bus stops with charging stations, free public Wi-Fi, better street lighting, and modernized urban infrastructure all aim to improve the quality of life for locals.

Figure 3. The Smart Aqkol Smart City Framework's Architecture: A Comprehensive Model of Urban Digitalization and Service Provision [34]

2.4. Nur-Sultan: An Adaptive Framework for Sustainable Development and Urban Development in Kazakhstan

Kazakhstan's capital, Nur-Sultan, is a key hub in the nation's political and socioeconomic environment. After being named the national capital in 1997, the city formerly known as Astana underwent a swift metamorphosis, transforming from a rural outpost into a thriving, contemporary metropolis with a population of more than a million. Large-scale urban development was sparked by this calculated move, making Nur-Sultan a shining symbol of Kazakhstan's aspirations for modernization and sustainable development [35].

With an emphasis on smart infrastructure, environmental stewardship, and socioeconomic inclusiveness, the city's spatial planning incorporates sustainable urbanism principles. Nur-Sultan, the political, administrative, and economic center of northern Kazakhstan, is located on the Ishim River and covers an area of around 722 square kilometers. A dedication to balanced land use and connection is shown by the urban morphology, which represents a purposeful design culture and combines large government buildings, residential areas, and green spaces.

A young, expanding population with rising urban density and a varied sociocultural makeup define Nur-Sultan's demographic profile. To properly manage housing, transportation, and public services, adaptable urban strategies are required as the city continues to draw internal migration motivated by economic possibilities and higher living standards [36]. Nur-Sultan's development program has a strong emphasis on sustainability, which is demonstrated by its attempts to improve public transit, investments in renewable energy, and climate-responsive architecture. In line with Kazakhstan's more general environmental goals and the Sustainable Development Goals (SDGs) of the UN, the city's infrastructure prioritizes energy efficiency, waste management, and water conservation.

Concurrently, Nur-Sultan has made digital transformation a pillar of its urban governance. The implementation of smart city technologies, like as data-driven public safety systems, intelligent traffic management, and e-governance platforms, has been made easier by initiatives under the national Digital Kazakhstan program. These initiatives seek to enhance quality of life, promote public involvement, and optimize municipal service delivery.

Additionally, by utilizing Kazakhstan's transcontinental connection within the framework of the Belt and Road Initiative, Nur-Sultan's strategic economic positioning benefits from its role as a regional transport and logistics hub. The city's geopolitical significance is highlighted by the large number of international organizations, diplomatic missions, and business hubs it is home to.

But Nur-Sultan also must deal with issues that are common to quickly urbanizing cities, such as socio-spatial inequality, environmental concerns, and infrastructure strain. To address these complications, the city's ongoing urban development policies place a high priority on multi-stakeholder engagement, equitable growth, and resilience building. In conclusion, Nur-Sultan's multimodal strategy that combines creative planning, sustainable practices, and digital innovation embodies Kazakhstan's urban ideals. Its development provides important insights into how capital cities develop in developing nations and how smart city ideas are incorporated into post-Soviet urban environments.

Based on Nur-Sultan's UNECE city profile and popular smart city frameworks, the following five key elements set Nur-Sultan apart from other smart cities:

- ***Planned Urban Development and the National Capital's Strategic Role*:** In contrast to naturally occurring cities, Nur-Sultan was constructed specifically to serve as Kazakhstan's capital. It has a master-planned urban layout with integrated green areas, government buildings, and cutting-edge infrastructure designed from the ground up for sustainability and administrative effectiveness [37].
- ***Combining E-Government Services with Digital Governance*:** Under the Digital Kazakhstan program, Nur-Sultan has established a complete digital public service ecosystem that facilitates easy citizen access to government services, real-time data sharing between agencies, and cutting-edge e-governance platforms that improve responsiveness and transparency [38].
- ***Prioritize Sustainable and Climate-Responsive Urban Infrastructure*:** The city places a high priority on ecologically friendly infrastructure and architecture, including energy-efficient structures, the integration of renewable energy sources, and intelligent water and waste management systems created to tackle the region's challenging resource and climate conditions [39].
- ***Multimodal Intelligent Transportation and Mobility Systems*:** To lessen traffic and pollution, Nur-Sultan places a strong emphasis on intelligent traffic management, modernizing public transportation, and non-motorized mobility. It does this by using GPS tracking, smart traffic lights, and encouraging environmentally friendly means of transportation [40].
- ***Geopolitical and Economic Center Making Use of Global Connectivity*:** The city's smart city model, which combines urban innovation with geopolitical and economic strategic positioning, is unique due to its role as a major regional transportation, logistics, and diplomatic hubs within frameworks such as the Belt and Road Initiative [41].

A conceptual framework that highlights the special features that set Nur-Sultan's smart city model apart from others is shown in Figure 4. The framework captures the city's unique approach to urban innovation and sustainable development by combining widely accepted smart city ideas with important features taken from the UNECE city profile.

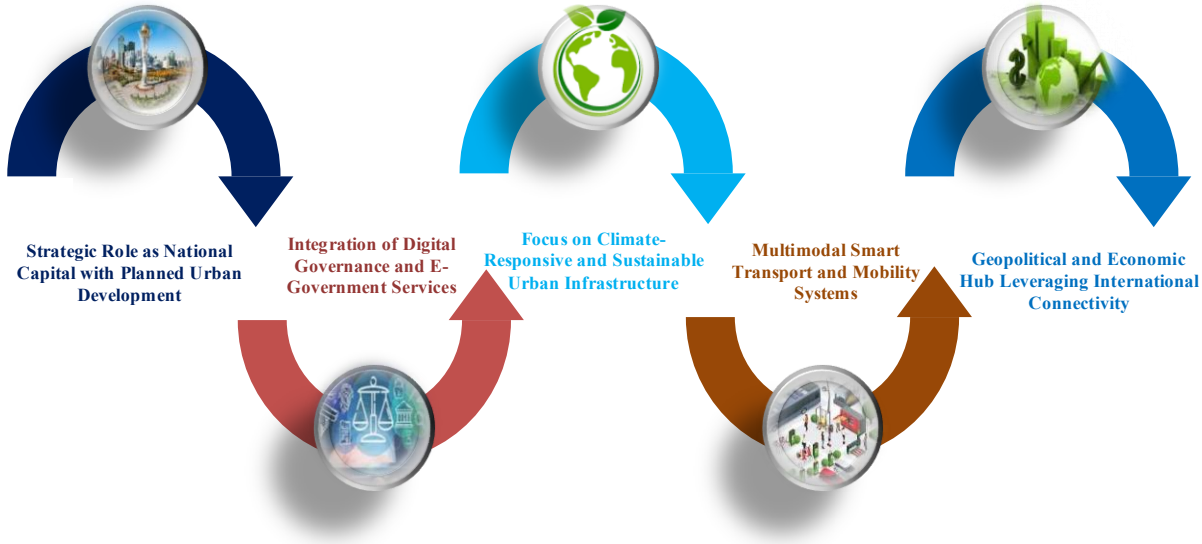

Figure 4. Conceptual Framework Showcasing the Unique Smart City Elements of Nur-Sultan [34]

2.5. Almaty City: Digital Transformation and Urban Futures in Central Asia

Almaty is now a prominent urban innovator in Central Asia thanks to its modern urban transformation, which represents a larger shift among developing cities toward digitally enabled, citizen-centric governing models. Almaty, which has long been a center for culture, business, and education, is using its legacy advantages human capital, institutional density, and geographic appeal to forward a development plan that is focused on the future and is based on digital infrastructure, integrated data systems, and proactive public services. The city's transformation strategy places more emphasis on integrating digital technologies with long-term urban planning goals, such as livability, inclusion, and

economic resilience, than on adopting technology as a goal in and of itself. The methodical upgrading of digital infrastructure, which is characterized by increased broadband coverage, increased mobile connectivity, and the implementation of sensor-based technologies that allow for real-time urban monitoring, is essential to this strategy. A more advanced layer of data integration, in which previously dispersed administrative datasets are combined into unified platforms that enable city authorities to produce actionable insights and coordinate policy responses across sectors, is supported by these basic investments.

Almaty's dedication to data-driven governance through the creation of interoperable technologies and a shared information architecture is a distinguishing characteristic of its digital transformation. The city decreases duplication, increases decision accuracy, and speeds up service delivery by establishing a "single source of truth" among municipal departments. Innovative data-sharing agreements with private sector entities enhance this governance paradigm by providing access to anonymized datasets in return for reciprocal contributions. These methods represent a growing recognition of data as a strategic public asset that can improve policy design while bringing up crucial issues of accountability, transparency, and trust. Almaty's shift to proactive public services, where eligibility for social benefits, transportation subsidies, or utility discounts is automatically established based on verified data rather than citizen applications, best illustrates the practical ramifications of this data approach. This change from reactive to anticipatory governance lessens the administrative load, enhances service equity, and portends a more significant change in the citizen-state relationship.

Almaty's realization that social sustainability and human capital must serve as the foundation for digital transformation is equally important. In an increasingly competitive global labor market, the city faces both the potential and the challenge of keeping talented graduates due to its large student population and dense concentration of higher education institutions. Therefore, initiatives to enhance urban quality of life, support innovative ecosystems, and create career pathways that complement the talents of a young, educated population are directly related to digital modernization. In this way, Almaty's urban future is conceived as a socio-technical project that incorporates people, infrastructure, and governance rather than just in terms of technology. Almaty's experience demonstrates how strategic vision, phased implementation, and citizen-focused design can come together to construct a resilient and future-ready urban trajectory as cities throughout the Global South look for models for scalable and context-sensitive digital transformation.

The distinctive governance and digital innovation elements that set Almaty's smart city concept apart from traditional methods are depicted in Figure 5, especially in emerging and transitional economy environments. Proactive service delivery, reciprocal public-private data interchange, integrated cross-departmental data governance, talent-centric digital strategy, and context-sensitive institutional adaptation are the five interconnected dimensions highlighted in the graphic. When taken as a whole, these components show a move away from modernization driven by technology and toward digital transformation driven by governance.

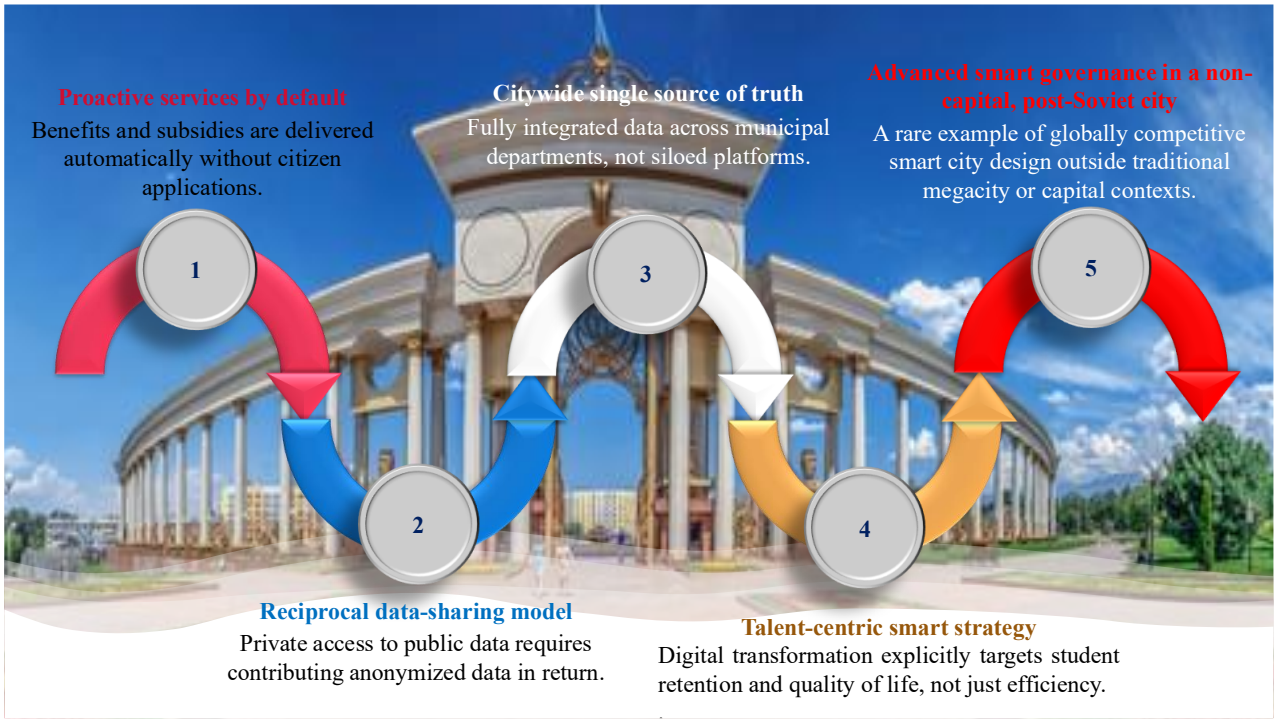

Figure 5. Unique Governance and Digital Innovation Features of Almaty as a Smart City [42]

Almaty differs from many other smart cities in the following five ways, especially when considering emerging and transitional economies:

- ***Proactive (anticipatory) public services*:** Almaty has institutionalized proactive service delivery, in contrast to most smart cities that still rely on application-based or on-demand digital services. Benefits, including utility savings for households with disabled members or subsidized transit cards for pensioners and students, are automatically provided to eligible residents without the need for requests. As a result, governance is changed from reactive administration to anticipatory welfare, which is still uncommon worldwide [43].
- ***Barter-Based Public–Private Data Exchange Model*:** Almaty uses a non-traditional data-sharing method in which private organizations can only obtain anonymized municipal datasets by providing their own non-personal data in exchange. This reciprocal "data barter" concept presents data as a shared civic asset rather than a unilateral government release, setting it apart from conventional open-data websites or strictly commercial data markets [44].
- ***One Truth Source for All Municipal Systems*:** Despite smart city branding, many cities have disjointed data ecosystems. Coordinated policy action and united decision-making are made possible by Almaty's intentional development of an integrated, cross-departmental data architecture that connects health, education, utilities, housing, and social services. Particularly outside of high-income areas, this degree of operational interoperability is still rare [45].
- ***Talent Retention, Not Just Efficiency, Is the Foundation of Smart City Strategy*:** Almaty specifically connects digital transformation to human capital retention, whereas most smart city programs focus on cost reduction or operational efficiency. With a sizable student body and a sophisticated infrastructure for higher education, the city presents smart governance as a means of enhancing urban appeal, career prospects, and quality of life directly addressing brain drain, a problem that is frequently disregarded in smart city frameworks [46].

The cross-case comparison reveals differentiated pathways toward smart city development in Kazakhstan. Nur-Sultan demonstrates a policy-driven model characterized by centralized governance and large-scale digital integration, while Almaty reflects a municipally driven innovation approach emphasizing mobility and service modernization. In contrast, Aqkol represents a pilot-scale implementation where targeted technological interventions produced measurable operational efficiencies. Together, these cases illustrate how city size, governance structure, and institutional capacity influence technology adoption strategies and sustainability outcomes, highlighting the importance of context-sensitive smart city frameworks. A cross-case comparison is summarized in Table 1, which presents an overview of smart city implementation across the Kazakhstan case studies.

Table 1. Comparative Overview of Smart City Implementation in Kazakhstan Case Studies

Dimension	Nur-Sultan	Almaty	Aqkol
Governance Model	Centralized national-led smart city initiatives	Municipal-led innovation with public–private collaboration	Pilot-scale centralized management
Technological Focus	Integrated urban platforms, digital governance systems	Mobility solutions, smart services, urban data platforms	Smart lighting, surveillance, utility automation
Scale of Implementation	Capital city, large-scale deployment	Metropolitan regional scale	Small-city pilot implementation
Sustainability Emphasis	Strategic planning and digital governance	Urban mobility and service efficiency	Energy efficiency and operational optimization
Measurable Outcomes	Improved administrative integration	Enhanced mobility management	Reduced electricity expenditure (~two-thirds)
Replicability Potential	Policy leadership model	Innovation-driven model	Scalable pilot model

3. The Role of Digital Government in Smart City Planning and Execution

Kazakhstan has made great success in digital governance, earning a prominent place in international e-government rankings that demonstrate the country's substantial advancements in administrative modernization and the provision of digital public services. According to the United Nations E-Government Survey 2024, Kazakhstan improved four spots from the previous evaluation period and achieved one of its best historical results, ranking 24th out of 193 nations on the E-Government Development Index (EGDI) [47].

With this accomplishment, Kazakhstan is now in the very high EGDI category, ahead of other large nations including China, Switzerland, and Turkey and alongside advanced economies.The Digital Kazakhstan Program, approved by the decree of the Government of the Republic of Kazakhstan in December 2017, is a fundamental document of digital transformation. It is aimed at developing ICT infrastructure, key digital services (including Smart City), automation of public services and digitalization of economic sectors. The program covers dozens of initiatives and projects, including pilot Smart City developments in five cities across the country[48].

Zerde Agency has developed the national Smart City reference standard (Order No. 152/NK dated July 2019). It forms norms and technological requirements for digital city management systems, smart lighting, IoT infrastructure and open data management. The standard serves as the basis for assessing the maturity of Smart City projects and is necessary

for their systematic implementation [49]. Kazakhstan's strong performance in the Online Service Index (OSI), where it ranks 10th internationally alongside digital champions like South Korea, Denmark, and Estonia, is a crucial aspect of its e-government success. This result demonstrates the range of services provided digitally as well as the usability and accessibility of public digital platforms. Kazakhstan's successful integration of information and communication technology (ICT) into public service channels, which allows citizens to interact with government services effectively and securely, is highlighted by the country's high OSI ranking [50].

Kazakhstan's leadership is apparent not only in international rankings but also in regional and structural situations. The nation continues to be the most e-government-ready member of the Commonwealth of Independent States (CIS), surpassing nearby countries like Russia, Armenia, and Uzbekistan. Furthermore, Kazakhstan has the highest EGDI score (0.9009) among landlocked developing nations (LLDCs), a group that suffers infrastructural and economic constraints, demonstrating its ability to overcome structural limitations through strategic digital investment [51].

High EGDI rankings reflect not only technological advancement but also institutional capacity that directly supports smart city project delivery. Strong digital government systems enable integrated data sharing across agencies, reducing administrative fragmentation during project implementation. Digital platforms facilitate real-time monitoring, transparent reporting, and faster decision-making, which are critical components of effective project management. Consequently, higher levels of e-government maturity improve coordination among stakeholders, streamline service deployment, and enhance the efficiency and accountability of smart city initiatives.

Multifaceted digital transformation projects promote Kazakhstan's rising position in the world's e-government rankings. The nation's ranking on the Telecommunications Infrastructure Index has improved by more than twenty spots because of significant gains from investments in telecommunications infrastructure. To improve administrative effectiveness, transparency, and the standard of public services, Kazakhstan has also made the implementation of cutting-edge technologies like blockchain, artificial intelligence (AI), and the Internet of Things (IoT) a top priority [52]. National strategies for the development of the digital economy, which prioritize cybersecurity, innovation ecosystems, and digital inclusion, complement these technological interconnections.

The strategic focus on digital governance has important ramifications for citizen involvement and public administration. Kazakhstan has minimized bureaucratic obstacles, enhanced service delivery results, and decreased friction in citizen-government interactions by improving digital service quality and increasing online availability. A larger institutional commitment to digital transformation is also indicated by the rise in worldwide rankings, which reflects concerted policy initiatives, bureaucratic reform, and cross-sectoral cooperation.

All things considered, Kazakhstan's results in the UN E-Government Survey 2024 establish it as a world leader in e-government development and serve as an example for other nations looking to quicken their digital transition. Its accomplishments, especially in the areas of online service delivery, infrastructure preparedness, and regional leadership, highlight how digital governance may improve public service delivery and institutional capacity in a variety of developing situations.

The research indicates that the percentage of people who use the internet increased from 31.6% in 2010 to 92.9% in 2023, a nearly threefold rise over a thirteen-year period. This steady expansion is a result of both increased digital infrastructure and broad digital adoption among various demographic groups, which fosters the development of technology-enabled urban governance.

For smart city systems, which depend on constant digital connectivity to provide e-services, gather real-time data, and promote public engagement, high levels of internet access are a fundamental requirement. Kazakhstan has demonstrated a level of digital preparedness equal to leading countries by achieving 90% internet usage since 2021, allowing for the successful implementation of digital public service platforms, e-health, e-governance, and smart mobility. Furthermore, the post-2018 plateau above 80% indicates maturation and stability in national connection, whereas the fast acceleration seen between 2010 and 2015 reflects early investment in telecommunications infrastructure.

This path lessens the major implementation risks related to unequal access and digital exclusion, which frequently impede smart city initiatives in developing nations. As a result, Kazakhstan's high and steadily increasing internet penetration creates a solid technological and social basis for smart city design, facilitating inclusive, scalable, and data-driven urban transformation [53]. The long-term evolution of internet usage in Kazakhstan, a few Central Asian nations, and Russia from 2001 to 2023 is shown in Figure 6, which shows significant variations in the rate and level of digital adoption.

The constant increase in the percentage of people utilizing the Internet from 1.01% in 2001 to 92.88% in 2023 shows Kazakhstan's leadership in digital connectivity among Central Asian nations. In contrast to its contemporaries in the region, Kazakhstan demonstrates both quick early adoption and long-term consistency, retaining parity with Russia, the region's benchmark digital economy, and achieving nearly universal internet usage by the early 2020s. Because it makes it possible to implement data-driven urban services, citizen-centric digital platforms, and real-time governance systems

on a broad scale, this degree of social connection is a fundamental requirement for the adoption of smart cities. Kazakhstan is positioned as the most institutionally and socially prepared country in Central Asia for the implementation of smart cities due to the country's widespread and mature internet usage, which considerably lowers obstacles to digital inclusion, user adoption, and system scalability.

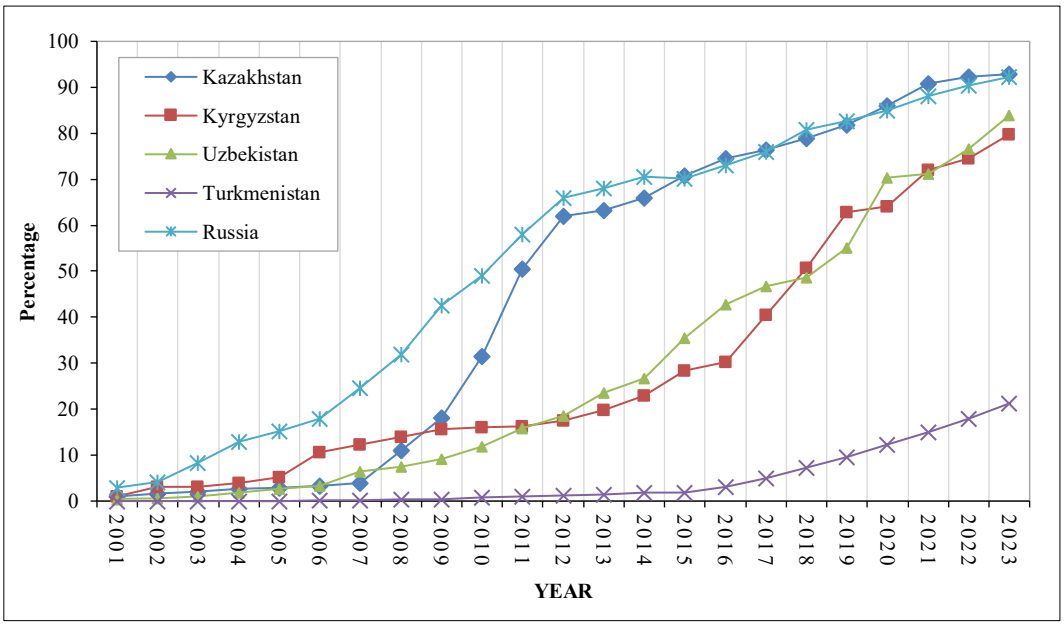

Figure 6. Trends in Internet Use (% of Population) in Russia, Kazakhstan, and a Few Central Asian Nations (2001–2023) [54]

Kazakhstan's strong performance in international e-government rankings illustrates that centralized digital governance can act as an enabling platform for smart city development. However, the results also suggest that digital government maturity alone does not guarantee integrated urban transformation. The gap between national digital capability and local implementation capacity highlights the importance of multilevel governance coordination. This reinforces the study's argument that project management serves as the operational bridge connecting national digital strategies with localized urban innovation outcomes.

3.1. Comparison of Digital Government Results

These findings align with international research indicating that advanced e-government systems provide a foundational infrastructure for smart city development by enabling data integration and service interoperability. Similar patterns have been observed in digitally advanced countries such as Estonia and South Korea, where strong digital governance accelerated urban innovation. However, the present study shows that, despite Kazakhstan's high e-government ranking, implementation disparities persist at municipal levels. This expands previous studies by demonstrating that national digital maturity does not automatically translate into local smart city effectiveness without adaptive project management mechanisms.

4. Stakeholder Involvement in Kazakhstan's Smart City Development

A key component of smart city development, execution, and sustainability is effective stakeholder participation. The government of Kazakhstan has made a conscious effort to improve accountability, responsiveness, and transparency in policymaking by institutionalizing stakeholder participation. This has resulted in a core governance framework that is extremely supportive of smart city efforts. The foundation of Kazakhstan's stakeholder engagement strategy is the creation and management of public councils, official forums intended to incorporate civil society viewpoints into national, regional, and municipal government decisions. With two-thirds of the seats going to representatives of civil society and one-third going to public officials, these councils offer a hybrid governance system that guarantees diverse input into policy deliberations and requires public institutions to take their proposals into consideration [55].

This framework's advantages are important for the creation of smart cities. First, public councils serve as long-term, legally required institutions that facilitate ongoing interaction with stakeholders in the private sector, civil society organizations (CSOs), and citizens. Smart city policies, which frequently involve intricate socio-technical systems, can be improved with widespread societal participation thanks to their advisory role in assessing public services and offering feedback on proposed legislation. A key factor in determining citizen adoption and the long-term sustainability of smart city technology is the transparency provided by these councils, which increases legitimacy and trust in digital and urban transformation strategies [56, 57].

Furthermore, participatory governance techniques pertinent to smart cities are supported by Kazakhstan's more extensive open government reforms, such as laws pertaining to information access and digital channels for public input. In keeping with the participatory governance model that is essential for inclusive smart city ecosystems, digital consultation tools, e-appeal systems, and online government service platforms increase the opportunity for stakeholders to express their opinions. In addition to facilitating a wider audience, these tools improve the government's ability to include a variety of stakeholder perspectives into planning and service delivery, especially in the areas of urban infrastructure, transportation, and e-government services [55, 57].

However, several improvements are required to fully realize the promise of stakeholder participation in smart city development. There are currently no consistent rules for asking for input, deadlines, or ways to close the feedback loop with contributors in public consultation procedures. It will be crucial to close these gaps by creating more transparent procedures, increasing the diversity of stakeholder representation, and offering council members and public officials focused capacity building. The role of councils as catalysts for co-created urban innovation will be strengthened by ensuring transparency in council operations, disclosing member selection processes, and granting them financial autonomy [55, 57].

In conclusion, a strong foundation for the development of smart cities is provided by Kazakhstan's governance framework for stakeholder participation, especially through public councils and developing digital engagement techniques. The development of smart cities depends on the institutionalization of participatory procedures, which foster cooperative decision-making, citizen co-creation, and adaptable governance. Kazakhstan is well-positioned to use stakeholder engagement as a strategic asset in carrying out astute, equitable, and sustainable urban development thanks to continuous advances in procedural clarity, inclusivity, and feedback integration [55, 57].

The main institutional pillars that encourage stakeholder participation in Kazakhstan’s smart city development is shown in Figure 7. To ensure efficient and long-lasting smart urban government, these include formal involvement methods, transparency and information availability, inclusivity and representation, and responsiveness to stakeholder criticism.

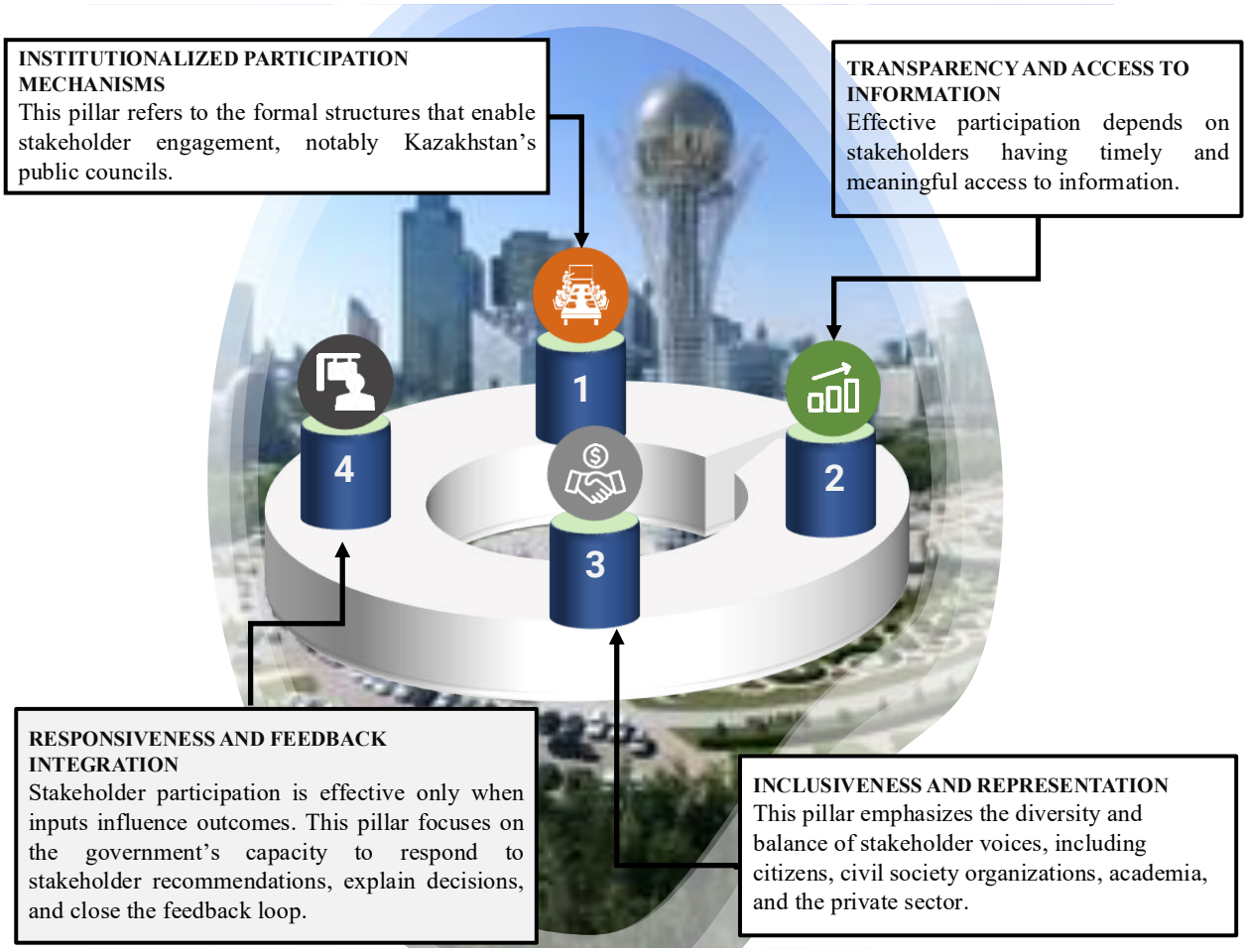

Figure 7. Institutional Foundations Encouraging Stakeholder Involvement in the Development of Smart Cities in Kazakhstan [56]

4.1. Comparison of Stakeholder Participation

The emphasis on institutionalized stakeholder engagement corresponds with global smart governance literature, which identifies citizen participation as a key determinant of sustainable urban innovation. Comparable participatory models have been documented in European smart cities such as Helsinki and Barcelona. Nevertheless, Kazakhstan's approach differs through its structured public council system, which integrates formal governance mechanisms with emerging digital participation tools. This hybrid model contributes new empirical insight into stakeholder coordination within transitional governance environments.

5. Project Management Challenges in Smart City Development: The Case of Kazakhstan

Kazakhstan's ambitious national ambition to use digital twin technologies, artificial intelligence, and the Internet of Things (IoT) for urban modernization is reflected in the country's smart city transformation, especially in Astana. However, the success of such intricate programs depends on successfully tackling complicated project management challenges, as seen in major smart city initiatives worldwide [58, 59].

Technically speaking, Kazakhstan has major issues with cybersecurity, interoperability, and system integration, particularly when combining cutting-edge AI and IoT-based technologies with outdated urban infrastructure. To ensure the dependability and scalability of smart city systems, strong architectural frameworks and standardized data governance models are essential due to the high severity of technological issues.

High capital expenditure requirements, long-term operating costs, and uncertainty about return on investment continue to be major financial obstacles. For large-scale digital infrastructure projects, maintaining finance throughout the project lifespan remains a crucial challenge, even though Kazakhstan has reduced certain financial risks through public-private partnerships. Organizational difficulties are as important, especially when it comes to coordinating various government agencies, business partners, and technology suppliers. Cross-sectoral cooperation can be hampered by disjointed governance structures and opposition to organizational change, which can have an impact on project schedules and results [60].

Despite being relatively mild, legal and societal issues are becoming more important. Proactive policy alignment and stakeholder engagement techniques are necessary to address issues related to data protection, regulatory compliance, citizen trust, and digital inclusion. Long-term sustainability is also seriously threatened by capacity and scalability issues, which are brought on by a lack of skilled workers and the difficulty of expanding pilot programs to citywide implementation. Overall, Kazakhstan's experience with smart cities shows that turning technological aspirations into operational success requires a comprehensive approach to project management [61, 62].

With an emphasis on IoT and AI integration, Figure 8 shows the main project management difficulties encountered in Kazakhstani smart city initiatives. Critical areas including technical, financial, and capabilities difficulties are highlighted by rating each difficulty according to its severity. Technical and capability issues rank among the most important, with both obtaining a high severity rating of 8 out of 10, according to an examination of the major difficulties associated with managing Smart City initiatives in Kazakhstan. This highlights serious problems with cybersecurity, interoperability, system integration, the lack of qualified personnel in AI and IoT, and the requirement for improved training [63].

Organizational obstacles come in second with a score of 7, which reflects persistent issues with coordination, complicated governance, and institutional opposition to change. These elements impede coherent progress and lead to fragmented project management. Sustainable finance and long-term project viability are complicated by financial problems, which are likewise scored at 7. These challenges include high costs, funding constraints, and uncertainty about returns on investment. Additionally, scalability concerns have a severity rating of 7, which highlights the difficulties in sustaining performance, guaranteeing future readiness, and scaling pilot projects to fully citywide implementations. Legal and societal challenges, which both received a score of 6, seem to be less important but are nonetheless important. While social obstacles focus on issues like the digital divide, citizen trust, and diversity, legal challenges center on data protection, regulatory compliance, and procurement restrictions [64].

This distribution of challenges shows a need for a comprehensive and integrated management approach that addresses technical and human capabilities shortages while simultaneously increasing organizational coordination. It will also be essential to prioritize scalable infrastructure, sustainable finance methods, and legal frameworks. All things considered, Kazakhstan's success depends on moving from discrete projects to cohesive, scalable, and revolutionary Smart City efforts.

The dominance of technical and capability-related challenges indicates that smart city implementation in emerging economies is constrained less by conceptual planning and more by institutional and technological readiness. This finding aligns with previous smart city studies emphasizing interoperability and human capital as critical barriers to scaling digital urban systems. Unlike mature smart city ecosystems in Europe and East Asia, Kazakhstan's challenges reflect a transitional governance environment where digital innovation progresses faster than organizational adaptation. From a project management perspective, this suggests that traditional infrastructure-oriented management approaches are insufficient, and adaptive, capability-driven project governance models are required. Therefore, project success depends not only on technology deployment but also on continuous skills development, institutional coordination, and lifecycle-based risk management.

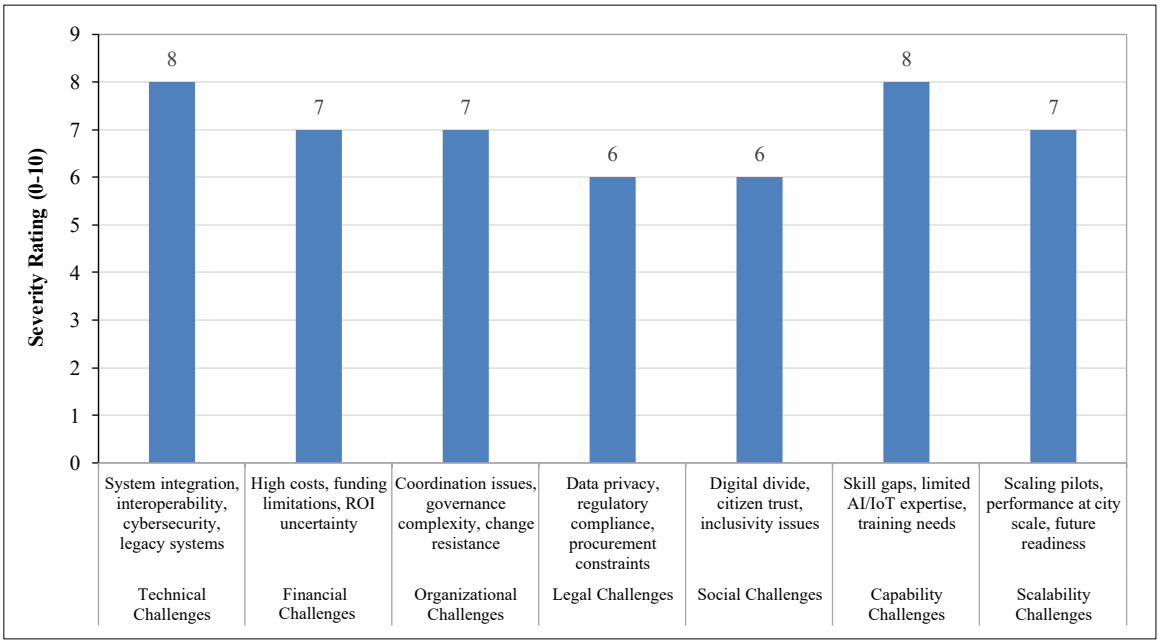

Figure 8. Project management challenges in smart city initiatives, including IoT and AI integration, are rated according to severity in Kazakhstan [65]

5.1. Comparison of Project Management Challenges

The identified dominance of technical and capability-related challenges is consistent with findings reported in prior smart city studies, which highlight interoperability, cybersecurity, and institutional readiness as primary barriers to implementation in emerging economies. Similar observations have been reported in studies of smart city initiatives in India and Southeast Asia, where rapid technological adoption outpaced organizational capacity development. However, unlike many previously examined contexts where financial constraints represent the primary limitation, the Kazakhstan case demonstrates relatively strong governmental investment but persistent coordination and skills-related challenges. This suggests that the success of smart city initiatives increasingly depends on governance maturity and human capital rather than solely on funding availability, extending existing project management literature toward capability-centered implementation models.

5.2. Technological Infrastructure and Integration

The success of smart city initiatives depends on a strong technological foundation, yet Kazakhstan faces significant challenges in this area. While major urban centers such as Almaty and Astana have relatively advanced ICT infrastructure, rural regions remain underserved, creating a pronounced digital divide. Broadband penetration in Kazakhstan is high in cities, with 4G coverage reaching approximately 95% nationwide and near universal 3G availability [66]. However, rural connectivity is far less reliable. According to ITU's Connect2Recover assessment, last-mile infrastructure in remote villages is weak, and coverage maps remain incomplete, leaving many communities without consistent access to mobile networks [67]. In fact, despite the technical feasibility of deploying fiber optic cables, there are still villages where cellular communication is entirely absent, making even basic digital services inaccessible [68]. This lack of connectivity severely limits the integration of smart technologies in rural areas.

Beyond ICT, physical infrastructure deficiencies compound these challenges. Many rural settlements lack essential amenities such as street lighting, which not only affects safety but also hinders the deployment of smart lighting systems. While projects supported by UNDP and EBRD have upgraded lighting in regions like Atyrau and East Kazakhstan, these

efforts rarely extend to smaller villages [68, 69]. Similarly, road infrastructure remains inadequate in many rural areas, with unpaved or poorly maintained roads preventing the installation of sensor-based traffic management systems and complicating logistics for smart utilities [70]. Automation and digital readiness also lag outside urban centers. Local administrations in rural areas often rely on manual record-keeping, with limited adoption of e-governance platforms. OECD and UNESCAP reports highlight uneven legal and operational readiness across regions, noting that rural municipalities lack both the digital skills and the investment incentives necessary for modernization [71, 72]. Consequently, while city residents benefit from IoT-enabled utilities and electronic public services, rural populations remain excluded from Kazakhstan's broader smart city vision.

Closing this gap requires coordinated investment in ICT backbone infrastructure and basic physical amenities. Without addressing these disparities, Kazakhstan risks creating "smart islands" in urban centers while leaving rural communities disconnected from the benefits of digital transformation.

Kazakhstan's smart city challenges are essentially comparative rather than absolute, based on subscriber and technological trends for important markets. Figure 9 illustrates Kazakhstan's strong rise in subscriber penetration (from 73% to 79%) and smartphone usage (from 85% in 2024 to 94% by 2030), although its technological transition lags peer countries in terms of 5G readiness and legacy network phase-out. Kazakhstan is expected to maintain a higher percentage of 4G connectivity in 2030 (47%) compared to Russia and Belarus, while 5G adoption reaches 42% [73]. This suggests a delayed transition toward the ultra-low-latency and high-capacity networks needed for sophisticated smart city services. Even though 2G and 3G networks are less common, their continued existence highlights spectrum inefficiencies that could prevent large-scale IoT deployments from integrating seamlessly. Kazakhstan's relative risk of falling behind in regional smart city competition is highlighted by markets like Uzbekistan, which show more active movements toward next-generation connectivity. To ensure that digital infrastructure does not limit the scalability and performance of future smart city ecosystems, Kazakhstan's main challenge is not user preparedness but rather expediting network modernization to match leading regional benchmarks.

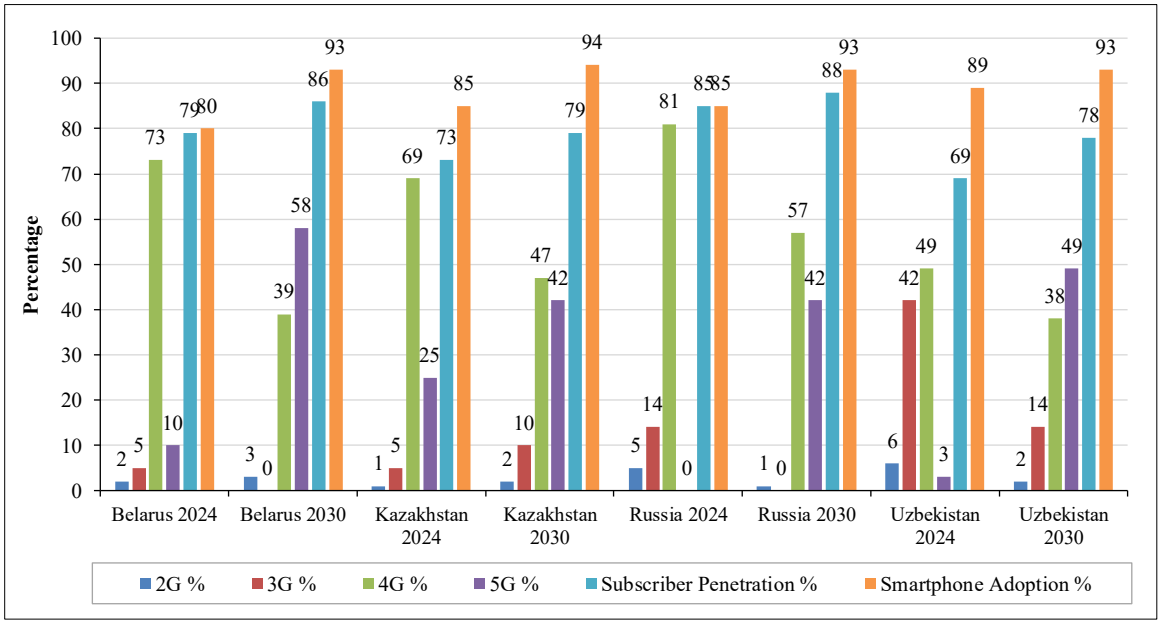

Figure 9. Subscriber and Mobile Technology Trends Across Key Markets (2024–2030) [74]

5.3. Human and Social Factors in Smart City Development: Skills, Literacy, and Cultural Acceptance

Smart city initiatives in Kazakhstan are shaped as much by human and social dynamics as by technology and funding. The interplay between workforce skills, digital literacy, cultural norms, trust, and privacy determines whether advanced systems translate into inclusive, day-to-day benefits for citizens across urban and rural contexts [75]. Kazakhstan has made notable progress building a digital government and enabling frameworks for private-sector digitalization. Yet, skills bottlenecks persist especially outside major cities slowing the uptake and effective operation of IoT, data analytics, cybersecurity, and e-governance tools. The OECD's diagnostic on business digital transformation emphasizes that the private sector's digitalization requires reliable broadband, stronger telecom competition, and improved digital security capacity, all of which hinge on human capital and institutional capability [66, 67]. In practice, municipalities and regional entities often lack staff trained to manage interoperable platforms, data stewardship, and secure service delivery issues also flagged in e-governance assessments as barriers to achieving "once-only," proactive services at scale [66,76] .

Despite high national ambitions and strong urban performance in e-government indices, digital literacy is uneven. A large mixed-methods study on citizen-centered services reports that 23.3% of users experienced technical errors, 15.2%

faced bureaucratic redundancies, and critically – rural respondents accounted for just 1.6% of survey participants, underscoring a participation and inclusion gap that mirrors literacy and access inequalities [66, 76]. Rural connectivity constraints compound this: in 2024, 1,424 villages lacked mobile Internet, and operators were incentivized to expand coverage to underserved settlements, reflecting the challenge of basic access as a precursor to literacy [67]. Generational differences are marked. Evidence from national discussions and diagnostic work shows older adults frequently prefer in-person service centers and require tailored guidance to navigate e-government platforms [66, 69]. The cultural tendency to seek human intermediaries—especially where trust in digital channels is not yet consolidated—reinforces the need for hybrid service delivery and age-sensitive literacy programs [66, 76].

When compared to leading and even mid-performing nations, Kazakhstan's human and social foundations for smart city development are still insufficient, according to data on public spending as a proportion of GDP. Kazakhstan's public spending in this area is only 0.24% of GDP, which puts it at the bottom end of the global spectrum and much below innovation-driven smart city leaders like Denmark (1.96%), Sweden (1.25%), and Finland (0.99) [77]. The systematic development of digital skills, advanced literacy, and institutional capacity all necessary for empowering citizens to interact with data-driven urban services, smart governance platforms, and technology-intensive public infrastructure is hampered by this relatively low level of investment. Even in comparison to several peer and transition economies, like Estonia (0.42%), Portugal (0.41%), and Korea (0.32%), Kazakhstan's investment indicates a low priority for the development of human capital. Inadequate funding diminishes chances for digital inclusion, public knowledge, and trust in smart city technology, which has consequences that go beyond technical proficiency to cultural acceptance. Kazakhstan's smart city aspirations are therefore likely to be limited by a weak human and social readiness base, despite advancements in connectivity and smartphone adoption [78]. This highlights the necessity of targeted increases in public investment focused on skills development, digital education, and participatory capacity-building to ensure sustainable and inclusive smart city implementation.

Kazakhstan's comparatively low investment in human capital development particularly in areas related to skills formation, literacy, and social readiness is highlighted in Figure 10, which compares public expenditure levels as a percentage of GDP across selected countries. These areas are crucial enablers for the implementation of sustainable smart cities.

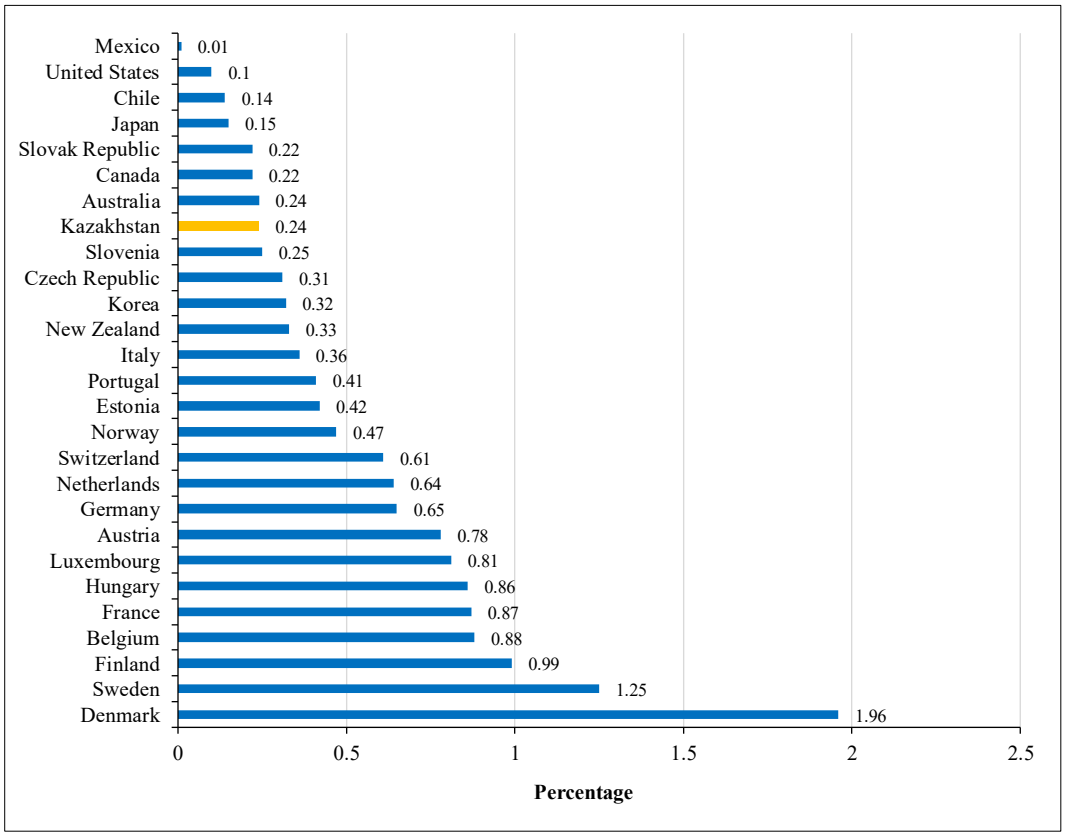

Figure 10. Public Expenditure on Human Capital Development as a Share of GDP: International Comparison [73]

When compared to worldwide standards, Kazakhstan's large percentage of low-skilled adults poses a significant human-capital hurdle to the successful development of smart cities. According to the findings, 75% of adults in urban regions and 84% of adults in rural Kazakhstan either lack basic computer skills or perform at Level 1 or lower when it comes to addressing problems in technologically advanced environments. According to these statistics, Kazakhstan is considerably behind digitally advanced smart city leaders like Finland (49%), Japan (48%), and Sweden (50%), and well

above the OECD average of 59% [73]. The prevalence of low digital competence indicates that residents have little ability to engage with e-governance platforms, digital mobility systems, and data-driven public services, even in metropolitan contexts—where smart city projects are usually concentrated [73].

This problem is made worse by the stark rural-urban divide, which raises questions about spatial inequality and unequal access to the advantages of smart cities. Kazakhstan's skills deficit highlights a structural shortcoming in digital literacy and applied ICT ability rather than just access to technology when compared to regional peers like Russia (61%) and the Slovak Republic (62%). In addition to limiting user acceptance and trust in smart city solutions, this skills gap also reduces the efficacy of co-creation and participatory urban governance models that depend on residents with digital empowerment. Therefore, rather than bringing about equitable, citizen-centric urban development, Kazakhstan's smart city projects run the risk of exacerbating already-existing socio-digital gaps in the absence of significant investment in adult education, digital upskilling, and inclusive ICT training, especially in rural areas.

A significant human-capital barrier to inclusive smart city development is highlighted by Figure 11, which shows that Kazakhstan especially in rural areas exhibits one of the highest proportions of adults with low digital problem-solving skills or no computer experience, significantly exceeding the OECD average and falling behind leading smart city economies.

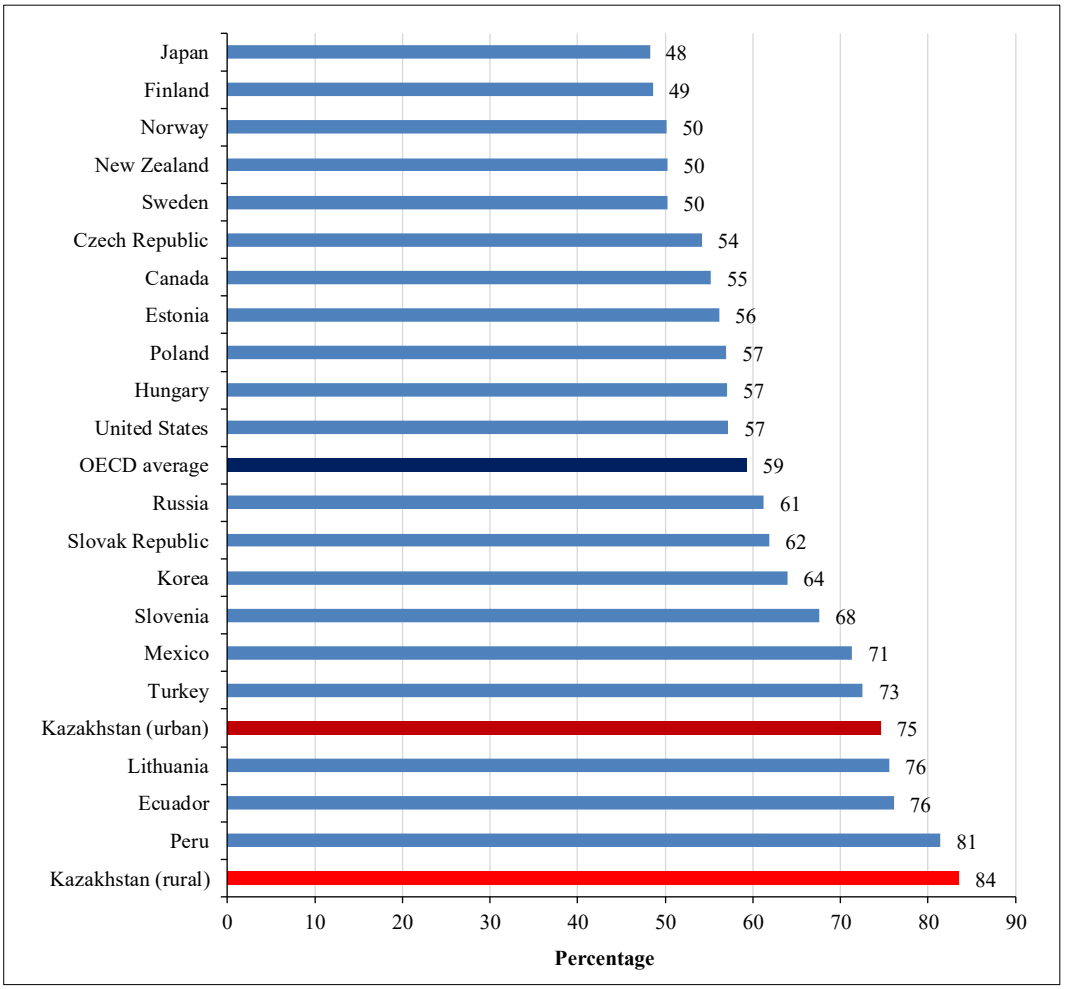

Figure 11. Proportion of Low-Skilled Adults in Technology-Rich Problem-Solving: International Comparison [73]

These findings demonstrate that smart city performance is strongly mediated by social readiness rather than technological availability alone. While Kazakhstan shows rapid growth in connectivity and smartphone penetration, the persistence of low digital literacy levels reveals a structural mismatch between infrastructure investment and citizen capability. This supports the argument in smart governance literature that human capital functions as a foundational layer of smart city ecosystems. Consequently, smart city initiatives risk reinforcing socio-digital inequalities unless project management frameworks explicitly integrate education, public engagement, and digital inclusion strategies as core project deliverables rather than secondary policy outcomes.

The results reinforce earlier OECD and UN studies emphasizing digital literacy as a critical enabler of smart city adoption. Similar digital skills gaps have been identified in several developing and transition economies;

however, Kazakhstan exhibits a stronger infrastructure base combined with weaker human capital investment. This divergence suggests that infrastructure-led smart city strategies may generate uneven outcomes unless accompanied by parallel investments in education and digital capability development, thereby extending existing smart city readiness models.

5.4. AI-Powered Digital Twin and Optimization of Urban Infrastructure in Astana's Smart City Project

Through a six-year, USD $190 million partnership with Presight, a world leader in big data analytics and applied artificial intelligence, the City of Astana has started a historic AI-powered smart city project. To further the city's larger digital transformation strategy, the agreement with the municipal administration (Akimat) seeks to digitize urban infrastructure, improve traffic management, and update public services.

The deployment of sensors and IoT-enabled infrastructure to create a real-time digital twin of Astana is a key component of the project. This digital duplicate will combine several data sources, such as sensor and visual data, into a single analytical platform. Predictive analytics, real-time situational awareness, and data-driven decision-making for urban operations from traffic flow optimization to emergency response coordination—are all made possible by such a system.

AI-driven video analytics platforms, sophisticated traffic management systems, and intelligent monitoring infrastructure are all part of Presight's function, which goes beyond the deployment of digital twins. The project aims to improve public safety outcomes, simplify travel, and lessen traffic by integrating current visual data sources into a digital twin architecture. The CEO of Presight claims that the technology would offer real-time information that enhance operational effectiveness and city operations.

Importantly, the program places a strong emphasis on creating value domestically; local Kazakhstani businesses are in charge of 60% of the project's scope, guaranteeing that workforce development and technology adoption stay integrated into the country's ecosystem. This is in line with policy objectives to boost the development of domestic knowledge and enhance job prospects in cutting-edge technology fields.

As demonstrated by the creation of cutting-edge AI infrastructure, such as a national supercomputer and AI command centers, which seek to improve municipal service delivery and urban governance, the smart city project supports larger national priorities in Kazakhstan's digital transformation. By connecting national capabilities in high-performance computing and applied intelligence with urban management, these investments demonstrate an integrated strategy to AI adoption.

Astana Presight smart city partnership shows how advanced analytics and AI-enabled digital twins can be used to optimize urban infrastructure, improve livability, and support resilient, sustainable city governance all the while developing local technological capacity and aligning with more general goals of digital policy. Kazakhstan's capital, Astana, is quickly establishing itself as one of the top smart cities in the world, standing tall alongside international leaders like Singapore, Dubai, Helsinki, Barcelona, and Seoul. Astana is making progress with a fully integrated AI-powered smart city ecosystem that integrates digital twins, extensive IoT deployment, and real-time AI analytics into a single platform, in contrast to many cities that have either embraced Internet of Things (IoT) systems or isolated digital models.

Centralized command centers and national-scale digital twins are hallmarks of globally recognized smart cities like Singapore and Dubai. Astana's citywide digital twin effort, which incorporates data from thousands of sensors and AI-enabled cameras, mirrors and in some cases rivals these accomplishments. Astana prioritizes holistic integration, which enables smooth coordination between traffic management, public safety, emergency response, and infrastructure monitoring, in contrast to cities where smart technologies are deployed in silos.

Astana's concept is notable for its real-time operational intelligence and predictive skills when compared to European smart cities that prioritize sustainability or urban design. Astana is at the forefront of next-generation urban administration thanks to AI-driven video analytics, situational awareness dashboards, and proactive emergency management. With robust public-private partnerships, significant investment, and a well-defined long-term vision, Astana is not only implementing global smart city standards but also establishing a new standard for AI-driven, data-centric urban transformation, demonstrating how emerging capitals can become global leaders.

A comparative overview of smart cities using AI-powered digital twin technologies and the Internet of Things (IoT) is shown in Table 2. It demonstrates how cutting-edge cities, like Astana, use these technologies for sophisticated urban governance and management.

Table 2. Comparative Table IoT & AI-Powered Digital Twins for Smart Cities

Smart City	AI-Powered Digital Twin	IoT Implementation	Primary Use Cases	Notable Features
Astana Smart City	Astana's Smart City project includes plans to create a digital twin of the city virtual model that uses real-time data from sensors and cameras to improve city operations, public safety, and traffic management.	The city is deploying sensors, connected cameras, traffic violation monitoring devices, and other IoT-enabled infrastructure as part of its Smart City rollout. These will feed data into AI systems for real-time analytics, traffic optimization, emergency response, and urban management.	Traffic and mobility optimization, AI-enabled public safety and surveillance, Real-time emergency response and city operations, Integrated IoT monitoring of transport and urban infrastructure.	City-wide AI-powered smart city platform with centralized command and control, Digital twin integrating real-time IoT, traffic, and surveillance data, Large-scale AI video analytics using tens of thousands of cameras, Predictive analytics for traffic, safety, and emergency management, Public–private partnership–driven smart city implementation [79].
Singapore (Virtual Singapore)	National-scale digital twin integrating real-time urban data, analytics & simulations.	Extensive IoT sensor networks for traffic, utilities, environment [80].	Urban planning, mobility optimization, infrastructure simulation	First national digital twin; used for planning, emergency simulation, smart grids [81].
Dubai, UAE	Dubai Live AI-powered city command hub using digital twin tech [82]	Smart management systems (waste, inspection, city ops) feed real-time data.	Real-time city governance and resource management.	Centralized AI platform integrates multiple city services [83].
Helsinki, Finland	3D digital twin (Helsinki 3D+) for planning & decision simulation [84].	IoT data used for energy and environmental monitoring.	Urban planning, energy efficiency, underground utility modeling.	Publicly accessible twins used by planners and researchers.
Rome, Italy	Leveraging digital twins with data & 5G for governance & resilience [85].	Smart city systems are supported by IoT & connectivity.	Governance, resilience, service improvements.	Award-winning smart city strategy using digital twins.
Varanasi (Kashi), India	Urban spatial 3D digital twin for planning & security [86].	Integrated with camera sensors & real-time feeds.	Infrastructure planning, crowd & traffic management.	First comprehensive digital twin in India for city planning.
Las Vegas, USA	City digital twin (expanding gradually) [87].	IoT integration across systems (traffic, buildings, utilities).	Mobility, emissions, water & noise management.	Digital twin expansion from downtown to city-wide.
Valencia, Spain	Digital twin for water network optimization [87].	Extensive IoT sensor use in network monitoring.	Water management, leak reduction, network efficiency.	~15,000 nodes provide real-time control & analytics [88].
Auckland, New Zealand	Digital twin for environmental & water quality insights [87].	IoT data from sensors & environmental monitors.	Environmental monitoring, public health insights.	Public digital twin for beach water quality prediction.
Ottawa / Canadian cities	GIS-based digital twin tools for planning [89].	IoT / GIS integration for water networks & asset management	Infrastructure planning, asset monitoring	Combines high-res data & digital models for decision-making.
Cary, North Carolina, USA	(No formal digital twin reported).	IoT implementations for traffic, lights & safety systems.	Traffic, safety, smart signals	Town-wide IoT sensors improve traffic, emergency access.
Seoul, South Korea	AI twin not explicitly cited [89].	Extensive IoT smart infrastructure (transport, services).	Mobility, connectivity, public services	AI used alongside IoT in smart city systems.
Barcelona, Spain	Digital twin not specified [90].	IoT sensor network for lighting, parking & services	Transportation, energy, data transparency	City OS uses open IoT data platform.

The comparison between pilot-based experimentation in Aqkol and large-scale deployments in Astana and Almaty reveals an evolutionary pathway of smart city development. Pilot cities function as innovation laboratories that reduce implementation risk and enable institutional learning before national scaling. This phased development model contributes empirical evidence supporting adaptive and iterative project management approaches in complex urban innovation environments.

Compared with global digital twin implementations in cities such as Helsinki and Valencia, Kazakhstan's initiatives remain in an early operational phase focused primarily on infrastructure optimization rather than predictive urban governance. While international cases emphasize open-data ecosystems and citizen-facing applications, Kazakhstan's approach currently prioritizes administrative efficiency and traffic management. This difference reflects varying stages of smart city maturity and highlights the importance of phased project management strategies in emerging digital ecosystems.

6. Conclusion

Overall, the findings both confirm and extend existing smart city research. While prior studies emphasize technology as the primary driver of smart urban transformation, the present study demonstrates that governance integration, stakeholder coordination, and human capital readiness play equally decisive roles in emerging economy contexts. The Kazakhstan case therefore contributes empirical evidence supporting a shift from technology-centric to management-centric smart city implementation models.

This study examined the role of project management approaches in advancing sustainable smart city development, with particular focus on Kazakhstan as an emerging economy undergoing rapid digital transformation. The findings demonstrate that successful smart city implementation depends on the coordinated integration of technological innovation, governance capacity, stakeholder collaboration, and sustainability objectives rather than technology adoption alone. The analysis of case studies from Aqkol, Astana, and Almaty reveals that digital government platforms provide an essential institutional foundation for smart city initiatives by enabling data-driven decision-making and improving

public service delivery. However, the results also indicate that technological readiness must be supported by adaptive project management practices capable of addressing organizational complexity, inter-agency coordination challenges, and evolving urban needs.

The study further identifies human capital development, stakeholder engagement, and institutional flexibility as critical determinants of project success. While Kazakhstan demonstrates significant progress in digital infrastructure and e-government performance, gaps remain in digital skills, participatory governance mechanisms, and integrated monitoring systems. These findings confirm existing smart city research emphasizing governance and social readiness while extending the literature by highlighting the central role of project management as a bridge between sustainability goals and digital transformation processes. The proposed framework contributes a structured model for aligning sustainability assessment principles with smart city implementation strategies tailored to emerging urban contexts.

From a practical perspective, the research provides policymakers, urban planners, and project managers with actionable insights for improving resilience, efficiency, and long-term sustainability in urban development projects. Future research should focus on quantitative validation of the proposed framework, cross-country comparative analysis, and the evaluation of long-term socio-economic impacts of smart city initiatives to further refine adaptive management approaches in rapidly evolving digital environments.

Collectively, the findings reposition project management as a strategic governance mechanism rather than a technical coordination tool within smart city development. The study demonstrates that sustainable smart cities emerge from the alignment of technological innovation, institutional capacity, stakeholder participation, and social readiness. This integrated perspective extends existing smart city research by empirically illustrating how project management frameworks can operationalize sustainability objectives in emerging economy contexts.

7. Declarations

7.1. Author Contributions

Conceptualization, A.G., Sh.S., and S.S.; methodology, A.G. and Sh.S.; software, A.G.; validation, A.G., Sh.S., and S.S.; formal analysis, Z.K., A.R., and Sh.S.; investigation, A.G.; resources, A.G.; data curation, A.G.; writing—original draft preparation, A.G. and Sh.S.; writing—review and editing, S.S.; visualization, A.G.; supervision, Z.K., A.R., Sh.S., and S.S.; project administration, Z.K., A.R., and Sh.S.; funding acquisition, Sh.S., Z.K., and A.R. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in the article.

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7.5. Institutional Review Board Statement

Not applicable.

7.6. Informed Consent Statement

Not applicable.

7.7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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