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Urban Tech And Smart Cities: A Study On Iot-Enabled Infrastructure And Its Impact On Urban Sustainability

Ar. Muhammad Zeeshan Zaheer
zeeshanzaheer@cuilahore.edu.pk
Assistant Professor, Department of Architecture & Interior Design, COMSATS University Islamabad, Lahore Campus, Member PCATP.

Farhana Naz
farhana.naz@lcwu.edu.pk
Assistant Professor, Interior Design Department, Lahore College for Women University Lahore.

Rimsha Imran
rimsha.imran@lcwu.edu.pk
Lecturer, Interior Design Department, Faculty of Arts and Social Sciences, Lahore College for Women University, Lahore, Pakistan.
Corresponding Author: * Ar. Muhammad Zeeshan Zaheer zeeshanzaheer@cuilahore.edu.pk

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ABSTRACT

This research explores the use of IoT-enabled infrastructure within the context of urban centers in Pakistan, measuring the implications such infrastructure has on urban sustainability. The research focused on the interest of the smart city technology available and the use of technology in transform municipal service, resource management and the quality of life in the urban cities in Pakistan. The research utilized a combination of qualitative and quantitative approaches, including surveys of 450 urban inhabitants, 35 municipal officer in-depth interviews, and the use of IoT sensors in the core cities of the Karachi, Lahore and Islamabad within the areas of transportation, water management and energy distribution systems. The results of resource efficiency were remarkable, with smart systems on integrated water management and wastage reduction of 23%; and intelligent traffic systems on management of time and reduction of time of average traffic by 18% in real time. The predominant challenges were limited technical human capital, poorly aligned and insufficient infrastructure investment, and apathetic behaviors towards provisions on data privacy and data protection. Even with the aforementioned challenges, the findings outlined evidence of urban sustainability and ranging improvements in energy use, pollution abatement, service, and smart city project implementation. The research proposes the minimum required smart city development in scope and sustain political will, public and private sector, and governance pan and partnerships. The provided research outlined the evidence based and recommended actions to urban planners and policy makers and offered the urban planners and policy makers the scope of IoT on urban development sustainability.

Keywords: *IoT-enabled infrastructure, urban centers, implications, infrastructure, sustainability, smart city technology, Pakistan.*

INTRODUCTION

The rapid pace of urbanization across the world has created significant challenges for city planners, policy makers, and local governments, especially for developing countries, where the growth of population is uneven to the growth of infrastructure (Aniekan, Peter et al. 2024). Pakistan, as one of the fastest developing countries in South-Asia, is under tremendous pressure to respond to the challenges of complex modern urban centers. Over 36% of the country's population lives in urban centers, and that is projected to become 50% by 2030, widening the challenges of resource allocation, service provision, and environmental sustainability. Rigid traditional urban infrastructure systems are easily strained and frustrated by the increasing demands of urban modernity. Needing flexibility and innovation, city planners use new technologies in the modular construction of smart cities. The new Internet of Things technologies fundamentally change the operating systems of cities for urban resource management and provision to people (Farooq 2024).

Redefining urban management, the Internet of Things presents new and unfiltered opportunities for the collection, analyses, and actionable steps concerning real-time data from urban areas embedded intelligent devices and sensors. This shift in technology in the management of urban areas changes the character of cities from the passive and unresponsive management of urban networks infrastructures to the active and intelligent adjustment of infrastructures in response to the real-time needs of urban areas. The management of waste and resources in cities will be optimally responsive to the needs of the urban residents while improving the quality of life. IoT-enables urban infrastructures possess the ability to enhance transportation, power, water, and waste management systems in a manner. The delivery of services in urban areas of Pakistan and their waste management systems direct the deficit of infrastructures, environmental resources, and unsophisticated problem environmental challenges (Ejiofor 2024).

IoT-enabled infrastructure has great potential, yet it has only been partially and unevenly adopted within Pakistan, with only pilot projects and initiatives which have not been fully integrated or systematically evaluated (Ugwoke, Abdulsalam et al. 2024). Karachi, Lahore and Islamabad have all started multiple initiatives under the smart city framework, but these 'coordinated' no- and low-cost initiatives run into streamlining problems and opposition from stakeholders mostly unfamiliar with the digital order. On top of all that, the almost total absence of pattern empirical work contextually assessing the impact of urban IoT on urban sustainability in Pakistan adds to the knowledge vacuum that undercuts evidence-based policy and smart investments. The implications of IoT-enabled infrastructure, in particular the challenges, need to be clearly laid out to facilitate the formulation of action-shaping policies to adjust and realign urban development in the country to meet the demands of sustainability (Mahmood 2025).

This study aims to provide an in-depth analysis of the deployment and effects of the Internet of Things (IoT) intelligence systems within the urban environment of three of the largest cities in Pakistan: Karachi, Lahore, and Islamabad. In particular, the study examines the real-world use of smart technologies in the transportation, water, and energy systems, and assesses their impact in shifting the pattern of resource use, service delivery, and the overall environmental effects. This study contributes to the literature by employing an integrated methodologies approach, which includes the quantitative dimensions of IoT urban smart system geo-fencing sensors, urban surveys, and qualitative analyses of city officials, to capture the impact and urban sustainability dimensions of smart urban technologies. This study does not only aim to capture the resource measurable benefits of IoT urban smart systems, but also the impediments of their extensive adoption, which include the technical, infrastructural, and governance gaps as well as the public concern of surveillance and data privacy. The study seeks to advance the understanding of better policies and more effective ways transforming urban centers of Pakistan into smart, environmentally, and economically sustainable cities, thereby improving the quality of life of urban dwellers, preserving natural ecosystems, and enhancing resource use efficiency.

Research Objectives

1. To evaluate how effective IoT-enabled infrastructure is on improving resource governance and operational efficiency within transportation, hydric distribution, and energy systems in Karachi, Lahore, and Islamabad.

2. To assess and evaluate the principal technical, economic, institutional, and sociocultural barriers for the broad adoption and integration of smart city innovations in the cities of Pakistan.
3. To assess how IoT-enabled infrastructure affects urban sustainability indicators such as energy and water use, pollution, and service delivery as experienced and reported by citizens and captured by sensors, and infrastructure on in-built urban sustainability.

Research Questions

1. In what ways do resource efficiency and sustainability measures shift in the sectors of transportation, water management, and energy distribution systems in urban centers of Pakistan, during and after the implementation of IoT-enabled infrastructure?
2. In the context of urban infrastructure of Pakistan, what are the main challenges and obstacles faced by local governments and stakeholders in the implementation and growth of smart city technology?
3. To what level do IoT-enabled smart city projects assist urban residents in the attainment of quality of life and service satisfaction, and also, do these projects produce sustainability and environmental results?

Significance of The Study

This research is meaningful to the diverse stakeholders involved in the urban development of Pakistan. To the policymakers and the government, this research is of high value in decision-making relative to smart city infrastructure, investments, and the technology order of interventions to maximize sustainability returns. For municipal managers, this research serves as an implementation guide, outlining possible challenges and lessons learned from the effective IoT infrastructure as deployments in resource-constrained settings. For urban planners, this research will outline how technology adoption tangibly influences their plans aimed at alleviating challenges around congestion, pollution, and resource scarcity. This study contributes to academia by addressing a significant gap in research on IoT use in developing countries, particularly South Asian cities. Moreover, it provides relevant market knowledge to tech developers and private industry stakeholders, helping them determine collaboration prospects for smart city solution development in Pakistan. In the end, the study serves the greatest public interest because it outlines ways to make cities in Pakistan more sustainable, effective, and attractive, helping to support the country's rapidly growing urban population while shielding the environment for future generations.

LITERATURE REVIEW

Progression of smart cities began with ideas and literature then resulted in practical advancements which utilizing digital tools to solve issues prevalent in cities. Initial ideas of smart cities focused mainly on built technologies and the connectivity of ICT. Over time the understanding of smart cities evolved and integrated cores of technology with sustainability and the governance framework with factors of social capital and quality of life (Singh, Solanki et al. 2022). Transformative technologies and frameworks cities need to adapt. The Smart connected cities revolutionized technology and the socio-economic impact of urban centers. The internet of Things (IoT) has become the foundational technology and urban digital ecosystems. The smart frameworks of cities are connected from the IoT 3 ecosystems. The perception layer of the devices collects real time urban data with sensors and actuators. The network layer distributes the data through different communication channels while the application layer of data analytics with strategic decisions takes place. This technology frameworks arms furnaces the ICS and controlled systems to monitor urban centers to make them efficient and responsive and predictive sustainability (Sarker 2022).

Smart traffic management systems can reduce congestion, enhance traffic flow, and minimize emissions in urban transportation. Consequently, the use of IoT technology in urban transportation systems reveals an enormous opportunity in assisting cities to reduce congestion, enhance traffic flow, and minimize emissions. Utilizing real time traffic data, adaptive traffic signal control systems in cities globally have reduced average travel time by 15 to 25 percent and considerably reduced fuel consumption and emissions (Bauer, Sanchez et al. 2021). Intelligent parking systems that assist users in locating unoccupied parking spots can reduce traffic volume caused by parking and lead to an overall 30% reduction in congestion and pollution. The public transport integration of IoT telecom technologies greatly improves service reliability and routine real time updates to passengers, thus reducing the dependence on private transport. The combination of various transport systems to improve accessibility enhanced user satisfaction and reduced the number of vehicle kilometers traveled. Enhanced user satisfaction stems from integrated mobility systems. Applied to the context of developing countries, however, such technologies face challenges in the urban infrastructure passing different coordination and investment obstacles. These challenges are indeed different from those of developed countries (Mylonas, Kalogeras et al. 2021).

A critical area in which sustainability benefits can be gained through IoT-enabled infrastructure is the management of water resources, particularly in water-stressed regions (such as Pakistan) (Ahsan 2023). Smart water management systems using sensor networks can identify distribution system leaks which, in the context of developing countries, can constitute 30-50% losses in water resources, thereby facilitating rapid repairs to conserve this valuable resource. Continuous monitoring of water quality enables swift responses to any events of water contamination. This public health protection capability reduces the risk of waterborne diseases. Demand-side management systems also cater to the consumers' need for detailed breakdowns of their water usage, while utilities can adopt effective real-time responsive pricing which conserves water during peak usage times (Ammara, Rasheed et al. 2022). Automated irrigation systems in urban green spaces reduce excess irrigation while improving the quality of the landscape by adapting water application to real-time soil moisture, weather, and plant needs. Research has shown that the implementation of comprehensive smart water management systems can lower water consumption by 15-30% and simultaneously improve the reliability of service and satisfaction of customers. Nevertheless, the systems' technical complexity, the need to deploy extensive networks of sensors, and the provision of appropriate data infrastructure are hurdles to implementation, especially in resource-poor urban areas (Shahzad, Javed et al. 2021).

The implementation of smart grid technologies in intelligent energy systems facilitates the integration of renewable energy sources and energy management at the consumer and utility levels (Aslam, Aslam et al. 2025). Utilities and consumers equipped with smart meters access real-time, detailed data about energy consumption in houses, which permits the identification of inefficiencies and targeting of energy-conserving interventions (Aslam, Aslam et al. 2025). Automatic fault detection and service restoration systems in smart grids reduce service interruption times, which enhances service reliability. Real-time automated systems for peak load management and control netting demand reduce or eliminate the need for costly investments in peak load generation and associated infrastructure. Research indicates that energy management technologies on smart grids can maximize their potential for energy efficiency and improve their overall operational efficiency by as much as 20%. These practices shift the reliance of renewable energy integration on smart grid technologies. Developing nations encounter challenges in the adoption of these technologies, such as large capital investments, inadequate human capital, utility regulations that are obsolete, and weaker frameworks for data and cyber protections (Aslam, Aslam et al. 2025).

Studies on smart city adoption in developing countries show a few common issues and challenges that give these contexts a different focus compared to developed countries. Limited funds allocate a narrower scope and scale to technology deployments, which often leads to piecemeal, fragmented pilot projects rather than comprehensive systemic implementations. Limited technical capacity affects not only sophisticated IoT infrastructure deployment but also ongoing operations and maintenance, generating a dependency on external expertise that threatens long-term sustainability. Weak institutional frameworks that fail to provide effective collaboration between siloed municipal departments and conflicting stakeholder silos, and poorly defined regulations create overlapping silos that obstruct integrated methodologies. Governance weaknesses in transparency, accountability, participation, and responsiveness to citizens lead to capturing smart city implementations by a few elites and the technology vendors rather than serving the public (Aghimien, Aigbavboa et al. 2022). IoT deployments rely on the predictability and availability of core infrastructure, such as power and telecommunication and digital networks. Weak legal and regulatory environments that poorly address privacy and data security create opportunities for coercive data collection, surveillance, and misuse (Jiang, Geertman et al. 2023).

Most available data on smart cities specifically in Pakistan is limited and concentrated on smart cities as conceptual data, policy studies, or small-scale pilot studies, which are not extensive and lack an empirical impact analysis on implementation. Cities in Pakistan have, as documented literature, initiated smart city projects, for example, intelligent transportation systems in Lahore, traffic management systems in Karachi, and solid waste management in Islamabad (Arshi, Khan et al. 2025). However, literature provides little evidence on the comprehensive impact and systematic evaluation on the implementation effectiveness and sustainability of the initiatives. Research on the development of smart cities in Pakistan has identified limited public investment and regulatory frameworks, inadequate human technical resources, and deficient stakeholder alignment as constraints. There has not been any comprehensive empirical accounted impact research on the implementation of smart systems that meets sustainability, which provides a significant gap in research for this study. This is important to understand for the development of evidence-based policies to navigate smart city development in Pakistan.

RESEARCH METHODOLOGY

The researchers adopted mixed-method research design to examine the impacts of Pakistan's IoT-enabled infrastructure on urban sustainability. The fieldwork was conducted in IoT-enabled infrastructure in the transportation, water management, and energy distribution systems of Pakistan's three largest cities: Karachi, Lahore, and Islamabad. To ensure representation of different socioeconomic status, age, and city zones, quantitative data was obtained using a structured survey of 450 urban residents who were selected by stratified random sampling. For the quantitative analysis of the system performance metrics, IoT sensor data was obtained from smart infrastructures that had been in place for six months and measured the parameters of traffic volume, water distribution, and energy consumption. For qualitative data analysis, 35 municipal officers (smart city planners, utility managers, tech administrators, and policy makers) involved in the management of the infrastructures were purposefully sampled and interviewed. The analysis utilized descriptive and inferential statistics to synthesize the quantitative data, and the qualitative data was coded using thematic analysis to surface common themes, issues, and viewpoints around challenges to sustainability, IoT use and impacts, and the integrated systems.

RESULTS AND ANALYSIS

Quantitative Analysis

Table 1: Demographic Profile Of Survey Respondents (n=450)

Characteristic	Category	Frequency	Percentage
City	Karachi	180	40.0%
	Lahore	165	36.7%
	Islamabad	105	23.3%

Age Group	18-30 years	162	36.0%
	31-45 years	189	42.0%
	46-60 years	81	18.0%
	Above 60 years	18	4.0%
Gender	Male	279	62.0%
	Female	171	38.0%
Education	Secondary or below	72	16.0%
	Undergraduate	207	46.0%
	Graduate/Postgraduate	171	38.0%
Occupation	Government employee	81	18.0%
	Private sector	189	42.0%
	Business owner	63	14.0%
	Student	72	16.0%
	Unemployed/Retired	45	10.0%

The demographic profile of survey respondents reveals a diverse sample representing various segments of urban populations across the three cities. Karachi contributed the largest proportion of respondents at 40%, reflecting its status as Pakistan's largest metropolis, followed by Lahore and Islamabad. The age distribution shows concentration in economically active groups, with 78% of respondents between 18-45 years, representing demographics most likely to interact with and benefit from smart city technologies. Gender representation shows male predominance at 62%, reflecting typical survey participation patterns in Pakistani urban contexts. Educational attainment indicates a relatively educated sample with 84% having at least undergraduate education, suggesting respondents possess adequate digital literacy to engage with and evaluate smart city services. Occupational diversity ensures perspectives from various employment sectors, though private sector employees constitute the largest group, followed by government employees and students.

Table 2: Awareness and Usage Of IoT-Enabled Services

Service Type	**Awareness (%)**	**Usage (%)**	**Satisfaction Level (Mean Score out of 5)**
Smart traffic management	68.4%	52.2%	3.6
Intelligent parking systems	54.7%	31.6%	3.4
Smart water metering	47.3%	28.4%	3.2
Energy consumption monitoring	61.8%	41.3%	3.5
Public transport tracking	72.0%	58.7%	3.8
Environmental monitoring	43.1%	19.1%	3.1
Online municipal services	76.9%	63.6%	3.7

Awareness and usage patterns of IoT-enabled services reveal significant variation across different smart city applications. Public transport tracking demonstrates the highest awareness at 72% and usage at 58.7%, reflecting its direct impact on daily commuting experiences and relatively mature implementation across cities. Online municipal services show highest awareness at 76.9% and strong usage at 63.6%, indicating successful digital transformation of administrative functions. Smart traffic management achieves substantial awareness at 68.4% with usage at 52.2%, though the gap suggests not all residents travel through areas with deployed systems. Energy consumption monitoring shows moderate awareness and usage, while smart water metering and environmental monitoring demonstrate lower engagement, possibly due to limited deployment or lack of consumer-facing interfaces. Satisfaction levels range from

3.1 to 3.8 out of 5, indicating generally positive but not exceptional user experiences, with public transport tracking receiving highest satisfaction scores.

Table 3: Impact Of Smart Transportation Systems

Metric	Before IoT Implementation	After IoT Implementation	Change (%)
Average travel time (minutes)	52.3	42.9	-18.0%
Traffic congestion index	7.8	6.4	-17.9%
Average vehicle speed (km/h)	24.5	31.2	+27.3%
Fuel consumption (liters/100km)	11.2	9.6	-14.3%
CO2 emissions (g/km)	198.4	169.7	-14.5%
Traffic violations reported	8,420	10,680	+26.8%
Accident rate (per 10,000 vehicles)	6.7	5.8	-13.4%

The impact of smart transportation systems demonstrates measurable improvements across multiple performance indicators following IoT implementation. Average travel time decreased by 18%, from 52.3 to 42.9 minutes, representing substantial time savings for commuters and increased productivity. Traffic congestion index improvement of 17.9% indicates better traffic flow management through adaptive signal control and real-time traffic monitoring. Average vehicle speeds increased by 27.3% from 24.5 to 31.2 km/h, reflecting reduced stop-and-go conditions and smoother traffic movement. Environmental benefits include 14.3% reduction in fuel consumption and 14.5% decrease in CO2 emissions, contributing to both economic savings and environmental sustainability. Interestingly, traffic violations reported increased by 26.8%, likely reflecting improved enforcement capabilities through automated monitoring rather than increased violation rates. The 13.4% reduction in accident rates demonstrates safety benefits from better traffic management and improved enforcement.

Table 4: Water Management System Performance

Parameter	Traditional System	IoT-Enabled System	Improvement (%)
Water loss rate (%)	31.7%	24.4%	-23.0%
Leak detection time (hours)	48.2	6.8	-85.9%
Repair response time (hours)	72.5	18.3	-74.8%
Water quality incidents	127	41	-67.7%
Consumer complaints (per month)	842	385	-54.3%
Billing accuracy (%)	76.4%	94.2%	+23.3%
Operational cost (PKR millions/month)	18.6	15.1	-18.8%

Water management system performance shows dramatic improvements following IoT implementation across multiple operational dimensions. Water loss rates decreased from 31.7% to 24.4%, representing a 23% reduction that translates into substantial water conservation and revenue recovery for utilities. Leak detection time improved remarkably from 48.2 hours to just 6.8 hours, an 85.9% reduction enabled by continuous sensor monitoring and automated alert systems. Repair response times similarly decreased by 74.8% from 72.5 to 18.3 hours, minimizing water waste and service disruptions. Water quality incidents dropped by 67.7% through real-time monitoring of contamination parameters and rapid intervention capabilities. Consumer complaints decreased by 54.3%, reflecting improved service reliability and responsiveness. Billing accuracy improved from 76.4% to 94.2% through automated meter reading, reducing disputes and improving revenue collection. Overall operational costs declined by 18.8%, demonstrating efficiency gains that help offset IoT infrastructure investments.

Table 5: Energy Distribution System Efficiency

Indicator	Pre-Implementation	Post-Implementation	Change (%)
System losses (%)	18.3%	14.7%	-19.7%
Power outage duration (hours/month)	12.4	7.8	-37.1%
Fault detection time (minutes)	82.5	18.2	-77.9%
Peak demand (MW)	2,847	2,634	-7.5%
Renewable energy integration (%)	8.2%	13.6%	+65.9%
Consumer satisfaction score	2.8/5	3.6/5	+28.6%
Revenue collection rate (%)	82.1%	91.4%	+11.3%

Energy distribution system efficiency demonstrates substantial improvements across reliability, efficiency, and sustainability metrics following IoT implementation. System losses decreased from 18.3% to 14.7%, a 19.7% reduction representing significant energy conservation and revenue recovery through better monitoring and theft detection. Power outage duration dropped by 37.1% from 12.4 to 7.8 hours per month, substantially improving service reliability through faster fault detection and automated response systems. Fault detection time improved dramatically by 77.9%, from 82.5 to 18.2 minutes, enabling rapid isolation and restoration of service. Peak demand management strategies enabled by real-time monitoring reduced peak loads by 7.5%, deferring expensive infrastructure expansion investments. Renewable energy integration increased by 65.9% from 8.2% to 13.6%, facilitated by smart grid capabilities that accommodate variable generation sources. Consumer satisfaction improved by 28.6%, reflecting better service quality and enhanced transparency through consumption monitoring tools. Revenue collection rates increased by 11.3% through improved billing accuracy and reduced theft.

Table 6: Perceived Benefits Of Smart City Technologies

Benefit Category	Mean Score (out of 5)	Standard Deviation
Improved service quality	3.8	0.92
Time savings	4.1	0.84
Cost savings	3.5	1.06
Environmental benefits	3.6	0.98
Enhanced convenience	4.0	0.87
Better information access	3.9	0.91
Increased safety	3.4	1.12
Government transparency	3.2	1.18

Resident perceptions of smart city technology benefits reveal time savings as the most highly valued attribute, scoring 4.1 out of 5, reflecting the direct personal impact of reduced commute times and improved service efficiency. Enhanced convenience follows closely at 4.0, indicating appreciation for digital services that reduce physical travel requirements and simplify interactions with municipal systems. Better information access scores 3.9, demonstrating value placed on real-time updates for transportation, utility services, and municipal information. Improved service quality receives strong recognition at 3.8, validating objective performance improvements. Environmental benefits score 3.6, showing awareness of sustainability contributions though perhaps less personal immediacy than time and convenience factors. Cost savings receive moderate recognition at 3.5, possibly reflecting limited direct cost reductions visible to consumers despite system-level efficiencies. Increased safety scores 3.4, while government transparency receives lowest scores at 3.2, suggesting this benefit may be less evident or require longer timeframes to materialize. Standard deviations indicate reasonable consensus on most benefits, with higher variation on transparency and safety perceptions.

Table 7: Challenges And Barriers To IoT Adoption

Challenge	Severity Rating (out of 5)	Rank
High implementation costs	4.3	1
Limited technical expertise	4.1	2
Inadequate infrastructure	3.9	3
Data privacy concerns	3.8	4
Insufficient policy framework	3.7	5
Poor inter-agency coordination	3.6	6
Cybersecurity risks	3.5	7
Resistance to change	3.3	8
Lack of citizen awareness	3.2	9

Barriers to IoT adoption assessment identifies high implementation costs as the most severe challenge, rated 4.3 out of 5, reflecting budget constraints facing Pakistani municipalities and the substantial capital requirements for comprehensive smart city infrastructure. Limited technical expertise ranks second at 4.1, highlighting human capacity deficits in designing, implementing, and maintaining sophisticated IoT systems. Inadequate existing infrastructure scores 3.9, indicating dependencies on reliable power, telecommunications, and digital connectivity that may be lacking in some areas. Data privacy concerns rate 3.8, demonstrating awareness of potential risks though perhaps less acute than cost and capacity barriers. Insufficient policy frameworks score 3.7, suggesting regulatory ambiguity creates implementation uncertainties. Poor inter-agency coordination at 3.6 reflects institutional fragmentation challenges. Cybersecurity risks score 3.5, indicating recognition of threats but possibly incomplete understanding of vulnerabilities. Resistance to change and lack of citizen awareness receive lower severity ratings at 3.3 and 3.2 respectively, suggesting these are perceived as less critical barriers compared to financial, technical, and institutional challenges.

Qualitative Analysis

Theme 1: Technical Capacity Constraints

Municipal officers noted technical capacity constraints, 3: 86 (4.7%) implementing and sustaining smart cities. Interviews indicated a lack of in-house expertise on IoT, data analytics, and systems integration, resulting in outsourcing reliance on consultants and technology vendors. There were concerns about knowledge sustainability when vendor support contracts end and about the feasibility of implementing the planned support. The generic nature of training was often seen as inadequate. The public sector's recruitment and retention of skilled personnel was described as "extremely difficult." The absence of a local technical ecosystem to support and innovate was noted as a reason dependency on foreign expertise (and the inability to localize the technology). There was a strong demand for advanced capacity building, smart city technology hubs, and university partnerships.

Theme 2: Financial Sustainability And Investment Challenges

All phases of smart city development, from the initial investment to the operational phases, are weighed down by financial constraints. Municipal officials report budget competing priorities, limited revenue bases, and fiscal constraints foremost on budget managers' mandates that all but constrain smart city investments, even when the advantages are acknowledged. The substantial initial investments needed to deploy IoT infrastructure create entry barriers, while investment payback periods and complicated business case development remains a concern. Operational and maintenance costs that project planners fail to recognize are budget busters and jeopardize the sustainability of the systems that have been put in place. The officials' complaints about the structuring of public-private partnerships that meet the public interest but also allow the private partner to obtain a payoff are not unprecedented. Other officials cited the absence of smart city funding mechanisms and the ad-hoc allocation of budgets across departments pointing to the need for legislative policies that permit underway sustained investments as priorities for fiscal policies.

Theme 3: Data Governance And Privacy Concerns

Data governance has proven to be a multi-faceted challenge with concern for the collection and protection of personally identifiable and sensitive information, the security and ownership of information, access rights and ethical use of data collected from IoT sensors. Most city officials noted the absence of adequate regulation of legal smart city data collection, storage, and use and, hence, the absence of clarity with respect to legally permissible practices and rights of citizens. While privacy concerns were acknowledged, and the potential consequences of systematic and protective privacy mechanisms were clearly articulated, their absence in practice led to inaction. The need for equilibrium between data openness for innovation and the transparency versus privacy protection and security was ill-defined, with vague or no articulation of data rights and commercialization. Cybersecurity risks were acknowledged, but complacence in their resolution stemmed from the absence of adequate resources and technical capabilities. The need for ethical smart city implementations through cross-border comprehensive security and privacy frameworks was evident. The civil governance challenge of innovation versus the close protection of sensitive data domination was also described.

Theme 4: Inter-Agency Coordination And Institutional Integration

Fragmentation and the lack coordination of municipal departments and government agencies developed into the most important barriers to the integrated development of smart cities. Officials described the organizational structures as sheathed with silos, with each department working independently to create and operate their own budgets, priorities, and technological frameworks which created barriers to more wholistic approaches. In smart city initiatives, transportation, utilities, and planning and IT departments coordinate which creating barriers to conflicts of priorities and bureaucratic complexities. The lack of smart city coordination frameworks or cabinet level chief technology officers that cut across departments limits their strategic integration. Interoperability barriers are created as systems are swallowed by integration when departments have different procurement cycles, technical standards and vendor preferences. Respondents have noted the existence of political shields where the autonomy of departments is defended and collaboration is perceived to erode institutional sovereignty. Several officials emphasized the achievements of institutional reforms to be the smart city structures and integrated planned mechanisms and the creation of other incentives to promote collaboration across departments. The challenge exists beyond the borders of municipalities, cooperating provincial and federal government agencies are also important.

Theme 5: Citizen Engagement And Digital Inclusion

Municipal officials pointed out that communication gaps and a lack of citizen input during planning processes have made engagement challenging but have also remained critical to success. They reported that explaining the benefits of smart city projects to citizens, getting the citizens' support to fund such projects, and getting citizens' contribution to the planning processes has proven challenging. Disparities in digital literacy and access to the internet also create risks of exclusion at the opposite end of the continuum, where technology benefits only the privileged, educated, and affluent, and where marginalized communities are digitally unconnected and unskilled. Accessibility in technology also poses challenges, as most of the digital user interfaces are only in English, and Urdu and regional language speakers are left with no access. Contrasting with the stated priorities of citizens, officials reported the black community engagement in project design as a reason for community disengagement in project ownership post implementation. Citizens' concerns of surveillance and unconsented monitoring by a government of intrusive technologies lack engagement through adequate transparency and dialogue and are reported as sources of disengagement.

Theme 6: Policy And Regulatory Framework Gaps

Developing and integrating smart cities into existing frameworks has been primarily viewed as a governance challenge. municipal governance administrators describe operating defunct regulatory frameworks and building smart municipal governance on archaic municipal infrastructures. Cognitive dissonance exists between public procurement frameworks developed for static traditional municipal infrastructures and those designed for dynamic digital service delivery. Infrastructure building codes and development governance frameworks smart city developers ignore building and construction smart city integrated building and construction codes. Utility frameworks designed on ancient monopoly utility infrastructures ignore innovative IoT provided utility services. Urban governance developers need developed frameworks for hierarchically integrated smart urban governance that vision, priorities, standards and governance implementation frameworks for smart city integrated designed and delivered public urban services and the dynamic integration of coordinated urban service stakeholders. frameworks for data controlled and governance innovation cyber secured and responsive service delivered and dynamic integrated infrastructures and services. Multiple urban service stakeholders provided integrated augmented frameworks showing the need for aligning rapid governance policies with the developed and dynamic integrated tools and services they modular provided urban service frameworks, demonstrating the need for a dynamic integrated modular smart urban integrated public service.

The evidence presented for this research indicates that the adoption of IoT-enabled infrastructures can provide considerable sustainability advantages in the Pakistani urban context while also indicating severe implementation issues that continue to be obstacles to the attainment of Smart City functionality. Quantitative results show evidence of improvements across resource and environmental efficiencies and the value of services provided. Specifically, the research demonstrated 23% reductions in water loss, 18% savings in time lost to traffic, and improvements in the efficiency of energy distribution to the extent that it became noteworthy. Not only are the results comparable to the research conducted elsewhere in the world that indicates the effectiveness of IoT technologies, but also the magnitude of the improvements speaks to the level of inefficiencies that historically characterized the Pakistani cities, thus indicating the potential of digital technologies in situations where old infrastructures are used and significant improvements are possible. The improvements in the utility of water supplied, and specifically the time to identify and respond to leaks, the fault in the supply system, and the management of water quality provide important evidence of the contribution real time monitoring and automating response systems can provide to bridging the utility management systems gaps.

While there are positive findings that suggest that smart city initiatives are moving forward on a technical level, qualitative analysis indicate that there are serious and sustained challenges at the level of implementation that directly impact the long-term viability and growth of smart city programs. The challenges related to technical constraints, inadequate finances, institutional silos, and policies identified by city managers point to structural issues that will require integrative frameworks at the level of implementation that go beyond the scope of single initiatives. The gap between the effective performance of systems and low adoption rates in many service areas points to the reality that performance alone will not lead to smart city success. There needs to be parallel attention to building implementation capacity, reforming institutions, developing governance structures, and engaging in civic collaboration. The low scores on citizen satisfaction, in contrast to the performance improvements, suggest that there are unmet expectations that need to be addressed on the user interface, communication, and the ease of accessing the service. Emerging issues relevant to public confidence, such as privacy and security of personal data, will need to be addressed before they become serious impediments as more data are collected to monitor smart city developments.

The implications of these research findings for developing ‘smart cities’ in Pakistan and other developing countries are notable. The successful implementation of focused initiatives within the transportation, water, and energy sectors proves the effectiveness of targeted, sector-specific approaches that yield measurable benefits while building experience and capacity over time. Nonetheless, the identified challenges of coordination and issues of interoperability suggest that integrated planning and combined technical frameworks are essential even in sector-focused efforts. The concerns over the financial viability of these projects indicate the necessity of innovative financing approaches, value-driven phased implementation that sustain further investment, and comprehensive life-cycle cost assessments that include operational and maintenance expenses for the post-deployment period. The focus on building local capacity and the transfer of knowledge by municipal actors insists that efforts to acquire new technology must include equally purposeful initiatives to build local capability, diminish vendor lock-in, and develop viable self-sustaining technical ecosystems.

CONCLUSION

This research has shown the challenges and potential advantages that IoT-enabled infrastructure can offer for urban sustainability in different cities in Pakistan. For the quantitative results, the smart city technologies developed in Pakistan can improve resource efficiency, and environmental and service value for smart cities. They show marked decreases in water loss, traffic congestion, energy waste, and operational costs. These results support the technical feasibility of the IoT solutions for the urban sustainability challenges of the rapidly urbanizing population of Pakistan. The research also attests that unsustainable urban growth and development challenges improve significantly with the effective application of smart city technologies on various elements for urban sustainability in cities, enhancing residents’ environmental quality of life and urban economic efficiency.

Contrary to the expectations of the study, potential civil service improvements will require additional investments in technical and financial resources, as well as in coordination and governance. Procurement strategies alone are insufficient to advance work in smart cities, as preparation and adaptive capacity in the public sector are equally necessary. Stakeholder expectations and adaptive capacity influence the development of smart public services, with policy, financing, and engagement structures all needing radical reform to bring control over the data spiral. The observed objective improvements technically perform augmented citizen dissatisfaction levels only suggest that additional resources need to over perform in engagement, communication, and accessibility.

The findings of this study can help build evidence-based policies to help plan urban development in Pakistan. This study documents the actual implementation of the planned initiatives in the three focus cities, measuring the actual sustainability impacts, and recording challenges, which moves the work toward actionable insights on implementation challenges and suggests how they can be addressed. It appears that the development of smart cities in Pakistan should focus on targeted and strategically phased implementations that concentrate on the primary impact areas and the simultaneous development of relevant capabilities, institutions, and governance to sustain the initiatives. In the context of improved urban governance and sustained investment in the development of enabling infrastructure, IoT-enabled urban infrastructure will transform urban areas and the lives of urban residents.

RECOMMENDATIONS

From the findings of the research, the proposals outlined appear to be the most important for smart city stakeholders, policymakers, and city leaders. To fill the gaps with city smart funding and financing constructs, city authorities can develop anchor financing mechanisms and explore constructs such as public-private partnerships, green bonds, and contracts with outcome-based financing. Local smart city academic partnerships, with technology providers and international organizations, should develop comprehensive capacity building to foster sustainable local expertise with IoT, analytics, and smart city management. To achieve coordinated city development, a national smart city policy outlining a vision and standards for data governance, privacy, protection, and cybersecurity needs should be established. To integrate planning, procurement, and silo departmental implementation, city authorities should establish smart city inter-departmental coordination bodies with the necessary powers and resource allocation. To gain evidence to support the next level of funding, the implementation of multi-phased strategies should start with projects that have a high tangible value and use stakeholder generated evidence for planning and support. For public support, trust and transparency, diverse community perspectives should be integrated, communicated and explained in planning and even implementation cycles. Digital exclusion must be addressed within the engagement processes. In closing, there is a need to put in place structured frameworks to monitor and evaluate the impacts of sustainability, which will assist in documenting lessons for the future and enabling modification of approaches as smart city projects progress and develop based on empirical evidence.

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