Eco Cities (2023) Volume 4 Issue 2
doi: 10.54517/ec.v4i2.2674

ORIGINAL RESEARCH ARTICLE

Analysing the drivers of smart city implementation using DEMATEL method

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ABSTRACT

Indian cities are becoming more and more populated, and the technological, environmental, social, political, and economic infrastructure of those cities is deteriorating, necessitating the development of more innovative methods to enhance public utilities and services. The growth of smart cities encourages the creation of a stable, networked, and sustainable metropolitan structure. The "100 Smart Cities Mission" was started by the Indian government to encourage planned development. However, there is also a literature of criticisms of the indicators used by the smart city mission. A thorough investigation is necessary to identify the critical infrastructure, important resources, and development patterns for smart city planning. The purpose of my study is to achieve and move towards Smart City Mission goals in a holistic framework. This research paper proposes a weighted criteria to assess the eligibility factors identified from the literature studies of the Smart City Mission, to analyze the complex relationships among the indicators, to develop a holistic approach, and to classify factors based on the drivers of dependence and implementation. The findings of this study shed light on the key drivers and barriers to the implementation of smart city initiatives. The DEMATEL method provided a valuable tool for analyzing the complex interrelationships between different factors and identifying the most influential drivers. The results can guide policymakers, city managers, and other stakeholders in developing more effective strategies for smart city implementation. However, the study also highlights the need for further research to explore the context-specific factors that may affect the drivers of smart city implementation in different regions and cities. Overall, this study contributes to the growing body of literature on smart cities and provides practical insights for decision-makers seeking to promote sustainable and inclusive urban development.

Keywords: smart cities; urban development; DEMATEL method; infrastructure; criticisms; weighted criteria; implementation drivers

1. Introduction

Since the mid-20th century, global urbanization has surged, particularly in Asia, where the urban population has quadrupled[1,2]. India is expected to play a significant role in this urban expansion, with its population skyrocketing and a shift towards manufacturing and services. Recognizing the challenges posed by rapid urbanization, the Indian government introduced the Smart Cities initiative in 2014. A smart city utilizes

ARTICLE INFO
Received: 13 September 2023 | Accepted: 17 November 2023 | Available online: 25 November 2023

CITATION
Gohil KS, Srivastava S. Analysing the drivers of smart city implementation using DEMATEL method. *Eco Cities* 2023; 4(2): 2674. doi: 10.54517/ec.v4i2.2674

Information and Communication Technologies (ICT) to address urbanization issues and promote sustainable development.

The primary goals of this study are threefold: first, to identify the success indicators critical for the development of smart cities; second, to subclassify these indicators for a more nuanced understanding; and third, to develop a comprehensive and holistic framework aimed at achieving the goals set forth by the Smart City Mission[2]. The study investigates several aspects of smart city development, with a focus on crucial indicators. In terms of technological impact, the study emphasizes the importance of using electronic devices and sensors to improve monitoring, planning, and governance, as well as the necessity for cybersecurity measures and inclusive practices[3].

Environmental effect considerations focused on fostering cleaner air through initiatives such as carpooling, electric automobiles, and pedestrian-friendly infrastructure, with a focus on long-term sustainability investments[4]. Economic consequences are investigated in terms of attracting investments, promoting economic growth through improved IT infrastructure, and implementing varied development strategies[5]. The importance of technology in improving social progress is analysed, as is the contribution of infrastructure to social and economic well-being. Finally, political influence is explored in terms of fostering proactive ethical behavior, adaptable standards, and collaboration for coordinated action in city planning and management[3].

Smart city goal

Strives to balance technological development with economic, social, and ecological concerns. Prioritizes harmonious coexistence with the environment, technological advancements, and social growth. Success depends on a robust partnership between the public and private sectors to develop initiatives, employ smart technology, and manage resources collaboratively[3].

A successful smart city offers a high quality of life for citizens while fostering economic development through connected services and optimized infrastructure. The collaborative effort between residents and local authorities is crucial for the sustainable growth of smart cities[1,3].

2. Literature review

The surge in global interest in the development of smart cities has prompted governments worldwide, including India, to prioritize technology and innovation for enhancing urban living conditions. In India, the Smart City concept has been a focal point, aiming to leverage technology to improve citizens' quality of life and enhance urban infrastructure. Despite these ambitions, the implementation of smart city projects in India has encountered challenges, necessitating a closer examination for sustainable and inclusive development.

2.1. Research focus

The literature review delves into the current state of research on smart city implementation, emphasizing the drivers influencing successful initiatives. Key factors highlighted include governance, technology, finance, and citizen engagement, all crucial for shaping smart city projects. A comprehensive understanding of these drivers, analysed using the DEMATEL method, is aimed at providing insights to inform decision-making by policymakers and city managers and address potential challenges.

2.2. Technological integration

The literature underscores the integral role of technology in smart city success, advocating for the incorporation of IoT, big data, and AI. Efficient urban infrastructure management, heightened citizen participation, and overall quality of life improvement are envisioned through the strategic integration of these

technologies. The literature emphasizes a collaborative and participatory approach involving citizens, policymakers, and stakeholders to co-create smart city solutions.

2.3. Review of selected studies

Several studies contribute to the understanding of smart city implementation dynamics. Roy[3] stresses sustainable and inclusive development, pinpointing challenges such as inadequate infrastructure and limited citizen participation. Suresh and Ramachandran[6] provide a comprehensive overview, emphasizing governance, finance, and infrastructure while acknowledging the need for policy effectiveness and stakeholder involvement.

Eremia et al.[7] highlight citizen engagement and participation in smart city projects but fall short in analysing policy and governance frameworks. Aggarwal and Solomon[8] conduct a quantitative analysis, suggesting technology-driven project management tools to enhance citizen participation. Razmjoo et al.[9] identify barriers and propose policies, emphasizing citizen participation and addressing ethical concerns.

The concept of smart cities has emerged as a focal point for urban development, aiming to leverage technological advancements to enhance the economic prosperity of societies. As noted by Dhere and Bendale[10], technological progress has historically shaped social relations, influencing institutions, customs, and organizational structures within societies. With the advent of smart city initiatives, the focus has shifted towards integrating information and communication technology (ICT) into various aspects of urban life, including infrastructure, governance, and public services. However, while smart city projects aim to improve the material environment and economic growth, their impact on social relations remains a subject of debate[10].

Initially rooted in the integration of ICT and digital technologies, smart cities have evolved to encompass broader dimensions, including citizen participation and complex governance structures involving various stakeholders. However, the proliferation of smart city initiatives has led to challenges, including inflated expectations, inadequate strategic planning, and overinvestment in projects with limited results. Moreover, the dominance of technological discourse, driven by corporate entities, has overshadowed other critical aspects such as policy innovation, leadership, and citizen engagement, which are fundamental to the success of smart city endeavours[11].

In the realm of smart city economics, the discourse is characterized by a neoliberal perspective, viewing urban challenges as opportunities for corporate investment and profit generation. Estimates project a substantial increase in the global market size of smart cities, highlighting the commercialization of urban spaces and the involvement of multinational corporations. However, critical issues such as data selection, market competition, and the impact on local economies remain unresolved. Moreover, the financing and business models of smart city projects often face constraints, leading to project stagnation or unsustainable outcomes. Addressing these challenges necessitates a holistic approach that goes beyond traditional infrastructure models to embrace innovative, inclusive, and sustainable financial frameworks, coupled with effective governance mechanisms that prioritize citizen participation and well-being[11].

Pricope[12] explores the imperative of smart city development amidst contemporary economic, pandemic, and geopolitical challenges, emphasizing its role in addressing multifaceted urban issues and enhancing quality of life. Through literature meta-analysis, comparative-critical analysis of indicators, and cluster analysis, the study aims to furnish decision-makers with a practical framework for implementing effective urban management strategies aligned with sustainability and citizen well-being. The research underscores the susceptibility of urban development to disparities exacerbated by economic, social, political, and military pressures, emphasizing the need for cohesive approaches to mitigate vulnerabilities[12].

The findings highlight the pivotal role of economic development in shaping urban dynamics and resilience, underscoring the intricate interplay between economic factors and urban sustainability. By elucidating the influence of broader socio-economic contexts on urban disparities, the study underscores the significance of holistic approaches in fostering resilient urban ecosystems. Furthermore, the research underscores the pressing need for supranational, national, and local decision-makers to adopt coordinated measures that prioritize balanced development, environmental stewardship, and community well-being in the face of evolving global challenges[12].

2.4. Recent trends and case studies

Recent studies, such as Chandran et al.[13] proposing an integrated urban water resources management framework for Coimbatore, and Murphy[14] emphasizing tailored strategies for developing countries, contribute valuable insights into smart city challenges and opportunities. Dwivedi and Gomes[15] review the Smart Cities Mission in India, recognizing achievements but identifying challenges such as insufficient funding and emphasizing effective governance and citizen participation.

2.5. Emerging technologies

Studies like Rani and Kumar[16] highlight the importance of actuators in smart city frameworks, stressing the need for more comprehensive research in this area. Beniwal et al.[17] cost analysis of a smart photovoltaic system underscores its financial feasibility for sustainable development.

2.6. Challenges and opportunities

Hoque and Prakash[18] provide an overview of the Smart City Mission in India, recognizing challenges like inadequate funding and limited citizen participation. Despite acknowledging its transformative potential, they stress the need for sustained efforts and innovative approaches.

2.7. Research gaps

The literature review reveals certain research gaps, including the need for more studies exploring stakeholder perspectives, evaluating long-term impacts, and addressing the social, economic, and political dimensions of smart city development.

In conclusion, the literature review presents a comprehensive overview of smart city research, highlighting key drivers, challenges, and emerging trends. The identified gaps pave the way for the proposed study to contribute nuanced insights into the drivers of smart city implementation, offering valuable guidance for policymakers and urban planners.

After completing a thorough literature review, a list of indicators was chosen, which were further subclassified into criteria that were most important for the study. The criteria's determination and the framework used in the study are explained in the next chapter.

3. Research framework of the study

The proposed research framework aims to analyze the drivers of smart city implementation using the DEMATEL method. The study will consist of two main phases. The first phase will involve identifying the indicators through a comprehensive literature review and their impact on the development of smart cities. The broad indicators identified for the study are:

1) Technological impact;
2) Environmental impact;
3) Economic impact;

4) Social impact;
5) Political impact.

These indicators will be further narrowed down to nine criteria, including (**Table 1**):

Table 1. Indicators of smart city development.

	Criteria's	References
C1	Inadequate Infrastructure—A key challenge for smart city development, as it can hinder the deployment of necessary technology and services.	Venter[19], Moayedi and Mokhtar[20]
C2	Limited Financial Resources—A significant barrier to achieving smart city goals, as adequate funding is essential to support the development and implementation of smart technologies.	Nam and Pardo[21], Giffinger et al.[22]
C3	Digital Divide—A critical issue that must be addressed to ensure equitable access to smart city infrastructure and services.	Kourtit et al.[23], Zhong et al.[24]
C4	Lack of Citizen Participation—An obstacle to realizing the full potential of smart cities, as active citizen engagement is essential for the success of smart city initiatives.	Caragliu et al.[25], Anthopoulos and Fitsilis[26]
C5	Data Privacy Concerns—An important consideration for smart city development, as it is necessary to protect the privacy and security of citizens' data and personal information.	Alawadhi and Al-Khalifa[27], Kshetri[28]
C6	Lack of Skilled Workforce—A challenge that must be addressed to ensure the successful implementation and maintenance of smart city technologies and services.	Komninos[29], Lee et al.[30]
C7	Integration of Disparate Technologies—A key factor in achieving the seamless functioning of smart city systems, as different technologies must be integrated to work together effectively.	Ficco et al.[31], Lee et al.[32]
C8	Inadequate Policy Governance—A critical issue that must be addressed to ensure effective governance and regulation of smart city initiatives.	Caragliu et al.[25], Huguenin-Virchaux and Meijer[33]
C9	Lack of Environmental Sustainability—An important consideration for smart city development, as it is necessary to ensure that smart city initiatives are sustainable and do not have a negative impact on the environment.	Deakin and Reid[34], Hollands[35]

The study gathers a survey of 4 subject-matter experts, wherein, they were asked to give a value to each challenge/criterion to denote the relationship between them by using a comparison scale of 0 to 4, with: The responses are represented in **Tables 1–5**.

1) Being "no influence"
2) Being "low influence"
3) Being "medium influence"
4) Being "high influence"
5) Being "very high influence"

Respondent 1:

Table 2. Response/data from respondent 1.

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
C1	NA	-	-	4	-	3	-	4	-	1	-	2	-	2	-	3	-	2
C2	-	3	NA	-	-	3	-	2	-	3	-	2	-	1	-	1	-	2
C3	-	2	-	3	NA	-	-	1	-	3	-	3	-	2	-	1	-	1
C4	-	3	-	3	-	3	NA	-	-	4	-	3	-	3	-	2	-	2
C5	-	2	-	1	-	1	-	2	NA	-	-	2	-	1	-	2	-	1
C6	-	4	-	3	-	3	-	4	-	2	NA	-	-	2	-	4	-	2
C7	-	2	-	1	-	2	-	3	-	2	-	3	NA	-	-	2	-	2

Table 2. (*Continued*).

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
C8	-	4	-	2	-	3	-	4	-	1	-	3	-	2	NA	-	-	3
C9	-	4	-	3	-	3	-	2	-	2	-	2	-	3	-	3	NA	-

Respondent 2:

Table 3. Response/data from respondent 2.

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
C1	NA	-	-	4	-	3	-	4	-	1	-	2	-	2	-	3	-	2
C2	-	3	NA	-	-	3	-	2	-	3	-	2	-	1	-	1	-	2
C3	-	2	-	3	NA	-	-	1	-	3	-	3	-	2	-	1	-	1
C4	-	3	-	4	-	3	NA	-	-	4	-	3	-	3	-	2	-	2
C5	-	2	-	1	-	1	-	2	NA	-	-	2	-	1	-	2	-	1
C6	-	4	-	3	-	3	-	4	-	2	NA	-	-	2	-	4	-	2
C7	-	2	-	1	-	2	-	3	-	2	-	3	NA	-	-	2	-	2
C8	-	4	-	2	-	3	-	4	-	1	-	3	-	2	NA	-	-	3
C9	-	4	-	3	-	3	-	2	-	2	-	2	-	3	-	3	NA	-

Respondent 3:

Table 4. Response/data from respondent 3.

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
C1	NA	-	-	3	-	3	-	4	-	2	-	2	-	1	-	4	-	2
C2	-	3	NA	-	-	4	-	2	-	3	-	3	-	1	-	2	-	2
C3	-	2	-	3	NA	-	-	1	-	4	-	4	-	2	-	1	-	0
C4	-	4	-	3	-	3	NA	-	-	3	-	3	-	4	-	2	-	2
C5	-	2	-	1	-	2	-	1	NA	-	-	2	-	2	-	1	-	0
C6	-	4	-	4	-	4	-	4	-	2	NA	-	-	2	-	3	-	1
C7	-	2	-	1	-	2	-	4	-	2	-	4	NA	-	-	2	-	2
C8	-	3	-	2	-	4	-	4	-	0	-	4	-	2	NA	-	-	3
C9	-	4	-	4	-	4	-	2	-	2	-	2	-	4	-	3	NA	-

Respondent 4:

Table 5. Response/data from respondent 4.

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
C1	NA	-	-	4	-	3	-	4	-	1	-	2	-	2	-	3	-	2
C2	-	3	NA	-	-	3	-	2	-	3	-	2	-	1	-	1	-	2
C3	-	2	-	3	NA	-	-	1	-	3	-	3	-	2	-	1	-	1
C4	-	3	-	3	-	3	NA	-	-	4	-	3	-	3	-	2	-	2
C5	-	2	-	1	-	1	-	2	NA	-	-	2	-	1	-	2	-	1
C6	-	4	-	3	-	3	-	4	-	2	NA	-	-	2	-	4	-	2
C7	-	2	-	1	-	2	-	3	-	2	-	3	NA	-	-	2	-	2

Table 5. (*Continued*).

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
C8	-	4	-	2	-	3	-	4	-	1	-	3	-	2	NA	-	-	3
C9	-	4	-	3	-	3	-	2	-	2	-	2	-	3	-	3	NA	-

After collecting the responses from the experts, an average matrix was created of all the respondents to move on to the second phase of the study.

In the second phase of the study, the DEMATEL method will be used to determine the cause-and-effect relationship between the nine identified criteria. The DEMATEL method is a widely used multi-criteria decision-making tool that can effectively analyze complex systems by modelling the interrelationships between various criteria. The method involves several steps, including:

1) constructing the initial direct-relation matrix;
2) calculating the total relation matrix;
3) calculating the reachability matrix;
4) calculating the impact matrix;
5) calculating the influence matrix;
6) identifying the cause-and-effect relationship between the criteria.

By applying the DEMATEL method to the identified criteria, the study will provide a comprehensive understanding of the drivers of smart city implementation and their interrelationships, which can guide policymakers and city planners in developing effective strategies for the development of smart cities.

4. Research methodology

Analysing the challenges for implementing the success indicators/measures for development using the DEMATEL (decision-making trial and evaluation laboratory) method. It includes a mixed approach to quantitative and qualitative data analysis. After determining the success indicators mentioned above in the literature review, the exploration was further subdivided, which identified a total of nine challenges involved in the hinderance of achieving the goals of smart city development.

The study uses the DEMATEL method, which solves complicated intertwined problem groups and includes a visual representation of the impact-relations map for the identification of the cause-and-effect chain components. A brief description of the method is provided in the sub-section that follows.

Decision-making trial and evaluation laboratory

The DEMATEL Method uses a multi-criteria procedure to determine the results. A multi-criteria method in data analysis is a technique used to evaluate and prioritize alternatives based on several criteria or factors. It is commonly used in decision-making processes where there are multiple options to choose from, and each option has several attributes or characteristics that need to be considered.

The basic idea behind a multi-criteria method is to use a mathematical model to combine different criteria in a way that provides a single score for each alternative. The score can then be used to rank the alternatives and make a decision.

Some common multi-criteria methods include Analytic Hierarchy Process (AHP), the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS), and Simple Additive Weighting (SAW).

Multi-criteria methods are useful because they allow decision-makers to take into account multiple factors and weigh them according to their relative importance. This can lead to more informed decisions that are based

on a more comprehensive analysis of the available information. In addition, multi-criteria methods can help reduce bias and subjectivity in decision-making by providing a systematic and objective approach to evaluating alternatives.

The DEMATEL method is a widely used tool in decision-making and problem-solving processes that aims to identify the causal relationships between factors affecting a particular issue. It is a structural analysis approach that enables decision-makers to evaluate complex problems by understanding the interdependence and interaction among various factors.

The method involves constructing a direct-relation matrix and an inverse-relation matrix based on the opinions of experts or stakeholders. The direct-relation matrix illustrates the degree to which each factor directly influences or depends on other factors, while the inverse-relation matrix represents the degree to which each factor is directly influenced or dependent on other factors.

By calculating the average values for each cell in both matrices, it is possible to determine the causal relationships between the factors. Once the causal relationships are established, the method can be used to identify the critical factors and develop effective strategies to address the issue. The DEMATEL technique consists of several mathematical steps explained below:

Step 1: The DEMATEL technique uses a scale from 0 to 4, with 0 denoting no influence and 4 denoting high influence, and experts are asked to assess the correlations between the n criteria**,** a (i, j = 1, ..., n). The average of these experts' opinions is calculated using Equation (1):

$$A = [a_{ij}] = \frac{1}{p}\sum_{K=1}^{p} x_{ij}^{k} \qquad i, j = 1, \dots n \tag{1}$$

where p is no. of experts (no. of experts were four).

Step 2: The matrix normalization is obtained applying Equations (2) and (3),

$$D = m \times A \tag{2}$$

where:

$$m = \min\left(\frac{1}{max_i(\sum_{i=1}^{n} a_{ij})}, \frac{1}{max_j(\sum_{j=1}^{n} a_{ij})}\right) \qquad i, j = 1, \dots n \tag{3}$$

After Equating, the average matrix was created of all the respondents to further determine the Normalized Initial Direct-relation matrix.

Normalized initial direct-relation matrix obtained:

Step 3: Calculate the total relation matrix. Equations (4) and (5) can be utilized for this:

Step 4: Computation of total relation matrix "T":

The total relation matrix $T = [t_{ij}]_{n \times n}$ is determined by summing the direct effects and indirect effects using equation

$$T = B(I - B)^{-1} \tag{4}$$

where I, is the Identity Matrix.

Step 5: Calculation of the prominence and relation values:

$$R = \sum_{j=1}^{n} t_{ij} \text{ for all } i \tag{5}$$

$$C = \sum_{i=1}^{n} t_{ij} \text{ for all } j \tag{6}$$

Total relation matrix was obtained:

After determining the Total Relation Matrix, $Ri + Ci$ and $Ri - Ci$ were calculated, taking out the average of all the criteria's, which further determines the degree of influence. (+) indicates these criteria influence other criteria—the cause group; (−) indicates these criteria are influenced by other criteria—the effect group.

$Ri + Ci$ reveals how much importance the variables hold, denotes the degree of criteria with other criteria, and $Ri - Ci$ reveals the kind of relation with criteria.

A cause-and-effect relationship is a relationship between two or more variables where changes in one variable (the cause) can directly or indirectly influence changes in another variable (the effect).

In the context of the DEMATEL method, cause-and-effect relationships are used to identify the key drivers and barriers that impact the performance of the system being studied.

By identifying cause-and-effect relationships, the DEMATEL method can help decision-makers better understand the underlying dynamics of the system and make more informed decisions. This is because cause-and-effect relationships provide insights into how different elements of the system are interconnected and how changes in one element can impact the performance of the system as a whole.

By understanding this relationship, decision-makers can take steps to improve the quality of raw materials, which can lead to improvements in the quality of the final product.

Overall, the DEMATEL method is a useful tool for analysing complex systems and identifying cause-and-effect relationships. By understanding these relationships, decision-makers can make more informed decisions and improve the performance of the system being studied.

5. Discussion and results

5.1. Discussions

In **Table 6**, the row and column headers represent the criteria, while the numbers represent the strength of influence that one criterion has on another criterion. For example, in the first row, the value of 3.75 in the column for C2 (limited financial resources) indicates that C2 has a strong influence on C1 (inadequate infrastructure). The value of 2 in the column for C3 (Digital Divide) indicates that C3 has a moderate influence on C1.

Table 6. Average matrix.

	C1		**C2**		**C3**		**C4**		**C5**		**C6**		**C7**		**C8**		**C9**	
C1	0	3.75	3	4	1.25	2	1.75	3.25	2	0	3.75	3	4	1.25	2	1.75	3.25	2
C2	3	0	3.25	2	3	2.25	1	1.25	2	3	0	3.25	2	3	2.25	1	1.25	2
C3	2	3	0	1	3.25	3.25	2	1	0.75	2	3	0	1	3.25	3.25	2	1	0.75
C4	3.25	3	3	0	3.75	3	3.25	2	2	3.25	3	3	0	3.75	3	3.25	2	2
C5	2	1	1.25	1.75	0	2	1.25	1.75	0.75	2	1	1.25	1.75	0	2	1.25	1.75	0.75
C6	4	3.25	3.25	4	2	0	2	3.75	1.75	4	3.25	3.25	4	2	0	2	3.75	1.75
C7	2	1	2	3.25	2	3.25	0	2	2	2	1	2	3.25	2	3.25	0	2	2
C8	3.75	2	3.25	4	0.75	3.25	2	0	3	3.75	2	3.25	4	0.75	3.25	2	0	3
C9	4	3.25	3.25	2	2	2	3.25	3	0	4	3.25	3.25	2	2	2	3.25	3	0

The average matrix helps to determine the causal relationships and interdependencies between different criteria by calculating the average value of the direct and indirect influences of each criterion on other criteria. By analyzing the average matrix, it is possible to identify the key criteria that have a significant impact on the

other criteria and the criteria that are most affected by the other criteria. This information can then be used to develop strategies to address the identified issues and improve the overall effectiveness of the system. **Table 7** shows the normalized initial direct-relation matrix.

Table 7. Normalized initial direct-relation matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	SUM
C1	0	3.75	3	4	1.25	2	1.75	3.25	2	21
C2	3	0	3.25	2	3	2.25	1	1.25	2	17.75
C3	2	3	0	1	3.25	3.25	2	1	0.75	16.25
C4	3.25	3	3	0	3.75	3	3.25	2	2	23.25
C5	2	1	1.25	1.75	0	2	1.25	1.75	0.75	11.75
C6	4	3.25	3.25	4	2	0	2	3.75	1.75	24
C7	2	1	2	3.25	2	3.25	0	2	2	17.5
C8	3.75	2	3.25	4	0.75	3.25	2	0	3	22
C9	4	3.25	3.25	2	2	2	3.25	3	0	22.75
SUM	24	20.25	20.25	22	18	21	16.5	18	14.25	-

Table 8 shows the Normalized Direct Relation Matrix obtained from the Normalized Initial Direct Relation Matrix using the DEMATEL method. This matrix represents the strength and direction of the interdependence relationships among the elements being analyzed. Each row and column correspond to an element, and the numbers in the cells indicate the strength of the relationship between the row and column elements.

For example, the cell in row C1 and column C2 of the matrix indicates that the strength of the relationship between C1 and C2 is 0.15625. This means that C1 has a direct effect on C2, and that effect is relatively weak. Similarly, the cell in row C2 and column C1 of the matrix indicates that the strength of the relationship between C2 and C1 is also 0.15625, which means that C2 also has a weak direct effect on C1.

The Normalized Direct Relation Matrix is used in the DEMATEL method to identify the causal relationships among the elements being analyzed and to construct a structural model that illustrates the causal relationships between them. This model can then be used to identify the key elements that are driving the system and to develop strategies to address any problems or inefficiencies that may exist in the system.

Table 8. Normalized direct relation matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	0	0.15625	0.15625	0.166667	0.052083	0.083333	0.072917	0.135417	0.083333
C2	0.125	0	0.125	0.083333	0.125	0.09375	0.041667	0.052083	0.083333
C3	0.083333	0.125	0	0.041667	0.135417	0.135417	0.083333	0.041667	0.03125
C4	0.135417	0.125	0.125	0	0.15625	0.125	0.135417	0.083333	0.083333
C5	0.083333	0.041667	0.041667	0.072917	0	0.083333	0.052083	0.072917	0.03125
C6	0.166667	0.135417	0.135417	0.166667	0.083333	0	0.083333	0.15625	0.072917
C7	0.083333	0.041667	0.041667	0.135417	0.083333	0.135417	0	0.083333	0.083333
C8	0.15625	0.083333	0.083333	0.166667	0.03125	0.135417	0.083333	0	0.125
C9	0.166667	0.135417	0.135417	0.083333	0.083333	0.083333	0.135417	0.125	0

Total Relation Matrix Obtained: $T = D(I - D)^{-1}$

The Total Relation Matrix is obtained by using the DEMATEL method to analyze the cause-and-effect relationships among different criteria. In this method, experts are asked to evaluate the direct and indirect influences of each criterion on all the other criteria. The evaluations are then used to construct a network of relationships, and the Total Relation Matrix is derived from this network.

Table 9 shows the Total Relation Matrix obtained using the formula $T = D\ (I - D)^{-1}$, where D is the diagonal matrix of out-degree centrality values of each node in the network and I is the identity matrix. Each cell (i, j) in the table represents the strength of the connection between node i and node j in the network, with values ranging from 0 to 1. The higher the value, the stronger the connection between the nodes. The diagonal entries represent the self-loops of each node and have values equal to 0.

Table 9. Total relation matrix.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
C1	0.535468	0.610965	0.619408	0.642706	0.474895	0.555374	0.446759	0.529062	0.410484
C2	0.549986	0.391247	0.535315	0.484494	0.460822	0.477004	0.351438	0.390304	0.346129
C3	0.475271	0.462578	0.375965	0.415965	0.437217	0.476363	0.354231	0.35098	0.277606
C4	0.680865	0.606617	0.641577	0.526431	0.582361	0.614586	0.516844	0.512377	0.424672
C5	0.389293	0.317125	0.34518	0.362953	0.244097	0.355532	0.270469	0.310932	0.226109
C6	0.747718	0.654448	0.691295	0.709839	0.55116	0.538431	0.502667	0.60126	0.444051
C7	0.534483	0.445145	0.507555	0.548595	0.435871	0.527902	0.325533	0.43213	0.359804
C8	0.709965	0.588044	0.663034	0.680337	0.483502	0.629508	0.484888	0.443543	0.467443
C9	0.707361	0.618168	0.653502	0.604988	0.518355	0.580885	0.517628	0.546234	0.351268

5.2. Results

In DEMATEL, factors are determined as causes or effects based on their relative influence on other factors in the system. Factors that have a greater influence on other factors are considered causes, while those that are more influenced by other factors are considered effects. This has been elucidated in **Table 10**.

Table 10. Cause-effect drivers.

	Ci	***Ri***	***Ri + Ci***	***Ri − Ci***	
C1	5.33	4.825	10.155	−0.505	effect
C2	4.694	3.986	8.681	−0.707	effect
C3	5.032	3.626	8.659	−1.4066	effect
C4	4.976	5.106	10.082	0.13	cause
C5	4.188	2.821	7.009	−1.366	effect
C6	4.755	5.44	10.196	0.685	cause
C7	3.77	4.117	7.887	0.3465	cause
C8	4.116	5.15	9.267	1.033	cause
C9	3.307	5.098	8.405	1.79	cause

Looking at the table, we can see that Lack of Skilled Workforce (C6) has the highest value for $Ri + Ci$, indicating that it has a significant impact on the overall system. Additionally, C6 has a positive value for $Ri - Ci$, indicating that it is a cause factor. This suggests that C6 has a high level of influence on other factors in the system and plays a critical role in determining overall system behavior.

On the other hand, Digital Divide (C3), Data Privacy Concerns (C5), Limited Financial Resources (C2), and Inadequate Infrastructure (C1) have negative values for Ri-Ci, indicating that they are effect factors. These factors are more influenced by other factors in the system than having a significant influence on the overall system behavior. Therefore, they are considered effect factors.

Lack of Citizen Participation (C4), Integration of Disparate Technologies (C7), Inadequate Policy Governance (C8), and Lack of Environmental Sustainability (C9) have positive values for both $Ri + Ci$ and $Ri - Ci$, indicating that they are both cause and effect factors. These factors have a high level of influence on other factors in the system, but they are also influenced by other factors in the system.

Determining cause-and-effect factors is important in DEMATEL because it allows us to identify the critical factors in the system and understand how they are interrelated. This information can then be used to develop strategies for improving the overall performance of the system.

Figure 1 represents $Ri + Ci$ and $Ri - Ci$; the points below denote the effects, and the points mentioned above display the causes.

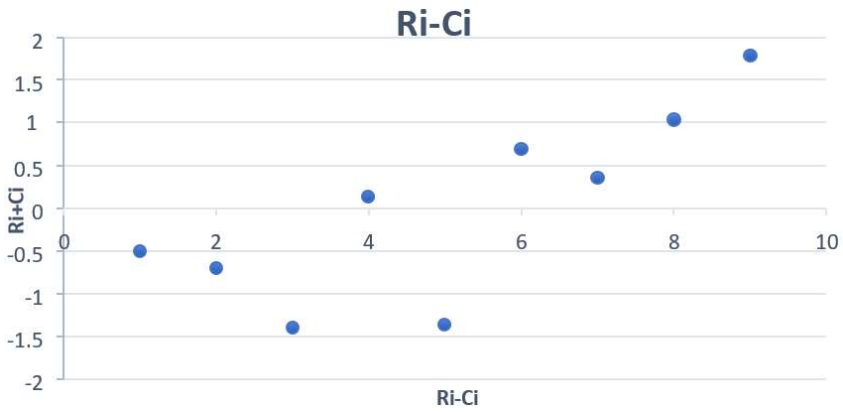

Figure 1. $Ri - Ci$ graph, representing causes and effects.

6. Conclusion and way forward

The challenges facing the development and improvement of smart cities are multifaceted and interrelated. The shortage of skilled workers, inadequate policy governance, integration of disparate technologies, lack of environmental sustainability, and lack of citizen participation are the causes that negatively affect smart city development. In turn, inadequate infrastructure, limited financial resources, the digital divide, and data privacy concerns are the effects of these challenges.

To address these challenges, a comprehensive approach is necessary, which involves collaboration between the government, private sector, and citizens. Smart city planners need to ensure citizen participation in decision-making, encourage the development of a skilled workforce, implement policies that promote environmental sustainability, and integrate technologies in a way that is beneficial to citizens.

6.1. Implications

6.1.1. Theoretical

The holistic approach proposed for smart city development emphasizes the importance of considering the interrelationship between the challenges facing smart cities. This approach aligns with the systems thinking approach, which considers the interconnectedness of different elements within a system. The implementation of this approach can lead to a better understanding of the complex and dynamic nature of smart city development, enabling planners to make more informed decisions.

6.1.2. Societal

The collaborative approach proposed for smart city development involves citizens, government, and the private sector working together towards a common goal. This approach can lead to increased citizen engagement and empowerment, fostering a sense of ownership and responsibility towards their city's development. Additionally, by promoting environmental sustainability and improving the quality of life for citizens, smart cities can create more inclusive and equitable communities.

6.1.3. Managerial

The comprehensive approach proposed for smart city development requires effective management and coordination among different stakeholders. Effective project management and governance can ensure that resources are allocated efficiently and that the project remains on track towards its goals. Additionally, the adoption of innovative financing mechanisms and the development of public-private partnerships can help address the financial constraints facing smart city projects.

6.2. Limitations

The proposed approach for smart city development may face several limitations, including a lack of political will and support, insufficient financial resources, and limited technical expertise. The involvement of multiple stakeholders can also lead to conflicting interests and a lack of consensus, hindering the decision-making process.

6.3. Concluding remarks

The development of smart cities presents both opportunities and challenges. The proposed approach emphasizes the importance of a comprehensive and collaborative approach that considers the interrelationship between the challenges facing smart cities. By doing so, smart cities can leverage the benefits of technology to create more sustainable, livable, and equitable communities. However, to realize this vision, effective management and coordination among different stakeholders are essential, along with addressing the limitations facing smart city development.

Author contributions

Conceptualization, KSG and SS; methodology, KSG and SS; software, KSG and SS; validation, KSG and SS; formal analysis, KSG and SS; investigation, KSG and SS; resources, KSG and SS; data curation, KSG and SS; writing—original draft preparation, KSG and SS; writing—review and editing, KSG and SS; visualization, KSG and SS; supervision, SS; project administration, SS. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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