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Aims and Scope

International Journal of Human Capital in Urban Management (IJHCUM) aims to offer an outlook on the utilization of human capital in urban management based on existing urban and metropolitan problems. The journal expects to eventually turn into a convergence point as a reference available to professionals, managers and researchers in the field of urban management. Topics of interest include but are not limited to the following disciplines: Human Capital in Urban Management; Urban architecture, design, development and planning; Urban communications and services; Urban civil engineering and related management issues; Urban economics, administrative and financial management; Urban transportation systems and traffic management; Urban social and cultural welfare; Urban ecology and related; environmental concerns; Urban Health, Safety and Environment; Sustainable urban infrastructure.

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International Journal of Human Capital in Urban Management (IJHCUM) is an open access, peer-reviewed journal affiliated with Municipality of Tehran focusing on employment and allocation of human capital for urban management, including urban multidisciplinary themes. IJHCUM is an integral partner with the scientific and technical communities, delivering superior Information products and services that foster communication, build insights and enables individual and collective advancement in urban management. Providing human capital information to the general public administration with description of contemporary advances in urban issues to be used in improving protection and management.

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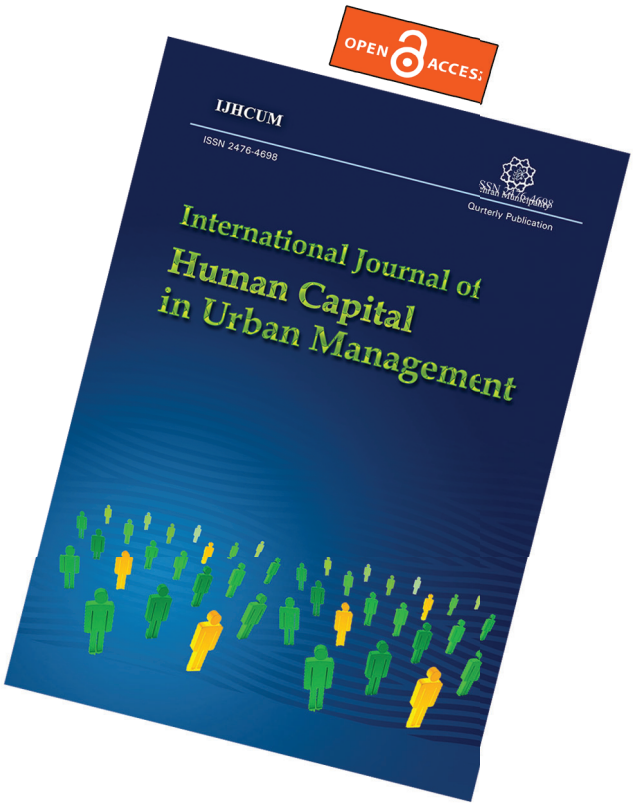

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ORIGINAL RESEARCH PAPER

Invisible lives, visible challenges: The socio-environmental impacts of undocumented Afghan immigrants on the host society

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ABSTRACT

BACKGROUND AND OBJECTIVES: Today's illegal immigrant crisis in general and the illegal Afghan immigrant crisis, in particular, are considered a continuous challenge of the current century since the mass migration of people from their country of origin has exponentially increased. Afghanistan has been one of the biggest refugee and humanitarian challenges in recent decades, with continuous suffering for millions of Afghans. This affected neighboring countries, including Pakistan. One million illegal Afghan immigrants reside in Pakistan without legal documentation. Such a huge number of immigrants negatively affects the social and environmental factors of receiving and host communities.

METHODS: This study employs a mixed research method to investigate the socioenvironmental implications of illegal Afghan immigrants on the host society of Peshawar, Pakistan. Surveys and interviews were used for data collection, and the data were analyzed thematically and integrated (triangulated).

FINDINGS: The study revealed a significant pressure on social services such as healthcare, education, employment, and housing in the host society. The burden on the healthcare system, pressure on the education system, and lack of employment opportunities and affordable housing were direct consequences. Social tension due to a sense of frustration and competition over resources was formed. Environmental degradation such as pollution, deforestation, and land degradation resulting from resource strain and overpopulation with illegality was also found. Besides The study critically assesses the responses of the government, NGOs, and community, emphasizing significant gaps in policy and implementation.

CONCLUSION: The findings highlight the need for an integrative approach that addresses these challenges through targeted policy reforms and that improves community engagement. This study advances the present literature on migration by providing novel insights into the socio-environmental dynamics of illegal immigration, offering an actionable recommendation for stakeholders and policymakers in similar contexts.

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INTRODUCTION

People immigrate due to political or financial situations that leave them with little to no other choice of living in their country of origin (Jennisen 2007). Massive immigration has occurred due to conflicts, wars, environmental accidents, and natural disasters (Sakellari and Skanavis, 2012). People with low resilience are forced to replace them (Gianuolis et al., 2014) with their worries about finding a peaceful place. According to the International Organization for Migration (IOM), around 281 million people, 3.6 percent of the total world's population, or one in every 30 persons, were forced to leave their homes because of various reasons such as war, violation of human rights, and discrimination (Mcauliffe and Oucho, 2024). Among them, approximately 15–20% are illegal migrants. Illegal or undocumented migration has become the fastest-growing form globally in recent decades (Hansen and Papademetriou, 2013; Iqbal *et al.,* 2024). It is defined as "movements that occur outside the regulatory norms of receiving, transit, and sending countries" (IOM, 2018). By increasing strict rules and regulations on human movements on borders, people with fewer rights or restrictions of mobility are forced to move in irregular ways (Jordan and Düvell, 2002). Hence, illegal migration is the result of strict limitations on legal movement. Illegal immigrants include both those immigrants who were forced to leave their country and those who left voluntarily (Messias *et al.*, 2015). Immigrants become illegal due to various reasons, such as entering a country without valid documents, asylum claim refusal, or overstaying after the expiration of the residency permit (IOM, 2018). The IOM defines undocumented migrants as "a non-national who enters or stays in a country without proper documentation. This includes a person (a) who has no legal documentation to enter a country but succeeds in entering clandestinely, (b) who enters or stays with fake documentation, and (c) who, after entering using legal documentation, has stayed beyond the time authorized or otherwise violated the terms of entry and remained without authorization" (IOM, 2011). Lack of documentation limits access to social, legal, and physical mobility and access to people's services. Undocumented Ness is a 20th-century social construction that refers to the absence of tangible proof of status and identity. It's not a fixed or permanent status of immigrants; it's changing over time, and individuals might move between illegal and legal. Therefore, both illegal and legal immigrants are not easily distinguished and are mutually exclusive groups of immigrants. Because of the absence of an authentic method of identification, valid data on undocumented immigrants are lacking, and existing data are mostly theoretical and estimated by cross-referencing different sources. According to the International Organization for Migration, there are 20-30 million undocumented immigrants estimated worldwide. Afghan immigrants first came to Pakistan in December 1979, due to the Afghan crisis and Soviet intervention. The situation in Afghanistan, as a result of everlasting and internecine conflict, causes massive displacement of Afghans within and across borders. They found their way to around a hundred different states, but the majority of them, around six million, sought refuge in Pakistan and Iran (Centlivres and Centlivres-Demont, 1988). The arrival of Afghans to Pakistan in the last four decades made Pakistan a host country with the largest single population of refugees in the world (Zieck, 2008). Globally, Pakistan has the fifth largest refugee population, having slightly more than 1.4 million registered refugees (IOM, 2018); almost all are from Afghanistan. In addition, approximately one million unregistered Afghan immigrants live in Pakistan (UNHCR, 2024). This large number of illegal immigrants without any legal permission to live are living in the country. If this population is taken into account, Pakistan would become the third-largest host nation for refugees worldwide. In the literature, various terms are used for illegal immigrants, such as undocumented immigrants, non-status immigrants, irregular immigrants, unauthorized immigrants, clandestine immigrants, etc. In this study, the term illegal Afghan immigrant was used for all Afghans residing in Pakistan who don't have legal documents for staying in Pakistan. Most were hosted by Pashtun ethnics, where asylum (Panah) exists in their culture and is considered a necessary and honorable choice that a group or individual takes to preserve the integrity of the tribe and their own lives (Centlivres and Centlivres-Demont, 1988). They give asylum in the form of hospitality. Still, in general, this hospitality is possible mostly when it is hypothetically reciprocal, and with time, the benefited ones, while returning to the home and capable, offer hospitality. Hospitality and sanctuary (*Manawatu*) have significantly

influenced the importance of the relationship between Pakistani and Afghani tribal groups in tribal zones (Centlivres and Centlivres-Demont, 1988). These sacrifices of host community members are mainly based on religious compulsion and cultural and humanitarian basis (Jathol and Yaseen, 2023). The government of Pakistan gives them refuge based on humanitarian grounds, not on legal grounds and treaties with the United Nations Commission for Human Rights (UNHCR). With the assistance of UNHCR, Pakistani authorities have set up camps to facilitate Afghan immigrants and avoid overpopulation and other negative consequences on host areas (Centlivres and Centlivres-Demont, 1988). Approximately 25 percent of refugees in Pakistan enjoy asylum, and the majority have lived there for the last four decades. However, Pakistan is not a party to both the 1951 convention and the 1967 protocol relating to the status of refugees. Therefore, the legal status of them is not clear (Zieck, 2008). Pakistan wasn't prepared to deal with any kind of immigrants because of its economic, social, and political situation. And it is proven that, whenever refugees settle in a specific region, they affect the political, social, and environmental sectors of the host community (Kounani and Skanavis, 2018). In addition, the absence of anticipation and proper planning for a penetrating increase in population arriving, specifically when the host community lacks integrated and sustainable management plans, causes unaffordable problems (Kounani *et al.*, 2020). Furthermore, the uncertain number of illegal Afghan immigrants and the lack of an official, accurate count of them create a major challenge for socioenvironmental service providers and policymakers in Pakistan. Their status of illegality further affected institutions like immigration, police, and officials like health, education, housing, landlords, employment, and the environment of the host community. Existing studies indicate that illegal immigration has multifaceted social and environmental consequences for host societies. Their nature of migration creates socio-political and environmental problems and puts pressure on land (Nath, 2011). They strain public resources and have negative impacts on the environment of the host, which include trail creation, campfires, wildfires, and litter (McIntyre and Weeks, 2002). They also contribute to environmental issues such as environmental degradation (Beare, 2012), deforestation, and pollution (Kherfan, 2016), which exacerbate the environmental circumstances of the community, which is already in a bad state, as Pakistan is one of the top 10 countries in the world that is most impacted by natural catastrophes and climate change (World Bank Group, 2022). Besides, the condition of their houses is overcrowded and creates an infrastructural issue (Hall *et al.*, 2013), which affects the environment of the host community. Immigration policies degrade the living situations of illegal immigrants and affect all aspects of their lives, from healthcare to employment (Tomkow, 2019), which have indirect effects on the public health of the host community. In addition, sticking rules against them has unintended economic consequences. They pose distressing threats to the labor force of the host (Gonzales and Chavez, 2012) and take away jobs from the local population (Halter *et al.*, 2014), which increases the ratio of unemployment in their residence (Rodriguez and Dawkins, 2017). The study done by the American Immigration Council AIC (2011) indicated that unauthorized immigrants are willing and more likely to work for lower wages and fewer desirable jobs than others. They received low wages as compared to others (Espenshade, 1995) and provided cheap labor, especially unskilled immigrants (Cortes, 2008), which brings competition and inequality in wages within the host community. Due to competition for low-skilled jobs, they increased violence (Light and Miller, 2018). Almost all of them are downgraded to a market of low-skilled labor (Passel and Cohn, 2009). They adversely impacted the wages of low-skilled native employees. Especially those who are more negatively affected who don't have high school diplomas (Borja's, 2013). Public education is also affected by them and leads locals towards private schools, which hypothetically decline public education funding support. They put pressure on the whole education system of the host (Khan, 2017; Jathol and Yaseen, 2023). Furthermore, a study in the U.S. on them argues that they put a burden on the healthcare system, contributing to suspicion and lower utilization rates for the healthcare system (Holmes, 2006). They have barriers to health and social services such as service access and quality of treatment (Doshi *et al.*, 2020); in addition, their fear of deportation discourages service utilization. Disputes occur between various government and

private organizations in providing care for them, which leads to situations that worsen the impact on social services access issues in the residence area (Chavez, 2013). From dispute resolution, undocumented immigrants can turn to violence instead of involving government authorities. They also have more adverse effects on welfare programs (Rodriguez and Dawkins, 2017). Moreover, Jacobsen (2001) determined three key issues: economic, security, and environmental resource burdens that pressurize and resist authorities in the integration of refugees with locals. Besides, their dynamic and continuously changing economic, political, and social conditions have a tremendous impact on individuals, families, and communities (Ayo´n, 2009), which indirectly exacerbates access to socioenvironmental services. Furthermore, in the Pakistani context, a study conducted by Jathol and Yaseen (2023) revealed that Afghan refugees in Pakistan pose an economic, political, and social threat to the country. Their hosting strain on resources such as social services, infrastructure, employment opportunities, healthcare, education, and the environment, and risk to overall country security (Jathol and Yaseen, 2023). They also raised issues regarding drug abuse and trafficking in the community. Another study by Khan (2017) concluded that Afghan refugees put a strain on Pakistan's environment, local economy, infrastructure, schools, and hospitals, and increased crime and the threat of terrorism. The study also showed that refugee willingness to work for less has driven wages downward (Khan, 2017). The overall impact of illegal immigrants on the host community is complex, contains both benefits and costs, and needs careful consideration of social, economic, and environmental factors in developing effective policies. The studies on migration mostly focus on a single dimension, such as the environmental or social consequences of immigrants on the host society. A notable theoretical gap exists in examining the socioenvironmental consequences of widespread illegal immigration in urban South Asia, especially in environmental degradation and resource strain. The significance of Peshawar as a main center for Afghan immigrants stems from both socio-historical and geographical closeness with Afghanistan, rendering it particularly affected by migratory influences. This study highlights the relationship among social services, resource scarcity, and migration, drawing from social and environmental theories. For a better understanding of the socioenvironmental impact of illegal immigrants on host society, social-ecological theory and social integration are considered well aligned. Social-ecological theory analyzes the interaction between environmental resources and individuals (Shogren, 2013). It elucidates the impact of the inflow of illegal Afghan immigrants on Peshawar's natural resources and social structure. In addition, social integration theory offers a framework for understanding the social problems and the impact of illegal Afghan immigrants on host community social services (Turner and Turner, 2013). This study combined these ideas to provide a systematic examination of the distinct socioenvironmental difficulties confronting Peshawar, elucidating the significance of this context within the wider migration studies. This technique ensures a logical framework in the literature review, developing from general migration theories to the particular socio-environmental dynamics within Peshawar, hence creating a clear theoretical framework for the research questions and aim. This study places itself in the rising frame of studies on the socioenvironmental impacts of immigration, especially focusing on undocumented Afghan immigrants residing in the host society of Peshawar. The existing studies have less access to undocumented immigrants (Chavez 2013), in general, and undocumented Afghans in particular. While work has been done on the social, economic, psychological, security, and environmental impacts of illegal migrants, there is a notable gap in the socioenvironmental impact of them on host society. To the best of the author's knowledge, generally, there have been wide-ranging studies on the socioeconomic and sociopsychological impacts of illegal immigrants, but studies on socioenvironmental impacts are lacking, especially on Afghan immigrants. Notably little attention is given to the challenges faced by the host society; rather, studies mainly focus on the challenges of immigrants. By filling this knowledge gap, this is the first study to uniquely focus on the socioenvironmental impacts of immigration in the context of Peshawar, which has been affected by illegal Afghan immigrants. Besides this, it contributes a new dimension to the existing literature by discovering how immigration not only affects social services but also the environmental sustainability of the host community. Furthermore,

most existing studies focus on developed regions such as Europe or America by providing a specific context analysis of the immigration impact in Peshawar, a city in a developing country, which further contributes to the existing literature. Moreover, this regional focus is more important for scholars, practitioners, and policymakers interested in the South Asian context. By filling the above-mentioned gap in the literature, this study contributes to the literature and provides a roadmap for policymakers, scholars, and practitioners. It also contributes to the environmental justice and migration fields by offering new insight into the local socioenvironmental consequences of illegal immigrants. This study aims to analyze the impacts of illegal Afghan immigrants on social services and examine their environmental consequences on the host society of Peshawar. In addition, it evaluates government, Non-Governmental Organization (NGO), and community responses to mitigate the challenges of undocumented Afghan immigrants. This will give an overview of challenges in socioenvironmental service access faced by the host society due to illegal Afghan immigrants and government, NGOs, and community responses to it. This study attempted to answer the following questions: What are the major challenges that illegal Afghan immigrants impose on the environment of Peshawar? How does the presence of illegal Afghan immigrants influence the social services of Peshawar? How operative are the responses of the government, NGO, and community in addressing the challenges posed by illegal Afghan immigrants in Peshawar? To achieve these objectives and answer these questions, the study was conducted in residential areas of Peshawar city, Pakistan, in 2024.

MATERIALS AND METHODS

It's essential to employ certain methods and approaches to know about a specific phenomenon, which helps us to produce scientifically sound knowledge. A mixed methodology was used in this study, combining both quantitative and qualitative methods to explore the strain on the socioenvironmental services of host communities due to undocumented Afghan immigrants. Social sciences scholars use this method to obtain rich data. In this study, this method was used to integrate findings from both numerical and in-depth, contextualized insight, which offers a comprehensive understanding of the phenomenon (Creswell and Creswell, 2017). It also necessitates employing both methodologies simultaneously, which provides a study-inclusive strength that surpasses that of either a quantitative or qualitative study. In addition, by combining the advantages of both methodologies, this strategy provides a more comprehensive understanding of the examined phenomenon (Fetters *et al.,* 2013). Furthermore, quantitative insights might be used to inform the interpretation of qualitative data, and vice versa. This method aligns with the study's focus on gaining a comprehensive understanding of the socioenvironmental impact of illegal Afghan immigrants and the responses of the government, NGSs, and community in the host society of Peshawar, Pakistan.

Study setting

The study was conducted in Peshawar, the capital city of the Khyber Pakhtunkhwa province of Pakistan. The study map is shown in Fig. 1. According to the census of 2017, it has a population of 4,758,762 citizens. and based on the AREU report, the estimated population of illegal Afghan immigrants is around 63,000 (Shahzad, 2023). The reason for selecting this area is because it's a major hub for all legal and illegal Afghan immigrants due to various factors such as locality and services (Iqbal *et al.*, 2024).

Recruitment and inclusion criteria

The first author was a resident of the study area and lived with both documented and undocumented Afghan immigrants and with the host community. In addition, the family background, socioeconomic position, and ethnicity were quite helpful in the recruitment and inclusion process of participants. The recruitment of participants was done directly and indirectly (through peers) by selecting them through a purposive sampling technique. Recruitment outreach was conducted in worship places, public parks, shopping centers, informal gatherings, and community centers frequented by the required population. The inclusion criteria were that all participants must be residents of Peshawar, older than 18 years, and have experience with undocumented Afghan immigrants in Peshawar, such as working or living in the neighborhood. Participants were selected based on their appropriateness for the

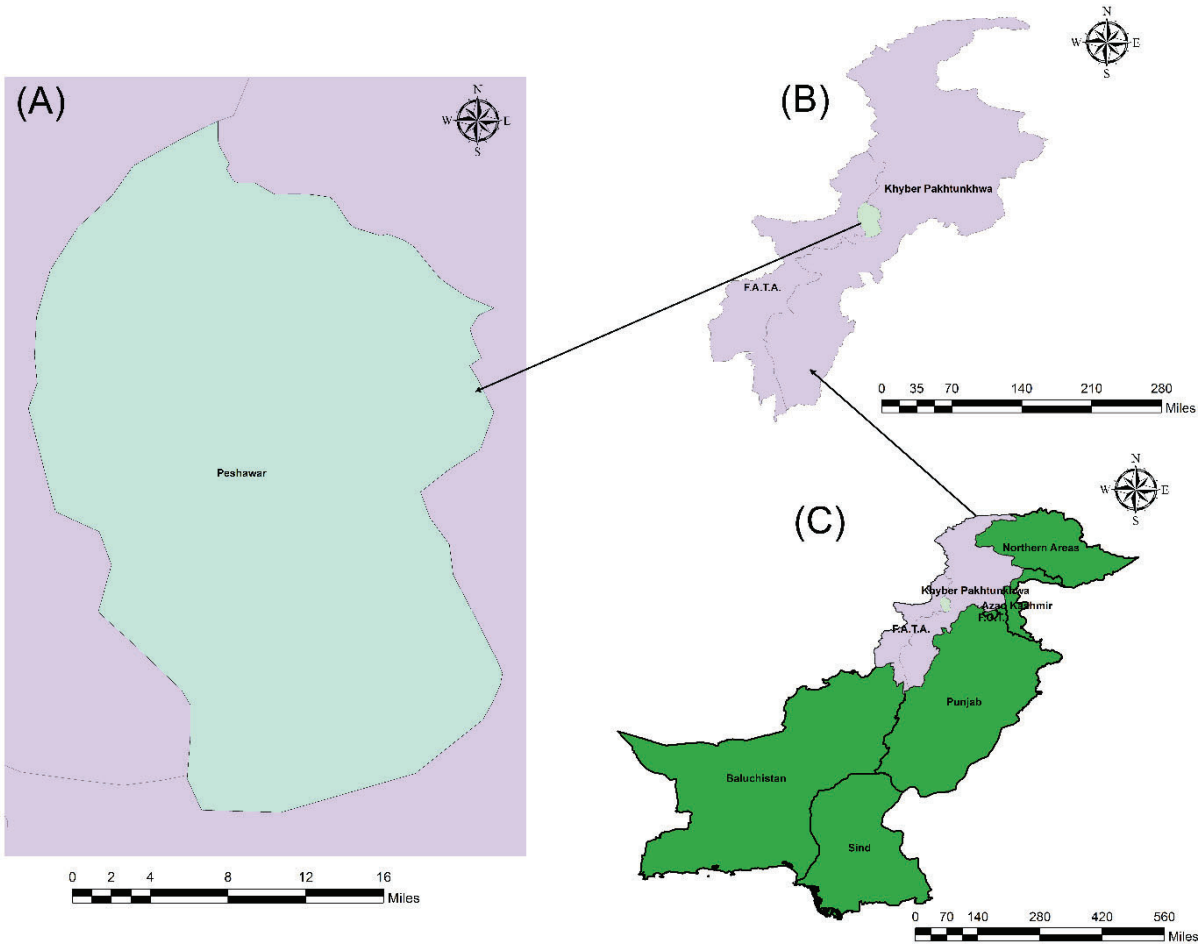

Fig. 1: Geographical location of the study area (a) Peshawar, (b) Khyber Pakhtunkhwa (c) Pakistan

assignment and their willingness to participate. The data was collected from those who were willing to participate in the data collection. Those who were not willing were excluded from the study, which ensures the reliability of the data.

Data collection

Qualitative data was collected through semi-structured interviews (Creswell and Creswell, 2017) with 20 key stakeholders: government officials, NGO representatives, community members, and leaders; see Table 1 for their sociodemographic characteristics. The saturation point was considered for the data collection limit. The interview aimed to get an in-depth understanding of the socioenvironmental consequences of illegal Afghan immigrants. After reviewing the literature and the researcher's experiences, under the supervision of an expert, an interview protocol was prepared for means of data collection. The interviews were conducted in Pashto because all participants, including the interviewer, were Pashto speakers, and later the author translated it into English. Each interview lasted approximately 50 to 70 minutes. Interviews were audio recorded with informed consent, anonymized, and transcribed verbatim. The researcher transcribes the data from verbal to written medium to clean up the reach, facts, and meaning.

Quantitative data were collected through a survey questionnaire administered to 384 participants, containing government officials, community members, and leaders; Table 3 contains their socioeconomic characteristics. The sample was taken

Table 1: Sociodemographic characteristics of participants

S. No	Occupation	Gender	Age	Marital Status	Family System	Role/ Status
1	Cloth's business	Male	48	Married	Joint	Community leader
2	Social worker	Female	27	Unmarried	Joint	NGO employ
3	Clerk	Male	29	Unmarried	Joint	Govt employ
4	Costermonger	Male	36	Married	Nuclear	Community member
5	Housewife	Female	30	Married	Joint	Community member
6	Salesman	Male	40	Married	Nuclear	Community member
7	Shopkeeper	Male	42	Married	Joint	Community member
8	Teacher	Female	31	Married	Nuclear	Govt employ
9	Cloth sillier	Female	26	Unmarried	Joint	Community member
10	Comedies seller	Male	21	Unmarried	Joint	Community member
11	Scavenger	male	31	Unmarried	Joint	Govt employ
12	Student	Female	24	Unmarried	Extended	Community member
13	Shopkeeper	Male	45	Married	Nuclear	Community member
14	Social organizer	Female	30	Unmarried	Joint	NGO employ
15	Dry fruits Business	Male	58	Married	Extended	Community leader
16	Coordinator	Female	34	Divorced	Joint	NGO employ
17	Plumber	Male	45	Married	Joint	Community member
18	Religious scholar	Male	53	Married	Extended	Community leader
19	Nurse	Female	32	Married	Nuclear	Govt employ
20	Teacher	Male	33	Unmarried	Joint	Govt employ

Table 2: Sample size determination table of Krejcie and Morgan

Population size	Sample size	Population size	Sample size	Population size	Sample size
10	10	340	181	2000	322
20	19	380	191	2500	333
30	28	420	201	3000	341
40	36	460	210	3500	346
50	44	500	217	4000	351
60	52	550	226	4500	354
70	59	600	234	5000	357
80	66	650	242	6000	361
90	73	700	248	7000	364
100	80	750	254	8000	367
120	92	800	260	9000	368
140	103	850	265	10000	370
160	113	900	269	15000	375
180	123	950	274	20000	377
200	132	1000	278	30000	379
220	140	1100	285	40000	380
240	148	1200	291	50000	381
260	155	1300	297	75000	382
280	162	1400	302	1000000	384
300	169	1500	306		

based on the Krejcie and Morgan table of determining sample size (see Table 2). The questionnaire included close-ended questions structured by authors, containing multiple choices and Likert scales with a response ranging from strongly agree "1" to strongly disagree "5," for gathering statistical information about the sociodemographics of participants and the socioenvironmental consequences of illegal Afghan immigrants. The questionnaire was pilot-tested with a small sample before administration on a full scale to ensure validity, reliability, and clarity (Flower, 2014). A purposive sampling technique was used for the selection of participants with different backgrounds and expertise relevant to the study objectives.

Table 3: Participant socioeconomic characteristics

Category	Code	Variable	Percentage	Frequency	Mode
Gender	1	Male	70	268	
	2	Female	30	116	1
Age	1	18-28	20	77	
	2	29-39	35.4	136	
	3	40-50	31.3	120	2
	4	51- more	13.3	51	
Civil status	1	Married	54.7	210	
	2	Unmarried	33.3	128	1
	3	Divorced/ separated	12	46	
Family system	1	Nuclear	36.7	141	
	2	Joint	54.4	209	2
	3	Extended	8.9	34	
Education	1	Illiterate	9.9	38	
	2	Primary	24	92	3
	3	High	45	173	
	4	Graduate	21.1	81	
Occupation	1	Employed	26.6	102	
	2	Unemployed	22.4	86	
	3	Self-employed	18.5	71	1
	4	Student	24.7	95	
	5	Housewife	7.8	30	
Monthly income	1	10,000- 20,000	12.8	49	
	2	21,000- 30,000	36.2	139	2
	3	31,000- 40,000	31.2	120	
	4	More than 40,000	19.8	76	
Source of Income	1	own	51.6	198	
	2	Family member	21.1	81	1
	3	Relative in foreign	27.3	105	

Data analysis

The qualitative data was collected through interviews; the interview verbatim was transcribed into English, and all potential information of participants that could lead to their identification was removed, and data was anonymized for their confidentiality. For the analysis of data, this study used template analysis (Brooks *et al.,* 2015). In the beginning, all authors familiarized themselves with the data distinctly by going through transcripts of the first five interviews. After this, in a preliminary data coding phase, they agreed on categories related to data. Then, under categories, themes were clustered, and relations were identified between each cluster. By comparing findings, an initial coding template was articulated. This template was separately applied to the three interviews by each author. After that, the template was adjusted and applied to all interviews; making final changes to the template helped to form a map of the different clusters under every category. Feedback on the coded categories was provided by a reference group consisting of people who had experience with illegal Afghan immigrants. The reason for choosing thematic analysis for the qualitative data was its flexibility and efficacy in recognizing recurring patterns and significant themes across varied participant replies. This strategy facilitated the identification of themes pertinent to socio-environmental concerns, aligning effectively with the study's examining nature and research objectives. NVivo12 software was used to code the transcripts and identify each cluster's density. Quantitative data was analyzed using Statistical Package for the Social Sciences (SPSS) software (version 26). SPSS was selected for its capacity to generate statistics and also descriptive statistics that offer a clear summary of service strain indicators such as education, healthcare, housing, and employment. For analyzing data, inferential statistics and descriptive statistics were used. Statistical tools such as percentages, frequencies, means, modes, and tabulations were employed to offer a

Table 4: Cronbach's Alpha Values

S.NO.	Items	No. of items	Cronbach's alpha values
a)	Challenges imposed on Access to social services	11	.853
b)	Employment opportunities	5	.798
c)	Education Access	5	.837
d)	Housing standard	4	.908
e)	Environmental implications	5	.854
f)	Health	4	.761
g)	Responses of government and NGOs	4	.789
	Overall Reliability	38	.828

nuanced picture of the scale of the issues identified. Additional statistical techniques, including reliability tests (Cronbach's alpha) and common method bias tests (Harman's single factor test), were conducted to ensure the consistency, validity, and reliability of the data. By a convergent design, the qualitative and quantitative data were collected and analyzed at the same time, and the data were compared. We employed a matching approach proposed by Creswell for convergence. It involves intentionally designing data collection instruments to have related items such that both instruments will clarify data about the same phenomena. Concretely, this involves matching scales of quantitative instruments with qualitative questions (Fetters *et al.,* 2013). By combining the advantages of both methodologies, this strategy provides a more comprehensive understanding of the investigated phenomenon (Fetters *et al.,* 2013). So, for a comprehensive understanding of the phenomenon, the findings of qualitative and quantitative analyses were integrated in this convergent way to enhance the validity and reliability of the data.

Ethics and dissemination

This study was approved by the institutional board of Hohai University. Informed consent was obtained from all the participants after they were informed about the purpose of the study. Surety of withdrawal at any stage was given to all participants without any consequences. Participant confidentiality was ensured by anonymity and secure data storage.

RESULTS AND DISCUSSION

Socioeconomic profile of participants

The target of the sample of this study was host community residents who have experiences with illegal Afghan immigrants. A total of 384 participants were selected for the survey of this study. Participant inclusion criteria were mentioned in the prior section, and purposive sampling techniques were employed for selection. As stated in Table 3, the majority (70%) of the participants were male, with age ranges of 18-28, 29-39, 40-50, and 51 and above being 20%, 35.4%, 31.3%, and 13.3%, respectively. The education level was distributed from illiterate to graduate; the majority (45%) of them were high school diploma holders, 21.1% were graduates, some 24% passed primary school, and 9.9% were illiterate. Most, 54.7%, of them, were married and lived in a joint family system. Most of them were employed, and their majority, 51.6%, source of income was doing the job, 21.1% depended on family members, and some 27.3% sources were relatively foreign.

Reliability Statistics

The study applied reliability analysis to check the internal consistency, validity, and reliability of the survey responses. To show the internal consistency of the model, Cronbach's alpha test of reliability was employed. Cronbach's alpha must be 0.700 or more (Mtebe and Raisamo, 2014). However, for initial research, the coefficient alpha in the array from 0.5 to 0.6 is tranquil at the least satisfactory level of reliability. Table 4 shows the reliability results, which are all highly consistent variables. In addition, because the data were collected from the host community, which was considered a single source, although respondents were selected from various backgrounds, there was still a chance of a common bias problem, so it was tested. To address the common bias method, Harman's single-factor approach was used on all items of all variables. The factors described only 31.62% of the variance, which was less than the threshold value, i.e., 50% (Aguirre-

Fig. 2: World cloud of participants while addressing their challenges

Urreta and Hu, 2019). Hence, its finding indicated that this study was not affected by common method bias and was able to go for further analysis.

Themes

The findings reflect three major themes by employing template analysis, a type of thematic analysis regarding the consequences of illegal Afghan immigrants on socioenvironmental services in the host society of Peshawar.

(1) Challenges imposed on access;

(2) Strain on socioenvironmental services provision;

(3) Responses of government, NGOs, and community.

Each theme is composed of sub-themes, which are listed in Table 5. Overall, illegality and overpopulation were major concerns for all aspects of this study. Fig. 2 shows the common word used during interviews by participants addressing their challenges in socioenvironmental services due to illegal Afghan immigrants.

Challenges imposed on access

Overpopulation

Overpopulation due to illegal Afghan immigrants has significantly affected resources, services, and the overcrowded living conditions of the host community. Participant highlighted that "Everywhere is overcrowded; wherever we go, we

Table 5: core concept of study with themes and sub-themes

Core Concept	Theme	Sub-theme
Challenges imposed by illegal Afghan immigrants	**Challenges imposed on access**	Overpopulation Criminality Corruption Corruption Begging
Socioenviron mental	**The strain on socioenvironmental services**	The burden on health services The strain on the education system Economic Downgrading Housing Scarcity Environmental issues
	Responses of government, NGOs, and Community	Government responses NGOs Responses Community responses

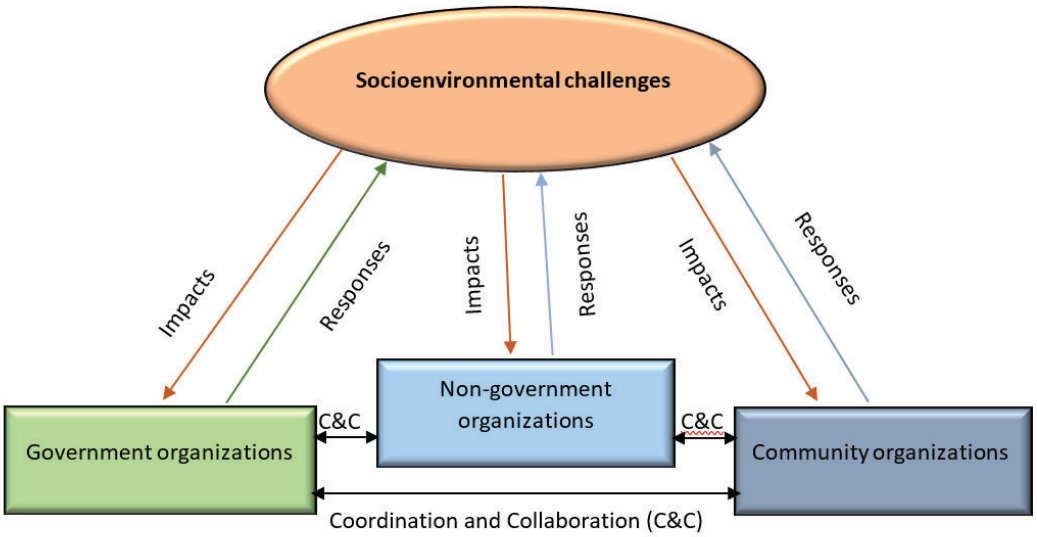

Fig. 3: Socioenvironmental challenges due to illegal Afghan immigrants impacts and responses flow

see overcrowded places. Those places where there was no one and considered horror are now full of people. Public places are full of people; when we go to hospitals, markets, or parks, we think all the people of Peshawar are here, but when we go to other places like Bus Rapid Transit (BRT), we think all people come here." Another participant shared, "Due to illegal Afghan immigrants, transport is congested. The places where we were reaching in 15 to 30 minutes now take around 60 minutes. It seems like society is overflowing at the layers." The findings of the study highlighted the multifaceted challenges in accessing socioenvironmental services in host communities by illegal Afghan immigrants. The results show that illegal Afghan immigrants increase the population of the host community, which puts a burden on resources and social services access. The study of Bouvier and Gardner (1986) also argues that immigration on a large scale is both illegal and legal, resulting in overpopulation and other problems. Overpopulation further puts a strain on education, housing, and healthcare (Bhatti *et. al.*, 2017). Their reproduction contributes to the high growth rate of the population of the host; this parallels with the study of Cox (1995), which claims that illegal immigration contributes to the highest population

growth rate, which worsens the lack of resources and unemployment. The finding also aligned with the study that has shown that illegal immigrants can lead to social challenges, including inequalities, social exclusion, and poverty (UNDP, 2015). In addition, the finding shows that the outrageous increase in population led to overcrowding in public spaces, created barriers to social services access, and scarce environmental resources by overusing them, such as woods, roads, and infrastructure. The study of Ajala (2014) also argues that immigration is a road that offers relief to overpopulation, and overpopulation leads to various problems such as pollution, water crises, and poverty. They use infrastructure services such as police, fire department, roads, water, sewage, trash, and compliance codes, which are provided on the taxes of community members. Because of the heavy burden, the system can't keep up with maintenance and upgrading, which puts a heavy burden on the infrastructure of the host community (Espenshade and Calhoun, 1995). Furthermore, it worsens the organization's challenges and declines the quality of life very badly.

Criminality

The perception of illegal Afghan immigrant's links with criminality is widespread in society. The enforcement agencies and society members think that illegal Afghan immigrants are involved in criminal activities such as smuggling of goods within and across the country, human trafficking, prostitute services, drug abuse, and providing easy access to drugs. One participant shared that "illegal activities are getting more and more in our society, and our society has become the main hub for them. Every day we hear some new information about crimes committed by illegal Afghan immigrants. They export goods in illegal ways to Afghanistan. And they do human trafficking by making cloudy castles for them. Most of them tell wrong stories and misguide people into sending them to the US and UK for a bright future." They are also involved in other criminal activities like drug abuse and selling and prostitution services providers. As Participant # said, "Illegal Afghan immigrants abuse drugs, which affect local community members, and additionally, because of them, drugs are easily available and accessible to everyone in society. Some aunts provide prostitutes at cheap prices and secret, uncacheable ways." Another participant shared, "We were feeling safe in our community before illegal Afghan immigrants, but now their presence makes us feel unsafe. Because of them, robberies, thefts, and other organized crimes like terrorism are increased." The study finding reveals that illegal Afghan immigrants are involved in different criminal activities like smuggling of goods, human trafficking, prostitution, thefts, robberies, and selling and abusing drugs. The study of Simes and Waters (2014) also argues that there is empirical evidence of an increase in crime by immigrants, which influences public attitudes and policies as well. It not only affects them but the whole host community's order and harms its security and safety (Jathol and Yaseen, 2023). Their involvement in criminal activity brings insecurity among the local population, puts pressure on law enforcement agencies, and further exacerbates their integration into the host community. The finding also highlights that they increase the crime rate of the community, which worsens safety and brings insecurity among the residents. It consisted of the finding of Khan (2017), which shows the threat of terrorism and the rise of crime due to Afghan immigrants in Pakistan.

Corruption

Corruption was also mentioned by participants while talking about access to social services. They were of the view that corruption in society was started because of the influx of Afghan immigrants to Pakistan. They commit corruption because they illegally access social services and unlawfully enter the country or other parts of the country. Participant shares that "Some bad habits, like corruption, were boosted by illegal Afghan immigrants because of their illegal status; they are accessing services like an excuse from detention, getting treatment, and other services in a backdoor by paying someone off." The government institutes are also taking bribes from illegal Afghan immigrants to avoid legal repercussions while navigating border control. As the participant shared, "Most of the illegal Afghan immigrants involved in illegal activities, I know about many cases when police caught them while doing illegal work like using alcohol. They just gave them some cash, and the police let them go. The police themselves ask them for bribes from illegal Afghan immigrants, which now spread among our community members as well. Because everyone is aware of it, no one

prefers detention over money. And on the border, most of them come illegally by giving some money to the border management team as bribes." This study's results emphasized the barrier of corruption in access to social services due to illegal Afghan immigrants. The study found that illegal Afghan immigrants give bribes to government officials to get access to social services and illegal means of entry to the country or other restricted areas. The study of Khan, Khan, and Khan (2021) on Afghan refugees' impacts on local society also found that they bring corruption-like social evils to society. This study finding also revealed that they do corruption to avoid deportation and arrest, which weakens enforcement authorities and implications of the law. This finding is consistent with the study done in Malaysia, which highlighted that to avoid deportation and arrest, immigrants use corruption as a tactic that impacts enforcement and destroys border manager logic (Frank, 2018). This behavior also affected locals' access to socioenvironmental services and exacerbated their behaviors by giving bribes to government officials to smooth their process and also avoiding arrest and detention. It's like a hidden tax on people because they have to pay for their processing, etc.; otherwise, they will not get what they want. The involvement of government officials in corruption is like selling the law of the country. This massive corruption has badly affected social services access and worsened the challenges imposed by illegal Afghan immigrants. It became one of the key barriers in navigating official processes and access to social services.

Mismanagement

Illegal Afghan immigrants worsen the already poor management system of social services and resource delivery. Their irregular influx and presence exacerbated overall management, distribution of resources, and access to social services. A participant mentioned that "the existing system was not properly managed to offer suitable access to every member of the community. Their management wasn't enough for locals, and the irregular movement of illegal Afghan immigrants made them more mismanaged. Their irregular movement creates barriers in access to social services and scarce existing resources." The study also revealed that the coordination among social services providers was missing. As a participant shared, "There are various projects of government organizations, non-government organizations, and community-based organizations, but all are done separately. Most of the service providers are working independently. They don't have to coordinate with each other, which is necessary for the effective and good management of the service they provide. Together they would make a comprehensive plan for the whole community, which will provide an environment that will offer easy and barrier-free access to social services for all community members." This finding highlights the harshness of mismanagement challenges due to the presence of illegal Afghan immigrants on already barely sufficient infrastructure. It's revealed that mismanagement of social services access and resource distribution are exacerbated by illegal Afghan immigrants. The distribution of aid and services intended for both illegal immigrants and locals has led to inefficiencies and inequalities, which bring social tension (IOM, 2018). This finding is also consistent with the Khan (2017) study, which found that Afghan refugees have pressure on infrastructure and resources, which leads to mismanagement. The study further highlighted that all service providers need comprehensive coordination and collaboration in mitigating the negative effects of them on the host community. These challenges need to be navigated and solutions found to ensure that all residents of the community have easy access to social services.

Begging

The illegal Afghan immigrant influx increased begging. The children and elders, mostly male and some female, are begging on the streets, roads, and other public places. It was due to economic hardship and their weaknesses. A participant shared their experiences that "illegal Afghan immigrants are mostly used to begging; most of their children are not going to school because of different reasons, so they start begging. Begging is easy but unethical for a physically fit person. Most of the illegal Afghan immigrants are well-fit for work, but still, they beg. Because of their begging, they produce bagging culture in the local community and also influence local community members to start bagging." Another participant says, "The main and worst issue illegal Afghan immigrants brought to our community is begging. We understand some of them start it because they have no other means of survival. But that doesn't mean that they have to beg or that most of them have to beg because

they could find other opportunities by trying. I know many illegal Afghans working in different places like workshops, stores, cafés, etc. If some of them find work, then all could also." The study found that begging is increased with the presence of illegal Afghan immigrants, which aligns with the study of Ojedokun and Aderinto (2015), who emphasize the involvement of migrants in street begging. They beg on streets, roads, and other public places that affect locals, and some start begging; they beg for their survival. The studies in the EU on the context of Romanian Roma migration highlighted begging as work and basic human rights for addressing issues of racism, discrimination, and poverty (Nowicki, 2024). This increased ratio of begging is the echo of wider socioeconomic challenges that exist in the community. Additionally, it's also irritating people and a risk to community security.

The strain on socioenvironmental services provision

The burden on health services

The study revealed that illegal Afghan immigrants pose a burden on the health services of the host community. The health system has a scarcity of resources and deficiencies in providing services to every member of the community. In addition, they become an additional unregulated burden on health services. A participant shared that "illegal Afghan immigrants imposed a burden on health care services by tripling the number of patients. There is a scarcity of medical equipment and other resources, and most of the hospital's beds are full; we have to wait for weeks for our turn. Overall demand for people is more than the current supply of health care services. We have to bear these issues because of them." Another participant shared that "everywhere illegal Afghans have some kind of burden. My aunt is a high blood sugar patient. We go with her for her monthly check-up with the doctor. We have to wait for hours there because of overcrowded conditions. That's stressful and even creates a problem for the patient; the patient is compelled to face that. In hospitals, people sleep on floors at night while waiting for treatment procedures. Seeking health care service and help is difficult nowadays." The finding revealed that the presence of illegal Afghan immigrants' overburdens healthcare services, worsens the quality of health of the host community, and exacerbates healthcare facilities, such as long waiting times and an increase in the cost of healthcare (WHO, 2019). Because of this, most of the community members live without appropriate medical care. The demand for healthcare services is increased; clinics, hospitals, and dispensaries are overcrowded, and medical equipment is being shortened. It shows the severe burden of them on health services (Jathol and Yaseen, 2023). Besides, they also put the burden on diseases that endanger both immigrant and host community health status. They also bear cattle with a lack of hygiene and appropriate cleanliness, which, as a result, spread various diseases (Jathol and Yaseen, 2023). The diseases, especially communicable diseases, increase, which poses a significant risk to public health (WHO, 2019).

The strain on the education system

This study found that illegal Afghan immigrants affected overall education quality; they brought a gap between teacher and student, overcrowded classrooms, and scarce educational resources. Participant says, "Schools are overcrowded, and due to massive student numbers, all students are suffering. I observed changes in my children's learning. They are not as like they were before. Schools here need educational and other certificates while giving admission to students, but illegal Afghan immigrants find illegal ways to get their children admitted, and that affects the overall education system." Another participant shared that "the education services and the resources required are not enough for the local community itself, and illegal Afghan immigrants scarce it to a worse level. My classroom has a capacity of 40 students, but I have 45 students, which now reached 55. It is difficult to give the same and adequate attention to every student. We need more teachers, administrators, equipment, classrooms, and even more schools." The study findings revealed that an increase in several students due to illegal Afghan immigrants badly impacted the quality of education and brought barriers to accessing quality education. This finding aligns with the study of Jathol and Yaseen (2023), which shows the difficulty of a host's access to quality education. They argue that their presence puts a burden on the education system by increasing the student-teacher ratio and scaring resources like textbooks, classroom overcrowding and strength, and tension on qualified teachers. These results deprived educational outcomes and also brought

social inequalities, and quality education access became limited (Amnesty International, 2023).

Economic downgrading

The study found that illegal Afghan immigrants have adverse economic impacts on the host community, especially in informal employment and business sectors. A participant mentioned that "locals are losing informal jobs because of illegal Afghan immigrants' influx. They do the same job for less money and also do more work than locals. They aren't eligible to do formal jobs; that's why they are compelled to do informal jobs without or with fewer conditions, and the employer takes advantage of the situation, which affects locals' informal employment opportunities." Another participant shared that "illegal Afghan immigrants' take over small businesses in Peshawar. It's difficult to compete with them; we have to endorse their hard work and unity. Most of their businesses are more famous than ours. They are also using illegal means of receiving and sending goods to avoid taxes, which strengthens their business, and because of that, they offer the same thing at a cheaper price than us. They are getting command of businesses, and it is frustrating. What do we do? We don't have other opportunities." The study also found that they affected the wages of workers. A participant says, "Stepping up of illegal Afghan immigrants into the labor market, falling wages, and increased competition among workers. Many laborers are compelled to do cheap labor because of them." The study results found that illegal Afghan immigrants have adversely impacted the job market of the host community by taking away jobs, mostly informal, and affecting the wages because of their willingness to work for less pay in a strict environment in which most host workers are not willing. They are agreeing to do work that no one wants to do due to hard work conditions and low pay (Khan, 2017). This finding is also in line with the study of Burns and Gimpel (2000), which found that illegal immigrants increased unemployment and lowered wages. They increased competition for jobs, especially in the informal sector and low-skilled, which also affects employment opportunities and wages. They put pressure on overall employment opportunities (Jathol and Yaseen, 2023). Furthermore, the result shows that many illegal Afghan immigrants are involved in small-scale informal businesses, which expand informal businesses, destabilize the businesses of local businessmen who are obeying formal regulations, and contribute to economic instability (IOM, 2018). Their influx also increased inequality and dependence on the informal economy and reduced economic mobility (World Bank, 2018). The economic displacement of residents was due to the competition for jobs and business opportunities and fluctuating market dynamics. The study conducted by Jathol and Yaseen (2023) also found that Afghan refugees pose an economic threat to Pakistan. This needs to be addressed to make sure that the host community has equal and easy economic opportunities and stable business access.

Scarcity of housing

This study found that illegal Afghan immigrants affected housing affordability and accessibility. Their high demands for houses make the prices of rent higher and creates difficulty in finding affordable and adequate houses for living. As that participant shared, "Finding an appropriate house is difficult because of the illegal Afghan immigrant's demands and their situation. Most of them are richer than locals, and they agree with all conditions of the house because of their illegal status and lack of required documents. All decent houses are rented by them, which now creates an issue of finding houses for both locals and themselves." Another participant says, "Due to the presence of illegal Afghan immigrants, the rents of houses become high as owners know that they will rent their houses whatever the demand is. On the other hand, illegal Afghan immigrants are also ready to pay a high amount of rent and accept other conditions of owners because of their needs and situation. This poses negative effects on housing, which locals suffer with unaffordable houses." The finding revealed that housing scarcity was worsened by overcrowdedness due to illegal Afghan immigrants, which increased the rents, made it difficult to find affordable houses, and strained overall infrastructure. A study by Belgasem (2005) argues that illegal immigrants led to overcrowding and infrastructure deteriorating by occupying abandoned houses. The inaccessibility, unavailability, and unaffordability of houses caused hardship for many residents in accessing housing. The study of Whitehead (2011) also shows the impact of immigration on the housing market, such as housing social requirements and costs. The study

findings revealed price hiking is a major issue for both community members and them, consistent with the study in Malaysia, which also found the negative impact of immigrants on housing prices (Leh *et al*., 2017). Besides, they not only increase rents or short adequate houses but also scarce utilities such as commodities, electricity, water, etc. It affects both locals and illegal immigrants to live in substandard housing conditions (Amnesty International, 2023).

Environmental challenges

The study found that illegal Afghan immigrants have terrible impacts on the environment of the host society. A participant shared that "Illegal Afghan immigrants are using wood for cooking and rope our heads. They are cutting trees for personal use, which abolishes greenery and affects air quality. They also cut trees for clearing land for living, which contributes to deforestation." Another participant says, "Illegal Afghan immigrants throw trash in open areas and fire that there, which pollutes the environment. They also throw their trash into canals, etc., which contaminates water. They don't care about others or themselves and even don't know the ethics of throwing trash. There was already a lack of water, which was further worsened by their presence." The study finding shows that illegal Afghan immigrants put pressure on the environment and major environmental challenges on the host community. Skanavis and Kounani (2016) also found that illegal immigrants have major environmental impacts on the receiving community. The environmental challenges include deforestation, as trees are cleared for housing, etc., and use of wood for fire and floor making; increased pollution (Jathol and Yaseen, 2023); water scarcity as demand for clean water increased (Romero, 2015); and natural resource degradation. Studies indicate that 82% of the population lacks clean water access, and about 30-40% of hospitalized patients are credited with waterborne disease (Ziad *et al., 2016*). It degrades the environment, has long-term implications for the region's sustainability, and contributes to climate change. It affected the overall quality of life of the entire residents of the community and endangered public health (Khan, 2017). Besides the poor waste management scenario considered as poor treatment technology, lack of recycling system, lack of collection capacity, and lack of manpower could lead to humanitarian and environmental hazards. The study also revealed that the refugee settlements lack proper waste disposal facilities, leading to the improper disposal of waste, including plastics and other non-biodegradable materials. In addition, increased use of biomass for cooking and heating in refugee camps contributes to indoor air pollution. This pollution can contaminate water sources, soil, and air, leading to respiratory and gastrointestinal illnesses. Furthermore, the study findings highlighted that illegal Afghan immigrants increased waste pollution, and their presence led to land degradation, which results in environmental pollution that will affect the public health and well-being of residents. The improper waste disposal practices among Afghan migrants, often due to lack of awareness and access to adequate sanitation facilities, contribute to environmental pollution and pose health risks to both migrants and host communities. The finding is consistent with the study of Kherfan (2016), who concluded that not eradicating the impacts of immigrants will lead to environmental pollution. In addition, human waste disposal by refugees contaminates local groundwater and causes the spread of diseases. It affected all people who lived in that society, and they suffered from various diseases like cholera, malaria, diarrhea, etc. This not only has consequences for the host society but also for the immigrant community as well.

Responses of government and community

Government level responses

The study reveals that the government is trying to mitigate the challenges imposed by illegal immigrants. As the participant claimed, "Our government implemented various projects, most of which are under progress, and their result is productive. To manage the situation, the government is continuously trying its best and doing everything within its capability. I know the situation is worse because of illegal Afghan immigrant's illegality and the country's less developed status. But I hope soon we will overcome the situation." However, this study also found that some community members opposed and complained about the government's claim. A participant shared that "most of the government plans and projects are in papers; they aren't properly implemented. And in the case of illegal Afghan immigrants, the government either has to make a plan to integrate them there or repatriate

them in peaceful manners." The study found that governments are struggling to mitigate the existing challenges of the community and also the additional challenges due to illegal Afghan immigrants, such as building camps to avoid overpopulation and their negative consequences on hosts (Centlivres and Centlivres-Demont, 1988). However, the fact is that as a developing nation, it has a lack of resources, which brings gaps in services access and resource delivery. In addition, due to the irregularity and absence of documented illegal Afghan immigrants, who are exactly unknown, they are difficult to manage without knowing their numbers and other characteristics. On the other hand, the lack of proper action from the government side has distrusted locals and made them face challenges. And there is also a gap between policy intent and predicted effectiveness.

NGO response

The study found that NGOs are responding well in providing supporting services. They are best at it, and their efforts are praised by community members as well. A participant shares that "NGOs are bridging the gap between government services and locals. They are providing social services like healthcare, education, and food to needy people in society. They also provide shelter to those who need it most. One NGO in our neighborhood installed a hand pump, which benefited many people in fulfilling their water needs." Another participant shared their experience, "It was very difficult in the absence of NGOs; I can't imagine what would happen if their support wasn't there. They are providing immediate needs of people; I know there is one NGO that provides shelter, medical care, and food, which is very supportive for the needy and for the whole community." The finding revealed that NGO works are praised mainly for mitigating the gap in supporting services left by the government and in addressing the immediate needs of people. They play a key role in supporting illegal immigrants, mostly filling gaps left by official policies (Kersch and Mishtal, 2016). Especially in the areas of health, education, and legal aid for illegal immigrants, by providing educational programs for children, vocational training for adults, and medical camps. Studies in Italy also argue that in the protection of the human rights of unauthorized immigrants, NGOs provide essential health services to them (Ambrosini, 2015). They are advocating for the rights of illegal Afghan immigrants, highlighting human policies and inclusion within the host societies. The same, in the Netherlands, civil society organizations continue to provide support and shelter to irregular immigrants, despite exclusionary administration rhetoric. (Ambrosini and Van, 2015). However, the study also observes some barriers that NGOs had, such as limited funds, the challenging security situation in Peshawar, and bureaucratic hurdles. However, they should make tough decisions to support deserving individuals, frequently reflecting national policy priorities (van der Leun and Bouter, 2015).

Community Responses

The study found that the local community responses are mixed, formal, and informal. It's both fatigue and resilience for the community. Most community leaders, like elders and religious scholars, play key roles in it. A participant shared, "We have illegal Afghan immigrants in our community; we have to integrate with them. They are new and strange to us, but we have to communicate with them, try our best to integrate with them, and make them productive members of our community. Because they are part of the community, and every act affects our community, we have to try for good sides that will benefit the community as a whole." On the other hand, a participant said, "We are frustrated due to the presence of illegal Afghan immigrants. We face many challenges in many sectors like education, health, and welfare services. They also scare our environmental resources. We took on shoulders too much." The community also plays a crucial role in managing the impacts of illegal Afghan immigrants, besides their various challenges. The study finding and observation found that some support based on the same ethnicity, culture, and religion was also found for illegal Afghan immigrants, which not only decreased their adverse effects but also introduced a way to integrate into the host community. The study by UNDP (2015) also found that some religious groups, local charitable organizations, and individual citizens have supported illegal Afghan immigrants in various forms, such as providing shelter, food distribution, informal education, and employment opportunities. To improve public safety and integration of immigrants into civic life, communities are enthusiastically working (Matos, 2008). On the other hand, the competition for social services such

as jobs, housing, education, and healthcare and the strain on resources create social tension between illegal Afghan immigrants and the local population. Additionally, the stereotypes and negative perceptions about illegal Afghan immigrants lead to economic insecurities and social anxieties, which result in social friction and outright aggression. This is consistent with the previous study, which shows humanitarian values, racism, and negative stereotypes were negative attitudes associated with illegal immigrants (Cowan *et al.*, 1997). This duality of community responses emphasizes the challenges of developing social cohesion in environmental resources, and illegal immigrants are seen as a burden instead of a benefit. The variety in responses is based on neighborhood, community, and also local policing practices, and faith-based engagement (Menjívar and Kanstroom, 2014). The study findings highlighted the need for more durable coordination between government and stakeholders to navigate and mitigate the challenges posed by illegal Afghan immigrants, who are not only impacted by the impacted community but also by the government and some NGOs as well, and they have responses as shown in Fig. 3. This is aligned with previous studies that show that for promoting sustainable development and addressing social and environmental challenges, collaboration and coordination are vital (IPCC, 2018).

Limitations and future research suggestions

The study has some limitations, while it offers a comprehensive analysis of the socioenvironmental consequences of undocumented Afghan immigrants. Although the approach of purposive sampling is effective in gathering in-depth data, it may limit the generalizability of the findings. Future studies could use probability sampling to validate these findings with diverse and large groups. In addition, the study's focus on Peshawar presents a contextual restriction. The findings are very useful for national socio-environmental strategies, although they might not fully reflect the experiences of other undocumented immigrants in the host area. In this case, a comparative study in different areas could lead to a better understanding of this issue and find region-specific challenges and their solutions. Furthermore, longitudinal studies investigating the socioenvironmental impacts of undocumented immigrants may improve our understanding of these phenomena over time. Despite these limitations, this study will trigger policy conversation and additional research, laying the groundwork for policymakers and researchers to address these critical challenges with greater insight and accuracy.

CONCLUSION

This study comprehensively analyzed the challenges in the socioenvironmental services of the host community due to harboring illegal Afghan immigrants. The finding revealed significant pressure on social services, including education, housing, health, and employment, combined with environmental degradation because of illegality, overcrowding, and resource depletion. It demonstrated that these issues extend beyond Peshawar, representing a broader sustainability issue for urban regions throughout South Asia that accommodate considerable populations of illegal immigrants. This study underscores the pressing necessity for specific-context solutions by analyzing these issues via a localized perspective, including both the current demands on social services and the overarching objective of regional stability. It also shows the importance of considering immigration in the context of community resilience, environmental policy, and urban management instead of standalone issues. Despite the efforts by government organizations, NGOs, and community organizations, the challenges still exist. These challenges are not only locally imposed, but they are also a broader issue of regional stability and sustainability. The study emphasized the need for a multi-faceted approach that comprises vigorous policy reforms, greater community engagement, and coordination among governmental and other concerned organizations to mitigate socio-environmental challenges posed by illegal Afghan immigrants. Policy reforms are necessary to address the socioenvironmental consequences of undocumented immigration. Government interventions, combined with large community engagement, can mitigate the pressure on social services and promote more harmonious relationships within the host society. Policies should also focus on mitigating environmental impacts by strengthening urban resource management, such as sustainable housing, waste, and water management, potentially with the partnership of community organizations and environmental NGOs. In addition,

this study's findings emphasize the necessity of cross-sectoral coordination among governmental agencies, NGOs, and local organizations to develop comprehensive strategies for addressing these challenges. Furthermore, the study highlights the need for greater awareness and understanding of the experiences of all immigrants, especially illegal Afghan immigrants, due to their large number, in Pakistan. This approach may foster the development of more resilient, inclusive, and adaptable policies for urban areas experiencing comparable migratory pressures. By adopting these recommendations, policymakers can help foster social cohesion and mitigate resource conflicts within impacted communities. By shifting focus from the commonly investigated security and humanitarian concerns of Afghan immigration to the socioenvironmental impact on the host community, this study offers a unique contribution to migration studies. This study offers innovative contributions to the enhancement of sociological understanding and the formulation of more vicarious policies that settle humanitarian assistance with sustainable global development in the context of instability. It also contributes to the theoretical understanding of immigration's socio-environmental impacts, showing that immigration-induced strain on resources can have broader implications for regional stability and sustainability. Secondly, concentrating on Peshawar addresses a significant void in migration studies by offering specialized perspectives on socio-environmental concerns that may resemble those encountered by other metropolitan centers in South Asia with equivalent migratory dynamics. Thirdly, the study proposes a paradigm for community and governmental partnership that highlights a comprehensive strategy for addressing migration-related challenges, potentially guiding future research and practice in associated domains. Furthermore, the findings from this study have implications beyond Peshawar, offering a model for examining the socio-environmental impacts of undocumented immigration in other contexts. By focusing on Peshawar's experience, this research provides a framework for similar urban centers facing comparable immigration pressures to assess their own social service and environmental capacities. This approach allows for adaptation and comparison in studies of undocumented migration in South Asia or globally, where undocumented populations often influence urban sustainability and resource availability. Moreover, the methodologies employed here, including thematic analysis and quantitative data examination, can serve as a template for further studies aiming to analyze the social and environmental impacts of undocumented immigrant populations in other regions.

AUTHORS CONTRIBUTIONS

Conceptualization, I. K and L.H.; Methodology, I. K; Supervision, L.H; Data collection and analysis, I. K; Writing—original draft, I. K; Writing—review and editing, I. K.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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Tehran Urban Research & Planning Centre (TURPC) takes a neutral position about claims on disputed territories, place names, international boundaries, jurisdiction in published maps, and institutional affiliations. TURPC is committed to retracting a paper after its publication if it becomes apparent that there are serious problems in its content, in terms of research and publication ethics (https://www.ijhcum.net/journal/process?ethics).

ABBREVIATIONS (NOMENCLATURE)

AREU	Afghanistan Research and Evaluation Unit
BRT	Bus Rapid Transit
C & C	Coordination and collaboration
Cos	Community organizations
GOs	Government organizations
IOM	International organization for migration
K.P	Khyber Pakhtunkhwa Province
NGOs	Non-Government Organizations
NVivo	Non-Voice Interaction VOICE
PBS	Pakistan Bureau of Statistics
QSR	Quality System Regulation
SPSS	Statistical Package for the Social Sciences
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNHCR	United Nations High Commissioner for Refugees
US	United States
WB	World Bank
WHO	World Health Organization

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ORIGINAL RESEARCH PAPER

Overcoming urban entrepreneurship challenges: Analyzing barriers to economic development

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ABSTRACT

BACKGROUND AND OBJECTIVES: Urban entrepreneurship is recognized as a significant driver of economic growth and innovation, particularly in urban areas. Entrepreneurs in urban environments face various challenges that can impede their success and hinder urban economic development. This research aims to identify and analyze these key barriers urban entrepreneurs face to provide insights into areas requiring intervention and support for sustainable urban economic growth.

METHODS: A literature review identified a comprehensive list of 30 challenges covering various aspects such as access to capital, regulatory complexity, market saturation, and competition from big corporations. These challenges were then analyzed using fuzzy Decision-Making Trial and Evaluation Laboratory analysis to assess their interrelationships and their relative importance in influencing urban entrepreneurship and economic development.

FINDINGS: The study identifies several critical barriers to urban entrepreneurship and economic development, including high operating costs, regulatory complexity, market saturation, and infrastructure deficiencies. Social inequality, economic instability, lack of government support, technological disruption, and competition from big corporations also emerged as significant challenges. These findings underscore the need for tailored interventions in urban management to foster entrepreneurial growth and support sustainable economic development. The results from the study, with values ranging from 5.7 to 12.8, highlight key factors impacting entrepreneurial growth in urban environments. Access to capital (6.0-12.5), regulatory complexity (5.8-11.5), market saturation (6.1-12.8), and infrastructure deficiencies (5.7-12.5) were identified as crucial obstacles. Understanding these challenges and their interconnections provides valuable insights for policymakers, urban planners, and stakeholders to develop targeted strategies and interventions to support urban entrepreneurship and foster sustainable economic growth. These findings provide insights for urban management and policy interventions to support entrepreneurship and foster sustainable economic growth in cities.

CONCLUSION: This study's findings underscore the importance of addressing key challenges faced by urban entrepreneurs to create a conducive environment for their success and promote sustainable urban economic development. By implementing targeted policies and interventions to mitigate these barriers, policymakers and stakeholders can foster innovation, create job opportunities, and enhance the vibrancy and resilience of urban economies. This research contributes to the body of knowledge on urban entrepreneurship and provides practical implications for promoting economic growth and prosperity in urban areas.

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INTRODUCTION

Entrepreneurship is a key driver of economic growth and innovation, from small start-ups to multinational corporations, contributing to individual success and societal progress (Gulati *et al.,* 2023). The importance of urban environments in fostering entrepreneurship has gained recognition, as urban areas provide dense populations, diverse talent, infrastructure, and networks that enable collaboration and market access (Ferraris *et al.,* 2020). The rise of urban entrepreneurship has been further fueled by digitalization, globalization, and demographic shifts, which have transformed business models and opened new opportunities for cross-border expansion (Tavassoli *et al.,* 2021). (Afshan *et al*., 2021) explored the resilience of women entrepreneurs during the Coronavirus Disease of 2019 (COVID-19) pandemic, while (Ahmed and Ahmed, 2021) highlighted the constraints faced by youth entrepreneurs in Ethiopia, underscoring the need for targeted support in emerging economies. (Appolloni *et al*., 2021) examined urban rooftop agriculture as a sustainable solution for urban food security, reflecting the integration of environmental sustainability in urban entrepreneurship. (Arabiun *et al*., 2024) investigated the role of digital leadership and employee job satisfaction in influencing organizational entrepreneurship. (Ferraris *et al*., 2020) explored how sustainable business practices in smart cities drive innovation and economic development. The impact of entrepreneurial ecosystems was examined by (Guerrero *et al*., 2021) and (Cherubini *et al*., 2021) with a focus on their role in fostering entrepreneurial success. (Franco and Rodrigues, 2022) developed indicators for measuring sustainable urban entrepreneurship, while (Tien *et al*., 2023) discussed green entrepreneurship's transformative role in Vietnam. (Zhang *et al*., 2024) analyzed the challenges faced by rural-to-urban migrant workers, emphasizing the importance of urban cultural diversity in entrepreneurship. (Konietzko *et al*., 2023) explored the role of environmental regulations and regenerative business models in entrepreneurship, while (Zhao and Weng, 2024) examined the impact of the digital economy on urban entrepreneurship. (Tellman *et al*., 2021) explored urban development, focusing on institutional entrepreneurs and financing business models for urban growth. These studies underscore the multifaceted nature of urban entrepreneurship and the barriers entrepreneurs face, highlighting the need for a nuanced understanding of both local and global factors affecting economic development. The study of urban sustainability in Jordan reveals that national research priorities lack specificity, calling for a clearer agenda that aligns with local needs in areas such as transportation and land use planning (Okour *et al*., 2024). (Sudmant *et al*., 2024) argue that urban research would benefit from a focus on replication and generalizability, which could enhance the translation of findings across disciplines and advance empirical studies in urban contexts. Studies on innovative development in low-carbon urban economies highlight the need for evaluating the impact of green fiscal policies on technological innovation, particularly in diverse city environments (Wang *et al*., 2024). Collectively, these studies stress the importance of bridging knowledge gaps through focused and cross-disciplinary research efforts in urban entrepreneurship. The main objectives of this study are

(i) To conduct a comprehensive review of the literature on urban entrepreneurship and the challenges faced by entrepreneurs in urban environments;

(ii) To employ fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) analysis to examine the interrelationships among the identified challenges and determine their relative importance;

(iii) To assess the implications of these challenges for economic development and the overall competitiveness of urban economies;

(iv) To provide recommendations for policymakers, urban planners, and stakeholders to address these challenges and foster a conducive environment for urban entrepreneurship and sustainable economic growth.

To achieve the objectives outlined in this study, this study will utilize the Fuzzy DEMATEL methodology. Fuzzy DEMATEL is a sophisticated analytical tool designed to analyze complex interrelationships among various factors or variables systematically. By employing fuzzy logic, DEMATEL accommodates the inherent uncertainties and ambiguities in real-world data, providing a more precise understanding of the relationships among the identified challenges in urban entrepreneurship. Through the application of fuzzy DEMATEL, this study

aims to unravel the intricate web of connections among these challenges, discern their relative importance, and identify critical leverage points for strategic interventions. With this methodology, it will be possible to produce useful insights that can guide the creation of policies, plans for urban areas, and business plans that promote inclusive and sustainable urban growth. This study was conducted at the Presidency College (Autonomous), Bangalore, India, and the Kalasalingam Academy of Research and Education, Krishnankoil, India, in January 2024.

Urban entrepreneurship: A distinct phenomenon

Urban entrepreneurship is shaped by the unique dynamics of urban environments, thriving in densely populated, diverse settings (Cherubini Alves *et al*., 2021). Unlike rural or suburban entrepreneurship, which may operate in more isolated areas, urban entrepreneurship benefits from proximity to customers, suppliers, collaborators, and diverse ideas (Konietzko *et al*., 2023). Urban areas act as melting pots for creativity, fostering collaboration and innovation (Zhou *et al*., 2020). The density of economic activity provides entrepreneurs with access to vital resources such as co-working spaces, incubators, and mentorship (Ciacci and Ivaldi, 2023), creating a support system that nurtures venture growth (Madaleno *et al*., 2022). This ecosystem generates a virtuous cycle of entrepreneurship, where successful ventures stimulate demand, attract investment, and contribute to economic resilience (Bathelt *et al*., 2023), drawing even more entrepreneurs to urban areas (Awonuga *et al*., 2024). Urban entrepreneurship plays a pivotal role in economic development by fostering innovation and growth within cities. Urban areas, as hubs of economic activity, attract diverse talent, ideas, and resources, creating a fertile ground for entrepreneurial ventures (Tien *et al*., 2023). Urban entrepreneurs, with their ability to identify opportunities in dynamic environments, contribute significantly to shaping the economic trajectory of cities (Franco and Rodrigues, 2022). Their ventures drive innovation, introduce new business models, and disrupt traditional industries, sparking further growth (Arief *et al*., 2021). Beyond business success, urban entrepreneurship contributes to job creation, poverty reduction, and wealth generation within local economies (Cullen and De Angelis, 2021). By addressing societal challenges, urban entrepreneurs also promote inclusive and sustainable development, focusing on issues such as affordable housing, healthcare access, and environmental conservation (Peter, 2021). Urban entrepreneurship not only drives economic growth but also has significant societal impacts, particularly in poverty reduction and social inclusion (Arabiun *et al*., 2024). Entrepreneurs from underserved communities often create businesses that address local needs, improving quality of life and promoting social mobility (Hosseini *et al*., 2020). Urban ventures can foster community engagement and cohesion, creating spaces for collaboration and cultural exchange (Bakhtiari and Jalilian, 2018). Urban entrepreneurship also advances environmental sustainability, with entrepreneurs developing solutions in renewable energy, waste management, and sustainable agriculture, contributing to a more resilient urban future.

Challenges of urban entrepreneurship in economic development

Urban entrepreneurship faces numerous challenges that hinder its growth and sustainability. Key barriers include access to capital, with entrepreneurs struggling to secure funding from limited resources like loans, grants, or venture capital (Rusu *et al*., 2022). Regulatory complexities add further burdens, increasing costs and administrative hurdles (Daniel *et al*., 2022). Market saturation, particularly in crowded urban areas, makes it difficult for new businesses to stand out (Ziyae *et al*., 2023), while infrastructure deficiencies such as inadequate transport networks and digital connectivity limit business operations (Zhao and Weng, 2024). Social inequalities, cultural barriers, and risk aversion are prevalent in urban environments, restricting opportunities for marginalized communities (Ahmed and Ahmed, 2021). Environmental issues like pollution and safety concerns further deter investment and consumer spending (Kong and Qin, 2021), while bureaucratic inefficiencies and economic instability make it difficult for businesses to thrive (Rizza and Lucciarini, 2021). A lack of access to affordable housing and healthcare services affects workforce stability and productivity. The interplay of these challenges compounds the difficulties faced by entrepreneurs. Regulatory issues may overlap with limited market access, and infrastructure gaps may discourage investment in certain areas.

These dynamics are exacerbated by demographic changes and technological disruption, which require entrepreneurs to continually adapt to shifting market conditions and consumer preferences (del Olmo-García *et al*., 2023; Dia *et al*., 2021). Socio-economic factors significantly shape urban entrepreneurial challenges, affecting resource access and market dynamics. In Mashhad, Iran, land speculation rather than business activity drove profitability, highlighting economic distortions (Hasani and Sarvari, 2024). In Wuhan, China, infrastructure, diversity, and policy factors were key to fostering entrepreneurial ecosystems for knowledge-intensive business services (Ma and Huang, 2024). Globally, better human capital and governance reduce necessity-driven entrepreneurship, promoting innovation and sustainable ventures (Arshed *et al*., 2023). Addressing these socio-economic barriers through targeted policies and investment can enable urban entrepreneurs to thrive and contribute to sustainable economic growth. Understanding the intricate interplay of these challenges is crucial for developing effective strategies and interventions to support urban entrepreneurship and drive inclusive economic development. Urban entrepreneurship faces multifaceted challenges, ranging from market misalignments to technological and socio-environmental constraints. A key factor is the alignment of entrepreneurial attitudes with market demands. Studies on Entrepreneurial Attitude Orientation (EAO) and market orientation in Malaysia demonstrate how fostering proactive, market-aligned behaviors can significantly improve entrepreneurial outcomes in urban settings (Karami *et al*., 2014). Similarly, leveraging advanced technologies like artificial intelligence and big data analytics, as evidenced in water resource management, highlights how technological innovation can overcome inefficiencies and create scalable urban business models (Kamyab *et al*., 2023). The interplay of economic, social, and environmental factors is crucial. A review of electric vehicle adoption shows how government incentives, infrastructure, and public awareness can shape business opportunities (Farajnezhad *et al*., 2024). Applying these insights, urban entrepreneurs can develop multidimensional strategies that balance mark*et al*ignment, innovation, and sustainability. This paper builds on these findings to present an integrated framework addressing urban entrepreneurship barriers.

Parameterization of challenges in urban entrepreneurship

In analyzing the challenges faced by urban entrepreneurs, this study employed a comprehensive approach to parameterize and categorize these obstacles. This process involves defining and contextualizing each challenge based on its impact, scope, and relevance within the urban entrepreneurial landscape. Table 1 shows the challenges faced by urban entrepreneurs towards economic development.

The key parameters used in this analysis include:

1. *Impact:* This parameter assesses the significance of each challenge on the overall success and sustainability of urban entrepreneurial ventures. Challenges are evaluated based on their direct and indirect effects on business operations, financial stability, and growth potential.
2. *Scope:* The scope parameter considers the extent to which each challenge affects different segments of the entrepreneurial ecosystem. This includes evaluating whether the challenge is specific to certain industries, geographic areas, or stages of business development.
3. *Relevance:* This parameter determines how pertinent each challenge is to the current urban entrepreneurial environment. Relevance is assessed by examining contemporary trends, regulatory changes, and emerging issues that influence entrepreneurial activities in urban settings.
4. *Interrelation:* To understand the interplay among challenges, this study analyzed how individual obstacles interact with and influence each other. This includes exploring how challenges like regulatory complexity might exacerbate issues related to access to capital, or how market saturation can affect competitive dynamics.
5. *Literature support:* Each challenge is supported by relevant academic literature that provides empirical evidence and theoretical insights into its significance. This includes reviewing previous studies and research findings to validate the presence and impact of each challenge.
6. *Contextual factors:* This study also considered contextual factors such as economic conditions, technological advancements, and demographic changes that may modify the nature

Table 1: Challenges faced by urban entrepreneurs towards economic development

Code	Challenges	Description	Literature review(s)
B1	Access to Capital	Difficulty in obtaining funding and investment to start or grow a business due to limited access to capital resources.	Rusu *et al.,* 2022
B2	Regulatory complexity	Complex and cumbersome regulatory processes, permits, and compliance requirements create barriers and increase costs.	Daniel *et al.,* 2022
B3	Market saturation	Overcrowded markets with numerous competitors offering similar products or services, make it challenging to attract customers.	Ziyae *et al.,* 2023
B4	Limited market access	Difficulty in accessing new markets, domestically or internationally, due to trade barriers, tariffs, or lack of distribution.	Ahmed and Ahmed, 2021
B5	Infrastructure deficiencies	Inadequate transportation networks, utilities, and digital connectivity hinder business operations and economic development.	Zhao and Weng, 2024
B6	Lack of skilled workforce	Shortage of qualified workers, leading to recruitment challenges and productivity issues.	Kayanan, 2022
B7	Digital divide	Disparities in access to technology, limit opportunities for online entrepreneurship and innovation.	Gerli and Whalley, 2022
B8	High operating costs	Rising costs of rent, utilities, and labor, squeezing profit margins and competitiveness.	Appolloni *et al.,* 2021
B9	Social inequality	Persistent disparities in income, education, and access to resources based on race, gender, or socioeconomic status.	Zhou *et al.,* 2020
B10	Cultural barriers	Norms and social expectations may discourage entrepreneurship or favour traditional employment paths.	Zhang *et al.,* 2024
B11	Risk aversion	Reluctance to pursue entrepreneurial opportunities due to fear of failure or financial insecurity.	Nyanga and Chindanya, 2021
B12	Urban congestion	Traffic congestion and limited space in urban areas, increase costs and commute times for businesses.	Krylatov and Raevskaya, 2024
B13	Environmental pollution	Pollution and degradation, pose health risks and environmental challenges for businesses and communities.	Kong and Qin, 2021
B14	Land use restrictions	Zoning regulations and urban planning restrictions limit land availability for business development.	Tellman *et al.,* 2021
B15	Limited networking opportunities	Challenges in building professional networks and partnerships due to geographical or social barriers.	Reuschke *et al.,* 2022
B16	Bureaucratic red tape	Excessive bureaucracy and administrative procedures, cause delays and inefficiencies for entrepreneurs.	Rizza and Lucciarini, 2021
B17	Economic instability	Volatility in economic conditions, affecting business confidence, investment decisions, and financial sustainability.	Moritz *et al.,* 2023
B18	Lack of government support	Insufficient policies and incentives to support entrepreneurship, innovation, and small business development.	Dorst *et al.,* 2022
B19	Access to affordable housing	Limited availability of affordable housing options, contributing to housing insecurity and workforce challenges.	Haffner and Hulse, 2021
B20	Transportation challenges	Inadequate public transportation and traffic congestion affect commuting times and business logistics.	Lindkvist and Melander, 2022
B21	Crime and safety concerns	High crime rates and safety hazards in certain urban neighbourhoods, deter business investment and economic activity.	Tulumello and Iapaolo, 2022
B22	Limited access to education	Lack of access to quality education and entrepreneurial programs essential for business success.	Debarliev *et al.,* 2022
B23	Demographic changes	Shifting demographics influence consumer preferences and workforce dynamics, posing challenges and opportunities.	del Olmo-García *et al.,* 2023
B24	Technological disruption	Rapid advancements in technology disrupt traditional industries and require adaptation from entrepreneurs.	Dia *et al.,* 2021
B25	Regulatory uncertainty	Uncertainty in government policies and regulations leads to compliance risks and investment hesitation.	Wang *et al.,* 2021
B26	Trade barriers	Tariffs, trade restrictions, and protectionist policies limit access to international markets and impede export opportunities.	Xu *et al.,* 2022
B27	Access to healthcare	Limited access to affordable healthcare services, results in productivity issues and financial burdens.	Afshan *et al.,* 2021
B28	Intellectual property rights issues	Challenges in protecting intellectual property, particularly in innovative industries with high levels of intellectual capital.	Ferraris *et al.,* 2020
B29	Access to information	Limited access to market data and business intelligence resources essential for informed decision-making in entrepreneurship.	Ye *et al.,* 2023
B30	Competition from big corporations	The dominance of large corporations' limits market competition and innovation among small businesses and startups.	Audretsch, 2021

and impact of the challenges.

By parameterizing the challenges based on these criteria, this study aims to provide a nuanced understanding of the urban entrepreneurial environment. This approach allows us to identify and prioritize the most pressing issues, offering a foundation for targeted interventions and strategic recommendations.

Table 1 highlights the major obstacles to economic development that urban businesses must overcome. Since it's still challenging to secure funding for business expansion, access to capital is the key obstacle (Rusu *et al.,* 2022; Zhao and Weng, 2024). Complex regulations make compliance more difficult and raise operating expenses (Daniel *et al.,* 2022; Wang *et al.,* 2021). A fierce competition brought on by market saturation makes acquiring new customers difficult (Ziyae *et al.,* 2023; Xu *et al.,* 2022). Growth opportunities are further restricted by limited market access resulting from trade obstacles and tariffs (Ahmed and Ahmed, 2021; Dia *et al.,* 2021). According to (Zhao and Weng 2024), insufficient infrastructure hinders operational efficiency, and a lack of competent labor has an impact on productivity (Kayanan, 2022). Online entrepreneurship is impacted by the digital divide, which restricts access to technology (Gerli and Whalley, 2022). The terrain of entrepreneurship is complicated by social inequalities, rising operating expenses, and cultural impediments (Appolloni *et al.,* 2021; Zhou *et al.,* 2020; Zhang *et al.,* 2024). Additional factors that hinder innovation include risk aversion, urban congestion, and environmental degradation (Nyanga and Chindanya, 2021; Krylatov and Raevskaya, 2024; Kong and Qin, 2021). An adverse business environment is produced by land use restrictions, limited networking opportunities, bureaucratic red tape, and economic volatility (Tellman *et al.,* 2021; Reuschke *et al.,* 2022; Rizza and Lucciarini, 2021; Moritz *et al.,* 2023). Workforce issues are made worse by a lack of government assistance and affordable housing (Dorst *et al.,* 2022; Haffner and Hulse, 2021). The environment for entrepreneurship is made more difficult by issues with transportation and criminality (Lindkvist and Melander, 2022; Tulumello and Iapaolo, 2022). Lastly, quick adaptation is required due to restricted access to high-quality education and rapid technological disruption (Debarliev *et al.,* 2022; Ferraris *et al.,* 2020). While taken as a whole, these difficulties highlight the difficulties faced by urban entrepreneurs while promoting sustainable economic growth (Afshan *et al.,* 2021; Ye *et al.,* 2023; Audretsch, 2021).

Research gap

Understanding the challenges faced by urban entrepreneurs is crucial for policymakers, urban planners, and stakeholders seeking to create an enabling environment for entrepreneurship and economic development in urban areas. By identifying and addressing these challenges, it becomes possible to develop targeted interventions and support mechanisms that foster entrepreneurial activity, promote business growth, and enhance the overall competitiveness and resilience of urban economies (Fritsch and Mueller, 2004; Welter and Smallbone, 2011). Despite the importance of this topic, there remains a gap in the literature regarding the systematic analysis of the barriers to urban entrepreneurship and their implications for economic development. Existing studies often focus on specific challenges or individual cities, limiting their generalizability and applicability to broader contexts (Mason and Harrison, 2006). There is a need for comprehensive research that examines the multifaceted nature of urban entrepreneurship challenges and their interrelationships, taking into account the diverse contexts and dynamics of urban environments.

MATERIALS AND METHODS

Data sampling

For this research on urban entrepreneurship challenges, a mixed-method approach will be employed to gather comprehensive data. The data collection process will involve both quantitative and qualitative techniques to ensure a thorough understanding of the identified challenges. Quantitative data will be collected through online surveys distributed to a sample of urban entrepreneurs across various industries. The survey will be designed to gather structured responses regarding the challenges they face in their entrepreneurial endeavors. The survey questions will be derived from the list of challenges identified in the literature review section. Row and column matrices were created to get pairwise relationships. A stratified random sampling technique will be utilized to ensure representation from different sectors. Three

distinct sectors have been identified: technology, manufacturing, and services. In the technology sector, 25 entrepreneurs will be sampled, representing startups and companies involved in software development, information technology services, and digital innovation. Similarly, 25 entrepreneurs from the manufacturing sector will be selected to explore challenges pertinent to manufacturing processes, supply chain management, and market competition. 20 entrepreneurs will be sampled from the services sector, encompassing businesses offering intangible services such as consulting, financial services, and healthcare. This stratified sampling will result in a total sample size of 70 entrepreneurs, providing insights into sector-specific challenges and facilitating a nuanced understanding of urban entrepreneurship dynamics.

Validation - Fuzzy Delphi Technique (FDT)

The FDT is a method that uses fuzzy logic with traditional one to collect and process expert opinions. This technique is used to address uncertainty and imprecision in expert answers. In FDT, a group of experts answers a series of questions, and their answers are processed for subjective judgments. Table 2 provides the measuring scale for various challenge scores Corresponding to Triangular Fuzzy Number (TFN) and Table 3 provides the validity and reliability of various challenges with a threshold value α=5.

Triangular Fuzzy Numbers (TFNs) are essential in mitigating subjectivity and uncertainty in decision-making, especially in the assessment of qualitative elements such as the significance of obstacles (Table 2). Linguistic phrases like "Very unimportant," "Unimportant," "Normal," "Important," and "Very important" are all represented in the provided Table 2 by a TFN, which is characterized by three values (l,m,u): the upper bound u, the most likely or central value m, and the lower bound l. "Very unimportant" is linked to the TFN (0.1, 0.3, 0.3), in which 0.1 to 0.3 is the range of importance. "Unimportant" is denoted by (0.1, 0.3, 0.5), which indicates a wider range of significance, with 0.3 being the most likely value. With 0.5 as the center value, "normal" is awarded (0.3, 0.5, 0.7), indicating moderate relevance. "Important" is equivalent to (0.5, 0.7, 0.9), where the range of significance is from 0.5 to 0.9, with a peak at 0.7. The TFN for "very important" is (0.7, 0.9, 0.9), which denotes a high degree of importance centered on 0.9. A more complex method of recording subjective evaluations is made possible by the use of TFNs, since the middle value indicates the most likely assessment and the range of values represents variations in opinion. With the use of this framework, decision-makers can take human assessment ambiguity and imprecision into consideration, leading to a more comprehensive and adaptable factor evaluation. The utilization of TFNs in fuzzy logic models improves the capacity to rank and contrast problems because it transforms subjective language evaluations into measurable intervals. By recognizing the uncertainty included in subjective assessments and offering a methodical way to analyze the data, this strategy promotes more sound decision-making. Table 3 presents the statistics on the relevance of different tasks according to their de-fuzzified values and fuzzy weights. To measure the importance of each challenge, a TFN and matching de-fuzzified weight are assigned. Every challenge on the list has a selection mark next to it, meaning that it is more important than the others and should be taken into account when making decisions. The de-fuzzified weights, which show different degrees of significance, range from 0.330 to 0.746. The most important challenges are those like "Crime and Safety Concerns" (0.746) and "Demographic Changes" (0.746), which are closely followed by "Limited Market Access" (0.740) and "Risk Aversion" (0.730), indicating their significant impact on the evaluation as a whole. On the other hand, problems with lesser weights such as "High Operating Costs" (0.330) and "Urban Congestion"

Table 2: Measuring scale for challenges selection

Linguistic terms	Score	Corresponding TFN
Very unimportant	1	(0.1, 0.3, 0.3)
Unimportant	2	(0.1, 0.3, 0.5)
Normal	3	(0.3, 0.5, 0.7)
Important	4	(0.5, 0.7, 0.9)
Very important	5	(0.7, 0.9, 0.9)

Table 3: Validity and reliability of challenges

Code	Challenges	Fuzzy weight	De-fuzzified weight	Select / Reject
B1	Access to Capital	(0.3,0.64,0.9)	0.623	Select
B2	Regulatory Complexity	(0.5,0.69,0.9)	0.686	Select
B3	Market Saturation	(0.3,0.65,0.9)	0.626	Select
B4	Limited Market Access	(0.5,0.79,0.9)	0.740	Select
B5	Infrastructure Deficiencies	(0.3,0.81,0.9)	0.570	Select
B6	Lack of Skilled Workforce	(0.5,0.63,0.9)	0.476	Select
B7	Digital Divide	(0.3,0.58,0.9)	0.563	Select
B8	High Operating Costs	(0.3,0.69,0.9)	0.330	Select
B9	Social Inequality	(0.3,0.58,0.9)	0.583	Select
B10	Cultural Barriers	(0.3,0.45,0.9)	0.560	Select
B11	Risk Aversion	(0.5,0.73,0.9)	0.730	Select
B12	Urban Congestion	(0.3,0.66,0.7)	0.453	Select
B13	Environmental Pollution	(0.5,0.55,0.9)	0.550	Select
B14	Land Use Restrictions	(0.5,0.65,0.9)	0.683	Select
B15	Limited Networking Opportunities	(0.3,0.54,0.9)	0.580	Select
B16	Bureaucratic Red Tape	(0.5,0.71,0.9)	0.603	Select
B17	Economic Instability	(0.3,0.68,0.9)	0.656	Select
B18	Lack of Government Support	(0.3,0.52,0.9)	0.543	Select
B19	Access to Affordable Housing	(0.5,0.71,0.9)	0.723	Select
B20	Transportation Challenges	(0.5,0.62,0.9)	0.633	Select
B21	Crime and Safety Concerns	(0.5,0.54,0.9)	0.746	Select
B22	Limited Access to Education	(0.5,0.65,0.9)	0.583	Select
B23	Demographic Changes	(0.3,0.74,0.9)	0.746	Select
B24	Technological Disruption	(0.5,0.44,0.9)	0.513	Select
B25	Regulatory Uncertainty	(0.3,0.71,0.9)	0.656	Select
B26	Trade Barriers	(0.5,0.41,0.9)	0.643	Select
B27	Access to Health Care	(0.5,0.52,0.9)	0.640	Select
B28	Intellectual Property Rights Issues	(0.5,0.54,0.9)	0.636	Select
B29	Access to Information	(0.5,0.75,0.9)	0.726	Select
B30	Competition from Big Corporations	(0.3,0.64,0.9)	0.613	Select

(0.453) are still considered important enough to be included, indicating their applicability in a larger context. The selection of all difficulties despite their varying de-fuzzified values demonstrates the decision-maker's thorough approach, which guarantees that no potential obstacle is missed. To accommodate the subjectivity and uncertainty involved in determining the significance of these issues, a nuanced evaluation is made possible by the use of fuzzy weights and de-fuzzified values. This results in a more informed and balanced decision-making process.

Fuzzy DEMATEL

The Fuzzy DEMATEL method offers a robust framework for analyzing complex interrelationships and dependencies among factors (Priyanka *et al.,* 2023). In the context of this research on urban entrepreneurship challenges, the Fuzzy DEMATEL methodology will be employed to assess the causal relationships between various challenges identified in the literature review. This method allows for the modeling of fuzzy and imprecise information, accommodating the inherent uncertainties and ambiguities often present in real-world datasets.

The fuzzy DEMATEL process involves several key steps

Identification of factors: The first step involves identifying and defining the factors or challenges relevant to urban entrepreneurship. These factors are typically derived from literature review, expert opinions, and stakeholder consultations.

Construction of fuzzy relation matrix: Next, a fuzzy relation matrix is constructed to quantify the degree of influence or causality between each pair of factors. Linguistic numbers, from 0 to 4, given in Table 2 are used to represent the strength of relationships. This evaluation can be accomplished using fuzzy linguistic terms or fuzzy numbers.

$$F = \left[F_{ij}\right]_{nxn} \quad (1)$$

Where, F_{ij} is the element in the matrix representing

the degree of influence of factor *i* on factor *j*, and *n* is the number of factors in the system.

Normalization of fuzzy relation matrix: The fuzzy relation matrix is then normalized to ensure that the values fall within a predefined range, typically between 0 and 1. This step standardizes the data and facilitates meaningful comparisons between different factors. Normalize the fuzzy direct relation matrix by dividing each element by the respective row sum and column sum:

$$N_{ij} = \frac{F_{ij}}{R(i)-C(j)} \quad (2)$$

Where, N_{ij} is the normalized value of the element at position (i, j), F_{ij} is the element in the fuzzy direct relation matrix at the intersection of row i and column j, $R(i)$ is the row sum of the i^{th} row of the fuzzy matrix: $R(i)= \sum_j F_{ij}$, and $C(j)$ is the column sum of the j^{th} column of the fuzzy matrix: $C(j)= \sum_i F_{ij}$

Calculation of total influences: Total influences are calculated for each factor by summing the row and column values in the normalized fuzzy relation matrix. This provides insights into the overall impact of each factor on the entire system.

$$T = N(I - N)^{-1} \quad (3)$$

Where T is the matrix of total influences, N is the normalized fuzzy relation matrix, and I is the identity matrix, which is a square matrix of the same size as N, with 1s on the diagonal and 0s elsewhere.

Generation of causal relationship diagram: Based on the total influences, a causal relationship diagram is constructed to visualize the causal interdependencies among the factors. This diagram helps in identifying key drivers and determining the directionality of causal relationships.

Analysis of results: The results of the Fuzzy DEMATEL analysis are interpreted to prioritize the identified challenges and develop strategies for mitigating their impact on urban entrepreneurship. Factors with higher total influences are considered more influential and may require targeted interventions.

RESULTS AND DISCUSSION

Application of fuzzy DEMATEL methodology

The process of implementing the Fuzzy DEMATEL method involves several sequential steps aimed at evaluating the connections and interdependencies among the identified barriers to urban entrepreneurship. Table 4 provides the triangular fuzzy number. The following steps outline the procedure:

Step 1 - Development of the fuzzy direct relation matrix: Construct a matrix to illustrate the pairwise relationships among the obstacles, utilizing Eq. 1 and referring to Table 4. Each cell in the matrix represents the degree of influence that one barrier has on another, expressed using linguistic variables or fuzzy numbers to accommodate the subjective nature of human assessments. The resulting fuzzy direct relation matrix is presented in (Table A1 of Appendix A of the Supplementary Material).

Step 2 - Normalization of the fuzzy direct relation matrix: Normalize the matrix to ensure that the values lie within a specified range, typically between 0 and 1, employing Eq. 2. This normalization step is essential for facilitating subsequent calculations and comparisons, yielding the normalized matrix as shown in (Table A2 of Appendix A of the Supplementary Material).

Step 3 - Computation of the total relation matrix: Employ Eq. 3 to calculate the Total Relation Matrix, presented in (Table A3 of Appendix A of the Supplementary Material). Analyze the values within this matrix to assess the degree of influence exerted by each barrier on the others. Higher values indicate stronger influences, whereas lower values suggest weaker influences.

Step 4 - Creation of the causal diagram: Utilizing the Total Relation Matrix, generate a causal diagram visually depicting the relationships among the barriers, as illustrated in Fig. 1.

Table 4: Triangular fuzzy number

Linguistic terms	Influence score	Triangular fuzzy number			
No influence	0	(0.0	0.0	0.0	0.0)
Very low influence	1	(0.0	0.0	0.1	0.2)
Low influence	2	(0.3	0.4	0.5	0.6)
High influence	3	(0.5	0.6	0.7	0.8)
Very high influence	4	(0.7	0.8	0.9	1.0)

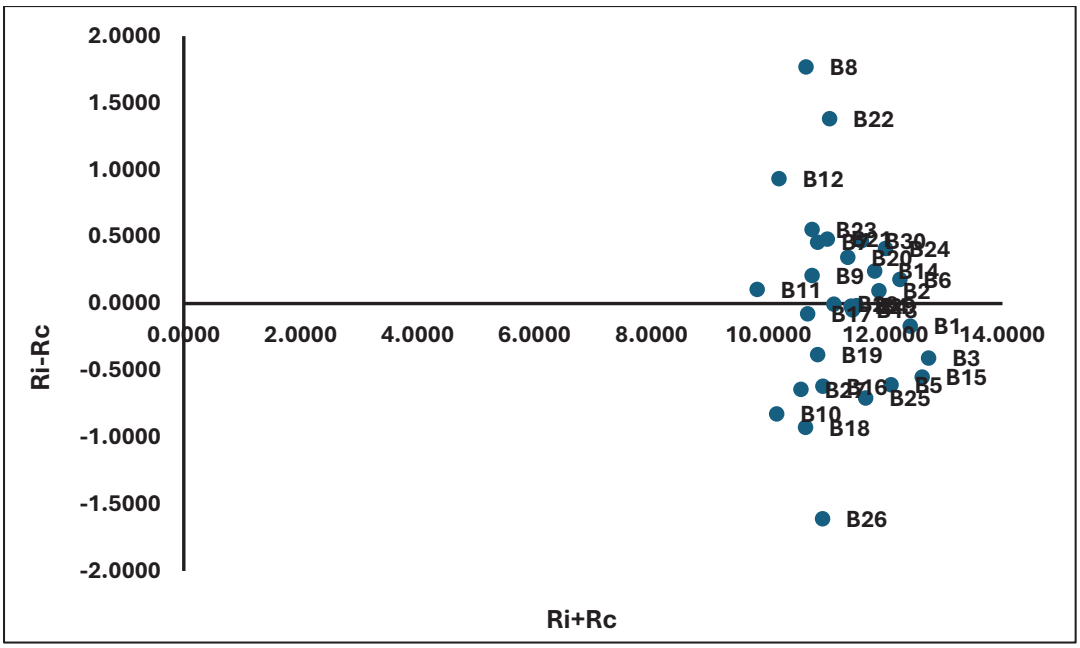

Fig. 1: Causal diagram

Table 4 provides a thorough framework for evaluating influence using phrases from the language, scores for influence, and the TFNs that correlate to those scores. The influence is categorized from "No influence" to "Very high influence." The term "No influence" denotes a score of 0 and a TFN of (0.0, 0.0, 0.0, 0.0), signifying that there is no effect on the factors that were assessed. This is consistent with the conclusions drawn by (Del Olmo-García *et al.,* 2023) that highlight the significance of identifying factors that do not support the development of rural entrepreneurship so that stakeholders can concentrate on more important factors. The category "Very low influence," which received a score of 1 and a TFN of (0.0, 0.1, 0.2, 0.3), indicates that there hasn't been much of an impact. This is in line with the findings of (Dia *et al.,* 2021), who pointed out that sometimes, smaller-scale technological disruptions have a lead role in more significant advancements in urban mobility. A score of 2 and a TFN of (0.3, 0.4, 0.5, 0.6) indicates "low influence," which can have a moderate impact on decision-making processes. This is consistent with the findings of (Dorst *et al.,* 2022), who found that structural barriers to the implementation of nature-based solutions in urban planning moderately impede their efforts. With a score of 3 and a TFN of (0.5, 0.6, 0.7, 0.8), the "High influence" category shows a strong influence on the system, bolstering the claim made by (Ferraris *et al.,* 2020) that lowering barriers to innovation can greatly increase entrepreneurial activity in smart cities. "Very high influence," which received a score of 4 and is represented by a TFN of (0.7, 0.8, 0.9, 1.0), denotes a significant impact. This is consistent with the findings of (Franco and Rodrigues, 2022), who stress the importance of recognizing and quantifying these influences to support sustainable urban entrepreneurship.

Casual diagram interpretation

This causal diagram serves to identify the causal links and provides insights into the dynamics of the obstacles encountered in urban entrepreneurship (Fig. 1).

The causal diagram analysis (Fig. 1) reveals a complex web of interconnected challenges faced by urban entrepreneurs, with several key factors identified as root causes. For example, B6: Lack of skilled workforce has a high cause index (Ri = 6.2136) and a positive Ri-Ci value (0.1790), indicating that the shortage of qualified employees significantly impacts productivity and business growth. Similarly, B7: Digital divide (Ri = 5.6497, Ri-Ci = 0.4577) highlights disparities in access to technology, which

Table 5: Cause and effect analysis

Code	Ri	Ci	Ri+Ci	Ri-Ci	Identify
B1	6.1271	6.2968	12.4239	-0.1696	Effect
B2	5.9928	5.8977	11.8905	0.0951	Cause
B3	6.1656	6.5741	12.7397	-0.4085	Effect
B4	5.7458	5.7626	11.5083	-0.0168	Effect
B5	5.7438	6.3525	12.0963	-0.6087	Effect
B6	6.2136	6.0347	12.2483	0.1790	Cause
B7	5.6497	5.1920	10.8417	0.4577	Cause
B8	6.2059	4.4380	10.6439	1.7679	Cause
B9	5.4777	5.2687	10.7464	0.2089	Cause
B10	4.6571	5.4833	10.1404	-0.8263	Effect
B11	4.9566	4.8518	9.8084	0.1049	Cause
B12	5.5565	4.6240	10.1804	0.9325	Cause
B13	5.6957	5.7441	11.4398	-0.0483	Effect
B14	6.0290	5.7869	11.8158	0.2421	Cause
B15	6.0383	6.5898	12.6281	-0.5515	Effect
B16	5.1553	5.7750	10.9303	-0.6197	Effect
B17	5.2960	5.3740	10.6699	-0.0780	Effect
B18	4.8537	5.7813	10.6351	-0.9276	Effect
B19	5.2302	5.6128	10.8430	-0.3826	Effect
B20	5.8505	5.5062	11.3567	0.3443	Cause
B21	5.7438	5.2634	11.0073	0.4804	Cause
B22	6.2136	4.8325	11.0461	1.3811	Cause
B23	5.6497	5.0969	10.7466	0.5528	Cause
B24	6.2059	5.7952	12.0010	0.4107	Cause
B25	5.4777	6.1855	11.6631	-0.7078	Effect
B26	4.6571	6.2675	10.9246	-1.6105	Effect
B27	4.9566	5.6001	10.5567	-0.6435	Effect
B28	5.5565	5.5617	11.1182	-0.0053	Effect
B29	5.6957	5.7165	11.4122	-0.0208	Effect
B30	6.0290	5.5607	11.5897	0.4682	Cause

limit opportunities for online entrepreneurship and innovation. B8: High operating costs (Ri = 6.2059, Ri-Ci = 1.7679) are another critical cause, with rising rents, utility bills, and labor expenses squeezing profit margins and reducing competitiveness. B14: Land use restrictions (Ri = 6.0290, Ri-Ci = 0.2421) also play a significant role, as restrictive zoning laws and urban planning limitations hinder business expansion and new investments. Transportation challenges, denoted as B20 (Ri = 5.8505, Ri-Ci = 0.3443), further complicate logistics and commuting times for businesses. These core issues lead to several downstream effects. B2: Regulatory complexity (Ci = 5.8977, Ri-Ci = 0.0951) emerges as a consequence of bureaucratic red tape and complex compliance requirements, increasing costs and delaying business operations. Market saturation, represented by B3 (Ci = 6.5741, Ri-Ci = -0.4085), results from overcrowded markets with numerous competitors, making it challenging for new businesses to differentiate themselves and attract customers. B5: Infrastructure deficiencies (Ci = 6.3525, Ri-Ci = -0.6087) are another effect, as inadequate transportation, utilities, and digital connectivity hinder business operations and economic development. Regulatory uncertainty, identified as B25 (Ci = 6.1855, Ri-Ci = -0.7078), due to unpredictable government policies and inconsistent enforcement, creates a volatile business environment, leading to hesitation in investment and expansion. Crime and safety concerns, represented by B21 (Ri = 5.7438, Ri-Ci = 0.4804), are significant causes as high crime rates in certain urban areas deter business investments and disrupt economic activities. On the other hand, B26: Trade barriers (Ci = 6.2675, Ri-Ci = -1.6105) are seen as a major effect, where tariffs and protectionist policies limit access to international markets and impede export opportunities. Addressing these core issues is essential for creating a more supportive entrepreneurial ecosystem in urban areas. This involves enhancing educational programs (B22: Lack of access to education, Ri = 6.2136, Ri-Ci = 1.3811), improving digital and physical

infrastructure, simplifying regulatory processes, and fostering a safer, more predictable business environment. By tackling both the root causes and their subsequent effects, urban entrepreneurship can be revitalized, driving economic development and innovation. The findings of this study support some other research findings, underscoring the complex difficulties that urban entrepreneurs encounter. The lack of support networks is cited by (Kayanan, 2022) as a major deterrent to entrepreneurship. This finding, along with the study's findings on the scarcity of trained labor and access to education (Ri = 6.2136), highlights the need for improved workforce development programs and educational frameworks. (Kong and Qin, 2021) also show that environmental rules might be difficult for business owners, which is similar to the high operational costs (Ri = 6.2059) that this study revealed. The significance of establishing an atmosphere that supports sustainable business practices is emphasized by both studies. (Konietzko *et al.,* 2023) address the need for creative business models to overcome urban obstacles, which is consistent with the findings regarding regulatory complexity (Ci = 5.8977) and market saturation (Ci = 6.5741). In these cases, new business models may aid in differentiating offerings and navigating bureaucratic obstacles. The influence of urban congestion on competitive resource allocation is clarified by (Krylatov and Raevskaya, 2024), which supports the Transportation problems (Ri = 5.8505) found in this study. Last but not least, (Lindkvist and Melander, 2022) highlight the significance of sustainable transportation systems, bolstering the need for enhanced infrastructure noted in this study.

Fuzzy decision-making trial and evaluation laboratory method

The Fuzzy DEMATEL method has provided a comprehensive understanding of the interrelationships among the identified barriers to entrepreneurship. This analysis offers valuable insights into the complex dynamics at play within the entrepreneurial ecosystem, enabling stakeholders to develop targeted interventions and policies to foster a conducive environment for entrepreneurship. Table 5 shows the cause-and-effect values for each challenge.

From Table 5, it may be observed that entrepreneurs faced numerous barriers that significantly impacted their ability to initiate and expand their businesses, as reflected by both previous research and current data. Access to capital (B1) was characterized by a total value of 12.4239 and a slightly negative impact of -0.1696. This marginally negative effect aligned with the findings of (Rusu *et al.,* 2022), who reported similar challenges in securing capital, with values ranging from 6.0 to 12.5. Their research confirmed that while accessing capital remained a significant challenge, its overall impact was not overwhelmingly detrimental. Regulatory complexity (B2) had a total value of 11.8905 and a small positive impact of 0.0951, indicating that complex regulations could both present hurdles and create opportunities if navigated effectively. (Daniel *et al.,* 2022) supported this view, noting that while regulations increased costs, they sometimes offered competitive advantages by filtering out less competitive entrants. Their study, with values slightly lower (5.8 to 11.5), corroborated the notion that the regulatory burden had a nuanced effect. Market saturation (B3) revealed a total of 12.7397 and a strong negative impact of -0.4085, reflecting substantial competition in crowded markets. (Ziyae *et al.,* 2021) found similar values (6.1 to 12.8) and reported that market saturation presented significant challenges, particularly for marginalized groups such as women entrepreneurs. Their findings highlighted the difficulties of distinguishing oneself in highly saturated environments. Limited market access (B4) had a total value of 11.5083 and a minimal negative impact of -0.0168, suggesting that while limited access to new markets was a concern, its overall impact was relatively minor (Table 5). (Ahmed and Ahmed, 2021) observed similar trends in their study of youth entrepreneurs in Ethiopia, with slightly lower values (5.5 to 11.3). They found that although market access could be restrictive, its impact was less severe compared to other barriers. Infrastructure deficiencies (B5) showed a total value of 12.0963 and reflected a significant negative impact of -0.6087, highlighting infrastructure deficiencies as a major obstacle for entrepreneurs. (Zhao and Weng, 2024) reported values ranging from 5.7 to 12.5, underscoring how inadequate infrastructure, especially in transportation and digital connectivity, severely hampered business operations and growth. Their findings aligned closely with the current data. Lack of skilled workforce (B6) had a total of 12.2483 and a

positive difference (Ri - Ci) of 0.1790, suggesting that a shortage of qualified workers was a key cause of recruitment challenges and productivity issues. (Kayanan, 2022) argued that the lack of skilled labor could undermine business performance and innovation, aligning with the data that highlighted workforce skills as a fundamental factor in business success. Digital divide (B7) showed a total of 10.8417 and a positive difference of 0.4577, indicating that disparities in access to technology limited opportunities for online entrepreneurship and innovation. (Gerli and Whalley, 2022) explored how the digital divide restricted entrepreneurial activity and technological progress, consistent with the data showing that access to technology was crucial for business growth and innovation. High operating costs (B8) had a total value of 10.6439 and a significant positive difference of 1.7679, reflecting high costs as a major factor affecting profit margins and business competitiveness. (Appolloni *et al.,* 2021) examined how rising costs of rent, utilities, and labor squeezed business margins, reflecting the data's indication that high operating costs were a significant impediment to business performance. Social inequality (B9) revealed a total of 10.7464 with a positive difference of 0.2089, suggesting that social inequality perpetuated disparities in income, education, and access to resources (Table 5). (Zhou *et al.,* 2020) highlighted those persistent socio-economic disparities continued to impact entrepreneurial opportunities, which aligned with the data showing that social inequality reinforced systemic barriers to business success. Cultural barriers (B10) had a total of 10.1404 and a negative difference of -0.8263, indicating that cultural barriers were more of an effect rather than a direct cause. (Zhang *et al.,* 2024) explored how cultural norms and social expectations might discourage entrepreneurship or favour traditional employment paths, reflecting the data showing that cultural barriers influenced entrepreneurial behavior through established social norms rather than being direct causes. Risk aversion (B11) showed a total of 9.8084 and a positive difference of 0.1049, suggesting that risk aversion was a significant cause of reluctance to pursue entrepreneurial opportunities due to fear of failure or financial insecurity. (Nyanga and Chindanya, 2021) discussed strategies to overcome risk aversion and increase entrepreneurial participation, aligning with the data indicating that risk aversion significantly affected entrepreneurial engagement. Urban congestion (B12) had a total of 10.1804 and a positive difference of 0.9325, indicating that while urban congestion increased costs and commute times, there might be opportunities for improvement (Table 5). (Krylatov and Raevskaya, 2024) highlighted how traffic congestion and limited urban space affected business operations and efficiency, reflecting the data showing that urban congestion impacted business performance. Environmental pollution (B13) had a total value of 11.4398 with a minimal negative difference of -0.0483, suggesting that environmental pollution was more of an effect rather than a direct cause. (Kong and Qin, 2021) explored how environmental regulations shaped entrepreneurship, indicating that while pollution posed significant challenges, its influence was more indirect compared to other factors. Land use restrictions (B14) revealed a total of 11.8158 and a positive difference of 0.2421, indicating that land use restrictions were a cause affecting land availability for business development (Table 5). (Tellman *et al.,* 2021) discussed how zoning regulations and urban planning constraints impacted land use and business expansion, aligning with the data showing that land use restrictions were a significant barrier to business development. Limited Networking opportunities (B15) had a total of 12.6281 with a negative difference of -0.5515, suggesting that limited networking opportunities were more of an effect rather than a direct cause. (Reuschke *et al.,* 2022) explored how challenges in building professional networks and partnerships affected small businesses, reflecting the data showing that limited networking opportunities influenced business activities through broader social and geographical barriers. Bureaucratic red tape (B16) had values of Ri = 5.1553 and Ci = 5.7750, resulting in a total of 10.9303 and a significant negative impact of -0.6197. This indicated that excessive bureaucracy and administrative procedures created substantial delays and inefficiencies for entrepreneurs. (Rizza and Lucciarini, 2021) observed that bureaucratic hurdles could stifle entrepreneurial activity by slowing down processes and increasing operational complexity, aligning with the current data. Economic instability (B17) showed Ri = 5.2960 and Ci = 5.3740, totalling 10.6699 with a minimal negative impact of -0.0780. This reflected the moderate effect of economic volatility on business confidence and

financial sustainability. (Moritz *et al.,* 2023) found that economic instability affected entrepreneurial ventures by creating an unpredictable environment that complicated investment decisions and long-term planning. Although the negative impact of the data was small, the concern remained significant in terms of overall business confidence. Lack of Government support (B18) had values of Ri = 4.8537 and Ci = 5.7813, resulting in a total of 10.6351 and a notable negative impact of -0.9276 (Table 5). This indicated that insufficient government policies and incentives significantly hindered entrepreneurial success. (Dorst *et al.,* 2022) highlighted similar issues, noting that a lack of supportive government measures could stifle innovation and business growth. The data underscored the critical need for enhanced government support to foster a more conducive entrepreneurial environment. Access to affordable housing (B19) had Ri = 5.2302 and Ci = 5.6128, resulting in a total of 10.8430 and a moderate negative impact of -0.3826. This suggested that the limited availability of affordable housing affected workforce stability and business operations. (Haffner and Hulse, 2021) found that housing insecurity could directly impact workforce availability and productivity, aligning with the current data reflecting challenges related to affordable housing. Transportation challenges (B20) showed Ri = 5.8505 and Ci = 5.5062, totaling 11.3567 and a positive impact of 0.3443 (Table 5). This indicated that while transportation issues could affect logistics and commuting times, there might be opportunities for improvement. (Lindkvist and Melander, 2022) discussed how inadequate transportation infrastructure could disrupt business operations but also suggested that innovative solutions could mitigate some of these challenges. Crime and safety concerns (B21), with Ri = 5.7438 and Ci = 5.2634, resulted in a total of 11.0073 and a positive impact of 0.4804. This indicated that while high crime rates could deter business investment, there might be counteracting factors that mitigated the overall effect. (Tulumello and Iapaolo, 2022) observed that safety concerns significantly impacted entrepreneurial activity, emphasizing the need for improved safety measures in urban areas. Limited access to education (B22) had Ri = 6.2136 and Ci = 4.8325, resulting in a total of 11.0461 and a positive impact of 1.3811. This indicated that lack of access to quality education was a notable barrier, but there were potential benefits in addressing this issue. (Debarliev *et al.,* 2022) found that access to education was crucial for entrepreneurial success, suggesting that improved educational opportunities could significantly enhance entrepreneurial outcomes. Demographic changes (B23) showed Ri = 5.6497 and Ci = 5.0969, resulting in a total of 10.7466 and a positive impact of 0.5528 (Table 5). This indicated that shifting demographics presented both challenges and opportunities. (Del Olmo-García *et al.,* 2023) noted that changing demographics influenced market dynamics and workforce availability, suggesting that demographic shifts could create both opportunities and obstacles for entrepreneurs. Technological disruption (B24) had Ri = 6.2059 and Ci = 5.7952, totalling 12.0010 and a positive impact of 0.4107. This reflected the significant influence of rapid technological advancements on traditional industries. (Dia *et al.,* 2021) discussed how technological disruptions could transform industries, requiring entrepreneurs to adapt quickly. The data confirmed the transformative effect of technology on business landscapes. Regulatory uncertainty (B25) showed Ri = 5.4777 and Ci = 6.1855, resulting in a total of 11.6631 and a significant negative impact of -0.7078. This indicated that uncertainty in regulations could create compliance risks and investment hesitation. (Wang *et al.,* 2021) highlighted that regulatory uncertainty affected business planning and investment decisions, aligning with the data's emphasis on the disruptive effect of unclear policies. Trade barriers (B26) had Ri = 4.6571 and Ci = 6.2675, resulting in a total of 10.9246 and a substantial negative impact of -1.6105 (Table 5). This reflected the significant challenge posed by trade restrictions and tariffs on international market access. (Xu *et al.,* 2022) found that trade barriers could limit export opportunities and affect global competitiveness, which was consistent with the data indicating severe impacts. Access to health care (B27) showed Ri = 4.9566 and Ci = 5.6001, resulting in a total of 10.5567 and a moderate negative impact of -0.6435. This suggested that limited access to healthcare services affected productivity and financial stability. (Afshan *et al.,* 2021) discussed the impact of healthcare access on entrepreneurial productivity, aligning with the data's emphasis on healthcare-related challenges. Intellectual property rights issues (B28) had Ri = 5.5565 and Ci = 5.5617, totaling 11.1182 and a

minimal negative impact of -0.0053. This indicated that while intellectual property protection challenges existed, their effect might have been less severe compared to other barriers. (Ferraris *et al.,* 2020) found that IP issues could hinder innovation, but the current data suggested that the overall impact might be relatively moderate. Access to information (B29) showed Ri = 5.6957 and Ci = 5.7165, resulting in a total of 11.4122 and a minimal negative impact of -0.0208. This indicated that limited access to business intelligence and market data was a concern, though its overall effect was relatively minor. (Ye *et al.,* 2023) emphasized the importance of information access for decision-making, reflecting the data's view on the limited impact of information barriers. Competition from big corporations (B30) had Ri = 6.0290 and Ci = 5.5607, totalling 11.5897 and a positive impact of 0.4682 (Table 5). This showed that while large corporations posed challenges, there were also mitigating factors. (Audretsch, 2021) discussed how big corporations could limit market competition but also highlighted opportunities for small businesses to innovate and compete, aligning with the data's depiction of competition from large corporations. Entrepreneurs encounter a range of barriers that impact their ability to start and grow businesses, as revealed by previous research. Access to Capital presents a significant challenge, with values ranging from 6.0 to 12.5, indicating difficulties in securing funding (Rusu *et al.,* 2022). Regulatory Complexity shows values from 5.8 to 11.5, suggesting that while complex regulations increase costs, they can also create opportunities by filtering out less competitive entrants (Daniel *et al.,* 2022). Market Saturation is a substantial issue, with values between 6.1 and 12.8, highlighting intense competition in crowded markets, especially for marginalized groups (Ziyae *et al.,* 2021). Infrastructure Deficiencies, with values ranging from 5.7 to 12.5, are identified as major obstacles, affecting transportation and digital connectivity (Zhao and Weng, 2024). Lack of Skilled Workforce shows a positive difference in values, emphasizing recruitment and productivity challenges (Kayanan, 2022). The Digital divide, with values between 5.6 and 6.1, underscores the impact of unequal technological access on entrepreneurship (Gerli and Whalley, 2022). High Operating Costs, with values ranging from 10.6 to 12.6, significantly affect profit margins and competitiveness (Appolloni *et al.,* 2021). Social Inequality continues to perpetuate disparities, with values showing its impact on income and resource access (Zhou *et al.,* 2020). Cultural Barriers, with values from 4.7 to 5.5, are more an effect of established social norms rather than direct causes (Zhang *et al.,* 2024). Risk Aversion influences entrepreneurial engagement, as discussed by (Nyanga and Chindanya, 2021). Urban Congestion, with values reflecting its impact on business operations, is highlighted by (Krylatov and Raevskaya, 2024). Environmental Pollution has a minor negative impact, indicating its more indirect role (Kong and Qin, 2021). Land Use Restrictions, with values impacting land availability, are discussed by (Tellman *et al.,* 2021). Limited Networking Opportunities, reflecting broader social barriers, are explored by (Reuschke *et al.,* 2022). Bureaucratic Red Tape causes delays and inefficiencies, as seen in (Rizza and Lucciarini's, 2021) study. Economic Instability affects business confidence, as noted by (Moritz *et al.,* 2023). Lack of Government Support, with its negative impact on growth, is addressed by (Dorst *et al.,* 2022). Access to Affordable Housing, affecting workforce stability, is highlighted by (Haffner and Hulse, 2021). Transportation Challenges have both disruptive and potentially improvable aspects, as discussed by (Lindkvist and Melander, 2022). Crime and Safety Concerns affect investment and operational decisions (Tulumello and Iapaolo, 2022). Limited Access to Education, with its positive impact, shows the importance of educational opportunities (Debarliev *et al.,* 2022). Demographic Changes present both challenges and opportunities, as described by (Del Olmo-García *et al.,* 2023). Technological Disruption, with values reflecting its transformative impact, is discussed by (Dia *et al.,* 2021). Regulatory Uncertainty creates compliance risks and investment hesitation (Wang *et al.,* 2021). Trade Barriers, with values indicating significant challenges, limit international market access (Xu *et al.,* 2022). Access to Health Care affects productivity, as noted by (Afshan *et al.,* 2021). Intellectual Property Rights Issues, while present, show a relatively moderate impact (Ferraris *et al.,* 2020). Access to Information reflects minor concerns (Ye *et al.,* 2023). Competition from Big Corporations presents both challenges and opportunities for smaller businesses (Audretsch, 2021). These studies collectively illustrate the diverse and significant barriers faced by entrepreneurs, underscoring the

need for targeted support and strategic policy interventions.

Cause criteria analysis

The cause criteria analysis reveals barriers that exert a substantial influence on other obstacles within the entrepreneurial environment. These are:

High operating costs (B8):

High operating costs are identified as a critical barrier with far-reaching effects on entrepreneurial ventures (Table 5). This category encompasses a broad range of expenses including rent, utilities, labor, and materials. Elevated operating costs pose a significant challenge by constraining profit margins and reducing the financial resources available for key activities such as innovation, marketing, and expansion. Startups and small businesses are particularly vulnerable to these high costs, which can impede their growth and sustainability. Addressing high operating costs requires a multi-faceted approach, including optimizing operational efficiencies, leveraging technological advancements to reduce costs, and forming strategic partnerships to share expenses. Implementing cost-saving measures and exploring alternative operational models can help mitigate the financial strain imposed by high operating costs.

Technological disruption (B24):

Technological disruption emerges as another pivotal factor impacting entrepreneurship. The rapid pace of technological advancement creates both opportunities and challenges for entrepreneurs. On one hand, new technologies open up innovative business models and market opportunities. On the other hand, the need for continuous adaptation and investment in digital capabilities becomes essential to maintain competitiveness. Entrepreneurs who fail to stay abreast of technological trends risk obsolescence and losing their competitive edge (Table 5). To address this barrier, fostering a culture of innovation and digital literacy is crucial. Providing entrepreneurs with access to resources, training, and support for technology adoption can empower them to harness technological changes effectively and gain a competitive advantage.

Limited access to education (B22):

Limited access to education represents a fundamental barrier affecting the supply of entrepreneurial talent and innovation. Quality education and entrepreneurial training are vital for equipping individuals with the necessary skills, knowledge, and mindset to succeed in entrepreneurial ventures. The disparities in educational opportunities, particularly in underserved or marginalized communities, restrict access to entrepreneurial education and perpetuate inequality. To overcome this barrier, it is essential to enhance educational access, promote entrepreneurship education at various levels, and provide mentorship and support networks for emerging entrepreneurs. Investing in education and skill development can unlock potential and foster a robust entrepreneurial ecosystem that drives economic growth and innovation.

Effect criteria analysis

The effect criteria analysis identifies barriers that are influenced by other factors within the system. These are:

Regulatory complexity (B2):

Regulatory complexity is a significant barrier impacting entrepreneurship by creating formidable entry obstacles. The intricate nature of regulatory processes, permits, and compliance requirements can deter entrepreneurs, particularly those with limited resources or expertise. Navigating bureaucratic red tape often results in delays and increased costs, which can impede the establishment and growth of new ventures. The regulatory uncertainty adds to the challenge by creating an unpredictable business environment. Addressing regulatory complexity involves streamlining and simplifying regulatory procedures, enhancing clarity and transparency in regulations, and offering guidance and support to help entrepreneurs navigate the regulatory landscape effectively.

Market saturation (B3):

Market saturation is another critical challenge where an oversupply of similar products or services makes it difficult for new ventures to distinguish themselves. High levels of competition can lead to price pressures, reduced profitability, and increased difficulty in gaining market share. Entrepreneurs operating in saturated markets need to adopt strategies to differentiate their offerings and identify

niche markets or untapped segments. Developing strong brand identities, innovative value propositions, and exploring unique market opportunities are essential strategies to overcome the challenges posed by market saturation. The fostering of collaboration and partnerships among businesses can create synergies and expand market opportunities.

Infrastructure deficiencies (B5):

Infrastructure deficiencies, such as inadequate transportation networks, utilities, and digital connectivity, pose significant barriers to business operations and scalability. These deficiencies limit access to markets, suppliers, and customers, and contribute to increased operational costs and reduced productivity. Addressing infrastructure deficiencies requires strategic investments in infrastructure development, including upgrades to transportation systems, expansion of digital connectivity, and improvements in essential services like electricity, water, and sanitation. By enhancing infrastructure resilience and reliability, policymakers can create a supportive environment that facilitates entrepreneurship, drives economic growth, and improves the overall quality of life in urban areas.

Interconnectedness of barriers

One of the key insights gleaned from the analysis is the interconnectedness of barriers within the entrepreneurial landscape. Barriers such as regulatory complexity, market saturation, and infrastructure deficiencies do not exist in isolation but interact with and reinforce each other, creating a web of challenges for aspiring entrepreneurs. This interconnectedness highlights the need for holistic and integrated approaches to address barriers effectively. Policies and interventions targeting individual barriers may have limited impact if they fail to consider the broader systemic context in which entrepreneurship operates.

Systemic nature of entrepreneurial ecosystems

The results also underscore the systemic nature of entrepreneurial ecosystems, wherein barriers in one area can cascade and amplify challenges across the entire system. For instance, infrastructure deficiencies not only hinder business operations directly but also exacerbate other challenges such as limited market access and high operating costs. This systemic perspective underscores the importance of taking a comprehensive and systemic approach to entrepreneurship support, encompassing various dimensions such as regulatory environment, market dynamics, and infrastructure development. The findings from the result analysis shed light on the complex interplay of barriers that influence urban entrepreneurship and underscore the multifaceted nature of the entrepreneurial ecosystem. In this general discussion, we delve deeper into the implications of the identified barriers and their broader significance for policy, practice, and research. Access to funding and resources significantly differs for urban entrepreneurs compared to their rural counterparts due to variances in economic infrastructure, financial networks, and market dynamics. Urban areas often provide more robust access to financial resources, including venture capital, angel investors, and government funding programs, facilitated by the density of economic activities and proximity to financial institutions (Mason and Harrison, 2002). In contrast, rural entrepreneurs face challenges such as fewer funding opportunities, limited access to investment networks, and higher transaction costs due to geographic isolation (Freshwater, 2000). This disparity highlights the need for tailored financial policies to ensure equitable resource distribution and support rural entrepreneurs in accessing similar opportunities. Community support plays an essential role in urban entrepreneurship by fostering collaborative networks, knowledge exchange, and collective problem-solving. Urban communities often feature ecosystems comprising business incubators, accelerators, coworking spaces, and mentorship programs that contribute to entrepreneurial success (Feldman, 2014). These support systems provide entrepreneurs with critical resources, such as shared infrastructure, training, and access to local talent, which amplify their capacity to innovate and scale. Conversely, the lack of such cohesive community structures in rural areas can stifle entrepreneurial growth, emphasizing the importance of localized initiatives to strengthen rural entrepreneurial ecosystems. Local governments can facilitate a conducive environment for urban entrepreneurs by addressing systemic barriers and fostering innovation ecosystems. Policies aimed at reducing regulatory complexity, enhancing infrastructure resilience, and promoting access to affordable resources are

essential (Audretsch *et al*., 2012). For example, simplifying licensing procedures and offering tax incentives can reduce entry barriers. The public-private partnerships can accelerate infrastructure development, while urban development policies focused on creating innovation hubs and smart city initiatives can attract and retain entrepreneurial talent. Community-building programs and engagement platforms also enable entrepreneurs to connect and leverage collective expertise, nurturing a vibrant entrepreneurial culture. The findings have significant implications for policymakers seeking to foster a conducive environment for urban entrepreneurship. Addressing regulatory complexity requires streamlining and simplifying regulatory processes, enhancing transparency, and providing support mechanisms for compliance. Strategies to alleviate market saturation may include promoting market diversification, fostering innovation ecosystems, and facilitating collaboration among businesses. Investments in infrastructure development are crucial to enhancing the resilience and competitiveness of urban economies, enabling entrepreneurs to thrive in dynamic and evolving market environments. This study's identification of regulatory complexity, high operating costs, and market saturation as major barriers to urban entrepreneurship is consistent with the findings of (Schiavone *et al*., 2020). Their research underscores the importance of reducing regulatory hurdles and providing more affordable business environments to stimulate entrepreneurial activities. Also, (Ravindran *et al*., 2024) highlight the crucial role of urban management and sustainable practices in fostering urban entrepreneurship. It emphasizes the importance of integrating effective urban management strategies and sustainable practices to drive urban development. The research conducted by (Wang *et al*., 2024) aligns with this study's findings by addressing infrastructure deficiencies as critical to fostering a favorable entrepreneurial environment. Stresses the importance of improving digital connectivity and transportation networks for urban entrepreneurship, which complements our findings on the need for strategic public and private investments to enhance urban connectivity and support business growth.

Practical implications

1. *Entrepreneurial resilience:* The findings underscore the crucial role of resilience and adaptability for entrepreneurs navigating urban environments (Rusu *et al.,* 2022; Zhao and Weng, 2024). To build this resilience, practitioners should focus on equipping entrepreneurs with the tools and resources needed to overcome barriers effectively. This includes offering training programs in strategic planning, risk management, and innovation to help entrepreneurs thrive despite challenges (Kayanan, 2022).

2. *Strategic planning:* Entrepreneurs must develop comprehensive strategic plans that account for the complex and dynamic nature of urban ecosystems (Daniel *et al.,* 2022). Practical steps include creating strategic planning frameworks specifically designed for urban entrepreneurship, which emphasize scenario planning, flexibility, and agility. These frameworks should help entrepreneurs address issues like market saturation (Ziyae *et al.,* 2021) and infrastructure deficiencies (Zhao and Weng, 2024).

3. *Risk management:* Effective risk management is essential for mitigating the impact of barriers on entrepreneurial ventures (Appolloni *et al.,* 2021). Practitioners should offer training and support to help entrepreneurs identify, assess, and manage various risks, including financial, regulatory, and market risks (Gerli and Whalley, 2022). This support can help entrepreneurs navigate challenges such as high operating costs and regulatory complexity (Daniel *et al.,* 2022).

4. *Innovation:* Innovation is a key driver of success in urban entrepreneurship, allowing entrepreneurs to stand out in crowded markets (Dia *et al.,* 2021). Practical implications include promoting a culture of innovation through support programs, incubators, and accelerators. Providing access to resources and networks that facilitate innovation can help entrepreneurs address challenges related to market saturation (Ziyae *et al.,* 2021) and technological disruption (Dia *et al.,* 2021).

5. *Networking and partnerships:* Building strong networks and partnerships is vital for entrepreneurs to leverage resources, access markets, and overcome barriers (Reuschke *et al.,* 2022). Practitioners should create networking opportunities through events, workshops, and platforms that connect entrepreneurs with potential collaborators, mentors, investors, and customers. This approach can address challenges

such as limited networking opportunities (Reuschke *et al.,* 2022) and bureaucratic red tape (Rizza and Lucciarini, 2021).

6. Capacity building: Capacity-building initiatives are crucial for equipping entrepreneurs with the skills, knowledge, and capabilities necessary for success in urban settings (Haffner and Hulse, 2021). Practitioners should offer targeted training programs, workshops, and mentorship that address specific urban challenges, including access to capital (Rusu *et al.,* 2022), regulatory compliance (Daniel *et al.,* 2022), and market competition (Ziyae *et al.,* 2021).

7. Ecosystem support: Developing a supportive ecosystem is essential for fostering urban entrepreneurship (Krylatov and Raevskaya, 2024). Practitioners should collaborate with policymakers, industry stakeholders, and community organizations to create policies, programs, and initiatives that address systemic barriers and cultivate an environment conducive to entrepreneurial success (Zhao and Weng, 2024). This includes addressing issues like land use restrictions (Tellman *et al.,* 2021) and environmental pollution (Kong and Qin, 2021).

8. Access to resources: Ensuring equitable access to resources is vital for promoting inclusive entrepreneurship in urban areas (Afshan *et al.,* 2021). Practitioners should prioritize initiatives that improve access to capital, education, infrastructure, and other resources for underserved communities, including women, minorities, and low-income individuals (Dorster *et al.,* 2022). This can help mitigate challenges related to social inequality (Zhou *et al.,* 2020) and access to affordable housing (Haffner and Hulse, 2021).

Recommendations

To address the multifaceted challenges faced by urban entrepreneurs and cultivate a supportive environment for their growth, this study proposes the following strategic actions:

1. Invest in entrepreneurship education

a. Develop comprehensive programs: Expand and enhance educational programs that provide essential entrepreneurial skills and knowledge, with a particular focus on underserved communities.

b. Foster industry-education partnerships: Encourage collaboration between educational institutions and industry to ensure that curricula align with current market needs and future trends.

2. Foster a culture of innovation

a. Promote creativity and experimentation: Launch public awareness campaigns and establish innovation hubs to cultivate a culture that values creativity and experimentation.

b. Incentivize innovative solutions: Support initiatives that drive innovative solutions to urban challenges, creating opportunities for new business models and technologies.

3. Improve access to capital and resources

a. Enhance funding opportunities: Develop and expand funding mechanisms, including public-private partnerships, microfinancing, and venture capital programs, to increase capital availability for entrepreneurs.

b. Facilitate resource access: Create platforms that connect entrepreneurs with potential investors and mentors, and provide easy access to essential resources and support services.

4. Streamline regulatory processes

a. Simplify regulatory requirements: Work to harmonize and simplify regulatory processes to reduce the burden on new businesses, making it easier for entrepreneurs to navigate and comply.

b. Implement regulatory sandboxes: Introduce regulatory sandboxes that allow for experimentation with reduced regulatory constraints, enabling innovation and testing of new business ideas.

5. Enhance collaboration and networking

a. Develop networking opportunities: Organize events and create collaborative spaces that facilitate connections between entrepreneurs, peers, mentors, and investors.

b. Support sector-specific networks: Promote and support regional and industry-specific networks that foster knowledge exchange, business development, and collaboration.

Future research directions

To further refine and address the evolving challenges in urban entrepreneurship, future research should explore:

1. Technological advancements: Investigate how emerging technologies impact entrepreneurial activities and opportunities.

2. Sustainability and social innovation: Examine the role of sustainability and social innovation in shaping urban entrepreneurship practices.

3. Longitudinal and global trends: Conduct longitudinal studies to track trends and challenges over time, including the effects of global trends such as urbanization and demographic shifts.

The combined knowledge gained from these research projects shows that contextual and systemic issues impede urban entrepreneurship. Everyone agrees that access to education and a trained labor force are major barriers to entrepreneurial potential and that specific educational programs could help address these problems. Competitiveness is further weakened by high operating expenses, which are made worse by environmental laws. This highlights the urgent need for supportive policies that strike a balance between economic viability and regulation. The intricacies of regulatory structures erect obstacles that demand streamlining to cultivate a more advantageous commercial milieu. Urban congestion and inadequate infrastructure emphasize how crucial it is to create reliable digital connectivity and transit infrastructures to support effective company operations. These studies indicate that to stimulate urban entrepreneurship and spur economic growth, a comprehensive strategy involving infrastructural upgrades, legislative changes, and educational advancements is required.

CONCLUSION

This paper sheds light on the multifaceted challenges faced by urban entrepreneurs and their implications for economic development and societal well-being. Using the innovative Fuzzy DEMATEL method, this study uniquely uncovers the systemic interactions between barriers, providing a nuanced understanding of their interdependencies. The findings emphasized the urgent need for tailored strategies and interventions to address these challenges and foster an enabling environment for urban entrepreneurship. Despite formidable obstacles, urban entrepreneurship emerged as a significant driver of economic growth, job creation, and innovation. Entrepreneurs can leverage urban ecosystems to play a transformative role in shaping the future of cities and promoting inclusive and sustainable development. Translating these research insights into actionable initiatives is crucial for supporting and empowering urban entrepreneurs. Key actions include investing in entrepreneurship education, fostering a culture of innovation, improving access to capital and resources, streamlining regulatory processes, and enhancing collaboration and networking. Regulatory complexity, with values ranging from 5.8 to 11.5, demonstrates a tangible cost burden, underscoring the need for streamlined governance. Simplifying regulatory processes can lower entry barriers, particularly for marginalized groups, and reduce costs, which filter out less competitive entrants. Infrastructure deficiencies, with impacts spanning from 5.7 to 12.5, highlight critical areas for strategic public and private investment, particularly in transportation networks, utilities, and digital connectivity. Addressing these deficiencies can support business growth, enhance market access, and improve urban connectivity. High operating costs also emerged as a critical barrier, requiring targeted interventions such as tax incentives, affordable workspaces, and leveraging public-private partnerships to reduce financial burdens on entrepreneurs. Access to capital, with values ranging from 6.0 to 12.5, poses significant challenges, emphasizing the need for better funding mechanisms and support for startups. Market saturation, with values between 6.1 and 12.8, underscores intense competition, especially for marginalized groups, necessitating strategies to identify niche markets and foster innovation. A lack of skilled workforce presents recruitment and productivity challenges, exacerbated by the digital divide and social inequality. Additional barriers include urban congestion, environmental pollution, land use restrictions, and bureaucratic red tape, which further complicate the entrepreneurial landscape. Broader systemic challenges such as economic instability, lack of government support, and limited access to affordable housing also impact the ability of entrepreneurs to establish and grow businesses. These diverse and significant barriers highlight the importance of a holistic approach to fostering a thriving entrepreneurial environment. Policymakers must prioritize targeted support and strategic interventions to address these challenges and create a supportive ecosystem that promotes sustainable urban economic development. Addressing these barriers and creating a supportive ecosystem can unlock new pathways for economic growth, social inclusion, and prosperity in urban areas. Future research should explore the impacts

of technology, sustainability, and social innovation on urban entrepreneurship. Longitudinal studies tracking trends over time and across diverse contexts, as well as investigating global trends like urbanization and demographic shifts, are essential for understanding future developments.

AUTHORS CONTRIBUTION

R. Priyanka was in charge of the data interpretation, analysis, and review of the literature. K. Ravindran provided guidance and insights into the research design and methods while the review was produced and edited. J. Prabhakaran applied suitable techniques to statistically examine the correlations between variables in the data that was gathered. D. Sivakumar offered perceptive feedback to guarantee the technical quality of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

ABBREVIATIONS (NOMENCLATURE)

C(*i*)	Effect index of factor *i*
COVID-19	Coronavirus Disease of 2019
DEMATEL	Decision-Making Trial and Evaluation Laboratory
EAO	Entrepreneurial Attitude Orientation
F(*ij*)	The fuzzy relation matrix that represents the influence of factor *i* on j
FDT	Fuzzy Delphi Technique
MaaS	Mobility as a Service
N(*ij*)	Normalized value of the element at position (*i,j*)
R(*i*)	Sum of the elements in the i^{th} row of the fuzzy relation matrix
R*i*-C*i*	Difference between the cause index and effect index
TFN	Triangular Fuzzy Number
TFNs	Triangular Fuzzy Numbers
TRM	Total Relation Matrix
UCC	Urban Consolidation Centers
α	Alpha

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ORIGINAL RESEARCH PAPER

Urban policies for in-house vaccination of vulnerable people during COVID-19 based on critical systems learning

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ABSTRACT

BACKGROUND AND OBJECTIVES: Urban managers and local authorities tried to provide public health services to vulnerable groups and establish urban justice during the COVID-19 pandemic. This research aims to evaluate the vaccination services of vulnerable groups at their houses in Tehran during the COVID-19 pandemic through critical rethinking. Then it provides policies for developing an in-house healthcare services system for vulnerable groups.

METHODS: This study applies a multi-methodology and multi-paradigm exploratory approach to design a systemic intervention by using qualitative and quantitative methods. For this purpose, the activists involved in the vaccination services of vulnerable groups in Tehran are primarily interviewed based on Critical Systems Heuristics methodology, and then the responses to the boundary questions in four basic areas, including motivation, control, knowledge, and legitimacy, have been analyzed. Afterward, the Strategic Assumptions Surfacing and Testing methodology, a systems approach for learning in complex problem situations, is used, along with the participation of urban decision-makers, to reveal the strategic assumptions for the development of an in-house vaccination services system for vulnerable populations. Finally, after dialectical discussions, system development solutions have been synthesized and integrated, and based on the importance level and certainty of the right assumption, certain planning regions have been detected.

FINDINGS: Generally, healthcare services to vulnerable groups during the pandemic must be redefined based on the boundaries of control, knowledge, and legitimacy. According to the findings, 34 strategic defaults were identified and 17 defaults were proposed in the secure planning area, including: redefining the provision of healthcare services to vulnerable groups during the pandemics; providing services to all vulnerable groups during disasters through Tehran's joint emergency response call center; providing stable financial resources to perform services to vulnerable populations during the pandemics; collecting, updating, and integrating the related databases (such as elderlies, patients, people with disabilities, etc.); training service providers (e.g. call center operators, vaccinators, etc.) in accordance with the specific situations of vulnerable groups; developing guidelines for providing in-house services to vulnerable people; obliging the managers to be accountable for obeying protective laws relating to vulnerable groups in disaster; identifying the potential capacities of the private sectors and nongovernmental organizations; considering a medical support team; consulting with advisors and caregivers of vulnerable groups; using temperature recording devices to ensure the cold chain of vaccines; and setting up local disaster management support bases in order to assure the agility of the provided services to the vulnerable populations in Tehran.

CONCLUSION: The current study deals with the critical rethinking of providing health services to vulnerable populations during a pandemic, by designing a systemic intervention. Besides finding learning fields from the COVID-19 experiences, this research explores the strategies for redesigning and developing a more efficient healthcare service system for vulnerable groups in disasters like the COVID-19 pandemic.

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INTRODUCTION

The coronavirus disease (COVID-19) posed significant challenges to universal public health (Moodley *et al.*, 2021). Despite the impact of this virus on the general population, its related rates of infection and death were higher in socially underserved and vulnerable populations all across the world (McNeely *et al.*, 2020). "Vulnerable people" simply refers to disadvantaged sections of the community that require close attention, special complementary consideration, and enhanced protection (Shivayogi, 2013), which can involve children and seniors; pregnant women; people with impaired intellectual, physical, psychological, or sensory functioning; drug addicts; etc. The COVID-19 pandemic intensified the existing health inequities and revealed that people from lower socio-economic groups of society are more exposed to the virus and more vulnerable to the disease (Dassieu *et al.*, 2021). The COVID-19 pandemic demonstrated that deprived and vulnerable populations of societies are mostly exposed to the detrimental effects of the pandemic (Ashcroft *et al.*, 2021). This recent pandemic provided a historic paradigm to examine and dispute the values of economic, social, environmental, and cultural belief systems (Haley *et al.*, 2021). Cities have two main tasks in dealing with public health crises; one is to deal with the sudden mass of sick people, and the other is to ensure normal living conditions for every resident, especially the most vulnerable ones. Local governments have to ensure higher living standards for their growing populations (Guida & Carpentieri, 2021). Implementing new policies during the pandemic, as the COVID-19 experience has proved, can play a significant role in mitigating its detrimental impacts and protecting lives (Ashcroft *et al.*, 2021). Authorities had to decide during the COVID-19 pandemic about the priority groups for vaccination in a changing socio-epidemiological landscape, where the success of large-scale non-pharmacological interventions needs widespread social acceptance (Jentsch *et al.*, 2021). In this area, extensive studies have been conducted to investigate the inequities caused by the pandemic. Bilal *et al.*, (2022) studied major cities in the United States to investigate the health inequalities, and unfair and systematic differences in health between different groups of people, across urban areas during the COVID-19 pandemic. They concluded a trend of inequalities in the field of health based on demographic characteristics such as race, ethnicity, neighborhood, and city. The results of their study revealed higher age-adjusted mortality in non-Hispanic Black populations, compared with non-Hispanic White persons in all the studied cities. Ngcamu & Mantzaris (2021) determined the socio-economic effects of COVID-19 on vulnerable communities in South Africa. They revealed the frustration of civil society organizations in providing humanitarian aid to the affected groups. They mentioned fragmentation, bureaucracy, mismanagement, and corruption of the South African government's administration as a negative factor affecting the well-being of vulnerable people, who live in informal settlements. Ndumbe-Eyoh *et al.*, (2021) investigated the factors affecting inequalities in the field of health. They showed that equity and justice have not been integrated in the planning and response phases of the COVID-19 pandemic. They stated that fully exploiting political opportunities can be the key to leading to social transformation. In a qualitative study, Kaihlanen *et al.*, (2022) examined the challenges experienced by vulnerable populations in Finland in using digital health services during the COVID-19 pandemic and deduced that along with the increasing digital health services, traditional face-to-face services must be offered to ensure equal access of all society groups to services. Using the examples of two social organizations that provide services to homeless and addicted people, Farkas & Romaniuk (2020) explored the support services for vulnerable populations during the COVID-19 outbreak and presented some insights for future social work. Through systematic review and meta-analysis, Nam *et al.*, (2021) compared the mental health effects of coronavirus disease on non-vulnerable populations and various vulnerable groups, including people with chronic diseases, patients with serious mental illness, elderly people, and pregnant women. The results of this study showed that the mental health of each vulnerable group has been impacted differently by the pandemic. In a qualitative study, Nasiri *et al.*, (2023) explored the leaders' experiences on how local authorities in Tehran prevent the spread of coronavirus infection among socioeconomically vulnerable groups. According to the experts' opinions, developing protection plans for vulnerable populations and providing resources outside of the

bureaucracy will help policymakers to be prepared for responding to disasters. Extensive studies have also investigated government policies and plans on how to ration the coronavirus vaccine, with a concentration on vulnerable groups. Applying a triple-coding method, Strodel *et al.,* (2021) analyzed the United States government programs in prioritizing the COVID-19 vaccine for incarcerated people over other vulnerable communities. They showed that COVID-19 vaccine allocation programs in 50 states and the District of Columbia do not prioritize incarcerated individuals. Moreover, there is little guidance on inmate vaccination protocols, and due to inappropriately prioritizing incarcerated individuals for vaccination, a critical opportunity to mitigate COVID-19 is missed. Jentsch *et al.,* (2021) formulated a mathematical model of SARS-CoV-2 infection, in which social and epidemiological dynamics interact. They identified four COVID-19 vaccine prioritization strategies: prioritizing people older than 60 years, prioritizing people younger than 20 years, vaccinating uniformly according to age, and a new contact-based strategy. They stated that the most effective vaccination strategy to reduce the mortality of COVID-19 is dependent on the time course of the pandemic in the population. Schmidt (2020) examined vaccine rationing and social justice in response to COVID-19 and argued that for ethical, epidemiological, and economic reasons, rationing approaches should prioritize structurally and historically disadvantaged groups, even if this results in shorter overall life expectancies. Although the complexity of cities has long been recognized by urban health scientists and decision-makers, it has not yet been functionally integrated into urban health research, policy, and practice (Gatzweiler *et al.*, 2023), and limited studies have dealt with managing the complexity of urban health systems. Haley *et al.,* (2021) addressed the value of integral critical systems during the COVID-19 outbreak and considered the potential role of systems thinking in managing communities' responses to the pandemic. They used examples from Brazil and the UK to investigate the validity of current disaster management systems. Nguyen *et al.,* (2023) examined the application of an integrated management approach to coping with the uncertainty of COVID-19 using a comprehensive systems intervention. To clarify the strengths and weaknesses of different management approaches, three different countries from Europe, Oceania, and Asia have been chosen as typical case studies. The results showed that decision-makers can take advantage of an integrated management approach in dealing with crises and definitively revealed this approach's superiority, regardless of the cultural environment. Actually, in the recovery phase of disaster management in the coronavirus disease, the attention of city managers was paid more than ever to keeping a rethinking and critical position of urban management experiences (Nasiri *et al.*, 2022). Using a critical systems heuristics perspective, Godage *et al.* (2023) evaluated the sustainability of a hospital digital health system in Sri Lanka through key stakeholders' engagement. A holistic approach is required to assess the sustainability of digital health systems, including obtaining multiple stakeholders'/beneficiaries' perspectives, based on Ulrich's concept (boundary judgment which is the initial judgment and overview of the system). They concluded that the theoretical concept of Critical Systems Heuristics (CSH) can be applied in the sustainability assessment of digital health systems by various stakeholders. Implementing ethics in medical Artificial Intelligence (AI) is a complex issue that requires a systems approach (Goirand *et al.*, 2023). Although CSH has been effective in developing critical systems thinking, it has not been fully exploited compared to soft system approaches, like Soft Systems Methodology (SSM) and cognitive mapping. This may be partially because of the complexity of the underlying idea of CSH (Hutcheson *et al.*, 2024). The system approach emphasizes considering the values of all stakeholders in the design and decision-making (Kunc (2024), Driscoll *et al.,* (2022), Samadi-Foroushani *et al.,* (2024), and Edson (2017)). A critical understanding of the system places the concept of borders at the center of systemic thinking and shows how different borders of a problem can lead to different perceptions and solutions (Midgley & Rajagopalan (2021), Ulrich & Reynolds (2020) and Ulrich & Reynolds (2010)). It requires paying special attention to deprived stakeholders, especially those who are affected by the plans but are not included in the design process. Applications of CSH are presented in (Midgley & Rajagopalan (2021), Algraini & McIntyre-Mills (2018), Dehghan Nayeri et al. (2020), Hutcheson et al. (2023)). Moreover, Strategic Assumptions Surfacing and Testing (SAST) is a systems approach for learning

in complicated problem situations (Barabba & Mitroff (2014) and Mitroff (2016). Using dialectical dialogue helps managers to encourage a collaborative approach to problem management. The involvement of a large number of decision-makers provides the possibility of different views and facilitates the implementation of new solutions. In recent studies (Novita Wahyu Setyawati *et al.* (2022), Bachri *et al.* (2021), Kholil *et al.,* (2021), Salahudin *et al.* (2019), Keyhanpour & Khalifehei (2023), Nasiri *et al.,* (2024), Zlatanović (2016) and Susanto *et al.,* (2019)), the application of SAST in providing strategic solutions for complex problems have been presented. With the spread of the COVID-19 pandemic, urban managers and local authorities in Tehran decided to provide public health services to vulnerable communities to establish urban social justice. For this purpose, before the introduction of the vaccine, measures such as testing for COVID-19 in sanatoriums; providing health, medical, and educational services and distributing health packages to working and street children and garbage collectors; and sending medical teams to garbage separation garages had been implemented. After the introduction of the vaccine, various plans were put on the agenda to increase urban justice for vulnerable groups, one of which was setting up a call center and providing in-house vaccination services to vulnerable groups in Tehran. According to Tehran's coronavirus disaster management headquarters, a total of 11556 doses of coronavirus vaccine were injected into the vulnerable groups at their houses (Tehran's Corona disaster management headquarters, 2023). Considering critical rethinking, the present study investigates the in-house vaccination service system of vulnerable populations using the hybrid approach of critical systems heuristics and strategic assumptions surfacing and testing. To this end, urban planners and decision-makers have been interviewed to evaluate the in-house vaccination system of vulnerable groups in four basic categories, including motivation, control, knowledge, and legitimacy, and discovered the boundary judgments of the beneficiaries. Besides clarifying learning areas of the COVID-19 pandemic experience, this research reveals the strategic assumptions of the development of the health service system in pandemics for vulnerable people, based on the SAST approach. Finally, by considering dialectical discussions and integrating system development solutions, a certain planning region is proposed. This research is conducted based on the collecting data in Tehran, Iran from 2020 to 2023.

MATERIALS AND METHODS

The current study is action research that analyzes the situation of the problem by focusing on the paradigm of critical systems and multiple methodologies (multi-method and multi-paradigm). In terms of approach, it is exploratory and mixed and uses a combination of qualitative and quantitative methods. The qualitative part of the method deals with the answers of the interviewees to the 12 questions and the integration of the solutions based on qualitative content analysis, And the quantitative part is the prioritization of the solutions based on the group score of experts. This study combines two systematic methodologies, CSH and SAST, to identify developing strategies for in-house vaccination service systems for vulnerable populations. In CSH, the components of the system and its environment will be organized into four basic categories, which include motivation, control, knowledge, and legitimacy (as shown in Table 1), to identify and examine the consequences of boundary decisions.

Strategic Assumptions Surfacing and Testing is a systems approach for learning in complex problem situations. Systems thinking and soft operations research have been successful in contributing to the management of complexity (Masys, 2015). SAST reveals the conflicts and aligns them all as the only way to achieve a constructive synthesis of various worldviews (Jackson, 2019) and (Jackson, 2016). The used methods in SAST are stakeholder analysis, defining assumptions, and ranking assumptions, all of which support the phase of assumptions surfacing in the methodology. The ranking of the assumptions will be done based on the following criteria:

- *What is the importance of these assumptions in terms of their influence on the success or failure of the strategy?*
- *How confident are we about the probability of occurrence or the truth of the statements in the assumptions?*

Finally, the most important assumptions, on which the proposed strategy of the participants depends, will be determined. In this research, the required information has been collected through library research, including documents, reports, related

Table 1: Twelve boundary questions of CSH (Ulrich & Reynolds, 2020)

	Social Roles	***Specific concerns***	***Key problems***
Motivation	*1. Beneficiary* Who is/ ought to be the intended beneficiary of the system?	*2. Purpose* What is/ ought to be the purpose of the system?	*3. Measure of improvement* What is/ ought to be the system's measure of success
Control	*4. Decision-maker* Who is/ ought to be in control of the conditions and resources for the success of the system?	*5. Resources* What conditions or resources are/ ought to be under the control of the system to succeed?	*6. Decision environment* What conditions of success are/ ought to be outside the control of the decision-maker?
Knowledge	*7. Expert* Who is/ ought to be providing the required knowledge and skills for the system?	*8. Expertise* What are/ ought to be the required knowledge and skills for the system?	*9. Guarantor* What are/ ought to be regarded as assurances of successful implementation?
Legitimacy	*10. Witness* Who is/ ought to be representative of those who are negatively affected by but not involved in the system?	*11. Emancipation* What are/ ought to be the opportunities of those negatively affected but cannot argue their interests?	*12. Worldview* What space is/ ought to be available for dealing with different worldviews among those involved in and affected by the system?

Table 2: Information of the interviewees

No.	Education	Expertise	Experience (years)	Responsibility
1	Master of Science	Strategic management	>20	Head of Tehran's Disaster Management Headquarters
2	Doctor of Philosophy	Sociology	<15	Social consultant and geriatrician
3	Master of Science	Urban management	>20	Operations manager and service system planner
4	Doctor of Philosophy	Health in disasters and emergencies	>15	service system planner
5	Doctor of Philosophy	Health in disasters and emergencies	>20	Consultant of medical emergency and health in disasters
6	Doctor of Philosophy	Industrial engineering	<10	service system analyst
7	Doctor of Philosophy	Operations research management	<10	service system analyst
8	Doctor	Medical science	>20	Human resource planner
9	Master of Science	Management	>20	call center operator
10	Master of Science	Social work	<15	Social consultant and specialist of disabled people
11	Master of Science	ICT	>20	call center operator
12	Bachelor of Art	Nursing	<10	Consultant of health and treatment services in medical emergencies
13	Bachelor of Science	HSE	<15	Registrant and vaccinator
14	Bachelor of Art	Management	>20	Planner and coordinator of the vaccination teams
15	Doctor of Philosophy	Psychology	>10	Counselor of psychological services in emergency and medical emergency

laws and regulations, previous studies, a system of in-house vaccination services for vulnerable groups, the call center of Tehran Municipality, and the semi-structured interviews of a combination of key actors involved in the vaccination services of vulnerable groups and urban decision makers of Tehran Disaster Mitigation and Management Organization (TDMMO). The interviewees have been identified by analyzing the beneficiaries of the studied vaccination system. The participants include service providers, such as call center operator, vaccinator, registrant, team coordinator, operation manager; and various specialists, such as social consultant and geriatrician, consultant of medical emergency and health in disasters, and counselor of psychological services in emergency. The details of these people are represented in Table 2. To identify solutions for the development of an in-house vaccination service system for vulnerable groups, the decision makers of TDMMO have participated in group interviews.

RESULTS AND DISCUSSION

Analyzing the extracted data of the vaccination service system of vulnerable groups from Tehran's Corona disaster management headquarters, revealed that in general, 8616 addresses had been registered from September 2021 to March 2023, and 11556 doses of vaccine were injected to vulnerable groups in 22 districts of Tehran; 35% of the vulnerable people who received this service were women and 65% were men. About 50% of this population requested in-house vaccination due to old age and 54% because of physical disability. Fig. 1 demonstrates the distribution of the provided services to vulnerable people during the aforementioned period. As this figure shows, the greatest demand for vaccinations is from November 2021 to January 2022 and the injected vaccine doses were also greater in this period compared to other months. According to Fig. 2, which presents the distribution of vaccination doses based on the districts of Tehran, districts 2, 4, and 5 have received more doses, and districts 19, 21, and 22 had the lowest demands. Fig. 3(a) depicts the medical diseases of

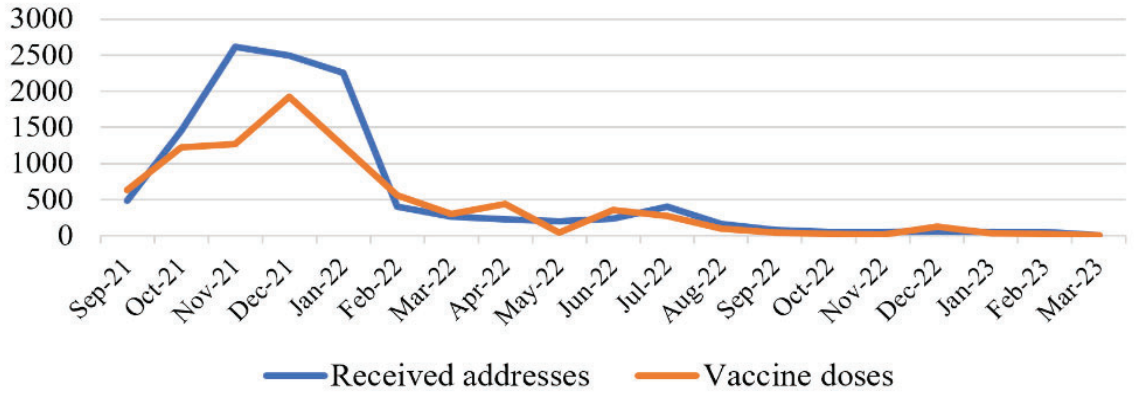


Fig. 1: Distribution of in-house vaccination services provided to vulnerable populations from September 2021 to March 2023 (Tehran's COVID-19 disaster management headquarters)

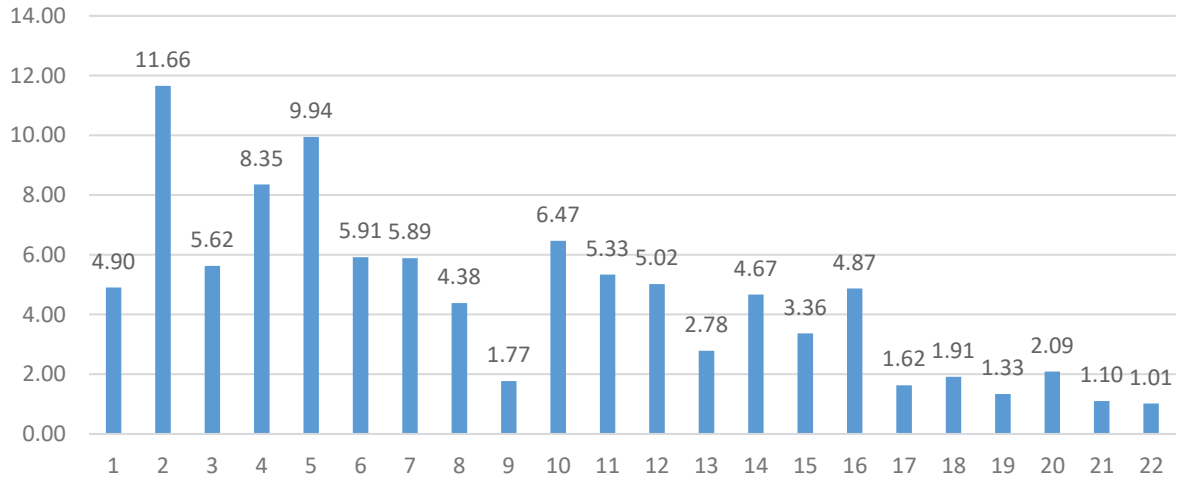
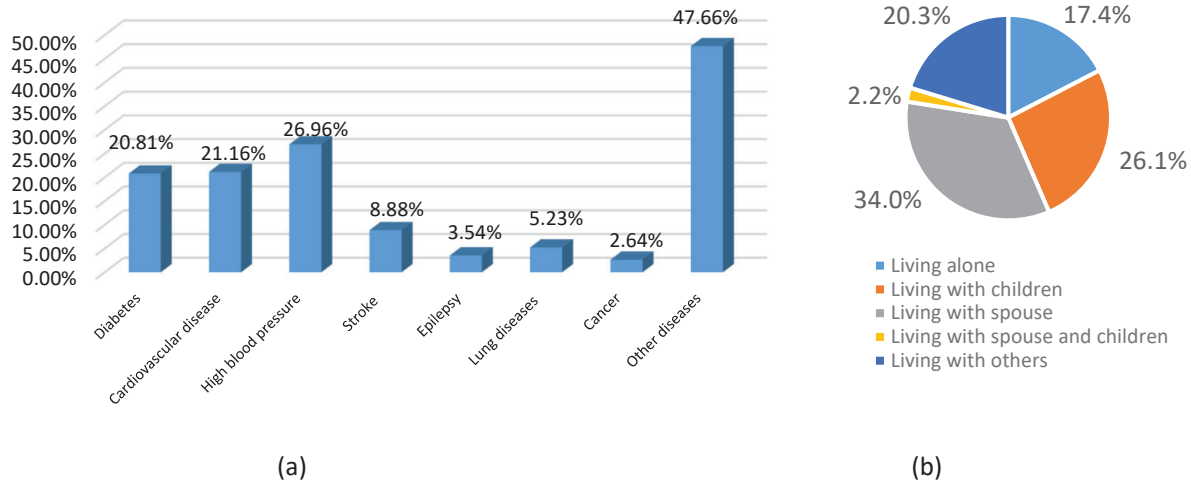


Fig. 2. Distribution of in-house vaccination services provided to vulnerable populations in different districts of Tehran (Tehran's COVID-19 disaster management headquarters)



(a) (b)

Fig. 3. a) medical records (percentage) and b) life companions (percentage) of vulnerable populations who received in-house vaccination (Tehran's COVID-19 disaster management headquarters)

the vulnerable groups. Examining the disease records reveals that among people who received in-house vaccination services, about 27% had high blood pressure, 21% had cardiovascular problems, and 21% reported diabetes. Some people had also stroke (9%), lung diseases (5%), cancer (2%), or other diseases (47%) in their records. Since every person may have stated more than one issue, the sum of these values is greater than 100%. Moreover, Fig. 3(b) shows the life companions of the vulnerable populations who received in-house vaccination; 17% of applicants lived alone, 26% lived with their children, 34% lived with their spouse, 2% lived with their spouse and children, and 20% lived with others. After analyzing the data of the in-house vaccination services system for vulnerable people, Ulrich's twelve questions have been posed in two cases, the current and desired ones ('was' versus 'ought to be'). The questions and the answers are represented in Table 3.

Considering the SAST methodology, the proposed solutions have been examined during the meetings with the decision makers of the TDMMO, and besides revealing the strategic assumptions of service system development, after dialectical discussions, system development solutions have been integrated. The participants were asked then to rate the proposed strategic assumptions based on two criteria, certainty, and importance, the average of which is represented in Table 4. The participants were also asked to state their opinions about other solutions and measures for solving the key issues. Finally, according to Fig. 4, a certain planning region has been found.

Considering the importance and certainty of the assumptions in Table 4, the certain planning region has been demonstrated in Fig. 4. The strategic assumptions in the first quadrant of the coordinate system represent the certain planning region, which includes the assumptions with higher importance and higher certainty. This includes S01, S02, S03, S04, S06, S07, S08, S09, S11, S12, S14, S18, S19, S20, S23, S28, and S33.

CONCLUSION

Recently, with the emergence of the COVID-19 pandemic, the world faced an enormous challenge in public health. Even though urban health scientists and decision-makers have long acknowledged cities as complex systems, very limited studies have analyzed urban health system issues using complex systems methodologies. Since the critical analysis of crisis management experiences in providing services to vulnerable people during the COVID-19 pandemic in Tehran has not been considered so far, the present study proposes a systemic intervention based on multimethodology-multiparadigm with an innovative combination of two methodologies (CSH and SAST), to critically rethink this issue, create areas for learning from the COVID-19 experience, and provide solutions

Table 3: Summarizing respondents' answers to Ulrich's twelve questions in the current and desired cases ('is' and 'ought to')

	Boundary judgement	The answer to 'was'	The answer to 'ought to be'
Motivation	Q1: Who were/ ought to be the clients of the in-house vaccination service system?	– The Elderly – Physically and mentally disabled people – Patients with special conditions – Managers of senior centers – Elderly family members	– The Elderly – Children – Pregnant women with young children – Physically and mentally disabled people – Patients with special conditions; Drug addicts and people without identity cards
	Q2: What was/ ought to be the purpose of the in-house vaccination service?	– Serving the vulnerable citizens of Tehran – Providing equal opportunity – Preventing the spread of pandemic	– Serving the vulnerable citizens of Tehran – Providing equal opportunity of vaccination to all citizens (social equity) – Preventing/mitigating the spread of pandemic
	Q3: What were/ ought to be the success criteria of in-house vaccination service?	- System startup - Positive feedback from citizens, including vulnerable people who were served and their families - Positive feedback from the Ministry of Health and Medical Education	– The ratio of the citizens who received in-house vaccination to the total vulnerable populations of Tehran – The ratio of the registered requests to the provided services – The waiting time of the vulnerable groups to receive the service – Complying with the expected schedule of vaccination – The quality of providing vaccination services – The level of satisfaction of vulnerable groups from service providers
	Q4: Who was/ ought to be the decision-maker of the in-house vaccination service system?	- The head of TDMMO, on behalf of Tehran's mayor	– Ministry of Health for determining the legal positions, roles, and relationships of the actors – State Welfare Organization of Iran for providing information of disabled populations – National Elderly Council of the Ministry of Labor and Social Affairs for considering the seniors – Tehran Municipality for its access to sanatoriums
Control	Q5: What conditions or resources were/ ought to be available under the control of the decision-makers for the success of the system?	– Volunteers – TDMMO human resources – Medical staff of Shahr Salem Company – Tehran municipality call center and system (137-6) – Municipal cars and taxis – Universities of medical sciences – Vaccinators and registrants – Ensuring the cold chain of the vaccines – Infectious waste management system – Legal gaps related to in-house vaccination services	– Trained volunteers – Financial resources – Databases of vulnerable groups – Efficient call center – Integrated information systems – Available vehicles (taxis, buses, etc.) – Efficiently informing citizens and vulnerable groups – Efficiently managing the volunteers – Legal provisions of in-house vaccination – Announcing capacities of Radio and Television, portals and billboards – GPS for tracking service provider cars – Using intelligent temperature stability in cool boxes to ensure cold chain supply
	Q6: What conditions or resources were/ ought to be as environmental factors?	– Maintaining the cold chain before receiving the vaccines – Receiving various types of vaccines – Coordinating the service delivery time – Receiving complete information – Receiving the same applicant's information from different calls	– Possibility of tracking the service status in an intelligent system by the applicants – Linking the information of vulnerable people to their contact numbers and addresses – The possibility of directing every call to a specific operator – Accessibility to medical information of vulnerable groups – Accessibility to different types of vaccines – Accessibility to emergency medical services in Tehran – The possibility of cultural compatibility between the vaccinator and the service applicant
Expertise	Q7: What kind of expertise and knowledge was/ ought to be necessary to provide in-house vaccination services?	– Registrant and Call center operator – Vaccinator – Driver – Protection unit – HSE inspector	– Vaccination service coordinator; - Registrant; - Vaccinator; - Call center operator; -Driver – HSE inspector – Emergency (doctor, nurse, etc.) – Psychologist and psychiatrist – Social worker and Backup team

Table 3: Summarizing respondents' answers to Ulrich's twelve questions in the current and desired cases ('is' and 'ought to')

	Boundary judgement	The answer to 'was'	The answer to 'ought to be'
Legitimacy	Q8: Which organization or what specialists were/ ought to be involved in designing in-house vaccination services?	– Tehran Disaster Management and Mitigation Organization (TDMMO) – Information and Communication Technology of Tehran Municipality – Shahr Salem Company – Health, treatment and medical education	– Specialist of health, treatment and medical education (doctors, psychiatrists, nurses, etc.) – Specialist of information and communication technology and System analyst and decision maker – Specialist of legal affairs and security unit – Counselors and caregivers of vulnerable groups – Non-profit organizations and Volunteers – Operating staff and Specialists of Safety, Health and Environment (HSE)
	Q9: Who was/ ought to be guaranteeing the success of the system?	– Self-declared reports of in-house vaccine providers	– Government: The Ministry of Health and Medical Education – Corona disaster management headquarters of the country – Tehran's corona disaster management headquarters
	Q10: Who were/ ought to be representing the interests of people who were affected during in-house vaccination?	– Managers of Tehran municipality – Managers of Tehran Disaster Mitigation and Management Organization – Managers of the Ministry of Health and Medical Education	– Tehran Provincial Government – Ministry of Health and Medical Education – Tehran Welfare Organization – Tehran Municipality – Tehran Disaster Mitigation and Management Organization
	Q11: Who or what were/ ought to be there for challenging the fulfillment of the officials' promises to the vulnerable groups?	– Mental perception of the service recipients – Mental perception of citizens – Social networks	– Legislation to support vulnerable people during crisis – Transparency and accountability in implementing laws – Providing transparent reports of the performance of the service providers – Governments' reputation – Media literacy of citizens and vulnerable groups
	Q12: What are/ ought to be the prospects of success?	– Equitable access to vaccination services in Tehran	– Efficient legislation in designing Tehran's disaster management command system – Determining the structure and responsibilities for managing pandemics in Tehran – Determining the position and role of municipality in providing services to vulnerable groups – Trusting the command system and effective cooperation with others – Having access to the information bank of vulnerable groups – Planning services to vulnerable groups to provide social justice – Publishing transparent performance reports

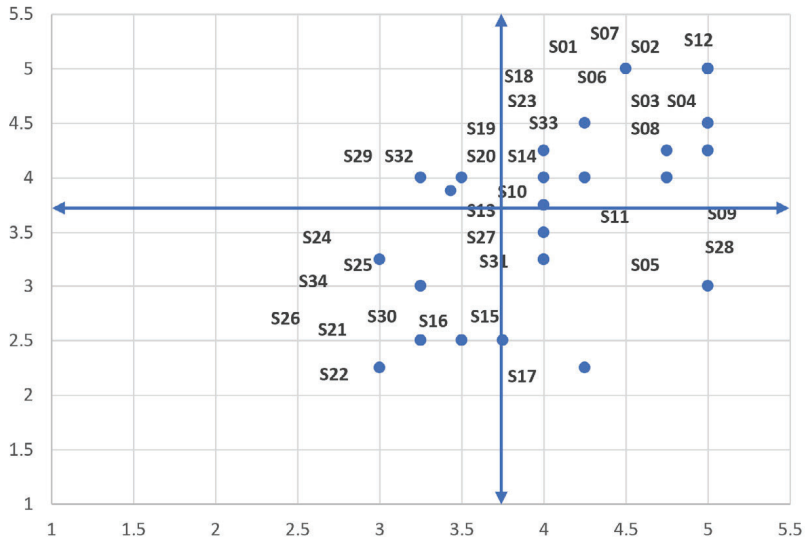


Fig. 4: Demonstration of the strategies by their certainty and importance to find the certain planning regio (The cut off point is determined based on the average of 3.7)

for redesigning and developing the health service system for vulnerable groups during the future pandemics. For this purpose, the extracted data of the vaccination service system of vulnerable groups from Tehran's Corona disaster management headquarters was first analyzed demographically. Then Ulrich's twelve questions have been considered under two scenarios ('was' versus 'ought') and the certain planning region is found by applying the Strategic Assumptions Surfacing and Testing methodology. The contribution of the study is considerable on two levels: firstly, in using an innovative combination of methodologies consistent with the complex dimensions of the problem's situation, and secondly in the application of this combination in providing services to vulnerable groups. Accordingly, the key strategies for system development are identified, which include: designing the pandemic command system; redefining the provision of healthcare services to vulnerable groups during the pandemics; providing services to all vulnerable groups during disasters through Tehran's joint emergency response call center (SOS); providing stable financial resources to perform services to vulnerable populations during the pandemics; collecting, updating, and integrating the related databases (such as elderlies, patients, people with disabilities, etc.); training service providers (e.g. call center operators, vaccinators, etc.) in accordance with the specific situations of vulnerable groups; developing guidelines for providing in-house services to vulnerable people; obliging the managers to be accountable for obeying protective laws relating to vulnerable groups in crisis; identifying the potential capacities of the private sectors and nongovernmental organizations; considering a medical support team; consulting with advisors and caregivers of vulnerable groups; using temperature recording devices to ensure the cold chain of vaccines; and setting up local disaster management support bases in order to assure the agility of the provided services to the vulnerable populations in Tehran. Generally, the research findings based on the Critical Systems Heuristics methodology identify the necessity of redefining the healthcare services system for vulnerable groups in the boundaries of control, knowledge, and legitimacy. This study revealed the values of all involved people and provided a context for critically rethinking the problem according to the concept of "boundary". After summarizing the problem by referring to the urban decision-makers and discussing the situation, it was possible to consider the values of all beneficiaries and consider them in designing the in-house services to vulnerable people. Moreover, the debates on testing the strategic assumptions among managers and urban decision-makers provided opportunities for organizational learning, enhancement of critical rethinking,

Table 4: Strategic assumptions of the development of an in-house health service system for vulnerable groups

Code	Strategic assumption of the development of an in-house health service system	Certainty	Importance
S01	The foundation of a committee for vulnerable groups by the National Disaster Management Organization (NDMO) in cooperation with other organizations that provide services for vulnerable groups, such as the welfare organization, the Ministry of Health and Medical Education, the Relief Foundation, etc., according to the upstream tasks of the documents	4.5	5
S02	Designing Tehran's pandemic crisis command system to clarify the legal positions, roles, and relationships of all parties in providing services to vulnerable groups during the pandemic	5	5
S03	Redefining the provision of health services to vulnerable groups during the pandemics in Tehran	5	4.5
S04	Providing stable financial resources to offer services to vulnerable groups during the pandemic	5	4.5
S05	Designing the vulnerable groups' service system in the Emergency Operations Center (EOC) and its approval in Tehran's disaster management headquarters	5	3
S06	Collecting and updating the database of vulnerable groups, including the elderly, patients, people with disabilities, etc.	5	5
S07	Integrating information databases of vulnerable groups, including the databases in Welfare Organization, Tehran Municipality, Ministry of Health and Medical Education, etc.)	5	5
S08	Planning to provide services to all vulnerable groups during disasters through Tehran's joint emergency response call center	5	4.25
S09	Redesigning the call center (137 system), for providing services to vulnerable groups in the EOC with the possibility of tracking and recording requests and comments/complaints	5	4.25
S10	Communicating with vulnerable citizens through mass media and social networks	4	3.75
S11	Evaluating the system's performance in providing services to vulnerable groups and identifying potential areas for development	4.75	4
S12	Providing legal documents for in-house services to vulnerable groups	5	5
S13	Defining legal requirements for entry of security guards to the houses of vulnerable groups	4	3.5
S14	Obliging the city managers and officials to be accountable and conduct transparent performance in enforcing protective laws for vulnerable groups in disasters	4.25	4
S15	Training volunteer forces to have an effective presentation in the service chain of vulnerable groups	3.75	2.5
S16	Scheduling and routing in-house services to vulnerable groups to reduce the waiting time	3.5	2.5
S17	Including a social worker and a psychiatric mental health nurse in the vaccination team	4.25	2.25
S18	Including a medical support team for advising vaccinators in specific situations	4.75	4.25
S19	Consulting with counselors and caregivers of vulnerable groups to adapt to the expectations and needs of different vulnerable populations (elderly, women, special patients, disabled, etc.)	4	4.25
S20	Tailored training of service providers (call center operators, vaccinators, etc.) based on the specific situations of each vulnerable group	4	4
S21	Holding specialized meetings at the national and local levels, with the participation of all involved actors in providing services to vulnerable groups	3.25	2.5
S22	Holding specialized maneuvers on providing services to vulnerable groups in disasters	3	2.25
S23	Identifying the potential capacities of private sectors and non-governmental organizations in providing services to vulnerable groups during disasters	4.25	4.5
S24	Training to prepare vulnerable people's caregivers/ nurses on how to take care of them during the pandemic	3	3.25
S25	Identifying and networking experts to form specialized teams for vulnerable groups and keep communication	3.25	3
S26	Flexibility in providing services to companions and caregivers of vulnerable groups during disasters	3.25	2.5
S27	Using a vehicle tracking system to ensure the security of the in-house vaccination supply chain	4	3.25
S28	Using temperature recording and warning equipment to ensure the cold chain of vaccines of in-house vaccination services to vulnerable groups	4.75	4
S29	Improving HSE supervision and inspection on infectious waste management of in-house vaccination services for vulnerable groups	3.25	4
S30	investigating the experiences of other countries in providing in-house vaccination services to vulnerable people	3.5	2.5
S31	Considering incentive policies and service compensation for volunteer forces	4	3.25
S32	Networking and strengthening communication to apply the capacity of non-governmental organizations in providing services to vulnerable groups during disasters	3.5	4
S33	Activating more local disaster management bases to improve agility in providing services to vulnerable groups in Tehran	4.25	4
S34	Expanding the provided services to vulnerable groups from the city to the provincial region, according to the received requests	3.25	3

integration, and consensus on the proposed solutions in certain planning. However, the limitations of the present study in terms of methodology and research implementation have revealed areas for future studies. Therefore, future research can apply other critical systems approaches in analyzing in-house services to vulnerable populations during the crisis and compare the results with this study. Moreover, the obstacles to implementing the proposed solutions may be analyzed and the functional model for developing the service system for vulnerable groups can be designed using soft systems methodology, while the participation of all involved stakeholders is considered. Designing a dynamic model of the health service system is another suggestion and the behavior of each proposed solution can be analyzed and compared over time. Besides, the current research has focused on urban management, while future research can consider the problem at local and national levels to identify the areas that can be developed at these levels. Other studies can focus on the needs of vulnerable groups (the elderly, people with disabilities, women, children, and patients with special conditions) during the crisis. A systematic review of other countries and cities' experiences in the field of providing services to vulnerable groups during the COVID-19 pandemic and finding their challenges, successes, and failures is another helpful area that needs further study to enhance the service systems to vulnerable people.

AUTHOR CONTRIBUTION

M. Samadi-Foroushani performed the literature review, and experimental design, analyzed and interpreted the data, and prepared the manuscript text, and manuscript edition. S.S. Miresmaeeli and Z. Molamohamadi performed the experiments and literature review, compiled the data, and manuscript preparation. A. Nasiri reviewed the results and revised the manuscript. All authors reviewed the manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

OPEN ACCESS

PUBLISHER NOTE

ABBREVIATIONS (NOMENCLATURE)

Abbreviation	Complete Word
CSH	Critical Systems Heuristics
EOC	Emergency Operation Center
ICT	Information and communications technology
NDMO	National Disaster Management Organization
SAST	Strategic Assumptions Surfacing and Testing
SSM	Soft Systems Methodology
TDMMO	Tehran Disaster Mitigation and Management Organization

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ORIGINAL RESEARCH PAPER

Revealing the impact of job satisfaction on turnover intention through organizational commitment as a mediation

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ABSTRACT

BACKGROUND AND OBJECTIVES: In the context of private school teachers in Indonesia, job satisfaction is considered a key factor in influencing teachers to remain in their positions within organizations. This study aims to examine the impact of job satisfaction on turnover intention with organizational commitment as an intervening variable among private school teachers, specifically at Muhammadiyah schools in Kapanewon Godean, Indonesia.

METHODS: The research method employed is a survey, with questionnaires distributed to 274 respondents. Of these, 205 completed questionnaires were successfully collected and analyzed. Data analysis was performed through Structural Equation Modeling utilizing SmartPLS 3.0 software.

FINDINGS: The results of the study indicate that job satisfaction has a significant positive effect on organizational commitment ($\beta = 0.649$; t-value = 12.705, $p < 0.005$), which in turn has a significant negative effect on turnover intention ($\beta = -0.473$; t-value = 6.674, $p < 0.005$). Additionally, organizational commitment was found to mediate the relationship between job satisfaction and turnover intention ($\beta = -0.307$; t-value = 5.607, $p < 0.005$). In other words, an increase in job satisfaction not only directly reduces teachers' intention to leave their jobs but also does so indirectly by enhancing their commitment to the organization.

CONCLUSION: This study highlights the importance of job satisfaction and organizational commitment in retaining high-quality teachers at Muhammadiyah schools. By enhancing job satisfaction, these schools can foster stronger organizational commitment, which, in turn, significantly reduces turnover intentions among teachers. These findings suggest that Muhammadiyah schools should prioritize creating supportive work environments that bolster teacher satisfaction and commitment, as this approach is key to sustaining a dedicated and effective teaching workforce.

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INTRODUCTION

Amal Usaha Muhammadiyah (AUM) has experienced rapid growth and significant advancements in recent years. This progress is evident not only in the increasing number of AUM institutions but also in their improved quality and expansion into remote areas and even internationally (Arifin, 2013; Oktavianto, 2023). AUM plays a crucial role in various strategic fields, including:

1) religious affairs,
2) social welfare,
3) politics and governance,
4) education.

Each of these areas represents Muhammadiyah's tangible contribution to building a just and progressive society. As one of the largest Islamic organizations in Indonesia, Muhammadiyah has actively contributed to educational development by establishing various institutions. Over time, Muhammadiyah has become known for its diverse facilities, including madrasahs, mosques, charitable organizations, and educational institutions. This commitment reflects Muhammadiyah's dedication to advancing education and community welfare, making it a crucial pillar in shaping a knowledgeable and morally upright society. Since 2022, the Indonesian government has launched the Government Employees with Work Agreements (GEWA) program. The Secretary of the Basic and Secondary Education Council of the Muhammadiyah Central Board has highlighted the program's impact on the appointment of honorary teachers in private schools, particularly on Muhammadiyah teachers. This has led to many teachers from Muhammadiyah schools transferring to public schools, raising concerns about a potential reduction in teaching staff at Muhammadiyah schools, which have long played a significant role in providing quality education in Indonesia. According to the Secretary of the Basic and Secondary Education Council of the Muhammadiyah Central Board, the program implemented by the Ministry of Education, Culture, Research, and Technology has caused significant upheaval, particularly among private schools now facing a shortage of teachers due to the migration of educators to public schools. To date, nearly 3,000 Muhammadiyah teachers have been accepted into the GEWA program, and this number is expected to continue rising. On the one hand, these teachers gain improved experience and welfare; on the other hand, their departure from Muhammadiyah schools presents new challenges. Many Muhammadiyah teachers who passed the GEWA selection and were appointed to public schools, with some even taking on roles as school principals, have introduced new complexities to the education sector. This impact affects the sustainability of educational quality in Muhammadiyah schools and raises concerns about the continued role of Muhammadiyah in nurturing the younger generation. Job satisfaction has long been studied as a critical antecedent of turnover intention (Pinnington *et al.,* 2024; Ning *et al.,* 2023). However, empirical findings show mixed results. While some studies confirm a strong inverse relationship (Madigan and Kim, 2021), others report weaker or context-dependent effects (Chen *et al.,* 2023). Moreover, existing research (e.g., Akinyemi *et al.,* 2022; Ariawan *et al.,* 2023; Williamson *et al.,* 2009) highlights organizational commitment as a key mediator between job satisfaction and turnover intention. Thus, this study aims to examine the impact of job satisfaction on turnover intention, with organizational commitment as an intervening variable among private school teachers, specifically at Muhammadiyah schools in Kapanewon Godean, Indonesia. Then, the distribution of the questionnaire was conducted from early February to the end of March 2023.

Literature review

Job satisfaction

Job satisfaction refers to the level of contentment employees feel about their work (Alshammari and Alenezi, 2023; Putra and Kudri, 2024). It describes the extent to which employees feel happy and have their needs met in the workplace. Job satisfaction is a positive feeling that arises from the evaluation of the characteristics of the job itself (Robbins and Judge, 2019). According to Luthan *et al*., (2019), job satisfaction represents how employees perceive the value and significance of their work. From several definitions, it can be concluded that employee job satisfaction reflects positive behavior characterized by a sense of happiness because the work they do can meet their desires and needs. Researchers at the University of Minnesota developed the Minnesota Satisfaction Questionnaire (MSQ) to measure an individual's level of satisfaction with various aspects of their job. Some indicators of job satisfaction identified

by Wiess *et al.,* (1967) include ability utilization, achievement, activity, advancement, authority, company policies, compensation, co-workers, creativity, independence, security, social service, social status, moral values, recognition, responsibility, supervision – human relations, supervision – technical, task variety, and working conditions. These indicators provide a comprehensive overview of the various factors contributing to an individual's job satisfaction. Job satisfaction has a significant impact on both individuals and organizations. Individuals who feel satisfied with their jobs tend to have better psychological well-being. Job satisfaction can reduce levels of stress, anxiety, and depression, as well as increase feelings of happiness and overall life satisfaction. Job satisfaction is also closely related to improved performance (Maryati *et al.,* 2019; Srimindarti *et al.,* 2020; Udin *et al.,* 2023). Individuals who are satisfied with their jobs tend to be more motivated, more dedicated, and more productive in carrying out their tasks. Furthermore, job satisfaction can enhance organizational efficiency. Satisfied employees are likely to be more collaborative, more innovative, and quicker in completing their tasks, which ultimately can improve the effectiveness and operational efficiency of the organization.

Organizational commitment

Organizational commitment refers to the emotional attachment, identification, and involvement an employee has with their organization (Hngoi *et al.,* 2024). It is a state in which an employee demonstrates support and attachment to the organization, including its goals, and has a strong desire to continue being a part of it (Robbins and Judge, 2019). Robbins and Judge (2019) identify three main dimensions of organizational commitment: (1) *Affective commitment*, which refers to the emotional bond and belief in the values of the organization. Employees with affective commitment experience an emotional bond and are highly engaged in supporting the organization because they share the same values; (2) *Normative commitment*, which is the sense of obligation to remain in the organization. Employees feel that they have a moral responsibility to stay loyal and continue their contributions because it is regarded as the appropriate action to take; (3) *Sustained commitment*, which refers to the awareness of the economic value gained from remaining in the organization, compared to the risks or losses that may occur if one leaves. Employees with sustained commitment tend to maintain their membership due to practical and financial considerations. These three dimensions illustrate how organizational commitment can be formed through various motivations, including emotional (Udin *et al.,* 2024), moral, and rational factors, all of which play a crucial role in maintaining the sustainability of the relationship between employees and the organization. Organizational commitment greatly influences both employees and their organizations as a whole, which is reflected in various aspects of behavior, performance, and organizational dynamics (Martono *et al.,* 2020). Employees with strong organizational commitment are more likely to exhibit superior performance and increased productivity (Djastuti *et al.,* 2019). They feel emotionally or morally bound to the organization's goals, which motivates them to work harder and achieve optimal results (Udin *et al.,* 2022). Furthermore, a strong commitment to the organization can enhance an individual's psychological well-being. Employees who feel connected to the organization and confident in their role within it typically experience higher job satisfaction and lower stress levels.

Turnover intention

Turnover intention is often seen as the psychological state that precedes an employee's decision to leave their current organization (Zhuge *et al.,* 2024). It also refers to the deliberate desire and intent to quit and seek alternative employment. This definition was first proposed by Mobley *et al.,* (1978). According to Paramita and Hendratmoko (2021), turnover intention reflects the likelihood of developing a desire or intention to leave the current workplace for another, which is often triggered by various factors, including a lack of job satisfaction. Akgunduz and Eryilmaz (2018) add that turnover intention refers to the developing thought or awareness of leaving the company where one works. Meanwhile, Haque *et al.,* (2019) explain that turnover intention is an early sign of the process of an individual's withdrawal or departure from their job or organization. Thus, turnover intention is not merely a desire to change jobs but also an important indicator that can reveal potential issues related to employee satisfaction and engagement within the

organization. Identifying and understanding the factors that trigger turnover intention is crucial for organizations to maintain workforce stability and develop effective retention strategies. Turnover intention essentially refers to the emergence of a desire or thought to leave the company where one works and seek new employment. This desire or thought becomes an early sign that the individual is beginning to consider withdrawing from their job. Although they may still be physically present at the workplace, their heart and mind are inclined toward leaving and seeking other opportunities (Salleh *et al.,* 2020). Turnover intention reflects a disconnect between expectations and reality in the workplace, which can serve as an important indicator for organizations to take preventive action in retaining their employees. Turnover has a significant impact on both individuals and organizations. Individuals who experience turnover often face uncertainty in their careers (Lee *et al.,* 2017; Zhu *et al.,* 2019). Moving from one job to another can lead to concerns about job stability, career prospects, and adjustment to a new work environment (Nawaz and Pangil, 2016). Furthermore, frequent job changes may hinder the development of deep skills and knowledge in a specific field. Fragmented experience can make it difficult for individuals to build the competencies needed to attain higher or more specialized positions.

Hypotheses development

Job satisfaction and turnover intention

Job satisfaction is a favorable emotional condition experienced by employees when their performance contributions are valued and their needs are adequately met in the work environment. According to Priansa (2017), job satisfaction is an essential element that influences how an employee performs their duties. Employees who feel satisfied tend to demonstrate high work performance and do not perceive their job as a burden in their lives. On the other hand, job dissatisfaction can hinder performance and lead to negative feelings toward the job, ultimately affecting the individual's productivity and well-being. Job satisfaction can be a significant predictor in measuring the level of employee turnover intention in a company. An increase in job satisfaction is usually inversely related to turnover intention; the higher the job satisfaction, the lower the employees' intention to leave the company. Numerous studies have shown a significant negative relation between job satisfaction and turnover intention. For instance, research conducted by Prasetio *et al.,* (2019) found that job satisfaction has a significant negative effect on turnover intention. Similar results were found in the study by Pinnington *et al.,* (2024), which stated that job satisfaction significantly reduces turnover intention. Another study by Yousuf and Saqib (2021) also supports this finding, showing that as job satisfaction levels increase, the intention to leave decreases significantly. These findings accentuate the importance of efforts to improve job satisfaction in employee retention strategies, as higher satisfaction can reduce employees' desire to leave the company.

H1: Job satisfaction has a significant negative effect on turnover intention

Organizational commitment and turnover intention

According to Edison *et al.,* (2017), organizational commitment is a positive emotional drive that motivates employees to commit to pursuing excellence and achieving performance, especially for those who want to advance their careers and feel that their contributions are important. Employees with high organizational commitment are generally more enthusiastic about enhancing the organization's competitiveness and providing optimal service. Meanwhile, Priansa (2017) explains that organizational commitment reflects how strongly an employee is attached to their organization and contributes to its long-term success. Employee organizational commitment is an important aspect that companies need to pay attention to, as this commitment becomes a key factor in lowering turnover rates. As organizational commitment increases, employees' intention to change jobs tends to decrease. Thus, it can be said that organizational commitment has a significant negative effect on turnover intention. Research by Chan and Ao (2019) supports this by showing a significant negative relationship between organizational commitment and turnover intention levels. Additionally, a study conducted by Kang *et al.* (2015) on employees in the hospitality sector also identified an inverse correlation between organizational commitment and turnover intention. These findings emphasize that increasing employee organizational commitment is a crucial strategy for companies to reduce turnover and retain talent within the organization. Previous studies

have indicated an inverse correlation between organizational commitment and turnover intention, as found in studies by Ardyputri and Ariyanto (2023), Chiedu *et al.* (2017), Ekhsan (2019), Chua and Hoi-Man (2023). Affective and normative commitment, as well as satisfaction with salary, promotions, and job characteristics, are significantly correlated with a decrease in the intention to change jobs (Manoppo, 2020). These results highlight the need for enhancing organizational commitment and job satisfaction to be effective strategies for minimizing employee turnover intention.

H2: Organizational commitment has a significant negative effect on turnover intention

Job satisfaction and organizational commitment

If an organization provides a high level of autonomy and adequate compensation to its employees, this is likely to increase their job satisfaction. Satisfied employees are more likely to develop a strong emotional and moral commitment to the organization (Williamson *et al.,* 2009). They not only feel morally obligated to stay committed but also choose to remain in the organization because they want to. Autonomy, as one of the indicators of job satisfaction, plays a crucial role, especially in professions such as teaching. With high autonomy, teachers have the freedom to apply creative methods in their teaching and interact with students, which in turn can enhance their motivation to teach. This autonomy also allows teachers to explore and evaluate various teaching methods, helping them identify the most effective approaches and eliminate less beneficial ones (Coelho *et al.,* 2011). Thus, providing autonomy and adequate compensation not only enhances satisfaction and commitment but also contributes to professional development and the improvement of educational quality. Empirical research by Bashir and Gani (2020) demonstrated that job satisfaction has a significant effect on organizational commitment among lecturers in India. This study emphasizes the importance of providing support, enhancing job satisfaction, and clearly defining organizational values to employees to increase their commitment to the organization (Sadaf *et al.,* 2022). Additionally, research by Al-Refaei *et al.* (2024) and Huang (2022) also found that job satisfaction significantly affects organizational commitment. These findings give prominence to the importance of job satisfaction as a key factor in strengthening employees' commitment to their organization.

H3: Job satisfaction has a significant positive effect on organizational commitment

Organizational commitment as a mediator

If an organization provides a high level of autonomy and competitive salaries to its employees, this will significantly enhance their job satisfaction. As job satisfaction increases, employees are likely to develop stronger emotional and moral commitment to the organization (Williamson *et al.,* 2009). When employee commitment is high, they become more attached to the organization's values and goals and feel motivated to maintain their membership within the organization. Consequently, their intention to switch to another workplace or turnover intention will decrease. In other words, providing autonomy and good compensation not only boosts job satisfaction but also strengthens employee loyalty and commitment, ultimately reducing the risk of turnover.

H4: Organizational commitment mediates the relationship between job satisfaction and turnover intention.

MATERIALS AND METHODS

Population refers to a group of people, events, or things that are the focus of a researcher's investigation (Bougie and Sekaran, 2019). In this study, the population includes all teachers at Muhammadiyah Schools at the kindergarten, elementary, and junior high school levels in Kapanewon Godean, Indonesia. According to Bougie and Sekaran (2019), a sample is a portion of the population selected to represent the entire population. This study employs a census approach, meaning all members of the population were included in the analysis. By including all teachers at Muhammadiyah Schools in Kapanewon Godean, the study ensures comprehensive coverage and provides robust, representative insights into the relationships between the variables studied. This study utilizes primary data, which is collected directly from respondents by the researchers, about the variables under investigation (Bougie and Sekaran, 2019). This study employs a questionnaire designed by the researchers as the data collection method to gather information on job satisfaction, organizational commitment, and teacher

turnover at Muhammadiyah Schools in Kapanewon Godean. This questionnaire serves as the primary tool for gaining direct insights from respondents regarding the variables being investigated, allowing the researcher to measure and analyze the relationships between these factors. Additionally, the measures of investigated variables are shown in Table 1. The distribution of the questionnaire was conducted from early February to the end of March 2023. Out of a total of 274 questionnaires distributed to 274 respondents, 205 questionnaires were returned and could be processed. Thus, the response rate was 75%. This figure indicates a fairly high level of participation, providing adequate data for further analysis in this study. Based on the analyzed data, there are 31 male teachers (15%) and 174 female teachers (85%) at Muhammadiyah Schools in Kapanewon Godean. This shows that the majority of teachers in these schools are female. In terms of age, the majority of teachers at Muhammadiyah Schools in Kapanewon Godean are in the 26–35 age group, totaling 72 (35%). The age group above 45 follows with 57 (28%), then the 36–45 age group with 43 (21%), and the 18–25 age group with 33 (16%). Additionally, the number of teachers with more than one year of service is 161 (80%), while those with less than one year of service number 44 (20%). This data indicates that most teachers have considerable work experience, with a predominance of productive age and more than one year of service. The analysis tool used in this study is Structural Equation Modeling (SEM), which was conducted using SmartPLS 3.0 software. SEM is a statistical analysis technique that allows researchers to test and model complex relationships between latent variables, both direct and indirect. Using SmartPLS 3.0, researchers can perform Partial Least Squares (PLS) SEM analysis, which is well-suited for models with small to medium sample sizes and data that do not meet normality assumptions. SmartPLS 3.0 also enables researchers to test reliability, validity, and path significance within the model, producing a robust model with strong predictive power. This technique facilitates a deeper understanding of the relationships between variables in the study and provides more detailed insights into the structure of the model being tested.

Table 1: Indicators of investigated variable

Variable	Indicators		Source
Job satisfaction	1.	Ability utilization	Martins and Proença (2012)
	2.	Achievement	
	3.	Activity	
	4.	Advancement	
	5.	Authority	
	6.	Company policies	
	7.	Compensation	
	8.	Co-workers	
	9.	Creativity	
	10.	Independence	
	11.	Security	
	12.	Social service and states	
	13.	Moral values	
	14.	Recognition	
	15.	Responsibility	
	16.	Supervision – human relations and technical	
	17.	Task variety	
	18.	Working conditions	
Organizational commitment	1.	Affective commitment	Meyer and Allen (1991)
	2.	Continuance commitment	
	3.	Normative commitment	
Turnover intention	1.	Thinking of quitting	Mobley *et al*,. (1978)
	2.	Intention to search for alternatives	
	3.	Intention to quit	

RESULTS AND DISCUSSION

In Table 2, the average turnover score of 2.163 indicates that teachers' desire to leave the school is relatively low. This suggests that the majority of teachers feel sufficiently satisfied to remain at the schools where they work. Overall, the level of job

Table 2: Descriptive analysis

Variable	Items	Mean	Description
Job satisfaction	I am satisfied because I am allowed to use my skills to complete my work (JS1)	4.117	High
	I am satisfied with the achievements and performance I have gained from my work (JS2)	3.854	High
	I am satisfied with the opportunities provided by the company to perform my work at all times (JS3)	4.088	High
	I am satisfied with the opportunities for advancement in my skills and work competencies (JS4)	3.985	High
	I am satisfied with the company's policies (rules) that are implemented (JS5)	3.541	High
	I am content with the compensation I receive in accordance with my work performance (JS6)	3.629	High
	I am satisfied with the relationships/ interactions with my colleagues (JS7)	4.044	High
	I am satisfied with the opportunity to be creative in the work I do (JS8)	3.966	High
	I am given the opportunity to work independently in completing my tasks (JS9)	3.937	High
	I am satisfied because the organization provides security for retirement and health insurance for employees (JS10)	3.156	Moderate
	I am pleased with the support the organization offers to employees, both physical and mental, that helps motivate them in their work (JS11)	3.409	High
	I am satisfied with the salary, position, and benefits provided by the organization because they enhance social status (JS12)	2.980	Moderate
	I am satisfied with the attention, recognition, and praise given by the company (JS13)	3.439	High
	I am satisfied because I am given the opportunity to use my own work patterns for the advancement of the company (JS14)	3.785	High
	I am satisfied with the way my supervisor handles employee complaints (JS15)	3.556	High
	I am satisfied with the supervision techniques used by my supervisor (JS16)	3.585	High
	I am satisfied because I am given the opportunity to engage in different activities, such as arts (JS17)	3.761	High
	I am satisfied with the working environment conditions, such as the availability of rooms and equipment provided by the company (JS18)	3.717	High
Organizational commitment	I feel happy to spend my career at this school (OC1)	3.419	High
	I feel proud to be a part of this school (OC2)	4.016	High
	I perceive the school's challenges as my own personal issues (OC3)	2.824	Moderate
	I never feel like I am a part of this school (OC4)	3.917	High
	I do not have an emotional attachment to this school (OC5)	3.746	High
	This school holds a lot of personal meaning for me (OC6)	3.771	High
	I do not feel a sense of connection to this school (OC7)	3.927	High
	I remain loyal and trust in one school (OC8)	3.171	High
	I do not believe that teachers should always be loyal to their school (OC9)	3.390	High
	Moving from one school to another seems very unethical to me (OC10)	3.112	Moderate
	One reason I choose to stay at this school is that I believe loyalty is very important, and therefore I feel a moral obligation to remain (OC11)	3.707	High
	If I were offered a better job elsewhere, I would not leave this school (OC12)	3.122	Moderate
	Good things will happen if someone is loyal to their school (OC13)	2.966	Moderate
	It would be very difficult for me to leave the school now, even if I wanted to (OC14)	3.122	High
	Leaving my school at this point would cause significant disruptions to many aspects of my life (OC15)	3.059	High
	Currently, staying with the school is a need that I highly desire (OC16)	3.673	High
	I believe I have multiple options if I choose to leave the school (OC17)	2.849	Moderate
	One reason I stay at this school is that leaving would require giving up benefits offered by the school that are not provided by other companies (OC18)	3.498	High
Turnover intention	I often think about quitting my current job (TI1)	2.249	Low
	I may consider seeking a new job next year (TI2)	2.200	Low
	As soon as possible, I will leave this school (TI3)	2.039	Low

satisfaction among teachers is high, with an average mean score of 3.697. However, there is variation in satisfaction levels across different aspects of their jobs. The lowest mean score was found for teachers' satisfaction with salary, position, and the facilities provided by the organization, with a mean score of 2.981, which falls into the moderate category. This indicates that while overall job satisfaction is high, some aspects are perceived as inadequate by teachers. Conversely, the highest mean score of 4.117 was recorded for teachers' satisfaction with the opportunity to use their skills to complete their work. This shows that teachers are highly satisfied with the opportunities they have to apply their skills and abilities in their daily tasks, contributing positively to their overall job satisfaction.

Based on Table 3, the validity test for job satisfaction indicates that out of the total items, 16 items are valid, while 2 items (numbers 2 and 9) are invalid. For the organizational commitment variable, there are 7 valid items, while 13 other items are invalid, indicating a need for special attention to the measurement instrument for this variable. For the turnover intention variable, all 3 tested items

Table 3: Validity test

Variables	Items	Loadings
Job satisfaction	JS1	0.587
	JS2	*0.496**
	JS3	0.660
	JS4	0.595
	JS5	0.727
	JS6	0.633
	JS7	0.508
	JS8	0.649
	JS9	*0.342**
	JS10	0.555
	JS11	0.739
	JS12	0.650
	JS13	0.768
	JS14	0.598
	JS15	0.689
	JS16	0.727
	JS17	0.706
	JS18	0.625
Organizational commitment	OC1	0.700
	OC2	0.704
	OC3	*0.129**
	OC4	*0.370**
	OC5	*0.477**
	OC6	0.582
	OC7	*0.417**
	OC8	*0.172**
	OC9	*0.368**
	OC10	*0.026**
	OC11	0.732
	OC12	0.555
	OC13	*-0.011**
	OC14	*-0.134**
	OC15	*0.169**
	OC16	*0.308**
	OC17	*-0.393**
	OC18	0.660
	OC19	*-0.472**
	OC20	0.507
Turnover intention	TI1	0.800
	TI2	0.916
	TI3	0.840

*Note: * not valid item*

Table 4: Construct reliability and validity

Variables	Items	Loadings	Cronbach's Alpha	Composite Reliability	AVE
Job satisfaction	JS1	0.582	0.910	0.922	0.429
	JS3	0.652			
	JS4	0.586			
	JS5	0.730			
	JS6	0.631			
	JS7	0.505			
	JS8	0.647			
	JS10	0.553			
	JS11	0.742			
	JS12	0.657			
	JS13	0.775			
	JS14	0.599			
	JS15	0.695			
	JS16	0.732			
	JS17	0.710			
	JS18	0.621			
Organizational commitment	OC1	0.744	0.797	0.852	0.456
	OC2	0.689			
	OC6	0.572			
	OC11	0.792			
	OC12	0.639			
	OC18	0.723			
	OC20	0.525			
Turnover intention	TI1	0.801	0.813	0.889	0.728
	TI2	0.912			
	TI3	0.843			

are valid. This result suggests that the instrument for turnover intention has good reliability; however, there are some aspects of the job satisfaction and organizational commitment variables that need further evaluation or removal to ensure accuracy in measuring these variables.

After removing the invalid items, the analysis results in Table 4 show that Cronbach's alpha for job satisfaction is 0.910, which is greater than 0.70, and the composite reliability is 0.922, also exceeding 0.70. This indicates that job satisfaction is highly reliable. For organizational commitment, Cronbach's alpha is 0.797, and the composite reliability is also above 0.70, confirming that this variable is reliable as well. The Cronbach's alpha for turnover intention is 0.813, and the composite reliability is also greater than 0.70, indicating that this variable is also reliable. The Average Variance Extracted (AVE) values are 0.429 for job satisfaction, 0.456 for organizational commitment, and 0.729 for turnover intention. According to the criteria set by Fornell and Larcker (1981), an AVE value above 0.4 is acceptable as long as the Composite Reliability (CR) is greater than 0.50. Therefore, although the AVE values for job satisfaction and organizational commitment are slightly below 0.50, these variables are still considered valid due to their high composite reliability. Based on this analysis, all variables in the study are deemed valid and reliable. Based on Table 5 and Fig. 1, the analysis indicates that job satisfaction positively influences organizational commitment. This is indicated by an effect coefficient of 0.649, which is significant with a P-value of 0.000, less than 0.005. This means that an increase in job satisfaction significantly enhances employees' organizational commitment. Furthermore, job satisfaction hurts turnover intention, with an effect coefficient of -0.150. This effect is also significant, as shown by a P-value of 0.039, which is less than 0.005. This suggests that higher job satisfaction leads to a significant reduction in employees' intention to leave the organization. Organizational commitment also hurts turnover intention, with an effect coefficient of -0.473. This effect is highly significant, with a P-value of 0.000, less than 0.005. This suggests that the higher the organizational commitment of employees, the lower their intention to switch jobs. Additionally,

Table 5: Path coefficients

Hypotheses	Original Sample	Standard Deviation	T Statistics	P Values
Direct effects				
Job satisfaction → Organizational commitment	0.649	0.051	12.705	0.000
Job satisfaction → Turnover intention	-0.150	0.072	2.082	0.039
Organizational commitment → Turnover intention	-0.473	0.071	6.674	0.000
Indirect effect				
Job satisfaction → Organizational commitment → Turnover intention	-0.307	0.055	5.607	0.000

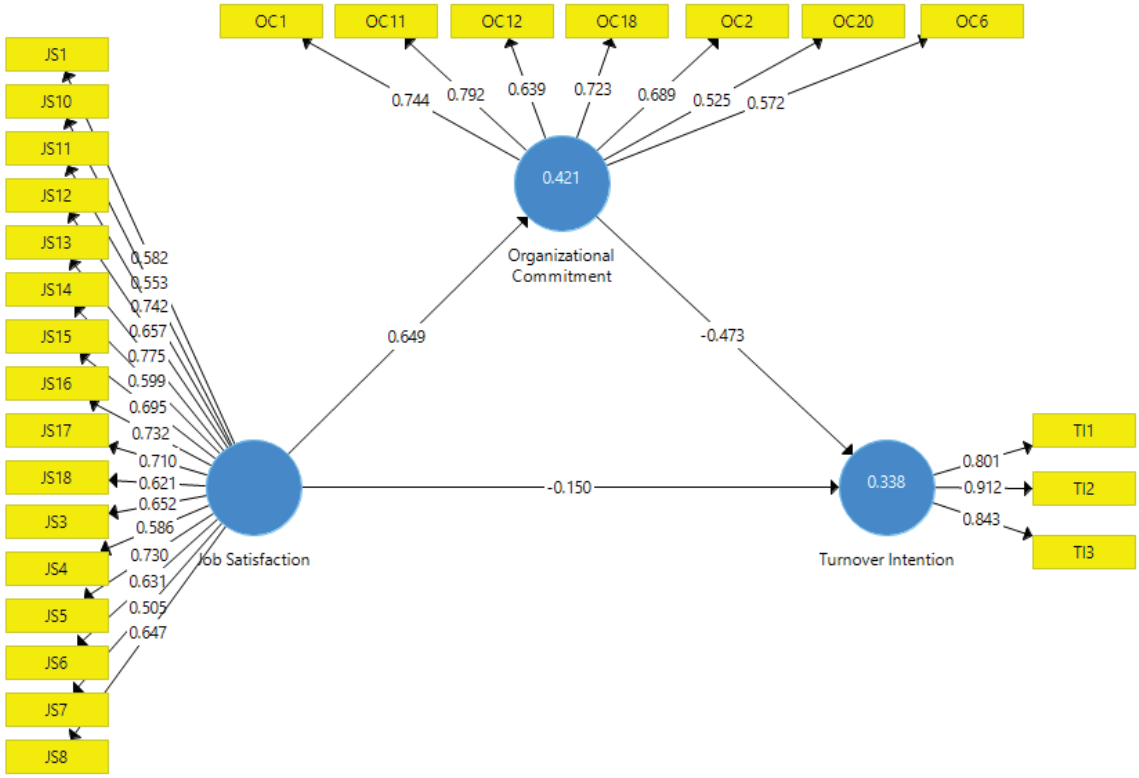

Fig. 1: A research framework

organizational commitment acts as a mediator in the relationship between job satisfaction and turnover intention. This is indicated by a P-value of 0.000, which is less than 0.005, showing that organizational commitment significantly mediates the effect of job satisfaction on the intention to leave the organization. Overall, these results indicate that job satisfaction not only enhances organizational commitment but also reduces turnover intention both directly and indirectly (through organizational commitment).

The effect of job satisfaction on organizational commitment

Empirical research shows that teachers in Muhammadiyah schools in Kapanewon Godean have a high level of satisfaction with the services provided by the school. This satisfaction encompasses various aspects of the services perceived as supportive of their duties and responsibilities as educators. The high level of job satisfaction positively impacts by increasing teachers' commitment to the

organization, thus creating a stable and productive work environment. Organizational commitment among teachers is also reported to be at a high level. These teachers demonstrate a strong desire to spend their careers at this school and feel proud to be part of this educational institution. The school holds deep personal significance for them, reflected in their loyalty and dedication in carrying out their daily tasks. Additionally, teachers feel a moral obligation to remain at the school, even when faced with better job offers elsewhere. This indicates a strong emotional bond and shared values between the teachers and the institution. Furthermore, the availability of various benefits and facilities provided by the school serves as an additional reason for teachers to continue working and contributing in this environment. Teachers are aware that leaving the school might mean losing various advantages that may not be available elsewhere. Therefore, staying and pursuing a career at Muhammadiyah School in Kapanewon Godean is seen as a highly desirable need, fulfilling both professional and personal aspects of their lives. By integrating the Conservation of Resources Theory (COR) proposed by Hobfoll *et al.* (2018), it can be understood that teachers will strive to conserve, protect, and maintain resources they deem valuable when faced with certain situations:

(1) When there is a threat of resource loss,

(2) When actual resource loss occurs,

(3) When they experience an inability to invest these resources.

In this context, if the organization provides a high level of autonomy and adequate compensation, such as high salaries, this will encourage employees, including teachers, to exhibit high levels of satisfaction. This high job satisfaction, in turn, will foster a stronger emotional and moral commitment to the organization (Al-Refaei *et al.,* 2024; Williamson *et al.,* 2009). Teachers will feel a moral obligation to remain committed to the organization, not out of compulsion, but because they genuinely desire it and see value in maintaining that relationship. Autonomy, in this context, plays a crucial role in allowing teachers to apply creative methods in the teaching process and interactions with students, aiming to enhance the quality of student learning. When teachers are given the freedom to experiment with teaching methods, it not only boosts their motivation but also provides them with opportunities to identify and refine the most effective teaching strategies (Coelho *et al.,* 2011). Conversely, they will also learn about less effective methods, which can be avoided in the future. Thus, providing autonomy and good compensation to teachers not only improves their job satisfaction but also supports the conservation of their psychological and professional resources. Teachers feel motivated to protect and develop these resources, which ultimately strengthens their commitment to the organization and reduces the likelihood of them moving elsewhere. The integration of COR theory with organizational practices highlights the usefulness of creating an adequate work environment where teachers feel valued and empowered to give their best for the students and the school. These results confirm previous findings by Bashir and Gani (2020), which demonstrated the strong impact of job satisfaction on organizational commitment among faculty in India. The study emphasized the importance of providing support, enhancing job satisfaction, and clearly defining organizational values to strengthen employees' commitment (Sadaf *et al.,* 2022). Research by To and Huang (2022) further supports these findings, showing that job satisfaction significantly impacts organizational commitment. Thus, the results of this study align with prior literature, highlighting the importance of factors such as organizational support and job satisfaction in reinforcing employees' commitment to their organization.

The effect of job satisfaction on turnover intention

The analysis shows that job satisfaction hurts turnover intention. This means that when teachers are satisfied with the services provided by the organization, their desire to leave for another place decreases. Conversely, the lower the job satisfaction experienced by teachers, the higher their desire to seek employment elsewhere. The desire of teachers to move to another place is recorded as low, which is supported by descriptive analysis showing that the mean turnover intention is categorized as low. Approximately 55% of teachers state that they do not consider leaving their current job, and 51% of teachers say they do not plan to look for a new job in the coming year. Additionally, 59% of teachers indicate that they will not leave the school anytime soon. These findings suggest that a high level of job satisfaction plays a crucial role in maintaining

teachers' commitment to the school and reducing their intention to seek job opportunities elsewhere. These results confirm previous findings by Prasetio *et al.,* (2019), which demonstrated that job satisfaction has a significant and negative effect on turnover intention. Similar findings were reported by Pinnington *et al.,* (2024), who stated that job satisfaction plays a crucial role in reducing turnover intention. Other studies, such as those by Yousuf and Saqib (2021), also support this conclusion, showing that an increase in job satisfaction is inversely related to a decrease in turnover intention. Additionally, research by Otache and Inekwe (2022) found a significant negative link between job satisfaction and turnover intention among PhD-holding lecturers at polytechnics in Nigeria. These findings consistently indicate that job satisfaction is a key factor in reducing turnover intention, both in educational settings and other sectors.

The effect of organizational commitment on turnover intention

The analysis shows that organizational commitment hurts turnover intention, meaning that the higher the teachers' commitment to the school, the lower their desire to leave the school. Descriptive analysis supports this finding by indicating that teachers' commitment is categorized as high, while their desire to leave the school is low. This finding aligns with research by Chan and Ao (2019), which found that organizational commitment is strongly inversely related to turnover intention. Additionally, research by Guzeller and Celiker (2020) on employees in the hospitality sector in the United States reinforces these results, showing an inverse relationship between organizational commitment and turnover intention. This conclusion underscores the importance of increasing organizational commitment to reducing turnover intention, both in the education sector and other industries. These results confirm previous findings by Ardyputri and Ariyanto (2023), Chiedu *et al.* (2017), Ekhsan (2019), and Chua and Hoi-Man (2023), which indicate a negative effect between organizational commitment and turnover intention. These investigations consistently find that higher organizational commitment is associated with lower intentions to leave the job. Additionally, Manoppo (2020) found that affective and normative commitment, along with satisfaction with salary, promotion, and job characteristics, are significantly correlated with a decrease in turnover intention. These results emphasize the critical roles of commitment and job satisfaction in retaining employees and reducing turnover intention.

The effect of job satisfaction on turnover intention, mediated by organizational commitment

If the organization provides a high level of autonomy and adequate compensation to employees, they are likely to show high levels of job satisfaction. This job satisfaction, in turn, will strengthen employees' emotional and moral commitment to the organization (Al-Refaei *et al.,* 2024; Williamson *et al.,* 2009). As employee commitment increases, they are more likely to support the organization's goals and feel motivated to maintain their membership within the organization, which significantly reduces their intention to leave. Based on the analysis, it was found that teachers' organizational commitment serves as a mediator in the link between job satisfaction and turnover intention. This means that high levels of job satisfaction experienced by teachers contribute to an increase in their commitment to the organization, which ultimately leads to a decrease in their desire to leave the school. In other words, when teachers are satisfied with their working conditions, it not only enhances their loyalty but also directly reduces the likelihood of them seeking employment elsewhere. These results underscore the importance of organizations focusing on improving job satisfaction as a strategy to strengthen employee commitment and reduce turnover intention. In practical terms, educational institutions and organizations must create environments where employees feel supported and valued. This goes beyond mere compensation; it includes providing opportunities for professional development, ensuring that employees have a voice in decision-making, and fostering a collaborative workplace culture. In schools, particularly, where the well-being of teachers directly impacts student learning, these strategies can lead to more dedicated and engaged educators, which improves both teaching quality and student outcomes. Additionally, when employees feel committed to their organization, they are more likely to go beyond basic expectations, contributing to a more productive and positive work environment.

CONCLUSION

The data analysis reveals that job satisfaction positively influences organizational commitment. This means that the higher the job satisfaction experienced by employees, the stronger their commitment to the organization. Additionally, job satisfaction also hurts turnover intention, indicating that as job satisfaction increases, employees' desire to leave the organization decreases. Furthermore, organizational commitment negatively affects turnover intention, meaning that the higher the employees' commitment to the organization, the lower their intention to move elsewhere. Finally, organizational commitment acts as a mediator in the relationship between job satisfaction and turnover intention. In other words, job satisfaction not only directly reduces turnover intention but also does so by enhancing organizational commitment. These findings underscore the essential values of job satisfaction and organizational commitment in retaining employees and reducing their intention to seek employment elsewhere. This study was conducted only with teachers at Muhammadiyah schools in Kapanewon Godean, so the results may not be fully generalizable to other contexts, such as different industry sectors or broader geographical areas. Additionally, this study used a cross-sectional design, meaning that data were collected simultaneously. This limits the ability to identify causal relationships between variables, as it cannot confirm whether changes in job satisfaction or organizational commitment would consistently lead to changes in turnover intention. Therefore, future research should consider using a longitudinal design to track changes in job satisfaction, organizational commitment, and turnover intention over time. This would provide better insights into the causal relationships between these variables. Future research could also focus on the multi-dimensional nature of job satisfaction, examining not only general satisfaction but also how specific factors such as working conditions, recognition, task variety, and supervision influence overall satisfaction levels. Researchers could explore how these factors vary across different employee groups, such as teachers in various educational settings or employees in different industries. Furthermore, integrating qualitative data collection methods, such as focus group discussions or in-depth interviews, with quantitative surveys could offer a richer and more comprehensive understanding of the factors influencing turnover intention.

AUTHOR CONTRIBUTIONS

T. Maryati was responsible for performing the methodology, literature review, and analyzing the data. U. Udin conducted the literature review, results, and discussion sections. M. Musoli compiled the data and drafted the manuscript. I. Wahyuni managed the article concerning its visualization, literary structure, and composition.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely witnessed by the authors.

disputed territories, place names, international boundaries, jurisdiction in published maps, and institutional affiliations. TURPC is committed to retracting a paper after its publication if it becomes apparent that there are serious problems in its content, in terms of research and publication ethics (https://www.ijhcum.net/journal/process?ethics).

ABBREVIATIONS (NOMENCLATURE)

AUM	Amal Usaha Muhammadiyah
AVE	Average Variance Extracted
COR	Conservation of Resources
CR	Composite Reliability
GEWA	Government Employees with Work Agreements
MSQ	Minnesota Satisfaction Questionnaire
PLS	Partial Least Squares
SEM	Structural Equation Modeling

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ORIGINAL RESEARCH PAPER

Sustainable tourism development model for policy formulation

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ABSTRACT

BACKGROUND AND OBJECTIVES: In recent years, sustainable tourism has gained significant attention due to integrating economic, social, and environmental goals into tourism development. Bangladesh, with its diverse cultural and geographical aspects, faces challenges in its tourism sector. To tackle these issues, a comprehensive and sustainable model for tourism development is needed, incorporating sustainability into all development and management phases. The study aims to develop a sustainable tourism development model for Bangladesh's socioeconomic and environmental resources.

METHODS: The study uses a qualitative research method guided by a review of the available secondary data – policies, literature, and domestic and international case studies. This study also applies the thematic analysis of the data gathered in the study method to address a policy gap in Bangladesh's tourism sustainability by identifying a whole system policy strategy.

FINDINGS: The sustainable tourism development model suggests cooperation between government agencies, local community members, the commercial sector, and non-governmental organizations. Environmental Impact Assessments, conservation, and climate change mitigation should be included in tourist management. The approach emphasizes community empowerment, non-uniform tourist benefits, and cultural conservation. The study suggests that Bangladesh's sustainable tourism development should be dynamic, flexible, and contingent on sustainability principles to its fullest (100%).

CONCLUSION: The sustainable tourism development model is a holistic approach to sustainable, inclusive, and equitable tourism policies, focusing on ensuring economic growth, environmental conservation, and social equity integration. By involving stakeholders and promoting community participation, the model addresses concerns about power, strategy, and interests, and promotes principles of eco-tourism, smart tourism, and climate resilience. This research contributes to a significant policy formulation for the tourism industry in Bangladesh by proposing a sustainable tourism development model.

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INTRODUCTION

Sustainable tourism has received increasing attention as a method of integrating economic, social, and environmental goals in tourism to cope with these challenges. Eroding the facets of Bangladesh are its cultural and geographical diversities, which make the country ecologically diverse and attract tourists worldwide. The government of Bangladesh is bestowed with the world's most prominent Mangrove Forest, 'Sundarbans,' a World Heritage Site, and the beach at Cox's Bazar, the longest sea beach in the world. Still, Bangladesh's tourism industry is lagging to some extent compared to any other nation in South Asia despite these allures. Challenges, including infrastructure, public policy systems, and the environment, as well as a lack of integrated policies and a sustainable environment, are some significant drawbacks that have congested the tourism sector's sustainable growth. There has been a growing realization that to address these challenges, Bangladesh needs a comprehensive and sustainable model for tourism development that will inform policy and practice. Ideally, such a model should incorporate sustainability into all the tourism development phases and its management involving stakeholders and the community. The existing theories and empirical studies focus on Sustainable tourism integrating economic development, environmental protection, and social equality. The Sustainable Development Theory emphasizes meeting existing requirements without sacrificing future needs, focusing on maintaining natural and cultural assets, reducing environmental harm, and promoting inclusion in tourist benefits (Brundtland, 1987; Shi *et al*., 2019; Pan *et al*., 2018). The Triple Bottom Line (TBL) concept evaluates tourism's economic, environmental, and social implications, highlighting its benefits such as Gross Domestic Product (GDP) growth, jobs, and infrastructure (Elkington & Rowlands, 1997; Streimikiene *et al*., 2021; Dwyer, 2005). Stakeholder Theory of Freeman (2010) suggests that all stakeholders should be involved in decision-making, reducing conflicts and serving different interests. Empirical research supports these theories, with African eco-tourism projects demonstrating that tourism can boost the economy while protecting biodiversity (Adetola, 2023). Asian community-based tourism models show that local participation improves social justice and cultural resilience (Scheyvens & Biddulph, 2018). However, implementing sustainable tourism frameworks remains challenging due to poor policy execution, stakeholder collaboration, and balancing economic, environmental, and social needs (Talukder *et al*., 2024a; Khatun *et al*., 2023). Sustainable tourism is a worldwide idea with solid academic roots; however, Bangladesh's socio-political, economic, and ecological environment makes sustainable tourism plans difficult. Bangladesh lacks a framework for planning, execution, and management that incorporates environmental, economic, and social issues. Understanding institutional, financial, and political barriers is essential to implementing global sustainability frameworks in Bangladesh's policy and operations. The study should improve stakeholder participation, balance competing interests, and ensure policies reflect all parties' aims. It's essential to examine inclusive, egalitarian, and culturally sensitive tourist development strategies for social justice and sustainable tourism. This study presents a comprehensive and contextually relevant Sustainable Tourism Development Model (STDM) to fill Bangladesh's sustainable tourism development deficiencies. The study connects global sustainability frameworks to Bangladeshi tourism's economic, social, and environmental aspects. The research aims to integrate sustainable concepts, engage stakeholders, promote environmental conservation, ensure social fairness, and align Bangladesh's tourism strategy with global standards while addressing local boundaries. It promotes collaborative governance by increasing stakeholder involvement and reducing disputes, environmental stewardship through eco-friendly activities and impact assessments, and social inclusion by strengthening underprivileged populations and protecting cultural heritage. The present study, therefore, has employed qualitative methodology and secondary data collection tools to examine the tourism sector of Bangladesh. As a research strategy, the current literature, the policies, and the case studies of other countries have been collected and analyzed to discover the factors influencing the country's sustainable tourism policies. It seeks to inform Bangladesh's tourism policymakers, practitioners, and stakeholders by providing rigorous scholarly knowledge. This study aims to address environmental degradation, cultural erosion, and socio-economic inequality by blending global ideals

with local realities. The context of this study combines theoretical and empirical data to provide sustainable tourism solutions for Bangladesh. The literature review identifies the variables of the study and explores the gaps in the literature. The methodology segment describes the methods and procedures of collecting and analyzing the relevant data of this study. This study develops a model that emphasizes stakeholder participation, environmental protection, and social equality, with implementation suggestions. The discussion section critically evaluates the STDM's effectiveness in addressing identified challenges and compares it to successful international initiatives. The study's findings are synthesized in the conclusion, emphasizing its importance for Bangladesh's tourist sector's long-term survival.

Literature review

Tourism has rapidly evolved as one of the most promising and ever-growing industries in the global economy. At the same time, the extensive development of tourism also has its problems, primarily related to the degradation of the environment, the deterioration of culture, as well as the inequality in the distribution of economic benefits (Kabir *et al*., 2024). 'Sustainable Development' aims to meet the current generation's present needs without sacrificing the future ones' needs, providing the foundation of this study (Brundtland, 1987). It maximizes the prospects of the tourism sector for the stakeholders and the community in mitigating environmental pollution, cultural insensitivity, and the economic crisis (Pan *et al*., 2018).

Economic sustainability

Tourism considerably boosts GDP and jobs, as shown by studies. Tourism strengthens country economies via foreign currency profits and infrastructure investment, according to Li *et al*., (2018). Tourism's GDP contribution in Bangladesh is low owing to inadequate infrastructure and policy integration (Talukder *et al*., 2024b). Tourism can diversify countries previously based on agriculture or industry, creating jobs and diversifying the economy. Hassan et al. (2020) observed that Bangladesh's tourist business is creating employment, particularly in Dhaka and Cox's Bazar. Tourism's economic effect is limited by regional disparities in benefits. Tourism diversifies economic activity, but overreliance on tourist earnings might render nations susceptible to external shocks such as natural disasters or global economic downturns (Jamgade *et al*., 2024).

Social sustainability

Tourism development must prioritize social sustainability, including fair benefit sharing and cultural preservation. Nicolaides (2015) demonstrates that integrating local populations in tourist management enhances social justice and minimizes socio-economic inequities. Limited community engagement in Bangladesh hinders inclusive progress. Tourism initiatives sometimes exclude local populations and distribute benefits unequally (Talukder & Hossain, 2021). Cultural tourism is valued for protecting history, yet worries about commercialization linger. Talukder *et al*., (2024c) cautioned that unrestrained rural tourism in Bangladesh might destroy traditional culture. Visitor destinations sometimes commodify local customs to meet visitor expectations, sacrificing authenticity. Bangladeshi tourist strategies generally lack fair benefit-sharing mechanisms (Scheyvens & Biddulph, 2018). The absence of such systems fosters inequality, especially in underprivileged populations (Talukder *et al*., 2024a).

Environmental sustainability

Tourism growth in environmentally fragile Bangladesh, where natural resources are in peril, requires environmental sustainability. Over-tourism in environmentally sensitive places causes habitat damage and biodiversity loss, resulting in environmental degradation (Abtahee *et al*., 2023). Khatun *et al*., (2023) showed how overtourism in Cox's Bazar and the Sundarbans caused deforestation, pollution, and ecological imbalances. The UNESCO World Heritage Site Sundarbans is threatened by illicit logging and tourist infrastructure construction. Eco-tourism is a sustainable option that mixes economic development with conservation aims, as supported by empirical data. Ecotourism in underdeveloped nations has shown potential in improving biodiversity protection and revenue for local populations, according to Buckley (2012). Poor policy enforcement and public awareness have hindered eco-tourism in Bangladesh. Environmental Impact Assessments (EIAs) effectively reduce environmental hazards in tourist projects. Shi *et al*., (2019) noted EIA success in Thailand and Costa Rica, and unchecked

environmental harm in tourism regions in Bangladesh results from poor EIA compliance.

Stakeholder Engagement

Stakeholder participation is essential for inclusive, participative, and varied tourism policy. Roxas *et al*., (2020) emphasize the significance of stakeholder collaboration for sustainable tourism objectives. Government, Non-Government Organizations (NGO), and the commercial sector multi-stakeholder forums minimize disputes and improve policy coherence. Bangladeshi stakeholder involvement is fragmented and lacks sectoral coherence (Song *et al*., 2021). According to Freeman (2010) and Shalowitz *et al*., (2009), empowering communities via participatory decision-making enhances the sustainability of tourist efforts. Nicolaides (2015) notes that power inequalities and institutional gaps in Bangladesh prevent local populations from participating. Research highlights the importance of private firms in supporting sustainable tourism. Bangladesh might learn from African public-private partnerships, according to Adetola (2023). These agreements encourage eco-friendly infrastructure and ethical tourism, although Bangladeshi regulations limit their use.

Policy Integration and Implementation

The existing prior studies have focused on tourism policy design and found that it requires integrating the theories with the unique features of local contexts. Hassan *et al*., (2020) have found that the tourism industry in Bangladesh must contextualize the global sustainability models with the local socioeconomic and environmental landscape. Effective policy formulation also necessitates stakeholder engagement, empowering the institutions and local people, and utilizing context-based strategies for ensuring a sustainable tourism sector in Bangladesh (Sherman & Ford, 2014; Talukder, 2020). Implementing sustainable tourism requires policy integration and execution. Cristofaro *et al*., (2020) highlight the effectiveness of integrating eco-tourism and community-based tourism into national policy in Costa Rica and Rwanda. These policies stress stakeholder involvement, comprehensive EIAs, and fair benefit-sharing. According to Talukder *et al*., (2024d), Bangladesh's tourism strategies face challenges in policy implementation due to insufficient institutional capacity, limited resources, and a lack of cross-sectoral coordination. Adaptive policy frameworks that account for local settings and global norms are needed to address these difficulties. Fig. 1 shows the variables of policy formulation and implementation for ensuring sustainability. Thus, sustainable tourism development in Bangladesh includes economic, social, environmental, and stakeholder participation. Sustainable tourism research and practice are supported by the integrated model's strong policy framework, tailored to Bangladesh's socio-political and ecological conditions.

MATERIALS AND METHODS

The study uses a qualitative research method guided by a review of the available secondary data – policies, literature, and domestic and international studies related to sustainable tourism Development (Hennink *et al*., 2020). This study followed an inductive research approach to find relevant information regarding the subject matter (Thomas, 2003). This study also applies the thematic analysis of the data gathered in the study method to address a policy gap in Bangladesh's tourism sustainability by identifying a whole system policy strategy (Clarke and Braun, 2017). A comprehensive literature review of the prior studies about Sustainable Tourism Development and the studies regarding tourism-related policy formulation has been conducted to explore the strategies and components of sustainable tourism development (Williams, 2018). The collected data have been analyzed thematically following the thematic analysis strategies suggested by Clarke and Braun (2017). For instance, this study has identified the themes by familiarizing and coding the data.

FINDINGS AND DISCUSSION

Formulating an STDM

Integrating Sustainable Development Theory into policy formulation

Sustainable tourism development theories, integrated with the features of the sustainable development theory, help the tourism policy. Sustainability-oriented tourism policies endeavor to balance economic growth, environmental protection, and social equity promotion (Kumar *et al*., 2024). The financial sustainability principle enhances economic development in terms of GDP increase, employment creation, and infrastructure investment

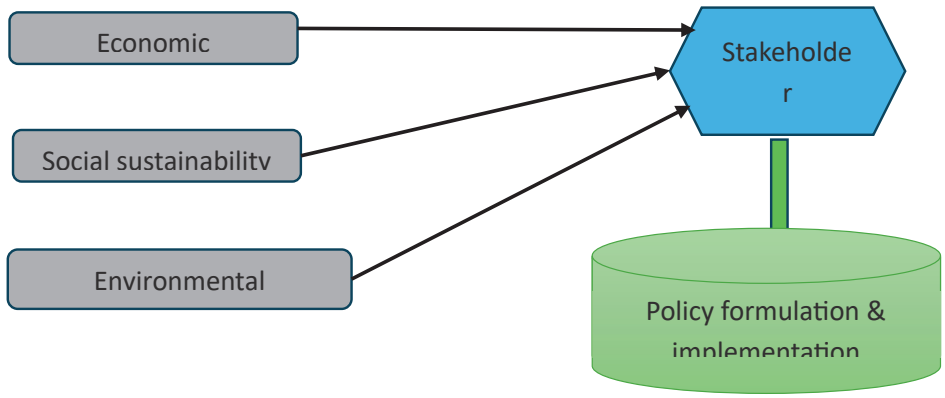

Fig. 1: Variable of integrated sustainable tourism development model (Author's compilation)

(Streimikiene *et al*., 2021). Sustainability in terms of environmental protection ensures biodiversity conservation, ecological deterioration reduction, and optimal utilization of natural resources (Buckley, 2012). Furthermore, sustainability in social equity promotion endeavors to ensure social justice, fairness in tourism activities, and community engagement in the development schemes (Eizenberg & Jabareen, 2017). Moreover, the stakeholder theory outlines the engagement of multiple actors in policy formulation to address the diversified interests within society (Freeman, 2010). However, according to Butler (1999), modifying the policies depends on the socioeconomic and environmental performance of the policies evaluated through effective monitoring and thorough assessment. Integrating STDM can promote sustainable tourism and assist policymakers in adapting to emerging complexities.

Integrating TBL Theory into policy formulation

The STDM, combined with the TBL theory, outlines the policies regarding balancing economic growth, environmental stewardship, and social equity (Zaharia & Zaharia, 2021). The TBL theory measures the effectiveness of the policy based on the three performance indicators, i.e., the economic outcomes, impacts on the environment, and serving social interests. Without being overly dependent on other industry support, financial aspects of the tourism policies need to be self-sustainability oriented by promoting GDP and revenue increase in the tourism sector, generating both permanent and temporary/ seasonal jobs, as well as contributing through the infrastructural development (Jamgade *et al*., 2024). Eco-friendly practices for minimizing pollution and degradation, biodiversity maintenance, and natural resource utilization through impact assessment are crucial aspects of environmental sustainability in tourism. TLB theory also highlights stakeholder engagement in terms of equitable treatment to every stakeholder, involving community people, preserving their culture, and ensuring the social sustainability of tourism policies (Dwyer, 2005). The TBL approach emphasizes continuous monitoring and evaluation to ensure balanced development across the three dimensions (Lindell *et al*., 2022).

Integrating Stakeholder theory into policy formulation

Stakeholder theory, integrated with the STDM, outlines the guiding principles for formulating all-inclusive, egalitarian, and fruitful tourism-related policies (Wicks *et al*., 2019). It focuses on addressing the interests and concerns of the stakeholders by engaging the relevant government entities related to tourism, traveling businesses, and NGOs related to the environment and wildlife welfare (Roxas *et al*., 2020). Stakeholder theory informs about the knowledge regarding community-level power, strategy, interests, and concerns, which multiply the perception and attitude of the stakeholders and must be considered in making decisions about tourism development (Bogale, 2023). Feedback from stakeholders about socioeconomic and environmental aspects is also actively integrated into policy formulation (Song *et al*., 2021). The contextualized views of the stakeholders, like local communities, provide

information related to cultural sensitivity and social equity, while business enterprises suggest economic consequences and viability in the marketplace (Talukder & Muhsina, 2024). The government and NGOs provide their worldview about tourism development rules, regulations, and sustainable practices (Nicolaides, 2015). Therefore, strategic integration of the sustainable development theory, TBL theory, and stakeholder theory helps formulate sustainable, equitable, and inclusive policies in the tourism sector. Please consult with the stakeholders to take their comments, add insightful suggestions in policy drafting and agenda setting based on their perspectives, and collaborate with them to execute and monitor policies. Stakeholder engagement thus develops consensus, addresses complexities, legitimizes, and improves tourism policies.

STDM

Overview of the model

The STDM uses Sustainable Development Theory, Triple Bottom Line Theory, and Stakeholder Theory to produce a sustainable tourist policy. The paradigm balances economic, environmental, and social factors and involves stakeholders in decisions (Streimikiene *et al*., 2021; Talukder *et al*., 2024b).

Components of the model

Sustainable development

• *Long-term balance*: Maintaining a long-term balance requires tourist development to prioritize economic advantages and ensure sustainability (Sathiendrakumar, 2013). The STDM policies have to emphasize the intergenerational longevity of resource utilization, i.e., not jeopardizing the prospects while mitigating the present challenges (Dwyer, 2023).

• *Balance among economic*, *environmental*, *and social dimensions*: The 'Sustainable development' concept stresses ensuring equilibrium among economic progress, social fairness, and environmental conservation aspects while generating a policy (Adanma & Ogunbiyi, 2024). It must be ensured that driving economic growth doesn't harm the ecological or social systems (Khan *et al*., 2020). However, complexities often exist in balancing the conflictual interests among the socioeconomic and environmental aspects in policy making (Brosius *et al*., 2019).

Therefore, the long-term balance principle of STDM outlines that tourist strategies and techniques must be proactive in tackling future difficulties while addressing a social problem and formulating policies to address it. However, overtourism leads to environmental degradation as well as socioeconomic crises. STDM endeavors to address all these concerns related to over-tourism.

Three essential pillars: *economic performance*, *environmental sustainability*, *and social responsibility*

• *Economic performance*: STDM seeks to assess the performance of the tourism policies related to economic growth in terms of financial earnings and revenue generation, employment creation, development of the tourism infrastructure, and GDP contribution to the national economy (Li *et al*., 2018).

• *Environmental sustainability*: Environmental conservation and resource management are needed in tourist plans to ensure sustainability (Brendehaug *et al*., 2017). In Bangladesh, where natural resources attract visitors, the policy must address sustainable usage to minimize depletion and deterioration (Talukder et al., 2024b; Islam, 2015).

• *Social responsibility*: The commitment to social responsibility highlights tourism's social consequences (Murphy & Price, 2012). It promotes social fairness, cultural preservation, and community well-being to ensure tourism benefits everyone (Jamal & Dredge, 2014).

Integrating these three fundamental elements ensures that tourist strategies are assessed holistically, preventing economic performance from overshadowing environmental and social sustainability. TBL in the STDM helps policymakers create more comprehensive, sustainable development policies.

Stakeholder engagement

• *Diverse inputs*: Stakeholder theory promotes broad stakeholder participation in policymaking. Government agencies, tourism firms, local communities, NGOs, and visitors are involved (Getz & Timur, 2012).

• *Community engagement*: Engaging community members stresses active community interaction (Shalowitz et al., 2009). It makes tourist strategies inclusive and reflects the needs and ambitions of the people most impacted (Scheyvens & Biddulph, 2018).

Fig. 2 demonstrates the components of STDM for

policy formulation in alignment with sustainability principles and relevant aspects of consideration.

Thus, STDM fosters democratic and participatory policymaking by involving stakeholders since multiple groups have conflicting interests regarding tourism development in Bangladesh, where considering stakeholder engagement is crucial for consensus building, which helps make the tourism policies public welfare-oriented (Talukder *et al*., 2024c).

STDM for policy formulation in Bangladesh

Implementing the STDM for Bangladeshi policy design has various benefits (Promsiri *et al*., 2022). This Model shows how to incorporate sustainable development theory, TBL theory, and stakeholder theory into formulating tourist policy in Bangladesh.

Enhanced economic performance

STDM has improved Bangladesh's tourist sector's economic performance (Islam, 2015). Tourism policies emphasizing economic sustainability within the TBL framework have created jobs, raised foreign currency revenues, and boosted GDP (Talukder, 2021). Diversifying business endeavors in the tourism industry has reduced dependence on other traditional sectors, making the economy more tourism-oriented (Hossen, 2023). Enhancement of economic performance has emphasized the economic sustainability requirement in Bangladesh's tourist initiatives (Khan *et al*., 2020). However, this advancement of the tourism industry must not overlook the utmost need for continuous monitoring, evaluation, and adaptation. Even though the economic indicators are favorable, unreviewed policies can often lead to over-commercialization (Kumar *et al*., 2024; Islam *et al*., 2023).

Improved environmental management

Tourism sector environmental management has improved by incorporating TBL environmental sustainability concepts into the STDM (Promsiri *et al*., 2023). Eco-tourism, environmental control, and green technology have minimized environmental deterioration, protected natural resources, and maintained biodiversity in tourist locations (Brendehaug *et al*., 2017). These environmental gains demonstrate the effectiveness of sustainability measures. Balancing tourist expansion and ecological protection remains difficult (Adanma & Ogunbiyi, 2024). Despite advances, pollution, habitat damage, and resource depletion from tourism threaten specific locations (Khatun *et al*., 2023). Further enforcement of environmental legislation, investment in sustainable technology, and promotion of responsible tourism among tourists and companies are needed to maintain these favorable trends (Carrick *et al*., 2023).

Social equity and community benefits

Using stakeholder theory, STDM has improved social equality and tourist advantages for communities (*Kumar et al*., 2024). Community engagement in decision-making has improved tourism income distribution, local community empowerment, and cultural heritage protection (Talukder & Hossain, 2021). Tourism-dependent localities have seen higher living conditions and fewer socioeconomic gaps due to social responsibility (Mihalic, 2016). Positive social effects support Stakeholder Theory in the STDM, which states that actively incorporating local communities and other stakeholders has made policies more inclusive and representative of local needs (Nicolaides, 2015). Tourism must continue to involve communities to maintain its social advantages. Specific groups can be marginalized if their opinions are not heard in policymaking (Sherman & Ford, 2014). Future policies should decentralize decision-making and boost community-led tourism.

Increased stakeholder collaboration

The STDM has improved cooperation between government agencies, local communities, tourist firms, and NGOs (Li & Hunter, 2015). This collaborative approach has produced more complete and coherent tourist policies that meet sustainable tourism development's many problems. It has also strengthened public-private collaborations and synergies. Stakeholder collaboration is a major STDM success. It emphasizes communal efforts to solve complicated environmental issues. Practical cooperation needs ongoing conversation, openness, and stakeholder confidence (Sherman & Ford, 2014). Manage conflicts of interest between groups, such as economic vs. environmental concerns, to ensure that all views are heard and policies are not biased. To maintain collaboration, future policies should include stakeholder participation and dispute resolution (Trivanović & Grujić, 2021).

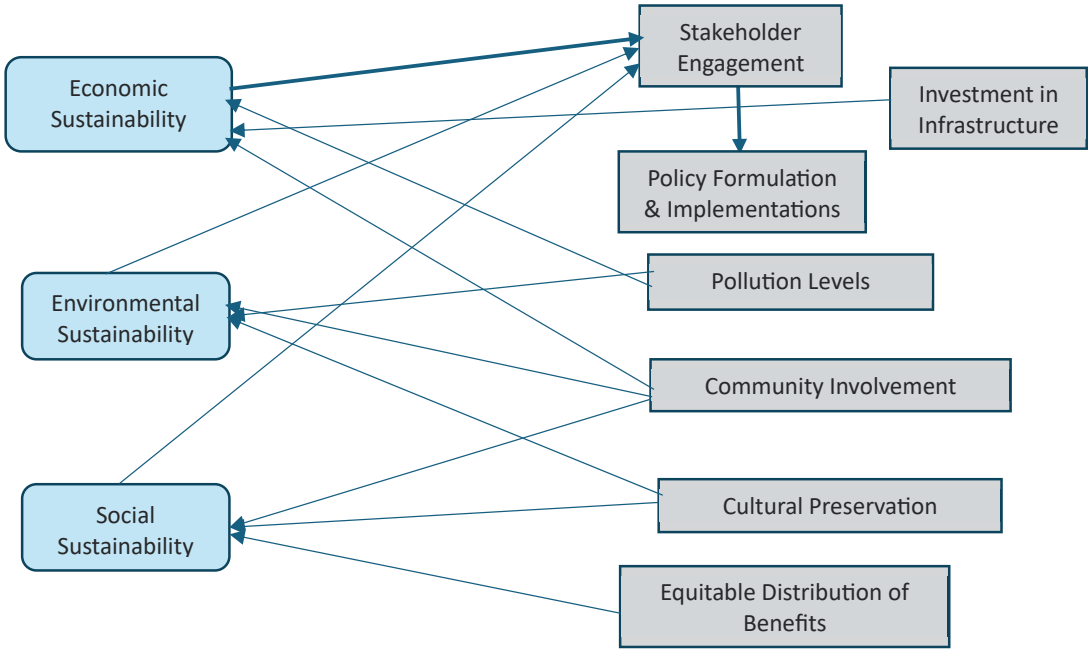

Fig. 2: Components of STDM for policy formulation

Policy innovation and adaptation

STDM adoption has led to a creative, adaptable, and forward-looking tourist policy. These plans use smart tourism and climate resilience techniques suited to Bangladesh (Hall, 2021). Tourism policy needs innovation and adaptability to succeed. STDM's focus on sustainability and stakeholder involvement fosters policy innovation (Sherman & Ford, 2014). However, fast global change, including technological advances and environmental issues, necessitates flexible and adaptable policy. Research, capacity-building, and knowledge sharing are necessary to update policy and handle new concerns. Local academics and research institutions can also strengthen policy innovation evidence (Kabera, 2017).

Therefore, Fig. 3 depicts the STDM, which provides a solid foundation for Bangladeshi tourism policy. Sustainable Development Theory, TBL Theory, and Stakeholder Theory have improved economic, environmental, and social consequences, ensuring the sustainability of the tourist sector (Hassan *et al.*, 2020; Talukder, 2021). However, overtourism, ecological risks, and stakeholder disputes need continuing work. Policymakers can keep Bangladeshi tourism sustainable, inclusive, and rewarding for all stakeholders by improving and adjusting the STDM. Bangladesh's tourism strategy should draw numerous essential conclusions from the STDM.

Promoting long-term economic sustainability

Tourism policy must promote long-term economic sustainability to ensure tourism endeavors' longevity and long-term development (Talukder *et al.*, 2024d). The STDM suggests that tourism can boost Bangladesh's economy by emphasizing economic performance. To preserve this expansion, tourism policy must address future economic concerns such as market volatility, shifting visitor tastes, and global economic changes. Tourism policy should involve economic diversification, infrastructural investment, and innovative goods to attract more visitors. To react to market changes, local labor capacity-building should be prioritized (Hossen, 2023).

Ensuring environmental protection and resource conservation

Environmental preservation and the conservation of natural resources must be integrated into the tourism policy. In this regard, sustainable practices help address the negative impacts of over-tourism

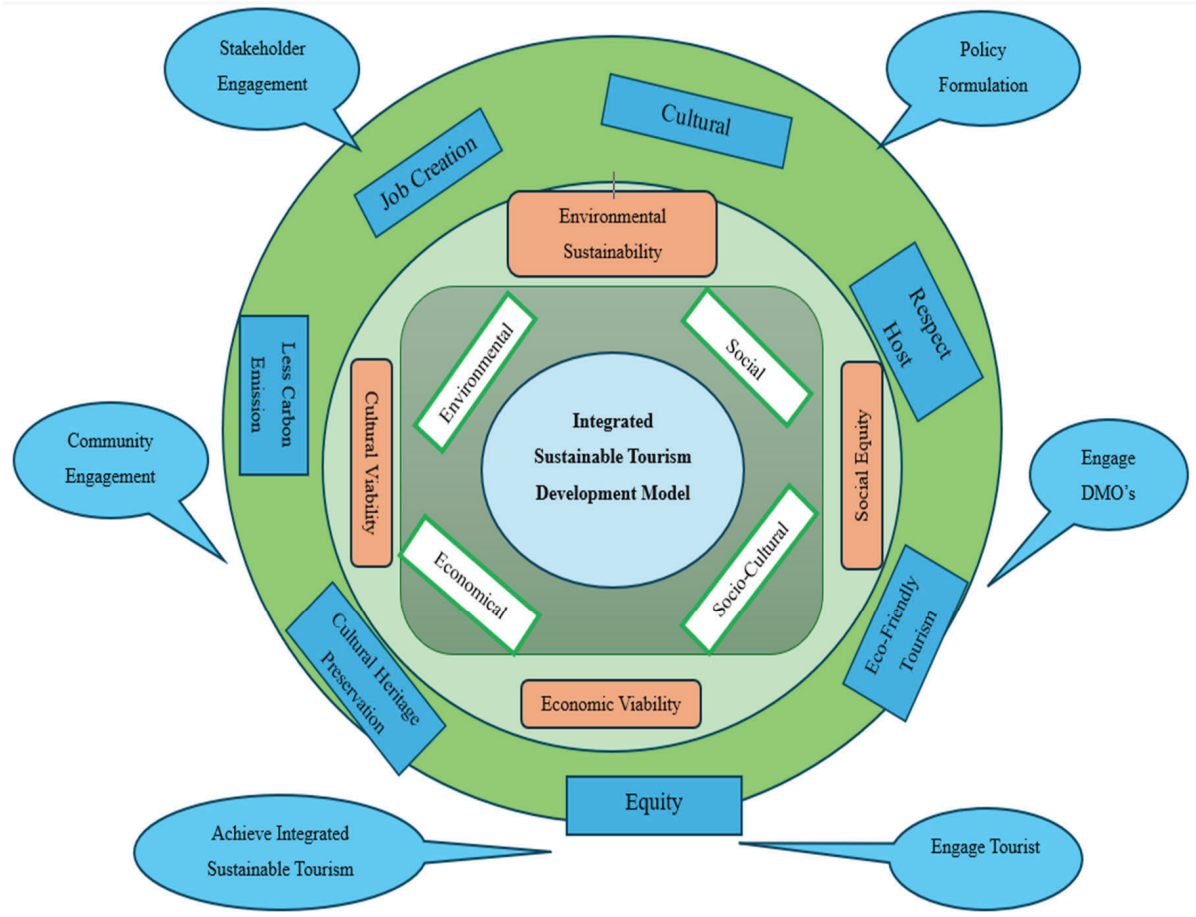

Fig. 3: STDM for policy formulation in Bangladesh (Source: Authors' estimation)

on natural ecosystems through the effective environmental regulations of STDM (Brendehaug *et al*., 2017). In Bangladesh, natural scenic beauties and wildlife destinations are vital tourist assets (Khatun *et al*., 2023). To ensure the security of natural resources, the tourism policy should encourage eco-tourism, stricter environmental regulations, and eco-friendly infrastructure, and foster ecological sustainability (Adanma & Ogunbiyi, 2024). Tourist projects should also conduct an EIA, and tourism-related laws should encourage tourism enterprises to use renewable energy, waste management systems, and waste-to-energy strategies (Carrick *et al*., 2023).

Fostering social equity and inclusive community development

The research shows that social justice and inclusive community development in tourist policy can improve social cohesion and benefit distribution. The success of the STDM's stakeholder involvement shows the relevance of local communities in decision-making about tourism development. Policymakers should establish community participation methods and guarantee that tourism benefits all groups. This might entail organizing community tourist boards, funding community-led tourism efforts, and protecting local communities' cultural history and social fabric (Islam *et al*., 2024). Policies should also address tourism-related socioeconomic inequities, including displacement and income inequality. Fig. 4 demonstrates the objectives of STDM for Policy Formulation

Implications for policy formulation authority

Balanced and Integrated Approach: The STDM suggests that tourist strategies should balance economic, environmental, and social factors (Hall,

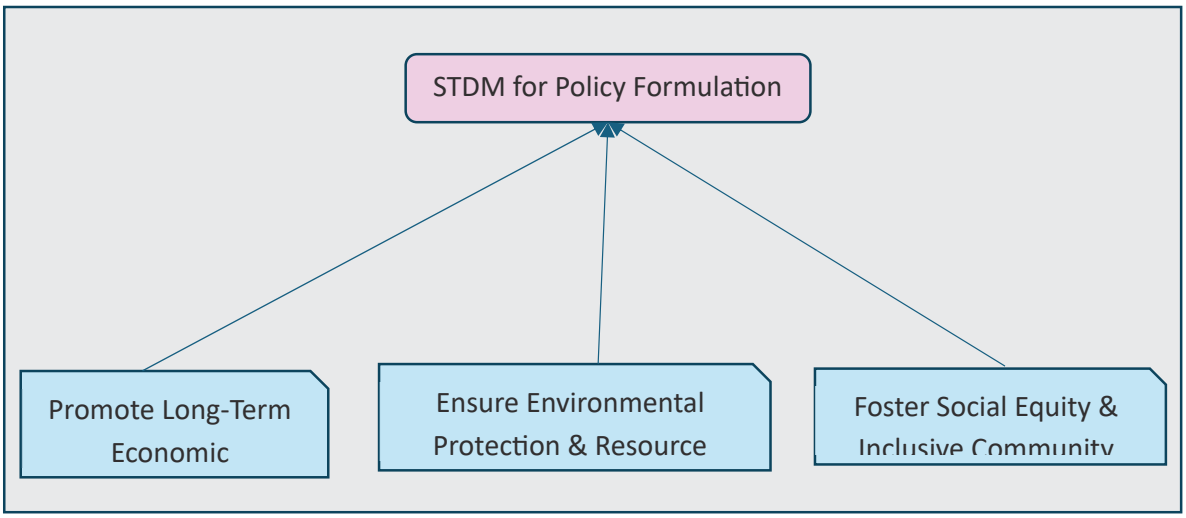

Fig. 4: STDM for policy formulation based on objectives (Authors' compilations)

2021). This comprehensive approach is necessary to achieve sustainable development objectives and ensure that tourism benefits all national development sectors.

Continuous Monitoring and Adaptation: Tourism is dynamic; thus, rules must be well-designed and flexible. To make timely modifications and improvements, the policy framework should include continuous monitoring, data collection, and feedback (Cristofaro *et al*., 2020).

Stakeholder Collaboration: Building strong collaborations between the government, corporate sector, NGOs, and local communities is vital for policy execution, as shown by STDM stakeholder cooperation (Kabera, 2017). To include all essential voices in decision-making, policies should promote and enable these partnerships. Tourism policymakers and stakeholders can follow this study's findings. Sustainable, inclusive tourism in Bangladesh can be achieved by integrating tourist policy with economic sustainability, environmental conservation, and social fairness. They will boost the country's tourist potential and benefit all stakeholders, including future generations (Graci, 2020). Therefore, this study addresses fragmented governance, little community engagement, and unregulated resource exploitation in the nation. Collaboration in tourist governance is needed to understand stakeholder dynamics and align interests. Eco-tourism incentives, capacity-building, and equitable revenue-sharing are among the study's creative TBL solutions to balance economic, environmental, and social aims. The concept stresses ongoing monitoring and adaptive management owing to tourism's dynamic nature. Overtourism in Bangladesh's ecologically fragile Sundarbans and Cox's Bazar is addressed utilizing EIAs, stricter laws, and green technology investments to mitigate environmental degradation and maintain economic viability. By harmonizing with global sustainability standards and addressing local restrictions, the STDM promotes sustainable tourism policy innovation for adaptive and inclusive tourism. Smart tourism and climate resilience show how new technology may promote sustainability, giving policymakers real solutions by linking theory to practice. This research shows how global sustainability ideas may be customized to solve emerging countries' particular issues. The study provides a reproducible paradigm for inclusive governance by identifying practical strategies for increasing cooperation among various stakeholders. The STDM framework balances economic, environmental, and social aims, resolving competing agendas in tourist policy. It introduces specific techniques for regulating overtourism in environmentally fragile places, a neglected subject in previous research. The research shows how to create flexible, participative frameworks that correspond with the best global practices.

Theoretical contributions of this study

This study focuses on sustainable tourism, policymaking, and governance theory in underdeveloped nations like Bangladesh. It applies sustainability ideas to developing countries to address poor governance, insufficient environmental conservation funds, uneven tourist advantages, and overtourism in environmentally fragile locations like the Sundarbans and Cox's Bazar. The study provides a theoretically advanced model that incorporates Sustainable Development Theory, TBL, and Stakeholder Theory to create a comprehensive sustainable tourism policy framework. STDM reconciles economic, environmental, and social goals in tourism policy. The model proposes EIAs, tougher controls, and eco-tourism initiatives to mitigate overtourism. Through stakeholder contact, the STDM encourages collaborative governance, decision-making, and conflict resolution. The study stresses local communities' role in tourism planning and policymaking and offers practical ways to distribute tourist earnings equitably, particularly to marginalized groups. The study offers solutions to overcome stakeholder engagement conflicts between stakeholders with competing interests, such as economic growth and environmental conservation. Sustainable tourism policy innovation and adaptation theory emphasizes the need for adaptive governance frameworks to manage climate change, visitor preferences, and global economic swings. Integration of smart tourism technology and climate resilience into sustainable tourism policy, continuous feedback loops and monitoring, overtourism management, social justice, and community-led development are notable contributions. The study emphasizes local community empowerment to improve social justice and cultural preservation in tourism, social equity, and community-led development paradigms. Future research should test the STDM in other developing nations with similar socio-economic and environmental issues, examine the theoretical implications of incorporating AI and smart tourism tools into sustainable tourism frameworks, and study policy effectiveness longitudinally.

Recommendations for the policy formulation authority

The STDM for Policy Formulation in Bangladesh yielded numerous essential proposals to improve tourist policy and promote sustainable development.

Integrating multidimensional goals into a unified policy framework: Integrating economic, environmental, and social goals into a single policy framework can increase policy Integration and Coordination and help tourist growth be balanced. Tourism strategies at all levels—national, regional, and local—should be coordinated by government agencies to meet Sustainable Development Goals (SDGs) (Griggs *et al*., 2014). Strategic actions include:

- *Establishing an inter-ministerial task force to oversee tourism policy formulation, ensuring coordination between the Ministry of Tourism, the Ministry of Environment, the Ministry of Finance, and other relevant bodies*.
- *Developing a comprehensive tourism policy document that explicitly integrates economic sustainability, environmental protection, and social equity objectives*.
- *Regularly reviewing and updating policies to reflect emerging challenges and opportunities in the tourism industry*.

Adopting eco-friendly practices across the tourism industry: Eco-tourism and green practices must be promoted throughout the tourism sector to increase visitor understanding and address Bangladesh's environmental issues. Protecting natural resources, reducing tourism's carbon imprint, and promoting sustainability will improve the country's appeal (Gavrilović & Maksimović, 2018). Strategic actions include:

- *Incentivizing businesses to adopt eco-friendly practices, such as using renewable energy, waste management, and water conservation measures*.
- *Promoting eco-tourism products, highlighting Bangladesh's natural and cultural heritage*.
- *Developing and enforcing environmental standards and certification programs for tourism operators and accommodations*.

Involving Local Communities: Policies should engage local communities in planning and decision-making to guarantee inclusive and equitable tourist development. Community participation and benefit sharing are essential to distributing tourist profits equitably and preserving local customs and traditions (Li & Hunter, 2015).

Strategic actions include:

- *Establishing community tourism boards that include representatives from local communities,*

NGOs, and tourism businesses to provide input on tourism planning and policy decisions.

• *Creating programs that empower local people to develop tourism initiatives with training, funding, and marketing support*.

• *Implementing benefit-sharing mechanisms ensures a portion of tourism revenues is reinvested in community-level developmental endeavors*.

Building the capacity of stakeholders in the tourism sector: Responsible government, companies, and local communities are needed to create capacity-building initiatives. Sustainable tourism, environmental management, and community participation should be taught in training (Waligo *et al*., 2013). Strategic actions include:

• *Developing training programs for government officials on sustainable tourism policy formulation, implementation, and monitoring*.

• *Providing workshops and seminars for tourism businesses on adopting sustainable practices and improving their environmental and social performance*.

• *Supporting educational initiatives that enhance awareness regarding sustainable tourism*.

Establishing robust monitoring and evaluation mechanisms: Strong monitoring and evaluation procedures for tourist Policies for Continuous Improvement are needed to guarantee the long-term effectiveness of tourist policies. This allows continual policy effect evaluation and identifying areas for improvement or modification (Lindell *et al*., 2022). Strategic actions include:

• *Implementing a regular data collection and analysis system on key tourism sustainability indicators, including economic performance, environmental health, and social equity*.

• *Conducting periodic evaluations of tourism policies to assess their effectiveness and make necessary adjustments based on findings*.

• *Engaging independent experts and stakeholders in the evaluation process to ensure objectivity and inclusiveness*.

Encouraging private investment in sustainable tourism projects: To promote private sector participation and investment, the private sector develops and implements sustainable tourism projects. Policies should stimulate private investment in sustainable tourism initiatives and public-private partnerships to support the tourist industry (Geoffrey Deladem *et al*., 2021).

Strategic actions include:

• *Providing incentives, such as tax breaks or grants, for private sector investments in sustainable tourism infrastructure, such as renewable energy, eco-lodges, and waste-to-energy strategies*.

• *Facilitating government and private sector partnerships to co-develop and co-manage sustainable tourism projects*.

• *Creating a favorable regulatory environment supporting innovation and entrepreneurship in sustainable tourism*.

According to Talukder and Kaiser (2024), Tourism policy in Bangladesh can be improved using the abovementioned suggestions. Bangladesh can establish a sustainable and resilient tourist business for future generations through policy integration, eco-tourism promotion, community involvement, capacity-building, monitoring, and private sector participation. Implementing these ideas would guarantee that tourism enhances the balanced development of Bangladesh's economy, environment, and society.

Future research directions

Studies should focus more on the critical areas of policy design to ensure the sustainable tourism sector in Bangladesh. Future studies should assess the long-term impact of tourism policies in the context of Bangladesh. The specific focus should be on the economic, social, and environmental aspects of the tourism landscape in further studies on the tourism industry of Bangladesh. Longitudinal studies should be conducted on the sustainability issues related to Bangladesh's tourism industry. Technology integration and AI tools in sustainable tourism should also be studied rigorously. The impact of infrastructural development on the sustainable development of tourism and the resilience of tourism in Bangladesh from all sorts of challenges should also be studied. Moreover, a specific focus should be emphasized on studying community-led tourism and its impact on addressing social inequity. Based on the STDM framework, further studies should examine how tourist policy resilience reduces environmental and economic hazards. The research advises applying the framework to other emerging nations with comparable socio-economic and environmental challenges.

CONCLUSION

The STDM is a holistic, long-term outcome-focused, stakeholder engagement-oriented Model. It will guide towards a sustainable, inclusive, and equitable policy formulation. It ensures economic growth, environmental conservation, and social equity integration for planning and managing tourism. If the policies are well-balanced, they will boost economic development, protect the environment from degradation, and promote social equity against unfairness. Stakeholder engagement and the community's participation are the essential features of this Model that will ensure an informed, inclusive, representative, and sensitive policy that will mitigate current problems and be proactive toward solving future problems simultaneously. The participatory Model enhances the local people's ownership and publicizes the tourism benefits accordingly. Attention to the stakeholders' viewpoint helps address concerns regarding the power, strategy, and interests of the relevant stakeholders in the tourism policies in Bangladesh. In the ever-evolving tourism landscape worldwide, tourism policies need to be measurable against the socioeconomic and environmental criteria so that they can adjust to the changing trends of tourists globally, ecological challenges, and the socioeconomic conditions of the tourism destinations. Principles of eco-tourism, smart tourism, and climate resilience will help overcome future crises in the tourism industry. Effective STDM implementation will encourage other developing nations to ensure sustainable development in the tourism industry.

AUTHORS CONTRIBUTIONS

M. B. Talukder synthesized the findings and discussion segment of this study and developed the integrative STDM for policy formulation which integrates diversified disciplines to face ecological, economic, and sociocultural issues in travel and tourism. Md. M. H. Sawon conducted a literature review of this study by reviewing the prior sources to select significant sustainability markers for tourism advancement. F. Kabir developed materials and methods part and aligned SDGs with the sustainable tourism practice for formulating STDM. Md. A. Hossain analyzed the STDM for policy formulation in Bangladesh and provided actionable strategy recommendations for the policy formulation authority.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely witnessed by the authors.

(https://www.ijhcum.net/journal/process?ethics).

ABBREVIATIONS (NOMENCLATURE)

Abbreviations	*Full Forms*
EIA	Environmental Impact Assessment
GDP	Gross Domestic Product
NGOs	Non-Governmental Organizations
SDGs	Sustainable Development Goals
STDM	Sustainable Tourism Development Model
TBL	Triple Bottom Line

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ORIGINAL RESEARCH PAPER

Analyzing ecological security impacts of land use changes through novel landscape ecology metrics and scenario modeling

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ABSTRACT

BACKGROUND AND OBJECTIVES: Rapid urbanization has significantly impacted land use and land cover, disrupting ecosystems and threatening ecological security. This study assessed the ecological security impacts of land use changes in the Lavasanat watershed from 2000 to 2040 using scenario modeling and landscape metrics. Findings show that urban expansion significantly reduces ecological security, with severe impacts under pessimistic scenarios. Sustainable urban planning policies are essential to mitigate these effects.

METHODS: Land use maps for 2000, 2010, and 2020 were created using Landsat imagery and processed with Environment for Visualising Images and Geographic Information System tools. The Markov chain and Cellular Automata-Markov models predicted land use changes to 2040 under current, pessimistic, realistic, and optimistic scenarios with IDRISI software. Landscape metrics, including the number of patches, landscape shape index, interspersion and juxtaposition index, class area, percentage of landscape, and largest patch index, were calculated at class and landscape levels using FRAGSTATS. The Integrated Valuation of Ecosystem Services and Tradeoffs model simulated ecological outcomes for each scenario.

FINDINGS: The pessimistic scenario showed a 32% increase in built-up land cover, with an 18% reduction in patch numbers and a 12% decline in landscape shape complexity. Meanwhile, the percentage of built-up land cover rose, forming large patches (the largest patch index rose by 28%). These changes disrupted the watershed's structure and reduced ecologically valuable areas.

CONCLUSION: The findings reveal that urban expansion significantly threatens ecological security, particularly under pessimistic scenarios. This study provides a novel framework for assessing ecological risks by integrating landscape metrics with scenario modeling. The results emphasise the need for sustainable urban planning to mitigate environmental degradation and enhance resilience. Structural landscape changes, including reduced patch complexity and increased fragmentation, were key drivers of ecological decline.

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INTRODUCTION

Starting in the 20th century, urban areas have served as the primary living environments for human populations. (Su *et al.,* 2011), As a result, Urbanization has emerged as a defining feature of social, cultural, and economic development (Lamine *et al.*, 2017; Rao *et al.*, 2021). Urbanization can contribute to the advancement of socio-economic development and the improvement of human life quality. However, irreversible shifts from semi-natural and natural ecosystems to impermeable urban extents have led to significant environmental and ecological problems emerging worldwide (Bhatta *et al.*, 2010; Habibi & Asadi, 2011; Su *et al.*, 2011; Wan *et al.*, 2015; Peng *et al.*, 2017; Kong *et al.*, 2017; Aburas *et al.*, 2018), causing considerable environmental and ecological challenges. This has led to transformations in population dynamics, industrial structures, and the visual composition of urban landscapes (Zhang & Su, 2016; Valeria *et al.*, 2015). The development of Human-Created areas will disturb the balance and dynamics of landscape functioning (De Montis *et al.*, 2019). These artificial structures act as disruptors, breaking the continuity and connections initially observed across extensive natural covers (Thaiutsa *et al.*, 2008; Fichera *et al.*, 2015). This fragmentation of the landscape is the most significant challenge of urban development (Alberti, 2004), impeding the flow of materials and energy and altering the course of these processes within the region (Huilei *et al.*, 2017). Hence, landscape fragmentation will impact the performance and ecosystem services of the region (Peng *et al.*, 2016), ultimately leading to ecological and environmental issues (Li *et al.*, 2010) such as urban heat islands, environmental pollution, soil erosion, and more (Zhang *et al.*, 2004; Reimets *et al.*, 2013; Zhou *et al.*, 2014). The expansion of human settlements and their activities in urban environments have led to significant changes in Land Use/Land Cover (LULC) patterns in urban areas (Weng, 2001: 201; Tv *et al.*, 2012; Yue *et al.*, 2013; Reimets, 2013). These changes in LULC structures have implications for social, economic, and environmental conditions (Prabu & Dar, 2018). Therefore, examining the relationship between urban expansion and land cover patterns can support urban environmental management (Huilei *et al.*, 2017). Urban planners and policymakers, using the results of LULC change analysis and land cover patterns, can address crises arising from the rapid growth of urban areas (Deng *et al.*, 2019). Identifying, monitoring, and tracking changes in land cover patterns is a complex process (Sun & Zhou, 2016). Hence, the most important method for understanding and determining LULC changes is the analysis of changes in land cover patterns (Fan & Ding, 2016). The ecological consequences of urban expansion can be comprehended by employing land cover metrics to describe and analyze dynamic changes in the regional land cover pattern (Foltete *et al.*, 2014; Luck & Wu, 2002; Schwoertzig *et al.*, 2016). Consequently, recent studies have paid significant attention to the relationship between urban expansion, land use changes, and land cover patterns (Jia *et al.*, 2019; Zhong *et al.*, 2019; Huilei *et al.*, 2017; De Montis *et al.*, 2019; Rimal *et al.*, 2018; Munthali *et al.*, 2019; Zhou *et al.*, 2020; Gharaibeh *et al.*, 2020; Maimaitijiang *et al.*, 2015; Vizzari & Sigura, 2015; Hassan, 2017; Calderon *et al.*, 2021). Currently, humans are confronting significant environmental concerns at both universal and local levels. Ecological Security (ES) has gained a significance in recent years equivalent to that of military, economic, political, and national security (Farmer, 2005; Glenn *et al.*, 1999; Duffy *et al.*, 2001; Andersen *et al.*, 1998; Albers and Goldbach, 2000; Brummett and Williams, 2000). Analyzing urban metabolisms, as demands increase, the rate of resource usage exceeds the capacity for resource generation (Browne *et al.*, 2011; Rees, 2012), leading to urban instability and, consequently ecological insecurity (Liu & Chang, 2015). In general, security is fundamentally tied to the close relationship between human survival and sustainable development within safe conditions. In safe conditions, the environment must be shielded from any form of threat, risk, or disruption (Novin *et al.*, 2022). Effective ecological security represents a state of being without threats and involves the human capacity to adapt to future environmental changes, along with the necessary natural resources required to address daily human needs, production, healthcare, and satisfying recreational activities (Chen *et al.*, 2018). ES also pertains to the well-being of the environment and the sustainability of land resources and ecosystems. This aspect can facilitate sustainable ecological services and address ecological necessities for generations to come (Liu et al., 2022; Wang *et al.*, 2021; Wu *et al.*, 2019; Lu *et al.*, 2018; Feng *et al.*, 2017; Guo, 2001). Ecological security of

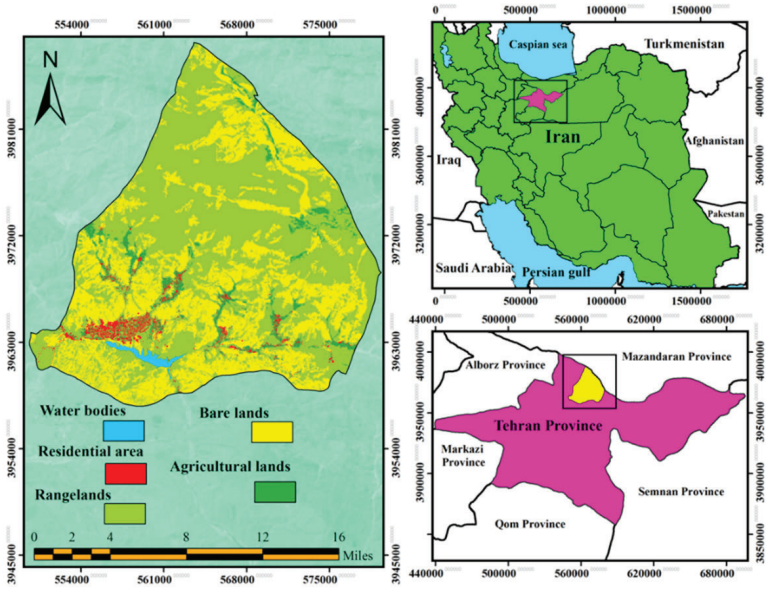

Fig. 1: Location and land use classes of the Lavasanat

the land forms a significant component of ecological security and holds a substantial influence on national security and sustainable social development (Gao *et al.*, 2012). Consequently, the land-use perspective has evolved into a prevalent approach for land utilization and evaluating land cover changes (Liu & Chang, 2015; Malaviya *et al.*, 2010). In recent years, studies about ecological security have increasingly concentrated on shifts in land-use patterns and have garnered considerable attention from researchers (Gao *et al.*, 2012; Zhang *et al.*, 2016; Liu *et al.*, 2018; Ma *et al.*, 2019; Wang *et al.*, 2019; Wang *et al.*, 2021; Fan *et al.*, 2020; Rao *et al.*, 2021). This study uniquely combines scenario modeling with advanced landscape metrics to evaluate ecological security, offering actionable insights for urban planning. As this research aims to evaluate the ecological security status for the time intervals of 2000, 2010, and 2020, as well as different land use scenarios for the year 2040, following the research requirement of structural investigation and evaluation, the software FRAGSTATS 4.2.1 was utilized to measure landscape metrics. The CA-Markov model, IDRISI software, and the scenario generator from InVEST 3.7.0 software were employed for predicting LULC scenarios for the year 2040. ENVI 5.3-based methods were utilized for LULC determination, and GIS-based methods were used for mapping. In recent years, LULC changes in areas near Tehran, the capital city, have seen significant growth due to urban development. The expansion of human-made areas, including urban growth, urban sprawl, and residential establishment within the Lavasanat watershed region, has resulted in changes to the extent of ecologically valuable land uses. This has become a fundamental challenge in this watershed. Thus, in light of the issues concerning the Lavasanat watershed, the current study aims to achieve the following objectives:

1. Temporal and spatial analysis of LULC changes

2. Analysis of landscape metrics across different scenarios of LULC changes

3. Analysis of how ES changes in the Lavasanat watershed based on various LULC scenarios over four decades, utilizing landscape metrics.

MATERIALS AND METHODS

This study employed Landsat satellite imagery from 2000, 2010, and 2020 to create LULC maps using ENVI 5.3 and ArcGIS 10.5. LULC changes were predicted for 2040 under four scenarios (current trend, pessimistic, realistic, and optimistic) using the CA-Markov model in IDRISI and the Scenario Generator model in InVEST 3.7.0. Landscape metrics (e.g., NP, LSI, IJI) were calculated using FRAGSTATS 4.2.1 at class and landscape levels. Validation included cross-referencing model predictions with

historical data and assessing uncertainty through sensitivity analysis.

Study area

As shown in Fig. 1. The study area, Lavasanat watershed, is located in the north and northeast of Tehran province, covering an area of 52,933 hectares. The Lavasanat watershed includes the Lavasan city and two districts called Lavasan Bozorg and Lavasan Kuchak. It is surrounded by Nur County to the north, Karaj County to the west, Damavand County to the east, and Tehran City to the south. The Lavasanat watershed is located between 51°24' to 51°50' east longitude and 35°46' to 36°03' north latitude. It consists of three sub-basins: Kand, Afjeh, and Lavark, with their primary rivers and tributaries directly feeding into the Latian Reservoir (Talari *et al.*, 2016).

Methodology

In this research, initially, LULC maps of the Lavasanat watershed for the years 2000, 2010, and 2020 were prepared using Landsat satellite images. The images were processed using ENVI 5.3 and ArcGIS 10.5 software. Based on the existing land uses in the area, the research objectives, and the spatial and radiometric resolution of the imagery, the land cover was categorized into five land use types: (residential areas include villages, industrial areas, and roads); barren lands; rangeland; water bodies; and agricultural lands. After obtaining the LULC maps, the changes were detected and analyzed over the three study periods. Model validation included comparing CA-Markov predictions with historical data to assess accuracy. Uncertainty was addressed through sensitivity analysis, where model inputs (e.g., transition probabilities) were varied to test robustness. Assumptions included consistent land use trends and uniform socio-economic conditions during the forecast period. Finally, for the assessment of the structural ES of the Lavasanat watershed, a set of landscape metrics was utilized. Due to the large number of available metrics, and intercorrelations among some, and to avoid generating redundant information, a subset of metrics at both the class and landscape levels were selected for this study based on a review of scientific resources (Weng, 2007; Tv *et al.*, 2012; Lee & Oh, 2012; Paudel & Yuan, 2012) and expert knowledge (Table 2). It is important to note that in this research, FRAGSTATS 4.2.1 software is used for quantifying changes in land surface conditions. A schematic diagram of the entire research methodology is presented in Fig. 2. Table 1 shows the characteristics of the satellite images used in the study, and Table 2 describes the landscape metrics employed for evaluating ES.

RESULTS AND DISCUSSION

Evaluation of LULC *changes in the periods of 2000, 2010, and 2020*

The map illustrating LULC changes across the periods of 2000, 2010, and 2020 for different LULC classes is presented in Fig.3. Data analysis indicates that the built-up areas have continuously increased from 2000 to 2020, while the agricultural lands have been decreasing. The rangeland areas showed a decline between 2000 and 2010, but due to increased rainfall, they have shown a slight recovery in 2020. The barren lands have also consistently decreased during these two decades, mainly due to their adjacency to built-up areas (Table 3).

Prediction of built-up area expansion in the Lavasanat basin under four scenarios using CA-Markov and Scenario Generator models:

The changes in LULC classes under the four scenarios, including the current trend scenario (S1), pessimistic scenario (S2), realistic scenario (S3), and optimistic scenario (S4), are illustrated in Fig 4.

Scenario 1 (S1): In this scenario, 2769 hectares of the four land cover classes, including water, barren land, rangeland, and agricultural lands, have been converted into built-up areas.

Scenario 2 (S2): In this scenario, 5538 hectares of the four land cover classes, including water, barren land, rangeland, and agricultural lands, have been changed into developed areas.

Scenario 3 (S3): In this scenario, 1384 hectares of barren land and rangeland have been converted into built-up areas.

Scenario 4 (S4): In this scenario, 692 hectares of barren land have been converted into built-up areas.

The changes in LULC for the four designed scenarios are presented in Table 4. The area of rangeland and barren land in scenario S2 is at its minimum due to the extensive growth of built-up areas by the year 2040. Scenario S2 exhibited the largest urban expansion, reducing green spaces by 15% compared to S1. This highlights the critical

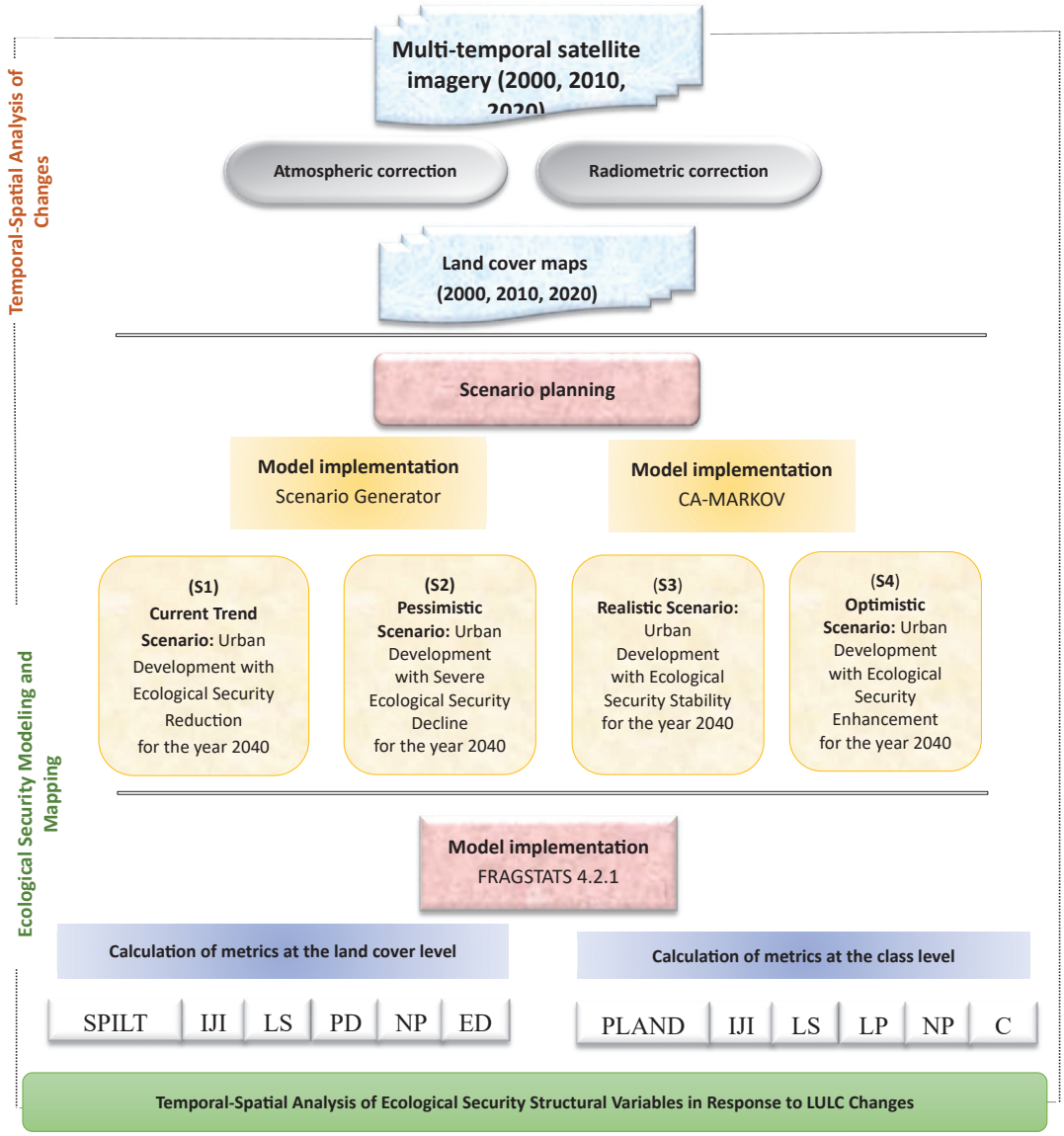

Fig. 2: Schematic diagram of the research methodology

role of policy intervention in mitigating ecological degradation. Results align with prior studies (e.g., Peng et al., 2017) linking urbanization to reduced landscape connectivity and biodiversity.

Assessment of spatiotemporal changes in land cover indices at different levels:

Analysis of the trend of metric changes at the class level:

(1) Status based on the NP metric: The number of human-made patches in the years 2000, 2010, and 2020 were 1626, 2943, and 3774, respectively. The predictions indicate that the number of built-up patches will decrease to 649 and 34 patches in Scenarios S1 and S2, respectively, by 2040. In Scenario S3, the human-made patches have decreased due to aggregation compared to 2020. However, in Scenario S4, the number of human-made patches has significantly increased due to the extension of urbanized areas in the entire study area. The number

Table 1: Overview of satellite imagery utilized in the study

Satellite	Resolution/sensor	Path/row	Resolution panchromatic	Date of acquisition	Source
Landsat 7[a]	ETM+	164/35	30	**May 15, 2000**	US Geological Survey (USGS)
Landsat 7[a]	ETM+	164/35	30	**May 25, 2010**	US Geological Survey (USGS)
Landsat 8[a]	OLI	164/35	30	**May 12, 2020**	US Geological Survey (USGS)

a-These data were collected from the official website of the US Geological Survey (USGS) (http://glovis.usgs.gov)

Table 2: Landscape metrics used in ecological security analysis

metrics	reference
NP	Jiang *et al.*, 2022; Sun *et al.*, 2022; Yang *et al.*, 2024
LSI	Sun *et al.*, 2022; Yang *et al.*, 2024
IJI	Sun *et al.*, 2022
PD	Keshtkar *et al.*, 2023; Sun *et al.*, 2022; Yang *et al.*, 2024
ED	Qiao *et al.*, 2024
SPLIT	Keshtkar *et al.*, 2023
CA	Moarrab *et al.*, 2021
PLAND	Sun *et al.*, 2022
LPI	Sun *et al.*, 2022; Yang *et al.*, 2024

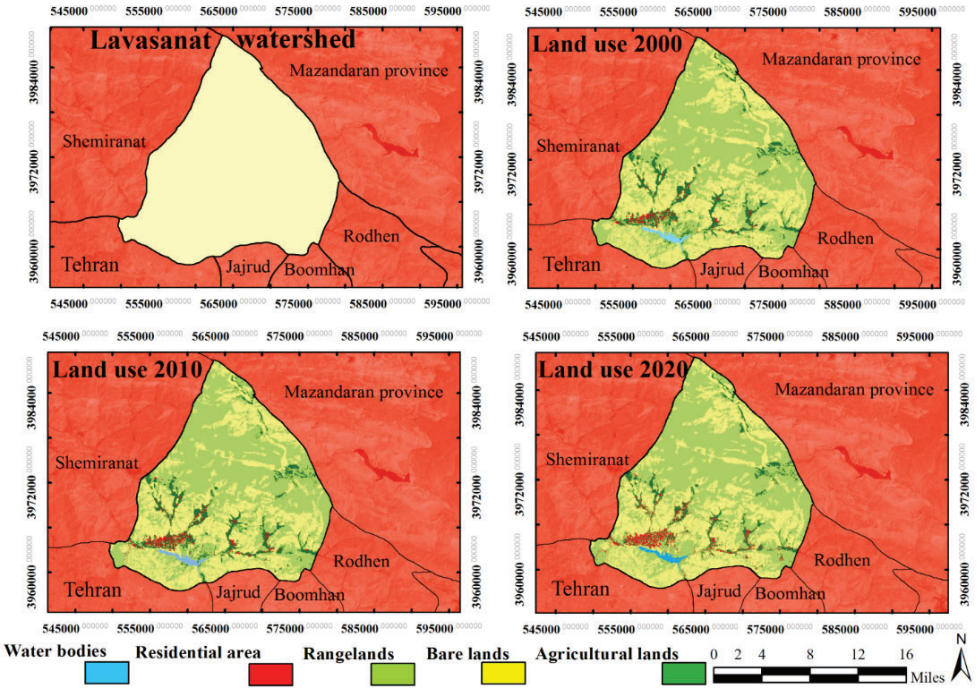

Fig. 3: LULC changes in the Lavasanat basin during the periods of 2000, 2010, and 2020

of green patches for the same years was 1248, 1648, and 1842, respectively. By 2040, in Scenarios S1 and S2, the numbers are predicted to be 1408 and 683, respectively. In Scenarios S3 and S4, the number of green patches will remain the same as in 2020 due to no expansion into agricultural lands. The number

Table 3: LULC area and changes in the Lavasanat Basin (2000–2020)

LU/ LC	2000		2010		2020	
	Ha	%	Ha	%	Ha	%
Water bodies	356.497428	0.67	358.83	0.68	358.744057	0.67
Agricultural lands	3324.36776	6.28	3204.586317	6.05	2228.660076	4.21
Bare lands	19117.362915	36.11	19079.384967	36.04	19015.562751	35.92
Rangelands	29704.299642	56.11	29601.808827	55.92	30289.395861	57.22
Residential area	430.629936	0.82	688.551379	1.31	1040.794871	1.97
Overall accuracy	95.72		96.26		95.32	
Kappa coefficient	0.948		0.943		0.936	

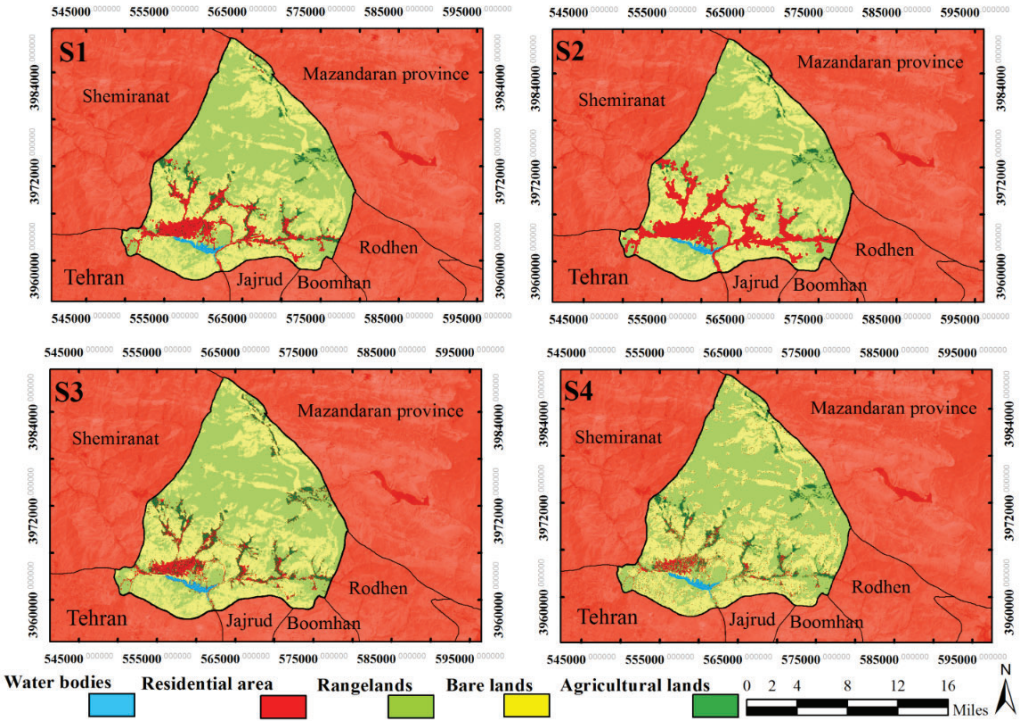

Fig. 4: LULC changes in the four designed scenarios for the year 2040

Table 4: Fluctuations in the area of predicted LULC scenarios for the year 2040

Predicted LU/LC Scenarios for the Year 2040	S1		S2		S3		S4	
	Ha	%	Ha	%	Ha	%	Ha	%
Water bodies	353.6075	0.66	333.245	0.62	358.7475	0.67	358.7475	0.67
Agricultural lands	1866.49	3.52	859.5725	1.62	2231.915	4.21	2231.915	4.21
Barren lands	18277.36	34.52	17838.8925	33.7	18881.615	35.67	18323.505	34.61
Rangelands	28626.1125	54.07	27322.585	51.61	29036.0175	54.85	30286.1275	57.21
Residential area	3809.5875	7.19	6578.8625	12.42	2424.8625	4.58	1732.8625	3.27

of bare land patches in the years under study were 113, 197, and 403, respectively. According to the predictions, this increasing trend will continue in Scenario S1, reaching 591 patches by 2040. In Scenario S2, due to excessive urban growth, the number of bare land patches will decrease to 238. In Scenario S3, the bare land patches will decrease compared to 2020, and in Scenario S4, due to urban development only occurring in these areas, the number of patches will increase to 423. The number of rangeland patches decreased from 10084 in 2000 to 9861 in 2010 but increased in 2020 due to changes in land use and increased precipitation. However, the predictions show that by 2040, the number of rangeland patches will decrease to 5461 in Scenario S1. In Scenarios S2, S3, and S4, the number of rangeland patches will be 4994, 5817, and 10995, respectively.

(2) Status based on the Contagion metric (CA): The area of built-up land in 2000, 2010, 2020, and Scenarios S1 and S2 in 2040 were 432.4, 689.82, 1040.86, 3809.58, and 6578.86 hectares, respectively. This increase indicates the growth of built-up areas. In Scenarios S3 and S4, there is also an increase in built-up areas, but it is limited to 2424.86 and 1732.86 hectares, respectively. The area of agricultural lands decreased to 3224.36, 3204.7, and 2331.9 hectares in the years under study. In Scenario S2, the agricultural lands reached their lowest area of 859.87 hectares. In Scenarios S3 and S4, these areas remained the same as in 2020 due to the applied restrictions. The area of bare land decreased in all years and scenarios. The area of rangelands decreased from 29762.61 hectares in 2000 to 29600.41 hectares in 2010 but increased to 30286.13 hectares in 2020 due to land use changes and increased precipitation. However, by 2040, the area of rangelands will decrease in Scenarios S1, S2, and S3. In Scenario S4, due to restrictions, the area of rangelands will be the same as in 2020.

(3) Status of land classes based on the metric (PLAND): The percentage of land covered by human-made patches has increased from 0.81% to 1.3% and then to 1.96 % over time, indicating the expansion of human-made areas in all years. According to the predictions in scenario (S1), this increasing trend will continue, reaching 7.19 % by the year 2040. The results of this metric of land cover patterns in agricultural lands have been 6.28%, 6.05%, and 4.21% in the years 2000, 2010, and 2020, respectively. The results indicate that this declining trend will continue in various scenarios until 2040. In contrast, the percentage of land covered by barren areas during the studied years was 36.11 %, 36.04 %, and 35.92 %, respectively. The results suggest that the decreasing trend for barren areas will continue in various scenarios until 2040. In the case of rangeland areas, the percentage was 56.11%, 55.92%, and 57.21% for the years 2000, 2010, and 2020, respectively. The predictions indicate that the decreasing trend for rangeland areas will also continue in different scenarios until the future.

(4) Status of land classes based on the metric (LSI): The LSI metric for human-made patches showed an increase over the years 2000, 2010, and 2020, with values of 54.72, 74.82, and 99.9, respectively, indicating an increase in complexity and irregularity of this land use class during the studied period. The predictions in scenarios (S1) and (S2) for the year 2040 show that this metric will reach 30.58 in scenario S1 and 11.40 in scenario S2, suggesting a simplification and regularity of the human-made patches in that time frame. The LSI metric for rangeland areas, on the other hand, had values of 43.68, 52.26, and 54.69 for the years 2000, 2010, and 2020, respectively. The predictions for scenario S1 in 2040 show that the shape metric will decrease to 43.55, indicating a simplified shape for this land cover class. The LSI metric for barren areas during the years 2000, 2010, and 2020 was 60.12, 60.66, and 62, respectively, indicating an increase in complexity and irregularity of this land use class during the studied period. The predictions for scenario S1 in 2040 show that this metric will reach 59.9, indicating a simplification and regularity of barren land patches at that time. In scenario S2, the LSI metric reached its lowest value among other scenarios. The LSI metric for rangeland areas was 65.3, 65.65, and 73.08 over the years 2000, 2010, and 2020, respectively. The results show that this trend will decrease in various scenarios until 2040.

(5) Status of land classes based on the metric (LPI): The LPI metric for human-made patches was 0.19%, 0.56%, and 0.91% for the years 2000, 2010, and 2020, respectively. According to the predicted scenarios, the LPI metric for human-made patches in scenario (S1) will reach 6.27% by the year 2040. In the case of agricultural lands, the LPI metric showed a decreasing trend from 0.82% in 2000 to 0.59% And then reached 36.0% in 2020 due to the expansion of

human-made patches. The predicted scenario (S1) shows that the size of the largest patch of agricultural land will be 0.32% in 2040. The LPI metric for barren areas decreased from 12.8% in 2000 to 4.32% in 2010 and finally to 4.13% in 2020. Based on the predictions, the size of the largest patch in scenario S1 will be 3.98% due to the disappearance and changes in past smaller patches in 2040. The LPI metric for rangeland areas was 43.93%, 43.37%, and 41.01% for the years 2000, 2010, and 2020, respectively. The predictions for scenarios S1, S2, S3, and S4 show that the size of the largest patch in this metric will be 38.6%, 36.98%, 37.38%, and 41.01%, respectively, in 2040.

(6) Status of land classes based on the metric (IJI): The IJI metric for human-made patches showed an increasing trend, with values of 54.72%, 63.54%, and 55.39% for the years 2000, 2010, and 2020, respectively. Based on the predictions, the IJI metric in scenario (S1) will reach 75.18% by 2040, indicating a tendency towards correlation and mixture of this patch with other patches. The IJI metric for agricultural lands also showed an increasing trend, with values of 33.63%, 46.43%, and 42.79% for the years 2000, 2010, and 2020, respectively. The predicted scenario (S1) shows that the IJI metric will increase to 54.35% in 2040 due to the correlation and mixture of this patch with others.

The IJI metric for barren areas continuously increased from 2.31% in 2000 to 6.3% in 2020 and then decreased to 14.32% in 2040 in scenario (S4). The results for rangeland areas show that the IJI metric had an increasing trend, with values of 55.39%, 55.05%, and 66.11% for the years 2000, 2010, and 2020, respectively. The predicted scenario (S3) indicates that the IJI metric will reach its lowest value of 37.59% in 2040.

Analysis of the trends in metrics at the land structure level

(1) Status of land structure based on the metric (NP): The number of patches in the land structure during the years 2000 to 2020 was 13,073, 14,651, and 17,016, respectively, indicating an increasing trend. The predicted scenarios show that the number of patches in the land structure will decrease to 8,117 in scenario (S1) and 5,954 in scenario (S2) by the year 2040. This reduction is primarily observed in human-made patches due to urban expansion. On the other hand, in scenario (S3), the number of patches increases to 9,683 due to the use of barren and rangeland areas for urban development, reaching 73,633 in scenario (S4) because of utilizing barren lands for urban expansion.

(2) Status of land structure based on the metric (PD): The metric for patch density during the studied years was 24.69, 27.67, and 32.14, in respective order, reflecting a rise in the number of patches per unit area over time. This trend, along with the increase in the total number of patches, demonstrates an increase in land fragmentation during the study period. The predictions indicate that the patch density metric will decrease to 15.33 in scenario (S1) and 11.24 in scenario (S2) by the year 2040. This reduction implies the integration of residential areas, which can be a disruptive factor. In scenario (S3), the metric also decreased to 18.29, indicating further integration compared to 2020, which is due to urban expansion and their cohesiveness. However, in scenario (S4), this value reached 139.10.

(3) Status of land structure based on the metric (LSI): The shape metric of the land structure during the years 2000, 2010, and 2020 was 51.34, 54.33, and 59.72, respectively, indicating an increase in complexity and geometric irregularity in the Lavasanat watershed's land structure. The predictions for LULC in the year 2040 in scenarios (S1) and (S2) show that this metric will decrease to 47.79 and 40.90, respectively. This decrease indicates a simplification and regularization of the land structure due to the increase in human-made areas by the year 2040.

(4) Land structure status based on the metric (SPLIT): The metric of perforation index for the years 2000, 2010, and 2020 was recorded as 4.82, 5.03, and 5.63, respectively. However, based on the provided predictions, the perforation index in scenario (S1) will be 6.21 by the year 2040. In scenario (S2), the metric will reach 6.37, and in scenarios (S3) and (S4), it will be 6.67 and 5.65, respectively. Consequently, in scenarios S1, S2, and S3, the dynamism and alterations in the land structure will increase, whereas in scenario S4, the noticeable changes in LULC will not be significant.

(5) Land structure status based on the metric (ED): This metric, representing edge density, was recorded as 86.86, 92.06, and 101.42 for the years 2000, 2010, and 2020, respectively. The increase in the edge density metric indicates a rising trend in the fragmentation and shape change of patches over

Table 5: Comparison of trends in metric changes at the land structure level for the studied years and various land use scenarios

Metrics / Time	NP	PD	LSI	SPLIT	ED	IJI
2000	13073	24.69	51.34	4.82	86.86	38.86
2010	14651	27.67	54.33	5.03	92.06	45.05
2020	17016	32.14	59.72	5.63	101.42	50.54
S1	8117	15.33	47.79	6.21	88.68	43.77
S2	5954	11.24	40.90	6.37	68.70	32.83
S3	9683	18.29	58.75	6.67	99.74	45.67
S4	73633	139.10	76.30	5.65	130.25	63.04

time. According to the predictions, the edge density metric in scenario (S1) will be 68.88 by the year 2040, indicating that the patches are more stable due to the maximum growth of human-made areas that have had the most significant impact on the area's shape change. In scenario (S2), this metric has decreased to its lowest value, which is 68.70, due to excessive growth in human-made areas. In scenario (S3), the metric reaches 99.74, showing a decrease compared to 2020, which is due to the unchanged LULC in agricultural and orchard areas. However, in scenario (S4), the metric reaches 130.25, where the expansion of human-made areas has been exclusively allocated to barren lands. Consequently, this excessive instability increase in patches has contributed to an overall increase in land instability.

(6) Land structure status based on the metric (IJI): The intermixing and juxtaposition index of land structure has shown a consistent increasing trend from 38.86% in 2000 to 45.05% in 2010 and then 50.54% in 2020. Furthermore, by the year 2040, in scenario (S2), this trend has decreased to its minimum value of 32.83%. Table 5 provides a comparison of the trends in metric changes at the land structure level for the studied years and various land use scenarios.

Changes in Land Use and ES:

The expansion of residential areas in the Lavasanat basin is the most significant driver of land use changes in this region, which will bring about irreparable environmental issues in the future. The growth of residential areas leads to the destruction of ecosystem structures and impacts ecological processes in the basin. Due to the lack of proper scientific planning and strategies for the Lavasanat basin, residential areas have scatteredly expanded during the years 2000, 2010, and 2020, occupying many crucial environmental spaces essential for ecological security. In scenarios S1 and S2, the expansion of residential areas will continue in a way that, by the year 2040, these areas will be homogenously integrated, leading to the loss of a significant portion of the basin's ecological infrastructure. The results of this study align with similar research studies (He *et al.*, 2014; Li *et al.*, 2011; Peng *et al.*, 2017; Kong *et al.*, 2017; Salvati & Carlucci, 2014; Van Vliet *et al.*, 2019). The uncontrolled expansion and development in this basin are expected to result in changes in land structure, subsequently disrupting the ecological and human-environmental balance. The unplanned growth of residential areas in the Lavasanat basin, besides creating undesirable urban spaces, will lead to issues such as land resource depletion and degradation of ecosystem services. The presence of urban constructions is an ongoing aspect in all land use scenarios, and without proper regulation and control, the residential areas in the basin can rapidly grow and cause problems like environmental pollution, soil and water erosion, and destruction of agricultural lands, as predicted in the various scenarios of this study. The results and findings of this research emphasize the accuracy of the statements made. For instance, in the four land use scenarios - current (S1), pessimistic (S2), realistic (S3), and optimistic (S4) - the built-up areas have respective areas of 38,078,250, 65,712,850, 24,207,400, and 17,261,550 square meters. As it is evident, changes in the area of built-up regions, being one of the structural components of the Lavasanat watershed, will also impact the overall performance of the area. For instance, in scenarios S1 and S2, where land use planners have not significantly influenced urban development and growth, built-up areas have continuously expanded, leading to the degradation of ecological structures. Consequently, over time, the Lavasanat watershed will provide fewer ecosystem

services and will face issues such as water and soil erosion. Therefore, the results of this study align with research conducted by Bathrellos *et al.,* (2017), Dong *et al.,* (2014), Sun *et al.,* (2001), and Lu *et al.,* (2015). Another example can be mentioned, in scenario S2 (pessimistic, characterized by urban development with a significant reduction in ecological security), with the increase in the area of built-up lands (CA), the number of patches (NP), and the complexity index (LSI) of these lands decrease, while the percentage of land cover (PLAND) increases, leading to the formation of large patches (LPI). This suggests that the basin's structure and subsequently its ecological structure has experienced significant disruption, and ecologically valuable areas have been lost. Additionally, the reduction in the ecological security of the land in this scenario is due to the elimination of small ecologically valuable patches by human-made areas, resulting in decreased complexity index (LSI), land cover percentage (PLAND), and patch size (LPI) for these areas. These findings indicate that improper land use planning will lead to significant changes in land structure, impacting ecological structures and functions, and ultimately affecting ecological security. All these findings and other presented results demonstrate that changes in ecological structures will influence ecological functions, consequently leading to alterations in ecological security.

The relationship between land cover patterns and ES

The relationship between land cover patterns and ES is a complex and challenging process that involves identifying, monitoring, and assessing changes in land surfaces due to their impact on environmental processes and functions. One of the most important methods for understanding and determining LULC changes in the Lavasanat basin is the analysis of land cover patterns. Land cover patterns can be quantified using land cover metrics. Combining land use maps of the Lavasanat basin with land cover metrics can help identify areas that are most vulnerable to changes in ecosystem services at the land cover level, which serves as an entry point for future land management opportunities in the region. The structure of land cover patterns (composition, configuration, and connectivity) in the Lavasanat basin plays a crucial role in preserving biodiversity and providing ecosystem services. However, human destructive activities, land conversion, and land fragmentation have had a significant impact on this structure, resulting in severe environmental effects for the area. This has reduced the extent of natural areas and heightened their spatial dispersion and fragmentation. The findings of this study indicate that unchecked urban development has exerted substantial effects on the ecological structure of Lavasanat, leading to the transformation of agricultural lands into other land uses. The most extensive transformation has been from agricultural lands to built-up lands. Furthermore, the agricultural land patches in Lavasanat have experienced a reduction in numbers, area, shape, and size over time, leading to a fine-grained and irregular structure of agricultural land patches, with large ecological value patches in 2000 being replaced by smaller and less ecologically valuable patches in 2020. The results indicate that the green spaces in this area are not in a favorable ecological structure and land cover changes suggest that land degradation is more prominent than the creation of new patches. The area of patches has decreased while new patches have been created. These findings align with the study conducted by Tong *et al.* (2017), which attributes changes in LULC patterns to accelerated urbanization and population growth. Unplanned urban development has had significant impacts on the ecological structure of Lavasanat. For example, ecologically valuable lands have been consumed by urban construction, gradually subdividing into smaller parcels and diminishing the ES of the region. These results are in line with similar studies (Alberti, 2004; Su *et al.*, 2010; Asfaw & Worku, 2019). The development of human-made areas in Lavasanat has disrupted the balance and dynamics of the environment and land cover, consistent with similar research findings (Huilei *et al.*, 2017; Peng *et al.*, 2016; Montis *et al.*, 2019). These developed areas have acted as interventions, severing the continuity and connection that were originally observed in vast green areas. As a result, ecological and environmental problems such as urban heat islands, environmental pollution, soil erosion, and water issues are emerging in the region. The results of this study show that in various land use scenarios for the year 2040, the number of patches (NP) of green areas in the pessimistic scenario (S2) is the lowest. The developed areas in the pessimistic scenario (S2) also have the fewest patches, which is due to the excessive expansion and integration of these lands. The green land area (CA) in the realistic (S3) and optimistic

(S4) scenarios, considering the restrictions imposed to prevent urban growth on these lands, remains the same as in 2020. The area of developed land in scenario S2 has increased significantly. In scenario S4, these lands have a smaller area compared to other scenarios. Bare and rangeland areas also have the smallest area in scenario S2 compared to other scenarios. Developed areas in scenario S2 have the highest percentage of land cover (PLAND). The bare land and meadow areas also have the highest complexity index (LSI) in scenario S4, attributed to the limited development in these areas. In scenario S2, due to the homogenization and expansion of built-up areas, these areas have the lowest complexity index among all scenarios. The built-up areas in scenario S2 have the largest patch size (LPI), while scenarios S1 and S3 have the next highest priority. In this metric (LPI), the agricultural land in scenario S2 has the smallest patch size, while in scenarios S3 and S4, it has the largest patch size. The results of the scenarios indicate that with an increase in the area of built-up areas (CA), although the number of patches (NP) of agricultural land will decrease, and landscape connectivity will increase, the complexity index (LSI) will decrease. However, with an increase in the land cover percentage (PLAND) of built-up areas, large patches (LPI) will form, leading to the loss of ecologically valuable areas and a reduction in ecological security in the basin. All these findings indicate that changes in land cover patterns will result in changes in ecological security in the basin.

CONCLUSION

The results of the different land use scenarios reveal significant changes in land cover patterns, which have led to a shift in ecological security in the Lavasanat basin. As Mondal & Southworth (2010) highlighted, LULC changes are one of the most influential factors affecting ecological systems. These findings indicate that reductions in agricultural lands (CA) are accompanied by a decrease in the number of patches (NP) and the elimination of smaller patches, resulting in reduced landscape homogeneity. Key metrics, such as the landscape shape index (LSI), land cover percentage (PLAND), and largest patch index (LPI), also show a downward trend, reflecting the loss of ecologically valuable areas and a decline in ecological security across the region. Policymakers and urban planners should prioritize sustainable urban development by enforcing land use regulations that protect green spaces and prevent excessive urban sprawl. Establishing ecological buffer zones around critical habitats can mitigate fragmentation and preserve biodiversity. Integrating predictive tools such as CA-Markov and FRAGSTATS into decision-making processes can improve the accuracy of ecological impact assessments. Furthermore, promoting compact urban growth and enhancing public engagement in planning initiatives will ensure more resilient and adaptive urban ecosystems. Limitations of this study include reliance on historical data, which may not fully account for future socio-economic changes and unforeseen environmental events. Additionally, the accuracy of predictive models like CA-Markov is influenced by the assumptions of consistent land use trends and uniform socio-economic conditions. Future research could integrate real-time monitoring data, socio-economic variables, and climate change projections to enhance predictive accuracy. Exploring the application of machine learning algorithms in land use modeling could further improve the robustness of ecological impact assessments. These insights are consistent with findings in prior studies (Aburas et al., 2018; Arnold *et al.,* 2018; Liang *et al.,* 2017; Woldesemayat & Genovese, 2021), which underscore the importance of integrating socio-economic and environmental factors in predictive models. Overall, the findings of this study underscore the importance of adopting sustainable land use practices and proactive urban planning strategies to mitigate the ecological impacts of rapid urbanization. These strategies will play a vital role in preserving ecological security and promoting long-term environmental resilience in the Lavasanat basin and similar regions.

AUTHOR CONTRIBUTIONS

Y. Moarrab conducted the literature review, designed the study, and performed data analysis and interpretation. V. Novin, as the corresponding author, compiled the data, contributed to manuscript preparation, and ensured the manuscript's clarity, structure, and final revisions. Both authors reviewed and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and/or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS (NOMENCLATURE)

NP	Number of Patches
LSI	Landscape Shape Index
IJI	*Interspersion and Juxtaposition Index*
PD	*Patch Density*
ED	*Edge Density*
SPLIT	*Splitting Index*
CA	*Class Area*
PLAND	*Percentage of landscape*
LPI	*Largest Patch Index*

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ORIGINAL RESEARCH PAPER

Economic and social transformation: The impact of urbanization on the informal worker

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ABSTRACT

BACKGROUND AND OBJECTIVES: This research explores the impact of urbanization on informal workers in Surabaya, focusing on street vendors and day laborers. Urbanization in Surabaya has triggered significant economic and social transformations, created new job opportunities, and also increased challenges for informal workers.

METHODS: The study employs a qualitative approach using in-depth interviews and participatory observation to collect data from informal workers.

FINDINGS: The findings indicate that 78% of informal workers experience significant income volatility, while 65% report facing high competition, and 72% lack access to essential resources. To cope, 68% extend their working hours, and 54% utilize social networks for support. Additionally, 61% of respondents benefit from government and non-profit support through training and economic empowerment programs, which have led to a 35% improvement in their skill levels. This study underscores the necessity for inclusive policies, as well as increased support for informal workers, to mitigate urbanization's challenges and improve their overall quality of life.

CONCLUSION: This research is expected to significantly contribute to understanding the dynamics of urbanization and its impact on informal workers, as well as offer practical solutions to improve their quality of life. Community support and optimized government policies can help address these challenges and create a more inclusive and sustainable urban environment.

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INTRODUCTION

In 2018, the United Nations estimated the total population of the planet was 7.7 billion, of which 55.28% live in urban areas. One billion people live in slums and informal settlements today, representing about 30% of the world's urban population. The 2030 Agenda for Sustainable Development and the New Urban Agenda focused on sustainable urbanization and human settlements. Urbanization is an unstoppable phenomenon, but it is a transformative process capable of galvanizing the momentum of many aspects of the global environment. The city of Surabaya ranks among the most urban metropolitan areas in Indonesia. Data from Indonesia's Central Statistics Agency (BPS) shows that the population in 2022 will be 3,108,926, with 99.06% living in urban centers. As the economic, industrial, and trade center of East Java, Surabaya attracts many rural communities that are looking for new opportunities. Its rapid development over the past few decades has ushered in significant social and economic transformations. One of these transformations is a shift in the livelihoods of rural people who migrate to urban areas. This growth has led to the expansion of formal employment sectors, including manufacturing, retail, and hospitality. However, the city's rapid expansion has also fostered the growth of the informal economy—a sector that includes street vendors, waste collectors, domestic workers, and informal service providers. Informal workers often operate without legal or social protection and are typically excluded from formal employment benefits such as health insurance, pensions, or minimum wage guarantees (Li and Gao, 2023; Hilson and Hu, 2022; Hudnall *et al*., 2022; Munawar et al., 2022). Surabaya's urban economy relies heavily on informal workers to support various industries and services. For example, informal street vendors provide affordable goods and food to city dwellers, while domestic workers allow the middle and upper classes to support their households. In essence, the informal sector functions as an important cog in the urban economic engine, yet remains marginalized and vulnerable (Hudnall *et al*., 2022; Munawar *et al*., 2022; Gurbanalieva, 2021; Mardiansjah *et al.,* 2021). BPS data from 2022 indicates an average annual per capita income of US$974.336,10 million for Surabaya residents, significantly higher than the average annual per capita income of villagers in East Java, which stands at US$362.987,96 million. This increase in employment opportunities has contributed to a lower open unemployment rate of 6.28% in 2022 compared to East Java's rate of 7.02%. Furthermore, economic growth in Surabaya City reached 5.26% in 2022, surpassing East Java's 4.92% growth rate. However, rural-to-urban migration also presents challenges in terms of social integration. Newly urbanized communities often struggle to adjust to different urban cultures, more demanding work environments, and increased social pressures. This can negatively impact their psychological well-being and the overall social sustainability of the community (Deller and Conroy, 2022; Octifanny, 2020). The shift from rural to urban livelihoods can exacerbate competition in the urban labor market. Rural communities with limited skills and education may struggle to find decent jobs, potentially increasing unemployment or informal employment. As these communities enter the workforce, they compete with existing urban residents and other rural migrants seeking employment (Kazak *et al.,* 2022). While formal and informal employment opportunities exist, availability is limited, especially in the formal sector with higher skill requirements. This intense competition between job seekers, including those transitioning from rural areas, can negatively impact the economic and social well-being of rural communities. However, this competition can also be a catalyst for innovation, improved workforce quality, and skill development among those who successfully navigate it (Takyi *et al*., 2023). The mass migration of rural communities to urban areas, known as urbanization, poses a potential threat to exacerbate existing inequalities within cities. Many rural communities transitioning their livelihoods often find themselves relegated to the informal sector or low-productivity jobs. This can lead to a widening socioeconomic gap between thriving urban centers and their less developed peripheral or rural counterparts (Magidi, 2022; Zoysa, 2021). Uncontrolled urbanization can create labor surpluses in certain sectors. Companies often prioritize hiring individuals with higher qualifications and experience for the same role, leaving many migrant workers struggling to find adequate employment. This can contribute to rising urban unemployment rates, particularly when job demand fails to keep pace with the influx of labor (Chen *et al*., 2021; Mitra, 2020). Meeting the needs of burgeoning urban populations

for housing, industry, and infrastructure often requires extensive land acquisition. This can lead to deforestation and the conversion of agricultural land and green spaces to urban areas, resulting in the loss of natural habitats, ecosystem damage, and decreased biodiversity (Damte *et al*., 2023; Ruas *et al*., 2022). Furthermore, rapid urban growth triggers increased demand for natural resources like water, energy, and land, potentially leading to environmental degradation and straining urban infrastructure. The influx of people, including rural migrants, fuels the consumption of these resources, potentially leading to excessive exploitation. This can manifest as over-extraction of groundwater, increased carbon emissions from fossil fuel dependence, and heightened waste and pollution from industrial activities (Yeyouomo and Asongu, 2023; Bibi and Kara, 2023). Identifying and addressing the issues mentioned above is crucial for formulating sustainable urban development policies and strategies in Surabaya. This is well-founded, as Surabaya, the second-largest city in Indonesia, is experiencing rapid urbanization, which allows for a comprehensive understanding of the economic and social changes taking place. Informal workers often do not receive the same protections and benefits as formal workers, so this research can uncover the challenges they face and propose solutions to improve their welfare. Additionally, the findings of this research can assist the government and policymakers in designing more effective programs and policies to support informal workers and reduce economic inequality. Research on the economic and social transformations resulting from urbanization affecting informal workers in Surabaya is highly relevant and urgent. The rapid economic growth of Surabaya has created widespread job opportunities but also heightened difficulties for those without access to formal positions. Therefore, an in-depth analysis of the impact of urbanization on informal workers can help understand these effects and identify ways to reduce economic and social inequalities. Many studies have been conducted on urbanization and economic growth in Surabaya, but there is still a lack of focus on informal workers. Most research tends to address general phenomena such as public infrastructure, social disparities, and mass migration without directly considering the implications for marginalized groups like day laborers, street vendors, and hawkers (Chen *et al*., 2023; Larato *et al*., 2023; Hamid *et al*., 2022; Thakkar, 2021). Therefore, this research aims to fill these gaps by providing a detailed depiction of the conditions and challenges faced by informal workers in Surabaya. The increasing urbanization is causing a surge in the population of major cities, which in turn intensifies job competition. Many migrants from rural areas seek opportunities in cities, adding pressure on job seekers. This fierce competition often leads to high unemployment rates in urban areas, posing a significant challenge to economic stability. In this context, the government must develop strategies to mitigate the negative impacts of urbanization on employment. Additionally, this research can provide recommendations to improve informal workers' access to basic services such as healthcare, education, and housing, ultimately enhancing their quality of life. This study will provide accurate and up-to-date data and information that can be used by academics, policymakers, and non-governmental organizations to design more targeted interventions. Besides the economic impacts, rising unemployment also brings significant social consequences. High unemployment can trigger social instability, such as increased crime rates and social tensions. These issues require serious attention from the government and stakeholders to address the negative impacts of urbanization and create a more stable and inclusive urban environment.

Literature review

Urbanization and economic transformation

The theory of structural change is a concept in sociology that focuses on the mechanisms of economic transformation experienced by developing countries, which initially are subsystems focused on the agricultural sector and transition toward more modern industrial and service-oriented economic structures. This theory explains changes in the ways societies interact, work, and live (Sakketa, 2022). In the context of urbanization, this shift in employment structure impacts increasing societal income. Individuals working in the industrial and service sectors generally have higher incomes than those working in the agricultural sector (Haas, 2021). Initially, before urbanization, rural communities tended to consume simple and affordable goods. However, after urbanization, urban communities tend to consume more modern and high-quality goods. This shift is due to increased societal income

and access to information and technology. Changes in consumption patterns lead to increased demand for goods and services. Additionally, Surabaya's society typically held traditional cultural values before urbanization. However, post-urbanization, Surabaya's society leans toward more modern cultural values. This change is driven by increased interaction between urban and rural communities. These shifts in cultural values impact the growing cultural diversity and have transformed Surabaya into an open and tolerant city. Urbanization refers to the increase in the proportion of the population living in urban areas. According to Lewis's theory of economic development, urbanization drives the shift of labor from the agricultural sector to the industrial and service sectors. This process is expected to enhance productivity and income levels. However, in reality, many workers are unable to access formal employment and end up working in the informal sector. The informal sector includes various types of jobs that are not regulated or protected by law, such as street vendors, domestic workers, and day laborers (Tignor, 2020). Urbanization, the large-scale migration of people from rural to urban areas, significantly impacts various aspects of life in Surabaya, Indonesia's second-largest city. This phenomenon has deeply reshaped the livelihoods of rural communities, leading to economic transformation within these communities. The main drivers of this migration are economic opportunities, job expansion, living standards, and the efficiency of productive cities through the growth of manufacturing productivity. Typically, rural communities rely on agriculture, which offers relatively low incomes. In contrast, cities provide numerous job opportunities in the industrial and service sectors, with much higher income potential (Mishra, 2023). Defines urbanization as the process of rural areas developing into urban centers. Alternatively, it can be seen as the development of rural areas into towns or villages that acquire urban characteristics (Jardine, 2022). This theory suggests that urbanization is a natural stage in human societal development, often leading to a shift from agriculture-based livelihoods in rural areas to industry- and service-based livelihoods in urban centers. Meanwhile, according to Mohanty, urbanization can be understood as the percentage of the population living in cities compared to the total population, or as a process of urban establishment. Thus, there are two implicit meanings of urbanization:

1- It refers to the processing and formation of urban complexity characteristics due to migration from a homogeneous area to a heterogeneous area.

2- It refers to the development of an initially homogeneous area into a heterogeneous area, causing unbalanced urban growth with many physical, social, economic, and cultural problems (Mohanty, 2020).

Social inequality

Urbanization often exacerbates social and economic inequalities. According to social inequality theory, urbanization can create larger disparities between groups with access to resources and economic opportunities and those without. Informal workers are often at a disadvantage, with limited access to education, healthcare, and adequate housing. These inequalities can hinder social mobility and reinforce the cycle of poverty (Benna and Benna, 2018). Referencing Julius Herman Boeke's theory of inequality and social conflict, the effects of urbanization can lead to increased income disparities if job availability is uneven. Some residents may have high-paying jobs, while others only secure low-paying ones. This creates significant economic inequality, even extending the cycle of poverty. Higher-income individuals tend to have better access to healthcare, education, adequate housing, and basic infrastructure. Meanwhile, low-income residents may struggle to meet basic needs (de Haan, 2020). Opportunities for quality employment and business may be more accessible to those with stronger educational backgrounds and connections, creating inequality in access to economic opportunities. Disparities in educational access and quality can become major issues in urban societies. Higher-income residents can choose better schools, while lower-income residents may have limited educational options. Additionally, significant social and economic inequalities can create social tensions. Dissatisfaction, injustice, and feelings of inequality can lead to potential conflicts among various groups in society. Furthermore, crime rates may also increase in situations of economic and social inequality (Oyelaran-Oyeyinka and Lal, 2017).

Economic dualism

The economic dualism theory proposed by Boeke and Lewis explains the existence of two parallel

economic sectors within a country: the modern sector and the traditional sector. The modern sector typically consists of large industries and formal enterprises, while the traditional sector includes small businesses and informal jobs. In cities experiencing rapid urbanization like Surabaya, this dualism becomes very apparent. Informal workers often face income uncertainty, limited access to social services, and poor working conditions. According to Boeke and Lewis's economic dualism theory, economic development is a process where the traditional economy gives way to the modern economy through the modernization of economic, social, and political structures. This transformation process involves the emergence of new ideas and the revival of old ones, such as individualism in society, economic rationalism, and minimization of behavior. Additionally, global economic integration supporting other institutions and markets results from transferring market values into the realm of significant economic efficiency and global wealth (Resina, 2022). The emergence of certain market economies results from the depreciation of market assets. The development of economic institutions' efficiency, reduction of transaction costs, and advances in communication and transportation are contributing factors to the transition from traditional to modern economies. Furthermore, this theory states that new market systems will bring new regions into the international economic orbit. The start of this process seems to be when European capitalist countries began expanding into Asia, Africa, and Latin America in the early 16th century (Elliott and Lemert, 2022). The modern sector, characterized by European capitalist countries, began to influence the underdeveloped sectors in the Third World. According to this theory, three main factors influence the transition from the traditional sector to the modern sector: economic efficiency, organized activities, and technological advancements. This has resulted in the development of production techniques, the creation of new products and materials, and the emergence of new products in economic activities. Newly industrialized countries in Asia, such as Hong Kong, South Korea, Taiwan, and Singapore, have shown significant progress through a liberal approach, enabling them to transform into developed countries. Other countries, such as Malaysia, Thailand, Indonesia, and Vietnam, have recently followed this path and are beginning to show results from adopting liberal principles and moving away from conventional economic systems (Das, 2022). The summary of the theories above encompasses various views on the impact of urbanization on economic and social transformations, particularly in Surabaya. The structural change theory explains how urbanization shifts employment from the agricultural sector to the industrial and service sectors, generally resulting in increased income and changing consumption patterns. Urbanization also causes changes in cultural values and lifestyles, from traditional to more modern. According to Lewis's theory, urbanization is supposed to increase productivity and income, but many workers end up trapped in the informal sector. The economic dualism theory proposed by Boeke and Lewis highlights the existence of two parallel economic sectors—modern and traditional—with informal workers often facing income uncertainty and lack of access to social services. The contribution of this research is to provide comprehensive data on the impact of urbanization on informal workers in Surabaya, which can be used by academics, policymakers, and non-governmental organizations to design more targeted interventions. The novelty of this research lies in highlighting how the structural economic and social changes caused by urbanization affect the lives and livelihoods of informal workers and how government policies and worker adaptation strategies can help address these challenges. Thus, this research is expected to make a significant contribution to understanding the dynamics of urbanization and its impact on informal workers and offer practical solutions to improve the quality of life for informal workers.

MATERIALS AND METHODS

Qualitative exploratory research serves as an important first step in the research process aimed at clarifying emerging issues and gaining a comprehensive understanding of the economic and social transformation resulting from the impact of urbanization on informal workers in Surabaya. As a preliminary investigation, this research approach acts as a foundational trace, reinforcing concepts to be used in broader studies with a wider conceptual scope. The main objective of exploratory research is to delve deeper into key issues, develop existing hypotheses, and generate initial ideas. Even for subject-specific research, it plays a crucial role by laying the

groundwork for future descriptive testing research. However, unlike research aimed at exploring specific fields or recording phenomena, exploratory research seeks to explain and illuminate the phenomena under investigation. This understanding can then be utilized to develop future hypotheses (Aithal and Aithal, 2023; Buzasi and Jager, 2021). This qualitative exploratory research employs a phenomenological design approach, suitable for exploring deeply rooted questions to investigate individuals' lived experiences of a phenomenon, as described by the subjects themselves or through their sources. This approach involves active listening and observation to understand and capture the detailed experiences and perspectives of the informants. From the researcher's perspective, phenomenology begins with general ideas and uses them as a springboard to identify specific issues for further investigation. This allows for flexibility and adaptation as new data and insights emerge. It is particularly valuable for addressing research questions that are ambiguous or uncertain.

The assumptions of qualitative designs

The first step in qualitative research is building a conceptual framework, which is the process of identifying and organizing key concepts and the relationships between those concepts in a study. This conceptual framework (see Fig. 1) serves as a map for understanding the phenomenon being studied. By developing a conceptual framework, researchers can identify important variables that need to be considered and how these variables are interconnected, thereby aiding in formulating hypotheses, designing research, and interpreting results.

Problem identification

Identify the problem or topic to be researched. This involves selecting relevant and important issues, as well as formulating clear research questions. Researchers need to understand the context and background of the problem to determine the direction of the research appropriately (see Table 1).

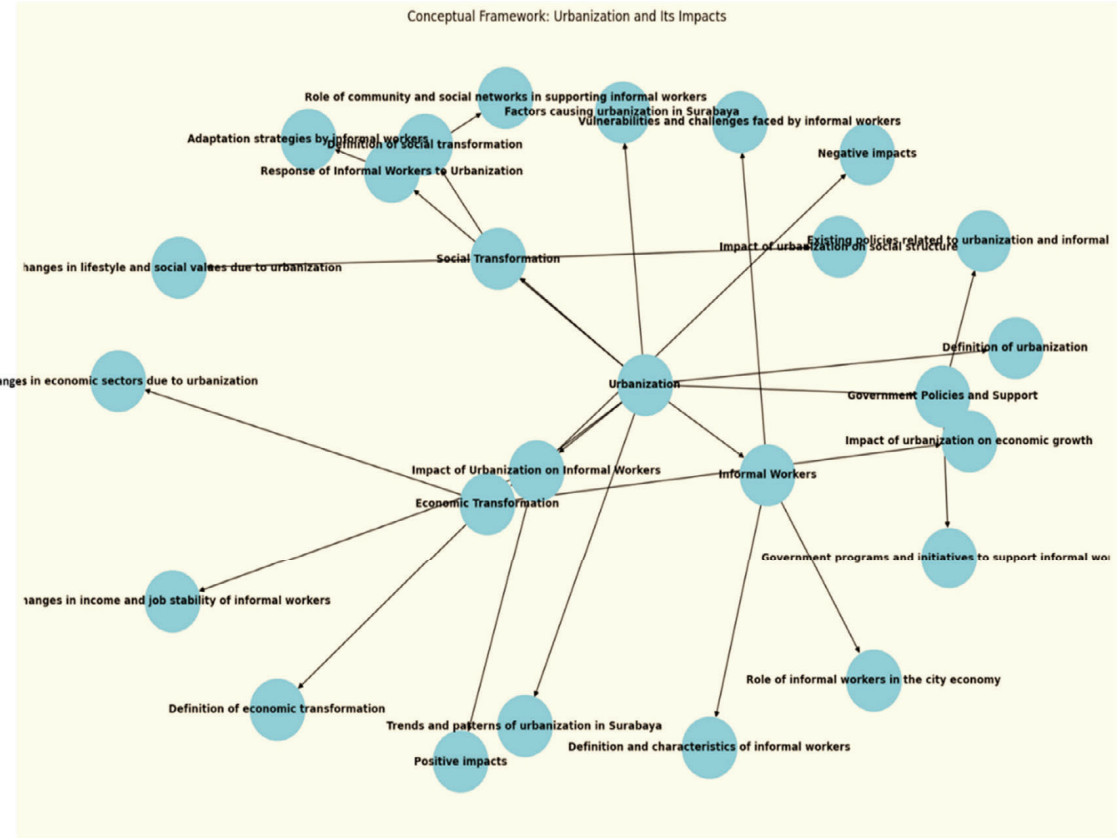

Fig 1: Conceptual urbanization and its impact on informal workers (2023)

Table 1: Identification of economic and social transformation problems and impact of urbanization on the Profession of Informal Workers in the city of Surabaya (source: Data processing results, 2023).

No.	Main Problems	Problem Descriptions	Measuring Instruments
1	Increasing Migration Flows	An increase in the number of people from villages to cities is looking for better jobs, higher wages, and better life opportunities. This triggers an increase in demand for housing, public facilities, and infrastructure that often cannot be met quickly.	Observation
2	Comparative Formal-Informal Employment Ratio	The number of formal jobs available is disproportionate to the number of job seekers, especially for those with low education or limited skills. As a result, many are forced to work in the informal sector with low wages, no social security, and unsafe working conditions	Observation
3	The Great Contribution of Urbanites to the Informal Sector	New migrants often do not have a strong social network in the city, making it difficult to get formal employment. They find it easier to find jobs in the informal sector, such as street vendors, scavengers, or domestic workers. This strengthens the informal economic structure and weakens the formal sector.	Observation
4	Growth of Slums	The rapid growth of slums around the city center is due to limited land and high housing costs. These slums often do not have adequate access to clean water, sanitation, and health facilities, making them a source of disease and other social problems.	Observation
5	Poverty and Homelessness	Poverty rates among migrants, especially those working in the informal sector, tend to be higher. Many of them live below the poverty line and are unable to meet basic needs. This condition can lead to the emergence of social problems such as homelessness, crime, and social conflicts.	Observation
6	Factors Supporting the High Unemployment Rate	Low levels of education, lack of technical and vocational skills, and discrimination against certain groups (e.g., women and people with disabilities) are barriers to obtaining formal employment. In addition, automation and technological changes also threaten the existence of some jobs.	Observation
7	Socialization of Lack of Infrastructure and Infrastructure	The limitations of infrastructure, such as roads, public transportation, and other public facilities, limit the mobility of the population and increase the cost of living. In addition, poor environmental quality due to pollution and poor waste management is also a serious problem.	Observation

Problem limitation

After identifying the problem, the researcher then narrows the scope of the study to remain focused. This limitation helps determine the research parameters, allowing the researcher to avoid overly broad coverage and ensure that the data collected is relevant to the research objectives. Here are the problem constraints:

- This research will limit its scope to informal workers in certain sectors, such as street vendors and casual laborers. Thus, the analysis will be more in-depth regarding the working conditions, income, and challenges faced by this group compared to other informal workers, such as online motorcycle taxi drivers and domestic workers.

- This research will limit the analysis of the impact of urbanization on the profession of informal workers within a specific time frame, namely the last five years (2019-2024). This limitation aims to understand the changes that occur due to rapid urbanization and government policies that may affect the informal sector during that period.

Informant profile

The selection of informants is carried out using the purposive sampling technique, which is a

Table 2: Determination of Informants (source: Own Data Research, 2024)

Criteria	Professional background	Reasons for selecting informants
Lead Informant (3 people)	- He is a street vendor who has been selling at the Genteng Market for more than ten years. He has extensive experience in dealing with various challenges in the market, including changes in the price of goods, competition with other traders, and adaptation to government policies.	- Relevance: All three are ideal examples of informal workers who are directly affected by urbanization. All three have worked hard in the market for many years and have deep experience of how urbanization changes affect their businesses. - Accessibility: All three are easily accessible and ready to participate in interviews. Her connections with the street vendor community allow her to provide an accurate picture of the working conditions and challenges faced by informal workers.
Additional Informants (3 people)	- He is a freelance daily laborer who works on building projects in the city of Surabaya. He has varied experiences in different types of jobs and often has to migrate to a new area to find a job.	- Diversity of Experience: The three informants have different experiences but are still relevant to the research topic. All three can provide perspectives on how migration and adaptation to informal work affect a person's life. - Family Perspective: As heads of families who are active in the local community, the three informants can also provide insight into how economic and social transformations affect their families and their communities as a whole.

deliberate selection based on certain considerations. The selected informant is considered to know the most about the problem to be researched. This helps researchers to dig up richer and more relevant information. (see Table 2).

Data collection

This research employs several qualitative methods to deeply understand the impact of urbanization on informal workers in Surabaya. First, in-depth interviews with informal workers like street vendors and daily laborers will explore their experiences, challenges, and hopes. Open-ended questions will allow respondents to share their stories and perspectives freely. Participatory observation will also be implemented, involving researchers in the daily activities of informal workers to observe social interactions, working conditions, and environments. Additionally, document analysis will collect secondary data from government reports, previous studies, and publications on urbanization and the informal sector in Surabaya. Focus group discussions with informal worker groups will further discuss their issues collectively. This method captures group dynamics and perspectives not evident in individual interviews. By combining these techniques, the research aims to provide a comprehensive understanding of the impact of urbanization on informal workers in Surabaya.

Data analysis

Qualitative data analysis involves three main stages. First, there is data reduction, where researchers filter relevant information according to the research objectives, eliminate unnecessary data, and categorize the data into more focused groups. Second, data presentation through descriptive narratives, tables, or diagrams to illustrate emerging patterns and themes. Techniques such as content or narrative analysis can be used to bring findings to life. Finally, drawing conclusions and verification involves analyzing results to draw relevant conclusions and ensuring accuracy through discussions with peers or confirmation from sources. Thus, qualitative data analysis not only produces findings but also provides deep insights into the social and economic context of the phenomenon being studied.

RESULTS AND DISCUSSION

Urban precariat in adapting amid economic and social changes

Rapid urbanization in the city of Surabaya has triggered significant economic and social transformations. Amid the increasingly complex urban dynamics, the figure of the informal worker emerges as an important actor. They are survivors who are working hard to adapt to the rapidly changing environment. However, behind the diverse

faces of the city, there is a vulnerable group of society, namely the urban precariat. This discussion focuses on understanding how informal workers, particularly street vendors and daily laborers in Surabaya, experience and adapt to urban precariat conditions. Through in-depth interviews regarding working conditions, income, and the challenges they face, the results are expected to reveal the survival strategies they have developed. In the context of the rapidly developing Surabaya, informal workers are often marginalized and face various obstacles. They live in uncertainty, with fluctuating incomes and limited access to resources. Therefore, this interview is relevant to understanding their life realities and contributing to formulating better policies to protect and improve the welfare of informal workers. As street vendors and daily laborers, the three informants described their working conditions with various challenges. The three informants have been trading for 11 years in various places and sometimes have to work up to 24 hours to meet their daily needs. Nevertheless, their economy remains unchanged and is still in a barely sufficient condition, with income only enough to meet basic needs. Meanwhile, three other informants have been trading for 15 years at Pasar Genteng, but their family's economic condition has also not seen significant changes. They are still facing economic difficulties and trying to adapt by limiting consumer spending, although their family's nutritional needs are still not being adequately met. Both groups continue to struggle to maintain their family's economic stability amidst competition and challenges in the face of inadequate facilities at their business locations [informants]. The six informants provided a diverse picture of the variations in their daily or monthly income. Two Informants have been trading for 11 years in various places, admitting that their earnings vary greatly, sometimes quite high on certain days, but often just enough to get by. Factors affecting income include trading location and the number of daily customers, with income fluctuating according to holiday seasons or special events. Four informants, each having traded for 15 years at Pasar Genteng, also face similar income variations. They mentioned that factors such as market conditions, competition with other traders, and local economic changes greatly affect their income. The presence of seasonal factors such as the month of Ramadan and other major holidays also affects their sales levels. When compared to their initial income when they started working in this sector, all informants felt that their income had not experienced significant improvement, and they still struggled to meet their family's basic daily needs [informants]. The three informants revealed various main challenges they face in this job. Informant 1 mentioned the intense competition with other traders as the biggest challenge, as well as the difficulty in obtaining a strategic location for trading. Informant 2 highlighted how government regulations, such as trading time restrictions and frequent enforcement actions, often disrupt their activities and reduce their income. Meanwhile, another informant revealed that limited access to resources such as business capital and raw materials greatly affects their ability to carry out their work. All informants agree that the lack of access to basic facilities and adequate resources is a significant barrier to achieving economic stability through their work in the informal sector [informants]. Based on the interview results, street vendors and day laborers in Surabaya adapt to economic and social changes by working longer hours in different locations. Those with 11 years of experience trade in various places and sometimes work up to 24 hours to meet daily needs, showing their flexibility. They also limit consumptive spending, focusing on essential expenses. Despite unchanged economic conditions, they try to curb non-essential expenditures to survive. Prioritizing necessities like food and shelter, despite inadequate nutrition, is crucial for their survival strategy amid economic challenges. With these strategies, informal workers strive to overcome the economic and social uncertainties and challenges they face while seeking ways to maintain the economic stability of their families (Lenzi and Perucca, 2023). This approach reflects their resilience and adaptability in facing a challenging work environment (Boschken, 2022; Leicht, 2022). This research reveals the gap between government policies aimed at informal workers and the realities faced by workers in the field. Despite several government initiatives to improve the welfare of informal workers, such as training and capital assistance, their implementation remains suboptimal. Bureaucratic complexity, lack of socialization, and limited access are major obstacles for informal workers in utilizing these programs. These findings indicate that existing policies are not fully effective in addressing the issues faced by informal workers

and require comprehensive improvements. The results of this study provide important input for the government and relevant stakeholders in formulating more targeted and effective policies to protect and enhance the welfare of informal workers. Moreover, this research also highlights the importance of directly involving informal workers in the planning and implementation of policies to ensure that the programs designed can meet their needs and aspirations, making the resulting policies more relevant and sustainable.

Urbanization and precariat: A case study of Surabaya (2019-2024)

The city of Surabaya, with its rapid economic growth and urbanization, reflects the urban dynamics of Indonesia. Behind the glittering skyscrapers and shopping malls, there lies a complex social reality, especially for marginalized groups such as informal workers. This interview focuses on the phenomenon of the urban precariat in Surabaya, particularly from 2019 to 2024. Precarity, a term that refers to a group of people living in unstable working conditions, low wages, and without social security, is becoming increasingly relevant in the context of rapid urbanization. Through a case study in Surabaya, this research aims to uncover how urbanization has shaped and influenced the lives of informal workers, as well as the challenges they face in adapting to such rapid social and economic changes. The three informants as street vendors and two informants as daily laborers provided a diverse picture of the impact of economic changes in Surabaya over the past five years. Street vendors have a significant impact on their work. Informant 1 noted that economic changes have caused fluctuations in demand for their goods, with certain periods experiencing significant declines. This is exacerbated by increasingly fierce competition and unstable market conditions. Informants 2 and 3 also feel the same way, with uncertain incomes due to demand changes influenced by macroeconomic factors. For daily laborers, the impact of economic changes is also quite heavy. Both informants noted that the demand for their services has decreased, especially during times of economic downturn. Informant 4 mentioned that construction projects, which usually provide jobs for them, are often delayed or canceled due to economic uncertainty. Informant 5 added that the cost of living is increasing, while their income does not match the rise. Both feel they have to work harder to meet their family's basic needs, even though the income they earn remains inadequate. [informants]. The three informants, street vendors, and daily laborers provided an in-depth perspective on the impact of urbanization on their daily lives. Informant 1, as a street vendor, feels great pressure from urbanization, where competition is getting tougher and the cost of living is rising. He admitted that his income was unstable, often decreasing because he had to face many new competitors. Informant 2 also felt a similar impact, especially in terms of job stability. The increasing number of newcomers opening similar businesses is reducing its loyal customers. Informant 3 added that although there has been an increase in access to city facilities such as electricity and clean water, their income is not sufficient to fully utilize these facilities. All these street vendor informants face significant challenges in maintaining their livelihoods amidst rapid changes. Meanwhile, three daily wage laborers also feel the impact of urbanization in their lives. Informant 4 mentioned that urbanization brings more construction projects, but the competition for jobs has become tighter, making the income uncertain. Informant 5 highlighted that the rising cost of living forces him to work harder to meet the family's basic needs. Informant 6 feels that access to city facilities, such as public transportation, is improving, but their income does not match the increase in daily living costs. Although there are several advantages to urbanization, such as better access to facilities, the main challenges faced by casual laborers are income uncertainty and job stability. All informants agree that urbanization brings significant changes that they must adapt to, albeit with many struggles [informants]. The informants, both street vendors and daily laborers, generally responded positively to the implementation of the ease of permit access (SIKM). They acknowledge that this policy helps regulate mobility and travel, especially for those who often work outside the city. However, several informants also complained that the process of obtaining the EoA is still considered complicated and time-consuming. Lengthy bureaucracy often becomes an obstacle for informal workers in meeting their job deadlines. The social security administrator for employment (BPJS) is an insurance policy recommended by the Indonesian Ombudsman and has received appreciation from

the informants. They realize the importance of social protection for informal workers. However, the registration process and the contribution assistance recipient (PBI) are still considered inefficient. Additionally, the informants also highlighted the lack of socialization regarding government policies related to improving access to health and social facilities for informal workers. This has caused many informal workers to be unaware of and not utilize these programs [Informants]. The street vendors developed strategies to cope with urban changes and business challenges, such as adjusting selling locations, extending working hours, and leveraging social networks for information and opportunities. Government and non-profit support through training programs also enhances their skills. Freelance daily workers adapt by taking additional jobs, diversifying work types, and actively seeking new projects. Social networks among laborers provide valuable job information. Support from family, friends, and organizations helps improve their competitiveness through skills training and access to tools. However, access to these programs remains limited, and their implementation needs improvement [Informants]. Urbanization in Surabaya has shaped and influenced the lives of informal workers in various ways. Street vendors and daily wage laborers must face fluctuating economic conditions, with uncertain demand and rising living costs. Street vendors face stiff competition from newcomers, as well as an unstable market condition, which often results in their income decreasing. Although access to city facilities such as electricity and clean water is increasing, their income is not enough to fully utilize these facilities. Freelance daily laborers, on the other hand, see more construction projects due to urbanization, but they have to compete fiercely to secure the available jobs. Income uncertainty and job stability have become the main challenges they face. All informants agree that urbanization brings significant changes that require continuous adaptation and struggle. Informal workers have developed various strategies to adapt to these social and economic changes. Flexibility in selling locations and extending working hours is key for street vendors. They also rely on a strong social network to share information about business opportunities. (Musinguzi, 2022). Support from the government and non-profit organizations through business training and economic empowerment programs also helps improve their skills. Freelance daily laborers show efforts to adapt by taking on additional jobs, diversifying the types of work, and actively seeking new projects. Social networks among fellow freelance daily laborers become a valuable source of information regarding job opportunities. Support from family, friends, and related organizations through skills training and access to work tools also helps them improve their competitiveness (Gurung, 2022; Orlyansky, 2021). The novelty of this research lies in highlighting the concrete adaptation strategies employed by informal workers in Surabaya in facing urbanization, as well as how community support and government policies can be optimized to address these challenges. This research provides new insights into how urbanization affects informal workers and the strategies they use to survive amidst the ever-changing urban dynamics.

Implications for practice

The study identifies economic opportunities as a primary motivator, highlighting the appeal of cities due to their diverse job options and increased earning potential. For practitioners, this underscores the need for targeted initiatives promoting economic growth and job creation in urban centers. Additionally, the study emphasizes improved accessibility to infrastructure and public services in influencing migration decisions. Therefore, urban development projects should prioritize enhancing these aspects to attract and accommodate migrating populations. Nevertheless, the study also underscores the social challenges accompanying such transitions. Practitioners should consider implementing support mechanisms and programs to facilitate the adaptation of rural communities to urban lifestyles and work environments. Addressing social pressures and promoting community integration will be crucial for fostering sustainable urban development (Raza *et al*., 2023; Hudnall *et al*., 2022; Chen *et al*., 2021; Gurbanalieva, 2021). The highlighted positive outcomes, such as increased income, improved healthcare, and better education, suggest that well-managed rural-to-urban migration can positively contribute to overall quality of life. Policymakers can utilize this information to design interventions that maximize these benefits while mitigating potential challenges. In summary, this study not only contributes to academic understanding but also

provides practical implications for urban development planning and policymaking in Indonesia.

CONCLUSION

Urbanization in Surabaya has brought significant changes to the lives of informal workers, particularly street vendors and daily laborers. This research found that urbanization creates new economic opportunities but also poses significant challenges for informal workers. Informal workers often face income uncertainty, intense competition, and limited access to city resources and facilities. They must develop various adaptation strategies to survive, such as extending working hours, relocating their trading spots, and utilizing social networks to share information and business opportunities. Support from the government and non-profit organizations through business training and economic empowerment programs is very helpful in improving the skills and capabilities of informal workers. However, access to those programs is still limited and needs to be improved. More inclusive policies and greater support from the government are urgently needed to address the challenges faced by informal workers due to urbanization. This research also highlights the importance of understanding the dynamics of urbanization and its impact on informal workers to formulate more effective policies. These findings provide new insights into how urbanization affects informal workers and the strategies they use to survive amidst the ever-changing urban dynamics. Thus, this research is expected to make a significant contribution to understanding the dynamics of urbanization and its impact on informal workers, as well as offering practical solutions to improve their quality of life. Community support and optimized government policies can help address these challenges and create a more inclusive and sustainable urban environment.

AUTHOR CONTRIBUTIONS

W. Wahyudi: Original Draft Writing, Conceptualization, Supervision, Project Administration. O. Sukmana: Data Collection, Data analysis, Writing, review, and editing. B. N. Avianto, Data Collection, Data analysis, Writing, review, and editing.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely witnessed by the authors.

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PUBLISHER NOTE

ABBREVIATIONS (NOMENCLATURE)

Abbreviations	Full Term
BPJS	**The social security administrator for employment:** social security programs for workers in Indonesia, including old-age insurance, work accidents, death, and pensions. The goal is to protect workers and their families, as well as provide financial support in difficult times.
BPS	**Central Statistics Agency:** The Indonesian government agency in charge of collecting, processing, and presenting statistical data for various needs, such as data on various aspects, such as population, economy, and society.
PBI	**Contribution Assistance Recipient:** Health insurance programs whose contributions are paid by the government are usually for the underprivileged.
SIKM	**Ease of permit access;** Documents required to enter and exit the city area for daily workers/ entrepreneurs/foreigners whose work location is outside the city area.

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CASE STUDY

Assessing sustainable urban development and its factors by using biomass energy

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ABSTRACT

BACKGROUND AND OBJECTIVES: The reliance on fossil fuels has led to significant environmental pollution, directly impacting public health and making breathing difficult for many. Also, the high density of environmentally damaging gases from fossil fuels in the earth's atmosphere has prevented heat from escaping from the earth's surroundings and intensified greenhouse effects. At the same time, it should be noted that oil and its derivatives are considered valuable national assets of the country, and their non-optimal consumption will cause irreparable losses. As a result, experts have suggested that clean energy must replace fossil fuels to reduce environmental pollutants.

METHODS: This study employs a comprehensive methodology involving library studies, including academic articles and government reports, and then a multi-criteria decision-making analysis based on an analytical network process, a Delphi questionnaire, and the participation of experts to identify the main criteria for sustainable urban development using biomass energy. These criteria include ecological limits, social sustainability and higher quality of life, justice and equality, social profit and loss, renewable energy sources, pollution reduction, and economic progress. The authors used the Analytic network process method and Super Decisions software to rank these criteria.

FINDINGS: Based on the Super Decisions program, social benefits and losses have equal weight and are 1.0, the highest ranking. Ecological constraints are ranked second, with a weight of 0.787998. Social sustainability weighs 0.787509, placing third. Justice and equality weigh 0.455988, ranking fourth. This indicates that the principles of sustainable urban development are important and successful, as assessed by this study.

CONCLUSION: This study emphasizes the importance of developing biomass energy in Iran, particularly in Mashhad, to reduce reliance on fossil fuels, enhance social sustainability, and improve environmental health. Despite Iran's potential in biogas production, the abundance of fossil fuels and lack of a unified authority have hindered progress. The research identifies key factors for sustainable urban development through biomass, such as social sustainability, ecological limits, and justice. Future research should include field studies, policy analyses, and economic assessments to create a more comprehensive framework for biomass energy development in Iran.

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INTRODUCTION

Renewable energy is crucial for sustainable development *(*Ordoo *et al., 2023).* The population of rich countries has grown considerably since 1950. According to statistical research and breakdowns, about half of the population lives in cities (Rezaei *et al.,* 2024). Population expansion in cities owing to unrestricted migration raises several concerns. To address this issue, the United Nations must meet its 2030 and 2050 targets for reducing Green House Gas (GHG) emissions and mitigating climate change (Issa Zadeh & Garay-Rondero, 2023). In addition, when cities were founded, rules, regulations, and laws were needed to govern residents' biological and psychological-social lives (Mashhadi *et al.,* 2023) (Jahanbakhsh Mashhadi et al., 2024). Cities are the hub of civilization, buzzing with economic and social activity. As science and technology have improved, city people's lifestyles and livelihoods have changed. Urban settlement growth and population have shown human progress (Melchiorri *et al.,* 2018). However, Cities in high-income nations, such as the United States and Europe, have undergone quick urbanization processes and attained high levels of density. Low- and middle-income nations' cities, which account for 90% of global urbanization, are set to begin, and these countries have already built major cities such as Beijing, Jakarta, Delhi, and Manila (Sun *et al.,* 2020) (Zhang *et al.,* 2022). As a result, global urbanization has brought scholars' and governments' attention to city sustainability. However, urban sustainability is unachievable without understanding sustainable urban development indicators' international and national relevance (Amoushahi *et al.,* 2022). On the other hand, Biomass energy is one of the most appropriate renewable sources, historically used and environmentally acceptable. Biomass has a distinctive role and is among the principal renewable energy sources (Tursi, 2019). Besides, biomass is the fourth most prominent energy source after fossil fuels, coal, oil, and natural gas. It is used for heat (wood heaters in households and heat and hot water in industry), cooking (mainly in underdeveloped countries), transportation (biofuels, ethanol, and biodiesel), and electricity generation. Biomass is a renewable organic resource from living organisms' activities (plants, algae, and animals). It has significant combustion flexibility and stability due to its high volatile matter concentration (80% versus 20% in fossil fuels) (Agbor *et al.,* 2011). Therefore, biomass may be burnt directly or transformed into solid, gas, or liquid fuels via biochemical and thermochemical processes. It has 10–40% greater energy density than fossil fuels. In contrast, it is a cheap and vital energy source (Nunes *et al.,* 2020). Research shows that more energy will be needed in the coming years due to the growth and consequent urbanization, as well as the economic reforms common in this century in many countries worldwide (Turkenburg *et al.,* 2012). Therefore, hydropower facilities, coal, or fossil fuels must provide this demand, which is difficult for many developing nations. Many nations have or will cultivate biomass resources (Al-Hamamre *et al.,* 2014). Consequently, urban community health is one of these components. Based on characteristics of urban community health, this research analyses biomass energy use and its impact on sustainable urban development. Mashhad, a city in northeast Iran, is a case study of this research. The subject pertains to the effects of biomass energy use on Mashhad's sustainable urban development. As a result, this manuscript's "primary objective" is to evaluate sustainable urban development factors and their determinants through using biomass energy. The "methodology" employed in this research involves a literature review and analytical approaches, utilizing multi-criteria decision-making techniques, precisely the Delphi method and the Analytical Network Process (ANP). The authors found that utilizing Multi-Criteria Decision-Making (MCDM) to study the effects of sustainable urban indicators can be considered a "research gap." On the other hand, this analysis, employing the Delphi approach and ANP, may be illustrated as the "novelty of the issue." The study's "target audience" comprises academics, stakeholders, relevant industry professionals, and policymakers involved in urban sustainable development challenges. The following section briefly explains the literature on the importance of biomass energy and its usage in urbanism. The aims and objectives of this study are sustainable urban development through biomass energy, focusing on reducing fossil fuel dependency, enhancing social sustainability, and improving environmental health. It identifies and ranks key criteria like ecological constraints, justice, and economic progress using the Delphi method and ANP to guide policymakers and stakeholders. The next section includes the methodology used in the research study and the

materials used. In this regard, the findings are first outlined and subsequently, an attempt is made to interpret the results. The final section clarifies the preliminary conclusions and limitations of the study, along with some recommendations for future research efforts.

MATERIALS AND METHODS

Literature review

Using biomass as an energy source emits CO_2, much as fossil fuels. However, the quantity of pure CO_2 created in the atmosphere eventually falls to zero since the CO_2 released during biomass burning matches the amount absorbed by plants during photosynthesis (Adetona & Layzell, 2023). Furthermore, using biomass as an energy source helps to minimize greenhouse gas emissions and global warming. Biomass is humanity's oldest source of energy. This energy-carrying product constantly stores solar energy and may be directly or indirectly turned into liquid fuels. All biofuels are derived chiefly from biomass (Abbasi & Abbasi, 2010). Moreover, Traditional fuel costs are continually growing and fluctuating, and their emissions contribute to environmental degradation. As a result, biomass, as a sustainable energy source, is required to fulfill society's diversified energy requirements and has the potential to replace fossil fuels (Tursi, 2019). In addition, the global biomass power market increased from 41.44 billion USD in 2022 to 45.17 billion USD in 2023, with a Compound Annual Growth Rate (CAGR) of 9.0%. It is estimated to reach 61.32 billion USD by 2027, growing at a CAGR of 7.9% (Agbor *et al.,* 2011). In 2022, Western Europe dominated the biomass energy industry, with Asia-Pacific coming in second. The biomass power market study focuses on Asia-Pacific, Western Europe, Eastern Europe, North America, South America, the Middle East, and Africa (Nunes *et al.,* 2020). The biomass power market is growing due to increased government assistance through subsidies and other regulations. New government regulations are being implemented to encourage sustainable power generation because of rising worries about climate change and the increase in GHG levels in the atmosphere caused by using traditional fossil fuels like coal and oil. For example, in India, the Ministry of New and Renewable Energy's National Biogas and Manure Management Program (NBMMP) offers subsidies for establishing home biogas plants, primarily for rural and semi-urban families. The initiative is carried out by state nodal authorities and organizations, including the Khadi and Village Industries Commission (KVIC) and Biogas Development and Training Centres (BDTC). It offers subsidies of up to 17,000 rupees ($230) for establishing biogas plants (Xin-gang *et al.,* 2023). However, the biomass power market is projected to be limited as alternative energy sources such as solar, wind, and geothermal become more competitive. Unlike wind power plants, biogas facilities are more vulnerable to cold weather since digesters require thermal energy to produce biogas continuously. The ideal temperature for bacteria to digest waste products is around 37°C. More thermal energy is required to continue output at temperatures lower than this threshold (Al-Addous *et al.,* 2017). Additionally, solar and wind power facilities rely on readily available raw resources. In contrast, biogas production is only practicable in rural locations where raw materials such as agricultural, manure, green, or food waste are readily available, which is acceptable. As a result, the popularity and simplicity of maintenance of other energy sources, such as solar, wind, and geothermal, restrict the expansion of the biomass electricity industry (Sayed *et al.,* 2021). Moreover, companies in the biomass electricity sector are exploring novel ways to create electricity, including biogas hybrid power plants. These facilities mix biogas with other renewable energy sources, such as solar power. Combining solar energy with biogas lowers the operating costs and labor necessary to manage agricultural waste. In 2020, Green Genius, a sustainable energy firm, opened a new biogas plant in Belarus, continuing this trend. In addition to providing green power, the new biogas facilities remove the stink from pig farms and convert organic waste into odorless liquid fertilizer. Green Genius develops sustainable energy projects (solar and biogas) in six European markets: Lithuania, Poland, Ukraine, Belarus, Spain, and Italy (Biomass Electricity Market Statistics, Growth Revenue, Outlook By 2033). On the other hand, A. Mersal's research shows that environmental planning is a practical requirement for creating a sustainable urban environment. With environmental planning, human needs are met, natural resources are used most effectively and sustainably, and environmental balance is achieved as far as practicable. This planning has countless

benefits, including protecting the environment, creating healthy ecosystems, removing environmental pollution, and creating green spaces (Mersal, 2016). Additionally, urban residents worldwide increasingly advocate for improved environmental conditions. They seek clean air, water, noise reduction, more vegetation, habitat protection, and stable soil conditions, contributing to improved health and quality of life (Alligood & Edelman, 2008). C. Tonne *et al.,* (2021) identify strategies to enhance health through sustainable urban development, such as integrated planning, evidence-based policymaking, and policy implementation monitoring (Tonne *et al.,* 2021). Moreover, effective governance and justice-based planning are critical for moving toward sustainable, healthy, and equitable urban development. Cities' physical expansion follows many geographical patterns, typically in urban sprawl, which are generated by multifaceted factors and have complex economic, social, and environmental consequences. The necessity to limit urban sprawl and its numerous negative implications by encouraging dense urban growth and urban densification reuse has received widespread attention in science and policy (Artmann *et al.,* 2019). According to the research by Al-Kayiem *et al.,* (2021), one of the most significant problems of sustainable urban development is guaranteeing a sustainable energy supply while avoiding negative environmental consequences. For example, the European Union Directive 2009/28/EC established a goal of obtaining 20% of total energy from renewable sources by 2020. This directive primarily addressed energy products, food waste recovery, and leftovers from agricultural and industrial processes (Al-Kayiem *et al.,* 2021). Due to the ongoing global population growth and the development of climate change circumstances, the research and implementation of sustainable biomass production technologies are becoming increasingly important to create a lucrative and sustainable bioeconomy (Usmani *et al.,* 2021). Likewise, green technologies, such as biofuels and bioproducts, are among the most effective options for lowering GHG emissions and addressing global warming while fulfilling human energy demands. Biomass now offers energy for many nations; however, accompanying technologies have yet to be broadly implemented due to low biomass production returns (Antar *et al.,* 2021). According to the study, Popp *et al.,* (2021) stated that biomass provides a clean and renewable energy source that can cause economic progress and reduce pollution (Popp *et al.,* 2021). However, in the case of sustainable urban development, according to the research by Gavaldà *et al.,* (2023), the characteristics of a sustainable city are attention to the significant environmental limitations, social sustainability and high quality of life, and comprehensive views, a new ethical framework, justice and equality (social justice), profit analysis, and social and environmental damage (Gavaldà *et al.,* 2023). Oryan and colleagues identified and ranked the main development priorities for solar energy, wind turbines, and biomass using the Analytical Hierarchy Process (AHP) method. The identification and ranking are presented in five axes: 1. Economic and financial, 2. Cultural and social, 3. Policy and regulations, 4. Technical, and 5. Structural (Ordoo *et al.,* 2022). Additionally, energy in the domestic market used to be heavily subsidized. The subsidies burdened Iran's economy, leading to wasteful energy consumption since low energy prices did not incentivize efficient energy use. (Ziyaei *et al.,* 2021) (Issa Zadeh and Rezaei, 2024). In summary, after reviewing the research background, the authors determined that the following directives for sustainable urban development exist in the literature: reducing emissions, ecological constraints, justice and equality, comprehensive views, foresight in decisions, financial development, social sustainability, and a higher quality of life, social profit and loss, a new ethical framework, and biomass as renewable energy sources. The methodology of the research study will be presented and discussed in detail in the following section.

Methods

This research method consists of two stages after extracting the research criteria. In the first stage, the extracted criteria are screened by experts according to the research topic, and then the requirements are ranked using the ANP technique. Each method is explained in detail in the following paragraphs.

Delphi questionnaire

The Delphi questionnaire is a typical instrument for getting expert opinions from experts and managers to identify the importance of and screen indicators. Designing a Delphi methodology questionnaire is

quite straightforward. To build a Delphi methodology, first define its goal. The Delphi approach has two goals: prediction and screening. Most management students utilize the Delphi approach to screen talks. In other words, this questionnaire aims to select the most significant indications from a list of indicators (Ren *et al.,* 2019).

ANP method

ANP and AHP are both MCDM methods. The ANP technique, unlike AHP, considers dependencies or links between criteria, sub-criteria, or alternatives. While AHP presupposes a tight hierarchical structure, ANP is intended to solve issues in which such elements interact to produce a network structure. In essence, AHP is a variant of ANP that is appropriate only when the criteria and sub-criteria are independent. ANP is a better solution for situations with interdependent criteria or sub-criteria since it supports networked interactions that AHP does not. The ANP technique provides a robust and complete framework for decision-makers to make accurate decisions based on factual facts or subjective assessments (Saaty, 2004). ANP streamlines complicated decision-making processes by structuring and arranging several factors and analyzing their relevance and preferences among alternatives. In this study, the ANP approach was developed using Super Decisions software. The flowchart of the study is in Fig. 1.

1. Making a research network diagram: This stage involves dividing the problem into criterion levels, sub-criteria, and choices, if any, and determining their linkages. The presence of links between standards is an essential consideration in this stage. These connections can be defined in several ways. You can choose the link between standards by consulting experts or using the Dimethyl or ISM approaches.

2. Forming *the matrix of paired comparisons*: At this point, the components of each level are compared pairwise to other related elements at a higher level, resulting in the formation of pairwise comparison matrices. Finally, a pairwise comparison of internal linkages will be made. The 9-point spectrum Mr. Saaty provides below should answer these pairwise comparisons in Table 1.

3. This numerical scale assists in making more precise judgments when comparing criteria and sub-criteria by allowing for a nuanced assessment of their relative importance. For instance, if you compare two criteria and find that one is significantly more critical

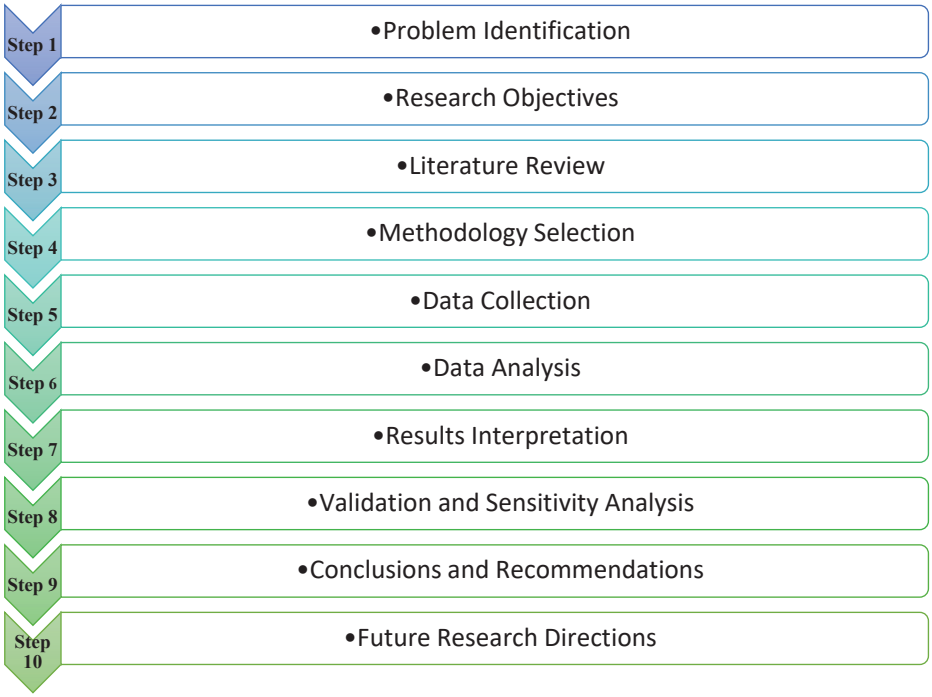

Fig. 1: The study flowchart

Table 1: Preference values for pairwise comparisons (Habibi et al., 2015).

Preferences	Numerical Value
Preferable, totally more critical, or desirable	9
Extreme preference, importance, or desirability	7
Strong preference, importance, or desirability	5
A little preferred, a little more critical, or a little more desirable	3
Equal preference, importance, or desirability	1
Preferences between the above intervals	2،4،6،8

Table 2: Triangular fuzzy numbers with a five-point Likert scale (Habibi et al., 2015).

Very important	Important	medium	unimportant	very unimportant
(0.75,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)

but not to the extent of being classified as "strongly preferred" (7), you might use the value 6. This flexibility enables you to make decisions that more accurately reflect the preferences and importance of the various elements within the decision-making process.

4. Calculating the incompatibility rate: In this step, the authors calculate the ANP inconsistency rate. If this rate is less than 0.1, it indicates the matrix's consistency.

5. Forming the initial super matrix: The authors form the initial supermatrix using the weights obtained from pairwise comparisons, which are the weights obtained in step 2 from pairwise comparisons.

6. Creation of a balanced super matrix: The balanced super matrix must be created after creating the initial supermatrix.

7. Creation of the limit supermatrix: The weighted supermatrix must be raised to infinite power so that each row converges to a number, and that number is the weight of the criterion, sub-criterion, or option (Saaty, 2004). The results obtained from the proposed method are presented below.

Methodology Fuzzy Delphi technique algorithm for screening

The fuzzy Delphi technique is valuable for determining the importance of criteria and identifying critical ones. Compared to the traditional Delphi technique, one of its key advantages is the ability to summarize and rank items remotely, making it highly efficient for screening purposes. The Delphi technique used in this study involved expert assessment and consensus building through iterative rounds. Experts assessed the importance of criteria related to sustainable urban development using biomass energy. This process follows the fuzzy Delphi method, which usually requires 2 to 3 rounds until a consensus is reached. This paper conducted three rounds back and forth to conclude.

The algorithm for the fuzzy Delphi technique involves the following steps:

1. Defining a suitable fuzzy spectrum to represent linguistic expressions.

2. Performing fuzzy summation of the fuzzified data.

3. De-fuzzifying the values to obtain crisp scores.

4. Selecting threshold intensity to screen and filter criteria.

To effectively use the fuzzy Delphi technique for screening, the first step is establishing an appropriate fuzzy spectrum to translate respondents' linguistic expressions into fuzzy values. For this purpose, it is possible to use the methods of developing fuzzy spectra or joint fuzzy spectra. For example, the triangular fuzzy spectrum for a five-point Likert scale on the importance of criteria is as follows in Table 2:

This standard method is used in this research. Expert opinions are collected after selecting or creating a suitable fuzzy spectrum. In the second step, experts' opinions should be analyzed. Several methods have been proposed for fuzzy aggregation of experts' opinions. If an expert's opinion is represented as a triangular fuzzy number (l, m, u), the simplest way to calculate the fuzzy average of experts' views is Eq.1 (Habibi *et al.,* 2015):

$$F_{ave} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n} \quad (1)$$

where:

Table 3: The results of the fuzzy Delphi questionnaire.

Criterion	Score	Rank
Biomass is a renewable energy source	3	1
Reducing emissions	3	1
Financial development	3	1
Ecological limitations	2/8	5
Social sustainability and a higher quality of life	3	5
Justice and equality	2/8	5
Social and environmental benefits and losses	2/6	7
Comprehensive views	0/133	10
A new ethical framework	0/133	10
Foresight in decisions	0/133	10

• $\sum l$ represents the sum of all L-components across the vectors

• $\sum m$ represents the sum of all m-components

• $\sum u$ represents the sum of all u-components

• n is the total number of vectors

• This gives the average $\mathbf{F_{ave}}$ as a vector, with each component averaged independently.

The values should be de-fuzzified after the fuzzy aggregation of experts' opinions. The researcher finally converts the final fuzzy values into a clear and understandable number using different methods, using the fuzzy approach. A clear value, the best means, can typically sum up triangular and trapezoidal fuzzy numbers. This operation is known as fuzzification. There are many complex methods for de-fuzzification. One of the simplest methods of de-fuzzification is average triangular fuzzy numbers. In the following formulas *(*Habibi *et al.,* 2015*)*, the defuzzification process is illustrated Eqs. 2-6:

$$F_{ave} = (L, M, U) \quad (2)$$

$$X_m^1 = \frac{L+M+U}{3} \quad (3)$$

$$X_m^2 = \frac{L+2M+U}{4} \quad (4)$$

$$X_m^3 = \frac{L+4M+U}{6} \quad (5)$$

$$\text{Crisp number} = X_m^1 = Z^* = \max\left(X_{max}^1, X_{max}^2, X_{max}^3\right) \quad (6)$$

Where:

• L, M, and U are the values to be averaged,

• X_m^1 is the resulting mean value, calculated as the arithmetic average of L, M, and U.

• X_m^2 is the resulting weighted mean.

• X_m^3 is the resulting weighted mean.

• Z^*represents the crisp number.

• This expression selects the highest value among $X_{max}^1, X_{max}^2, X_{max}^3$ as the "crisp number" Z^*.

The values do not change significantly and are always close to M. M, which is the average calculated by adding the potential values of m from several triangular fuzzy numbers. However, the precise value is deemed the highest. A threshold should be calculated after selecting the suitable procedure and filling the screening data. This threshold is generally 0.7. However, it changes depending on the researcher's judgment in each study. The requirement is satisfied when the precise value of the unfuzzification of the collected expert views exceeds the threshold. It is eliminated if the criterion exceeds the threshold *(*Habibi *et al.,* 2015*)*.

RESULTS AND DISCUSSION

The first step in this research was identifying and finally confirming variables using the fuzzy Delphi method, a quantitative research approach employed in descriptive studies and a tool for identifying variables (inputs and outputs). For this purpose, the most important variables were identified through a comprehensive theoretical review. These variables were then analyzed by a consensus of experts using the fuzzy Delphi method, with the results summarized below. In this technique, the expertise of the experts holds greater importance than their number. Typically, the number of experts involved is fewer than 50, ranging from approximately 5 to 20 participants. In this process, the identified variables are first presented to the experts for evaluation. The results of their evaluations are detailed in Table 3.

According to Table 3, Since the threshold value equals 0.159, the criteria of comprehensive and

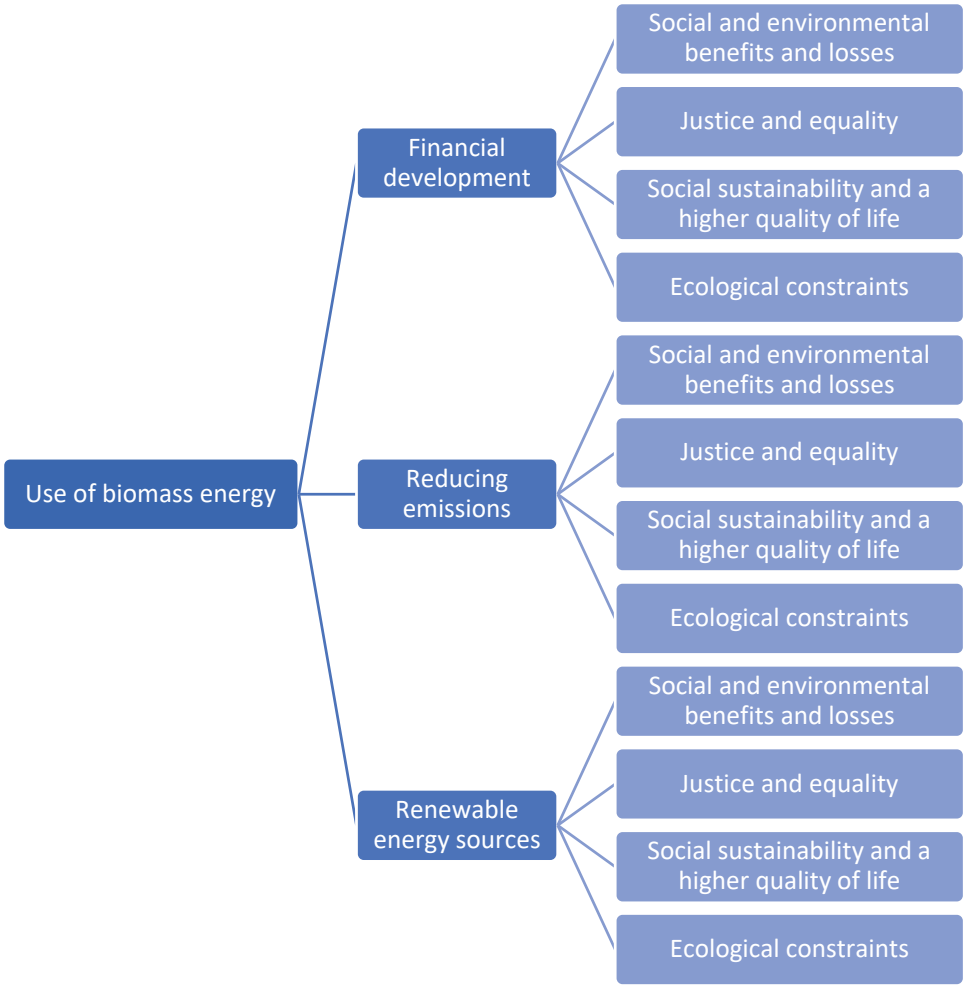

Fig. 2: ANP model after criteria screening.

holistic perspectives, a new ethical framework, and future perspectives in decisions are excluded from the research. Fig. 2, This figure is a concept map illustrating the various impacts and considerations associated with the "Use of biomass energy." It breaks down into three main branches:

1. Financial development: This branch explores the implications of biomass energy use on economic growth and is further connected to four specific areas:

- Social and environmental benefits and losses: This suggests that financial development through biomass energy could have mixed outcomes for society and the environment.

- Justice and equality: This indicator indicates the importance of fair access and distribution of resources as financial growth progresses with biomass energy.

- Social sustainability and a higher quality of life: This section highlights the potential of financial development to improve living standards and societal stability.

- Ecological constraints: Acknowledges that ecological factors may limit financial development related to biomass energy.

2. Reducing emissions: This branch focuses on how biomass energy can help lower greenhouse gas emissions. It is similarly connected to four key considerations:

- Social and environmental benefits and losses: Reducing emissions has societal well-being and

environmental health implications.

- Justice and equality: Reducing emissions with biomass energy could affect equitable access and social justice.

- Social sustainability and a higher quality of life: Emission reductions may contribute to overall quality of life and societal stability.

- Ecological constraints: Ecological factors limit how effectively emissions can be reduced with biomass.

3. Renewable energy sources: This branch represents biomass energy as part of a broader transition to renewable energy and is linked to the same four considerations:

- Social and environmental benefits and losses: Renewable energy sources, including biomass, can bring positive and negative impacts.

- Justice and equality: Emphasizes fair access to renewable resources and equitable benefits.

- Social sustainability and a higher quality of life: The shift to renewable energy sources aims to enhance societal welfare.

- Ecological constraints: Notes the natural limits to expanding renewable energy sources like biomass.

Each branch indicates that biomass energy, while promising emissions reduction and renewable energy development, must balance multiple socio-economic and environmental factors.

This section examines the ranking of the essential criteria in this research that passed the Delphi analysis filter. For this analysis, experts first completed paired comparison questionnaires, which were evaluated after being entered into the Super Decisions software. Initially, the paired matrices and their inconsistency rates were analyzed to identify and exclude outlier data, as their inclusion could increase errors in the analysis. Then, the analysis method follows a hierarchical structure, illustrated as a tree diagram. First, Table 4 discusses the experts' decisions about valuing the three main criteria from the perspective of the research's primary goal.

In Table 4, each number indicates the share of superiority or non-superiority of the criterion according to experts compared to other criteria. For example, the ratio of (1 and 3), which is equal to 3.25, shows that, according to the experts involved in the plan, the parameter of renewable energy sources is superior to the factors of financial development with a ratio of 3.25. In the same way, all criteria can be compared to each other to obtain a degree of superiority. The sub-criteria of the main variables of the renewable energy source factors have been discussed, and the geometric results of the experts' opinions are given in Table 5. In Table 5, each number indicates the share of superiority or non-superiority of the criteria compared to other criteria, according to experts. For example, the ratio (3 and 4), which is equal to 3.213, shows that, according to experts, the parameters of justice and equality affect the factors of social and environmental benefits, and losses are superior with a ratio of 3.213. The following discusses the sub-criteria of the main variables of pollution reduction factors, and Table 6 gives the geometric result of experts' opinions.

Table 4: A pairwise outcome matrix is used for the main criteria relative to the target.

	Financial development	Reducing emissions	Renewable energy sources
Renewable energy sources	3/25	5	1.00
Reducing emissions	0/318	1.00	
Financial development	1.00		

Table 5: Result pair matrix for renewable energy source sub-criteria.

		Ecological constraints	Social sustainability and a higher quality of life	Justice And equality	Social and environmental benefits and losses
Renewable energy sources	Ecological constraints	1.00	0.194	0.2	0.32
	Social sustainability and a higher quality of life		1.00	3.02	0.34
	Justice and equality			1.00	3.213
	Social and environmental benefits and losses				1.00

Table 6: Result pair matrix for emission reduction sub-criteria.

		Ecological constraints	Social sustainability and a higher quality of life	Justice And equality	Social and environmental benefits and losses
Reducing emissions	Ecological constraints	1.00	3.24	4.75	0.194
	Social sustainability and higher quality of life		1.00	2.32	0.34
	Justice and equality			1.00	0.33
	Social and environmental benefits and losses				1.00

Table 7: Coupled matrix of results for sub-criteria of economic progress.

		Ecological constraints	Social sustainability and a higher quality of life	Justice And equality	Social and environmental benefits and losses
Financial development	Ecological constraints	1.00	2.876	4.6	0.317
	Social sustainability and a higher quality of life		1.00	0.199	0.34
	Justice and equality			1.00	0.142
	Social and environmental benefits and losses				1.00

According to Table 6, the pollution reduction sub-criteria, ecological constraints are 4.75 times more important than justice and equality, 0.194 times more important than social and environmental benefits and losses, and 3.24 times more important than social sustainability. Also, for the variables of social sustainability and higher quality of life, 2.32 is more important than justice and equality, and 0.34 is more important than social and environmental benefits and losses. Likewise, the variable of justice and equality is 0.33 more important than social and environmental benefits and losses. In the following, the sub-criteria of the main variables of the factors of economic progress have been discussed, and the geometric result of the experts' opinions is given in Table 7.

According to Table 7 and the sub-criteria of economic progress, ecological constraints are 4.6 times more important than justice and equality, 0.317 times more important than social and environmental benefits and losses, and 2.876 times more critical than social sustainability. Moreover, for the variables of social sustainability and higher quality of life, 0.199 is more important than justice and equality, and 0.34 is more important than social and environmental benefits and losses. Finally, the variable of justice and equality is 0.142 more important than social and environmental benefits and losses. The following discusses the sub-criteria of the main variables of the renewable energy source factors, and the geometric result of the experts' opinions is given in Table 8.

According to Table 8 and the economic progress sub-criteria, ecological constraints are 0.2 times more important than justice and equality; ecological constraints are 0.194 times more important than social and environmental benefits and losses; and ecological constraints are 0.30 times more important than social sustainability. Furthermore, for the variables of social sustainability and higher quality of life, 3.02 is more important than justice and equality, and 0.34 is more important than social and environmental benefits and losses. The variable of justice and equality is 3.213 more important than social and environmental benefits and losses. Finally, according to Table 9, the weights of the main criteria have been investigated, and the ranking of these factors has been shown.

In Table 9, the highest rank is for justice and equality; the last is related to social sustainability and a higher quality of life. Ecological constraints and social and environmental benefits and losses rank second and third with a slight difference, respectively.

Table 8: Result pair matrix for renewable energy source sub-criteria.

		Ecological constraints	Social sustainability and a higher quality of life	Justice And equality	Social and environmental benefits and losses
Financial development	Ecological constraints	1.00	0.320	0.2	0.194
	Social sustainability and a higher quality of life		1.00	3.02	0.34
	Justice and equality			1.00	3.213
	Social and environmental benefits and losses				1.00

Table 9: Weights and rankings of Sustainable Urban Development criteria based on using Biomass.

Criteria	weights	Rank
Justice and equality	1	1
Ecological constraints	0.7879	2
Social and environmental benefits and losses	0.7875	3
Social sustainability and a higher quality of life	0.4559	4

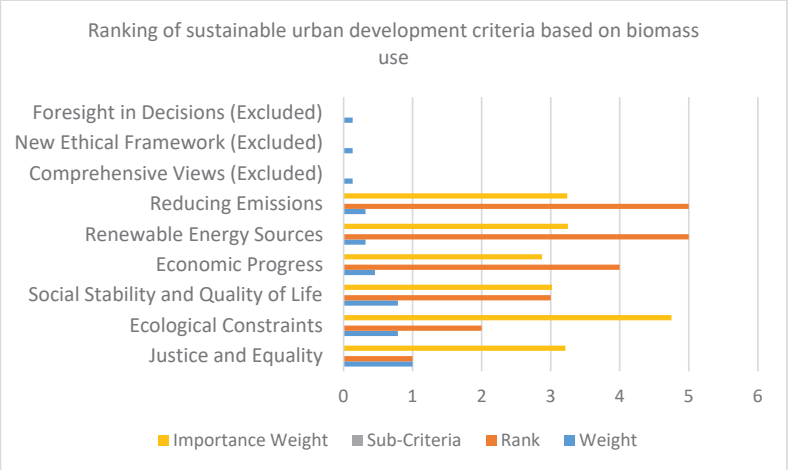

Fig. 4: Ranking of sustainable urban development criteria based on biomass use.

The studies were evaluated and weighed using Super Decision software. Based on these results, Table 9 and Fig. 3 show that social profit and loss ranked first, social sustainability ranked second, ecological limitations ranked third, and justice and equality ranked fourth concerning the use of biomass energy in alignment with urban sustainability development criteria.

According to Table 10 and Fig. 4, Justice and Equality emerged as the top criterion, emphasizing fairness and social balance. Ecological constraints and social stability are highly prioritized for environmental and social sustainability. While lower in rank, economic progress still holds importance for financial viability.

CONCLUSIONS

This study underscores the critical role of biomass energy in achieving sustainable urban development, particularly in Mashhad, Iran. The findings highlight the pressing necessity of transitioning from fossil fuel dependency to clean energy alternatives, leveraging Iran's rich natural resources, especially in biogas production. Key factors for sustainable development were identified, including ecological limits, enhanced

Table 10. Ranking of Sustainable Urban Development criteria based on Biomass use.

Criteria	Weight	Rank	Sub-Criteria	Importance Weight
Justice and Equality	1.0	1	Social Benefits and Losses	3.213
Ecological Constraints	0.7879	2	Environmental Protection	4.75
Social Stability and Quality of Life	0.7875	3	Social Development and Stability	3.02
Economic Progress	0.4559	4	Financial Development	2.876
Renewable Energy Sources	0.318	5	Energy Efficiency and Sustainability	3.25
Reducing Emissions	0.318	5	Greenhouse Gas Reduction	3.24
Comprehensive Views (Excluded)	0.133	-	-	-
New Ethical Framework (Excluded)	0.133	-	-	-
Foresight into Decisions (Excluded)	0.133	-	-	-

quality of life, justice and equality, and social and environmental benefits and losses. The study also identified three primary variables for integrating biomass energy: renewable energy sources, emission reduction, and economic progress. Notably, the equal weighting of social benefits and losses reflects societal values emphasizing fairness, justice, and inclusiveness in decision-making. These insights align with global trends advocating renewable energy adoption to address environmental and socio-economic challenges. However, the study also revealed significant barriers to biomass energy development in Iran, including the abundant availability of fossil fuels, the lack of a unified governing body, and minimal emphasis on clean energy within the existing policy framework. Comparatively, international benchmarks like the European Union's Directive 2009/28/EC illustrate the importance of legislated pathways for promoting renewable energy, a strategy Iran has yet to adopt effectively. This policy gap underscores the need for government intervention to establish a central authority that regulates and advances biomass energy initiatives. To address these challenges, several solutions are proposed. Establishing robust policy frameworks and implementing incentives aligned with global standards can attract investment and foster technical collaboration. Technological advancements should prioritize hybrid systems integrating biomass with solar or wind energy to enhance operational efficiency and overcome ecological constraints. Additionally, reallocating fossil fuel subsidies to support renewable energy projects and encouraging private-sector participation through public-private partnerships can bolster economic viability. Public awareness campaigns and community engagement initiatives are essential to garner grassroots support and understanding of biomass energy's benefits. Monitoring and evaluation mechanisms should be institutionalized to ensure the scalability and sustainability of biomass energy projects. The study also identified significant scientific gaps, primarily due to its reliance on literature reviews and theoretical analyses. Future research should focus on empirical validation through field studies, detailed cost-benefit assessments, and lifecycle analyses of biomass energy projects across different regions. Exploring the socio-economic impacts of biomass energy adoption, with particular attention to justice, equality, and community benefits, is essential. Comparative studies of biomass energy and other renewable sources under local conditions can refine strategies and enhance decision-making. In conclusion, accelerating clean energy development, mainly biomass, is not just a choice but a necessity for Iran. This transition can mitigate economic vulnerabilities linked to fossil fuel reliance while promoting environmental health and social equity. Government action is crucial in addressing institutional barriers, enacting supportive policies, and fostering a culture of sustainable development. By adopting these strategies, Iran can align with global sustainability goals and ensure a resilient and equitable energy future.

AUTHOR CONTRIBUTIONS

A.J.M. performed the literature review, analyzed and interpreted the data, and made the final edit. S.B.I.Z contributed to the literature review, manuscript preparation, and final editing. M.C.G.G. compiled the data and supervised the manuscript preparation.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work.

In addition, they have witnessed ethical issues, including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and submission, and redundancy.

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ABBREVIATIONS (NOMENCLATURE)

GHG	Greenhouse Gas
CAGR	Compound Annual Growth Rate
NBMMP	National Biogas and Manure Management Program
KVIC	Khadi And Village Industries Commission
BDTC	Biogas Development and Training Centers
CO_2	Carbon Dioxide
MADM	Multi-Attribute Decision Making
AHP	Analytical Hierarchy Process
F_{ave}	average as a vector with each component averaged independently
X_m^1	resulting mean value
X_m^2	resulting weighted mean
X_m^3	resulting weighted mean
Z^*	represents the crisp number
$\sum l \sum l$	represents the sum of all L-components across the vectors
$\sum m$	represents the sum of all m-components
$\sum u$	represents the sum of all u-components
L	value to be averaged
M	value to be averaged
U	value to be averaged

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CASE STUDY

A case study on the barriers to achieving a sustainable smart city

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ABSTRACT

BACKGROUND AND OBJECTIVES: Doha, Qatar, is committed to becoming a Sustainable Smart city as part of its Qatar National Vision 2030. This transformation is vital for bolstering regional economic resilience, advancing environmental sustainability, and promoting smart governance. Despite growing global interest in Sustainable Smart Cities, limited research specifically addresses Doha's unique challenges in this domain. Understanding these barriers is essential for informed policymaking and effective urban planning. This study seeks to identify and evaluate the primary obstacles impeding Doha's Sustainable Smart city development, with a focus on economic, technological, social, governance, environmental, and regulatory dimensions.

METHODS: A mixed-methods approach was used to analyze barriers to Sustainable Smart city development in Doha. The study began with a literature review to establish a theoretical foundation and identify global and regional challenges. This was enriched by qualitative input from Qatari stakeholders, including urban planners, policymakers, technology experts, and public-private sector representatives. Partial Least Squares Path Modelling was then employed to prioritize barriers by evaluating their impact on Sustainable Smart City progress. This approach combined theoretical insights with practical, context-specific expertise for a robust analysis.

FINDINGS: This research identifies key barriers to Doha's transition into a Sustainable Smart city: economic (25%), technological (20%), social (20%), governance (15%), regulatory (10%), and environmental (10%). Economic barriers, particularly high infrastructure costs, are the most significant, followed by technological readiness and social awareness. Governance issues, characterized by bureaucratic inefficiencies, complicate development, while regulatory barriers stem from outdated policies. Environmental challenges, including climate-related issues like water scarcity, further hinder progress. Compared to Abu Dhabi, Doha lags in regulatory frameworks (Doha 3, Abu Dhabi 4), public awareness (Doha 2.5, Abu Dhabi 3.5), and technological infrastructure (Doha 2.8, Abu Dhabi 4.2). Addressing these barriers through tailored strategies is essential for advancing Doha's Sustainable Smart City vision and enhancing public participation.

CONCLUSION: To address these challenges, the study recommends fostering public-private partnerships to secure funding, developing Sustainable, Smart city-specific regulations to improve governance, and launching awareness campaigns to enhance community participation. Targeted investments in advanced technological infrastructure and streamlined coordination among governing bodies are also crucial. By implementing these strategies, Doha can overcome its challenges and achieve its vision of becoming a sustainable, smart city aligned with its Qatar National Vision 2030.

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INTRODUCTION

Sustainable Smart Cities (SSCs) represent an integrated approach where advanced technologies and sustainable practices converge to improve urban living. These cities aim to enhance the quality of life, reduce environmental impact, and ensure social inclusivity through innovations such as the Internet of Things (IoT), big data analytics, renewable energy solutions, and efficient governance (Wei *et al*., 2021). Using real-time data to manage resources like water, energy, and transportation, SSCs offer solutions to common urban challenges, including population growth, pollution, and resource scarcity (Wuni *et al*., 2023). For example, cities like Amsterdam and Singapore showcase how technology can optimize energy use and waste management while promoting citizen engagement and environmental sustainability. At the heart of SSCs is citizen participation, which ensures that urban growth remains inclusive and transparent (Hammer *et al*., 2011). By using smart technologies, these cities improve efficiency in services like energy and water management, enhance safety, and reduce waste (Yousif *et al*., 2021; 2022). With a focus on equitable access to technology and governance, SSCs promote environmental sustainability and address climate change impacts. Qatar's National Vision 2030 aims to achieve a diversified and knowledge-based economy, with an emphasis on sustainable development (Al-Saidi and Zaidan, 2024). As the capital of Qatar, Doha plays a crucial role in this vision, aspiring to become a leader in sustainability, innovation, and resilience (Buniya *et al*., 2021). The city's transition towards an SSC is in line with global trends of integrating sustainability and technological innovation within urban environments (Albino *et al*., 2015). However, Doha faces unique challenges, including extreme desert climates, rapid urbanization, and a reliance on imported resources, which complicate the development of SSCs (Belčáková *et al*., 2019). In particular, resource scarcity, water management, and energy efficiency are critical issues that require innovative solutions in Doha's context (Berrone and Ricart, 2016). As Qatar moves beyond its reliance on oil and gas, integrating SSC concepts will help diversify the economy by promoting sustainable growth in sectors like technology, tourism, and finance (Griffiths and Sovacool, 2020). These factors make Doha an important case study for exploring the barriers and solutions to SSC development, particularly in resource-constrained regions. Despite substantial research on SSC development, limited attention has been given to cities in the Middle East, particularly Doha. While cities like Dubai and Abu Dhabi have made significant progress in implementing smart technologies, the socio-economic, cultural, and environmental contexts of Doha are different, requiring tailored approaches. The barriers to SSC development in Doha may not align with those identified in other cities, due to differences in governance structures, climate conditions, and technological infrastructure. This study aims to fill this gap by identifying and analyzing the specific barriers to SSC development in Doha (Yousif *et al*., 2021; 2022), offering insights that can guide the city's transition to a sustainable and smart urban model (Razmjoo *et al*., 2021). The objectives are to:

(i) Identify the unique barriers Doha faces in transitioning to an SSC, considering its socioeconomic, environmental, and technological conditions;

(ii) evaluate the applicability of smart city frameworks implemented in cities like Dubai and Abu Dhabi;

(iii) assess the environmental, economic, and governance challenges to SSC implementation in Doha, particularly focusing on resource scarcity, climate conditions, and technological infrastructure;

(iv) propose actionable recommendations to help local policymakers overcome these barriers and accelerate the development of a sustainable and smart Doha; and

(v) contribute to the academic discourse on SSCs in the Middle Eastern context, offering insights into the challenges of resource-scarce and arid environments.

The novelty of this study lies in its unique focus on Doha's specific challenges in the context of SSC development. While other research has examined the concept of SSCs in general terms or in the context of cities in the West and Asia, very few studies have focused on cities in the Middle East, particularly those facing extreme climatic conditions and rapid urbanization. By filling this gap, this study offers a unique perspective on how smart city models can be adapted to meet the environmental and socio-economic realities of arid and resource-scarce regions (Kumar *et al*., 2024). Furthermore, the findings of this research could help guide other cities in the Gulf Cooperation Council (GCC) region that face similar

challenges, making it a valuable contribution to both regional and global smart city studies. This research will provide evidence-based solutions to guide the integration of sustainability, technology, and innovation into Doha's urban planning strategies, supporting Qatar's National Vision 2030. This study was conducted during the academic year 2023-24 at Kalasalingam Academy of Research and Education, in India.

MATERIALS AND METHODS

Theoretical background

Key components of SSC development

Sustainable Smart Cities are defined by the integration of advanced technologies with sustainable practices to address modern urban challenges. Urban cities focus on improving urban living through the efficient use of resources while enhancing the quality of life for their residents. The following components are critical to the development of an SSC:

1. *Digital Infrastructure:* This refers to the use of technologies such as sensors, IoT devices, and data hubs to collect, analyze, and distribute data across various city functions. For example, Barcelona employs sensors to track waste levels, notifying collection services only when bins are full, and optimizing the waste management process (Griffiths and Sovacool, 2020). This allows for a more efficient use of resources and reduces unnecessary costs and emissions.

2. *Sustainable Energy:* A key objective of SSCs is to reduce their carbon footprint by incorporating renewable energy sources like solar, wind, and bioenergy. In SSCs, energy-efficient buildings may integrate solar panels, while smart grids are used to balance energy demand, reducing reliance on fossil fuels (Myers 2021). For instance, some smart cities deploy district heating and cooling systems that use renewable energy sources to maintain comfortable living environments without overwhelming the local grid (Neirotti *et al*., 2014).

3. *Smart Mobility:* Efficient and sustainable transportation systems are a hallmark of SSCs. These cities focus on developing public transit systems that optimize routes using real-time data, installing electric vehicle charging stations, and supporting bike-sharing networks (Buniya, *et al*., 2021). Copenhagen's bike-sharing system, for example, is integrated into the city's public transit app, allowing residents to switch seamlessly between transportation modes. This integration helps reduce traffic congestion and lowers the overall carbon emissions from transportation.

4. *Waste Management:* Advanced waste management systems are essential in SSCs, as they directly contribute to environmental sustainability. Many cities use smart waste bins that signal when they are full, enabling more efficient waste collection and reducing the carbon emissions from garbage trucks. These systems not only improve operational efficiency but also contribute to the city's overall sustainability efforts by optimizing resources and reducing waste sent to landfills (Elessawy, 2021).

5. *Citizen Engagement:* SSCs emphasize transparency and inclusiveness, encouraging residents to engage with city management through apps or portals that facilitate communication, decision-making, and access to services. Platforms that allow residents to voice concerns or report issues help create a sense of ownership and build trust in local governance. The involvement of citizens in decision-making is vital for ensuring that smart city projects are inclusive and address the needs of diverse urban populations (Kumar *et al*., 2020).

6. *Environmental Resilience:* SSCs also aim to be resilient to the impacts of climate change by incorporating green spaces, sustainable water management, and disaster preparedness strategies. For example, in Singapore, urban planning includes green roofs and vertical gardens, which help manage stormwater and reduce the urban heat island effect (Alsaeed *et al*., 2022). These measures contribute to improving the city's resilience to environmental stressors, making it better equipped to handle climate change impacts.

Each of these components is designed not only to improve urban living but also to adapt to future technological, societal, and environmental changes. SSCs integrate innovative solutions that address current challenges while providing a flexible framework for future developments in cities.

SSC development in the Middle East

The development of SSCs in the Middle East is gaining momentum as cities in the region seek to address urbanization and environmental challenges while fostering economic diversification. While the region is diverse in terms of culture and resources, many cities face common challenges, such as harsh

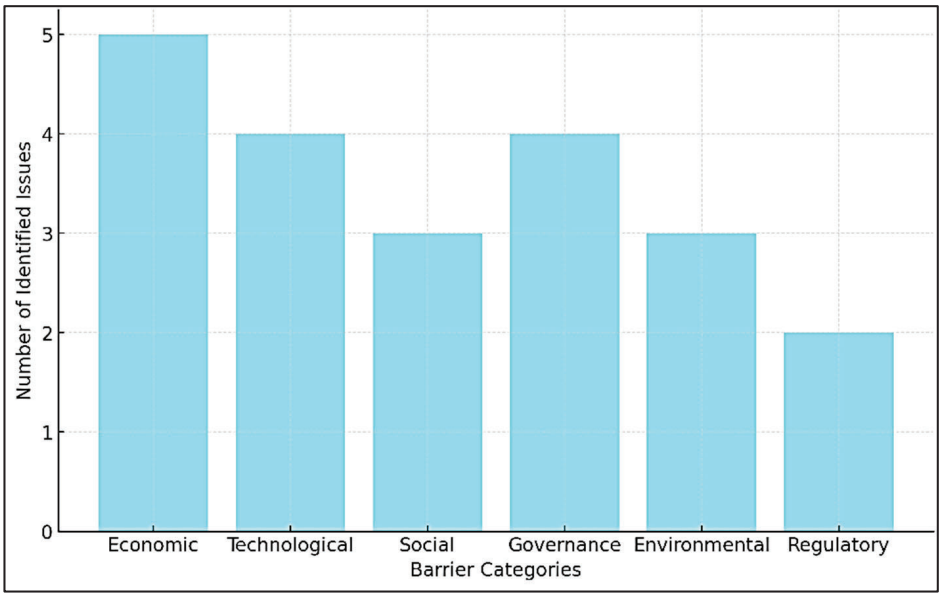

Fig. 1: Barrier categories to SSC development

climates, rapid urban growth, and resource scarcity. For instance, Masdar City in Abu Dhabi is one of the region's most prominent smart city initiatives, focusing on sustainability and renewable energy. The city aims to be zero-carbon, incorporating solar power and energy-efficient buildings (Razmjoo *et al*., 2021). Similarly, Dubai has integrated smart technology into various sectors, including government services, healthcare, and transportation. One notable initiative is the Dubai Paperless Strategy, which seeks to eliminate paper from government operations, contributing to sustainability and improving efficiency in governance (Angelidou, 2014). These cities exemplify the Middle East's commitment to SSC principles, though implementation varies based on available resources and strategic goals. Doha, Qatar, while also aiming to transition to a smart and sustainable city, faces a unique set of challenges. For example, regulatory frameworks to support SSC development are still evolving, and there is limited public awareness and understanding of the concept. As a result, Doha's ambitions to become an SSC are constrained by socio-economic and political factors, as well as the city's reliance on external expertise and technology.

Barriers to SSC development: A thematic exploration

While the Middle East has made significant strides toward developing SSCs, several barriers hinder the progress of smart city initiatives and are presented in Fig. 1. From Fig. 1, it may be noted that economic barriers were identified as the most significant issue, followed closely by technological and governance barriers. These three categories collectively represent the most substantial challenges faced in the context of the research. Social, environmental, and regulatory barriers were identified as less significant issues, suggesting that while they may still pose challenges, they are not as critical as the economic, technological, and governance factors.

n Doha, these barriers (Fig. 1) are particularly evident and can be categorized as follows:

1. *Economic barriers:* The development of SSCs often requires substantial upfront investment in technology, infrastructure, and ongoing maintenance. For Doha, these costs are compounded by the need to import technology and expertise. Local solutions for SSC challenges are often scarce, making projects more financially burdensome. Additionally, economic diversification efforts may divert resources away from SSC initiatives, further delaying implementation.
2. *Technological barriers:* SSCs depend on robust digital infrastructure, yet many Middle Eastern cities, including Doha, face challenges such as limited technological readiness and a lack of digital literacy

Fig. 2: Study area – Doha, Qatar

(Camero and Alba, 2019). The shortage of skilled personnel in emerging technologies can also impede the development of smart systems, making it difficult to deploy and manage these systems effectively.

3. *Social barriers:* Social acceptance of SSCs is vital for their successful implementation. In Doha, there is limited public awareness of SSC benefits, and residents may resist adopting new technologies or practices. Engaging the community in the transition to a smarter, more sustainable urban environment is key, but public education and outreach are still in the early stages (Al-Saidi and Zaidan, 2024).

4. *Governance barriers:* Effective governance is crucial for the success of SSCs, as these initiatives often require coordination across various governmental and private sector stakeholders. In Doha, regulatory complexities and interdepartmental coordination issues have slowed down SSC implementation. This lack of a unified governance framework creates hurdles for timely decision-making and action.

5. *Environmental barriers:* Doha's desert climate presents unique environmental challenges.

High temperatures and limited water resources make it necessary for SSCs in the region to integrate specialized solutions, such as advanced cooling technologies and efficient water management systems. The development of these solutions requires significant investment and research, which further complicates the city's transition to an SSC.

6. *Regulatory barriers:* Regulatory frameworks that support the development of SSCs are often underdeveloped or not fully adapted to the specific requirements of smart city projects. In Doha, the absence of clear regulations tailored to SSC initiatives complicates the approval and implementation process for these projects, resulting in delays and inefficiencies (Kumar *et al*., 2020).

The identification of these challenges is essential for guiding the region's future urban development and ensuring that SSCs contribute to long-term sustainability.

Study area

As of 2024, Doha, Qatar, located at approximately 25.276987° N latitude and 51.520008° E longitude, stands as a rapidly growing urban hub in the Middle East with an estimated population of 2.4 million, the majority of whom are expatriates (Fig. 2). The city experiences an arid desert climate characterized by extreme heat, with summer temperatures often exceeding 45°C, mild winters ranging from 14°C to 26°C, and minimal annual rainfall averaging around 75 mm. These conditions necessitate reliance on energy-intensive cooling and desalination systems, contributing to Qatar's status as one of the highest per capita carbon emitters globally. Doha faces significant challenges in achieving a sustainable smart city status due to its environmental constraints, including high energy and water demands, urbanization pressures driven by rapid population growth, and resource scarcity. Socio-economic factors such as income disparities, the diverse needs of a predominantly expatriate population, and inequality in access to resources further complicate sustainable urban planning. Governance hurdles, including the enforcement of sustainability regulations and the practical execution of Qatar's ambitious National Vision 2030, also impede progress. Additionally, fostering cultural and behavioural shifts toward sustainable practices remains a challenge. Despite these barriers, Doha's ongoing efforts and strategic initiatives position it as a pivotal case study for addressing sustainability in rapidly growing urban centres, particularly in extreme climates.

Methodology

The research methodology flowchart is presented in Fig. 3. From Fig. 3, it may be noted that the flowchart outlines a research methodology that begins with a literature review to understand the existing knowledge and identify research gaps (Kumar *et al*., 2024). This is followed by stakeholder interviews to gather insights from relevant individuals. Data is then collected through various methods, which are subsequently analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The analysis results in findings and conclusions that summarize the key insights and potential implications of the research.

Mixed-methods approach

This study employs a mixed-methods approach, integrating a literature review and qualitative data collection to provide a comprehensive understanding of the barriers to achieving an SSC in Doha. The literature review explored global and regional studies on SSC development, highlighting recurring challenges in economic, technological, and governance domains. Albreem *et al*., (2023) examined the adaptation of smart technologies in desert climates, revealing the critical need for robust ICT systems. Raghuvanshi and Sharma (2022) underscored the contextual nuances of smart city policies in emerging economies, stressing the importance of addressing region-specific barriers. Complementing these insights, qualitative input from urban planners, policymakers, and technology experts in Qatar provided practical perspectives on challenges such as governance coordination, funding limitations, and public engagement. Findings revealed interconnected barriers, including insufficient investment in infrastructure, fragmented policies, and weak enforcement mechanisms (Raghuvanshi and Sharma, 2022), alongside limited public awareness (Albreem *et al*., 2023). This mixed-methods approach combines theoretical and practical insights, offering a holistic understanding of the challenges facing Doha's SSC transition. The results highlight the need for targeted interventions, emphasizing collaboration among stakeholders, robust policy frameworks, and enhanced technological and social readiness.

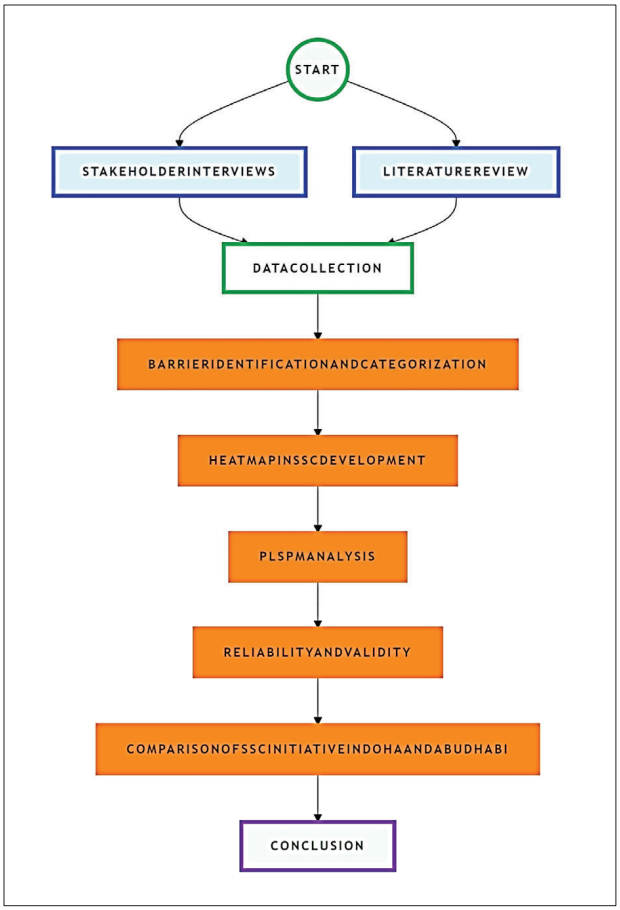

Fig. 3: The research methodology flow chart

Data collection techniques

Stakeholder's interview

Achieving an SSC in Doha is hindered by a range of interconnected barriers, including economic constraints, governance issues, and technological challenges. To gain a comprehensive understanding of these obstacles, data collection techniques combining a systematic review of existing research and stakeholder interviews were employed. The review identified common barriers in SSC projects, offering a foundation for examining Doha's unique context. Similarly, Albreem *et al.*, (2023) explored the impact of desert climates on smart technologies, revealing the critical importance of technological readiness and adaptability for SSC progress in Doha. Semi-structured interviews, a key data collection technique, were conducted with urban planners, government officials, and technology experts involved in Qatar's SSC initiatives. This method provided an in-depth exploration of specific barriers while allowing participants to share practical insights into governance coordination issues, funding limitations, and public awareness gaps (Rana *et al.,* 2019). The flexibility of this approach enabled stakeholders to elaborate on undocumented challenges and potential solutions. These data collection techniques combined with documented challenges with ground-level stakeholder perspectives, revealing recurring themes such as fragmented governance, weak policy enforcement, and insufficient social engagement. Addressing these barriers through targeted, informed strategies will be essential for Doha's advancement toward a sustainable and smart urban future. The provided Fig. 4 visually represents the stakeholder distribution in SSC development research for Doha, highlighting the diverse roles each

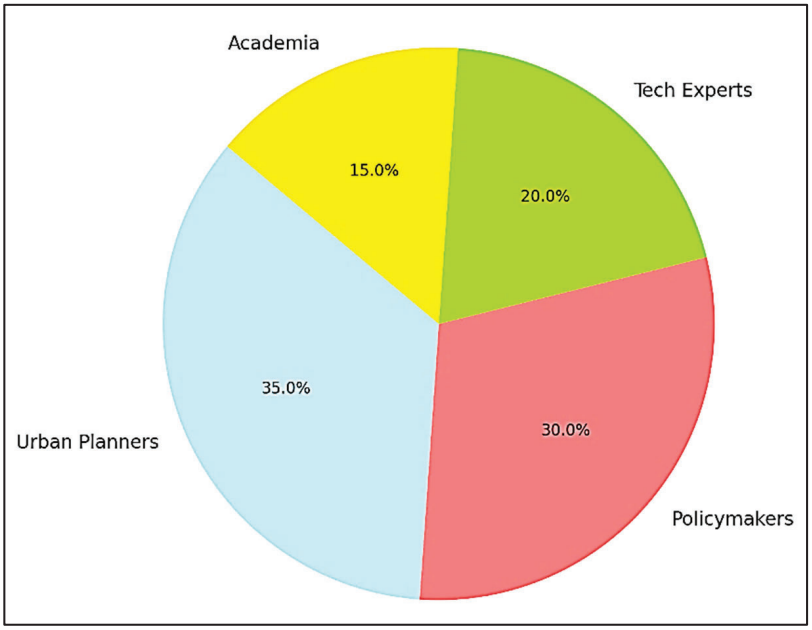

Fig. 4: Stakeholder distribution in SSS development

group plays in shaping the city's sustainable smart future. From Fig. 4, it may be observed that urban planners form the largest segment, constituting 35% of stakeholders, underscoring their critical role in designing sustainable, livable spaces for residents and businesses. Policymakers, making up 30%, are pivotal in creating enabling environments through policy frameworks, incentives, and streamlined regulations that drive SSC development. Tech experts account for 20% of stakeholders, contributing essential technical expertise to address the technological challenges and opportunities of SSCs. Their insights into emerging technologies, data analytics, and digital infrastructure are crucial for advancing SSC initiatives. Academia, representing 15% of the total, generates knowledge, conducts research, and educates future professionals in the field. Academics provide innovative solutions, best practices, and long-term policy recommendations to support SSC progress. The stakeholder distribution for SSC development in Doha, including subcategories, can be represented numerically as follows: Urban Planners account for 35 individuals, with subcategories divided into City Development Experts (15 individuals), Environmental Planners (10 individuals), and Transportation Specialists (10 individuals). Policymakers comprise 30 individuals, including Government Officials (15), Regulatory Agencies (10), and Strategic Advisors (5). Tech Experts total 20 individuals, distributed among Digital Infrastructure Experts (10), Data Analysts (5), and Emerging Tech Innovators (5). Academia includes 15 individuals, split between Researchers (10) and Educators (5). This allocation underscores the significant contributions of Urban Planners (35%), Policymakers (30%), Tech Experts (20%), and Academia (15%) to SSC initiatives.

Data acquisition involved a systematic review of relevant research to identify barriers and strategies in SSC development. Studies such as Albreem *et al.,* (2023) explored challenges in Gulf Cooperation Council (GCC) countries, particularly emphasizing technological readiness and adaptability critical to sustainable IoT solutions. Similarly, Rana *et al.,* (2019) examined barriers to smart city development in the Indian context, highlighting governance coordination issues, funding limitations, and public awareness gaps, which are also relevant to Doha's context. Additional insights were drawn from Randeree and Ahmed (2019), who emphasized the social dimensions of urban development in Masdar City, informing the role of community engagement and social inclusivity. Manikas *et al.,* (2022) provided a framework for food

security through resilient supply chains, illustrating sustainability considerations applicable to urban planning. Myers (2021) discussed urbanization challenges in the global south, offering a comparative perspective on Doha's urban development issues. The method for data acquisition involved identifying and reviewing relevant literature based on its focus on SSC development challenges and solutions. This was achieved by systematically selecting studies that aligned with the research objectives, ensuring that each study provided valuable insights into the barriers and strategies that impact SSC development. The literature was assessed for its relevance to Doha's context, drawing from research on technological readiness, governance frameworks, social inclusion, and sustainability practices in other regions. These studies were selected for their relevance to SSC challenges and solutions in comparable contexts. The systematic review provided a theoretical foundation, complemented by ground-level stakeholder interviews, ensuring a robust understanding of both documented challenges and practical insights. This combined approach was instrumental in addressing the research objectives. This approach not only established a theoretical foundation but also informed practical insights for addressing the challenges faced in Doha's SSC initiatives. Understanding the distribution and influence of these groups enables tailored research efforts to address their specific needs and priorities. Collaboration with urban planners helps identify practical challenges and opportunities while engaging policymakers to ensure research findings translate into effective policies. Partnering with tech experts fosters innovation and technology adoption, and involving academics builds a strong theoretical foundation for long-term success. A collaborative and inclusive approach among all stakeholders is essential to achieving SSC development in Doha.

Heatmap in SSC development

The heatmap of barriers to SSC development in Doha reveals differing priorities among stakeholders. The government and private sector view economic barriers as critical, focusing on financing and investment risks (Wei *et al*., 2021). Academia emphasizes technological challenges, while the community prioritizes social barriers related to public acceptance and engagement. Governance issues are a top concern for the government, highlighting bureaucratic inefficiencies, and the private sector stresses the need for regulatory stability. NGOs prioritize environmental barriers, focusing on sustainability and climate change. Regulatory challenges are mainly highlighted by the private sector, with calls for simplified processes and better coordination.

Analytical framework

Partial Least Squares Path Modeling (PLS-PM)

PLS-PM is a robust statistical technique used to analyze complex relationships between multiple interrelated variables, making it particularly suitable for SSC research. In SSC development, multiple factors, such as economic, technological, social, and governance-related barriers, are often interconnected, and PLS-PM is designed to handle these multidimensional relationships efficiently. It is a Structural Equation Modeling (SEM) method that simultaneously estimates relationships between multiple independent and dependent variables, allowing researchers to understand not only the direct impacts of each barrier but also the indirect impacts across various dimensions (Santamouris *et al*., 2018). PLS-PM can be applied in a case study on the barriers to achieving a sustainable smart city by systematically defining, estimating, and validating the relationships between key factors such as governance, technology, and sustainability. The various steps involved in PLS-PM are

1. *Model Specification:* Define the structural and measurement models based on the theoretical framework, identifying key barriers like governance, technology, and sustainability.
2. *Data Collection and Variable Definition:* Gather data from literature and primary sources, defining relevant variables (e.g., governance, technological barriers) from studies such as Elessawy (2021) and Alsaeed *et al.,* (2022).
3. *Model Estimation:* Apply PLS-PM to estimate relationships between the barriers, calculating path coefficients to assess both direct and indirect effects (Santamouris *et al.,* (2018)).
4. *Bootstrapping and Significance Testing:* Use bootstrapping to evaluate the statistical significance of path coefficients, ensuring the reliability of identified relationships in the model.
5. *Model Evaluation and Fit Assessment:* Evaluate the model□s fit using R^2 values to measure

how well the variables explain the variance in the SSC development outcomes.

6. *Result Interpretation:* Interpret the results to identify the most critical barriers to SSC development, comparing findings with similar studies like Kumar *et al.,* (2020) and Griffiths and Sovacool (2020).

7. *Model Validation:* Validate the model by cross-checking the findings with real-world data and other case studies to ensure the robustness and applicability of the results.

PLS-PM can be effectively applied in a case study on the barriers to achieving a sustainable smart city by following these steps: First, the structural and measurement models would be defined, identifying key barriers such as governance, technology, and sustainability. Next, data would be collected from literature and primary sources to define relevant variables, such as governance issues and technological limitations. The model would then estimate the relationships between these barriers, with PLS-PM calculating both direct and indirect effects. Bootstrapping would be used to assess the statistical significance of the path coefficients, ensuring the reliability of the model's results. The model's fit would be evaluated using R^2 values, which would measure how well the identified barriers explain the outcomes of SSC development. The results would be interpreted to pinpoint the most critical barriers. Finally, the model would be validated by cross-checking the findings with other real-world data to ensure robustness, providing valuable insights into the barriers and strategies for achieving a sustainable smart city.

Reliability and validity

In a case study on barriers to achieving an SSC, reliability and validity are essential for assessing key areas like Public-Private Partnerships (PPPs), SSC-specific regulatory frameworks, community awareness programs, investment in green technologies, and enhanced governance. Reliability ensures consistent measurement across different projects, such as the effectiveness of PPPs in addressing funding gaps or the impact of green technologies on environmental goals. Validity ensures that these initiatives truly contribute to overcoming barriers, like simplifying regulatory processes (Ahmad *et al*., 2024), increasing public engagement, or fostering efficient governance. Together, they ensure that the findings are both accurate and actionable, guiding effective strategies for SSC development.

RESULTS AND DISCUSSION

To ensure the reliability and validity of the findings, the study employed robust statistical techniques, including Cronbach's alpha and cross-validation. Cronbach's alpha assessed the internal consistency of responses, confirming that the data accurately reflected the constructs being studied. Cross-validation further strengthened the analysis by evaluating the model's predictive accuracy and ensuring its applicability beyond the specific dataset used (Razmjoo *et al*., 2021). Together, these methods validated the robustness of the model's rankings and provided confidence in the reliability of the results. This methodological rigor ensured that the findings could serve as a solid foundation for formulating effective policy recommendations to address barriers to Sustainable Smart City development.

Barrier identification and categorization

The development of SSCs faces barriers in economic, technological, social, governance, environmental, and regulatory areas. Addressing these challenges through targeted solutions such as public-private partnerships, technological investments, and improved governance can pave the way for successful SSC implementation. Fig. 5 highlights the distribution of SSC barriers in Doha, divided into six categories: Economic (25%), Technological (20%), Social (20%), Governance (15%), Regulatory (10%), and Environmental (10%). Economic barriers are the most significant, indicating critical financing and investment challenges. Technological and social barriers follow, emphasizing the importance of digital infrastructure and addressing cultural and workforce issues. Governance and regulatory hurdles reflect bureaucratic inefficiencies and unclear policies, while environmental barriers are relatively smaller but still impactful. To overcome these challenges, Doha should focus on economic policies, technological advancements, skill development, regulatory reform, and public awareness to enhance its SSC prospects and foster sustainable growth (Rajasekar *et al*., 2018). The findings from this study on the barriers to achieving an SSC in Doha closely align with existing research while also highlighting novel insights that are critical for advancing SSC development in the region.

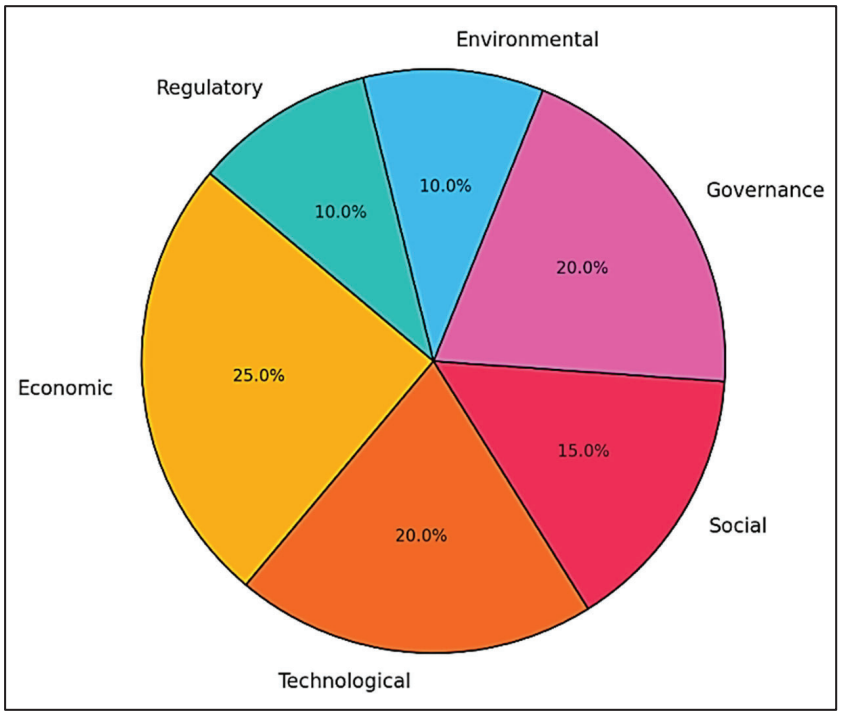

Fig. 5: The distribution of SSC barriers in Doha

Economic barriers

Economic barriers are identified as a major challenge in Doha, particularly due to the high costs associated with developing SSC infrastructure (Fig. 6). This includes significant investments in foundational systems such as ICT infrastructure and renewable energy sources, which are crucial for SSCs but are costly to implement in a city like Doha. Previous research has pointed to similar challenges in the Middle East, where cities often rely on imported technology and skilled professionals, further escalating costs (Neirotti *et al*., 2014). This study adds value by illustrating the interplay of these factors in the specific context of Doha, highlighting how budget limitations lead to underfunded SSC projects that constrain their scope and effectiveness. The novelty of this study lies in its focus on how financing and investment gaps specifically affect the scalability of SSC initiatives in a resource-rich city that is still developing its SSC framework.

Technological barriers

Technological barriers are also a significant concern, particularly in terms of data security and the lack of sufficient technological infrastructure to support SSC projects (Fig. 7). The study emphasizes that the reliance on extensive data collection from residents, a hallmark of SSCs, raises cybersecurity risks. Similar concerns have been raised in previous research, where inadequate technological literacy and the absence of a robust technological framework were identified as challenges for SSC adoption (Manikas *et al*., 2022). The findings here extend this understanding by discussing the real-world implications of these technological barriers in Doha, where existing infrastructure is not yet capable of supporting the demands of a fully operational SSC. This study's novel approach includes the identification of specific gaps in technological literacy among residents and administrators, which hinders both adoption and effective implementation.

Governance barriers

Governance barriers were perceived as a major obstacle to SSC development, particularly in terms of overlapping authority and bureaucratic inefficiencies (Fig. 8). Previous research has highlighted the importance of governance frameworks in facilitating

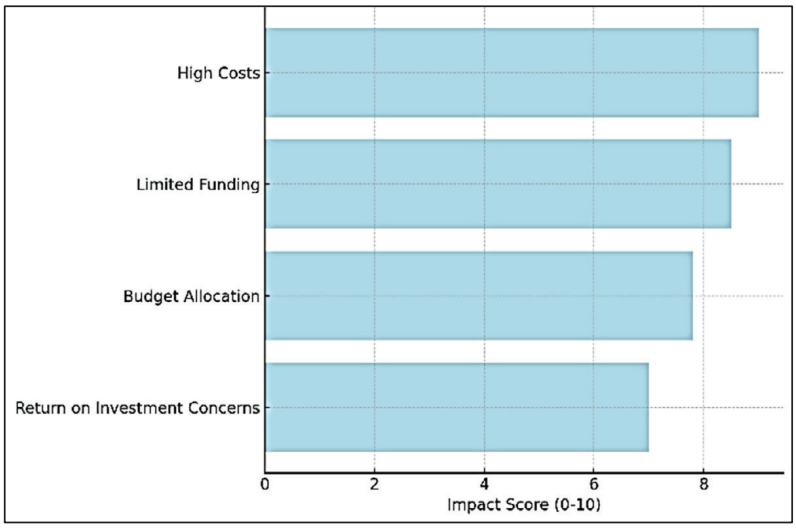

Fig. 6: Economic barrier sub-categories impact score on SSC development

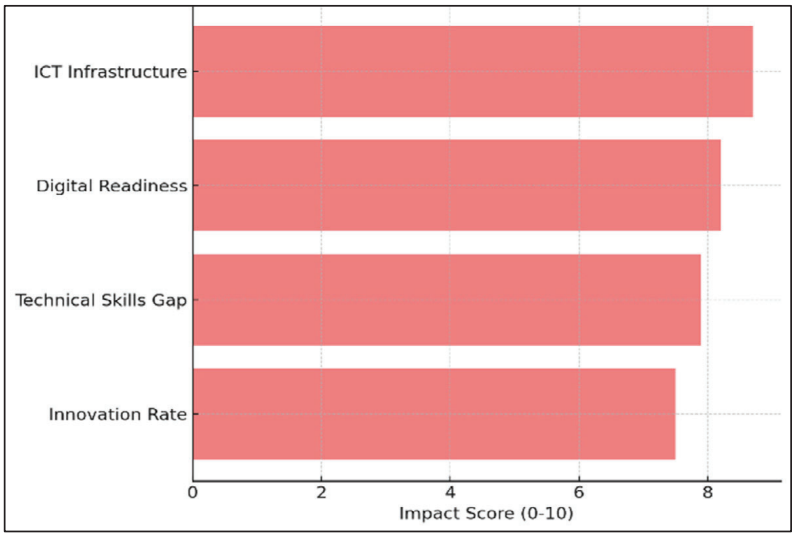

Fig. 7: Technological barrier sub-categories impact score on SSC development

smart city projects, especially in emerging economies (Chu *et al*., 2018). The study adds depth to this by exploring how regulatory complexity and a lack of clear accountability mechanisms impede the progress of SSC initiatives in Doha. The novelty of this study lies in its exploration of the governance challenges from the perspective of multiple stakeholders, including government bodies and private sector actors, highlighting the systemic inefficiencies that often delay projects.

Social awareness barrier

The social awareness barrier emerged as another significant barrier. In Doha, limited public awareness and engagement are critical obstacles that hinder the adoption of SSC initiatives (Fig. 9). This study corroborates findings from existing literature, where social acceptance and public participation are pivotal for the success of SSC projects (Albreem *et al*., 2023). However, it introduces the additional complexity of cultural factors, particularly concerns about privacy

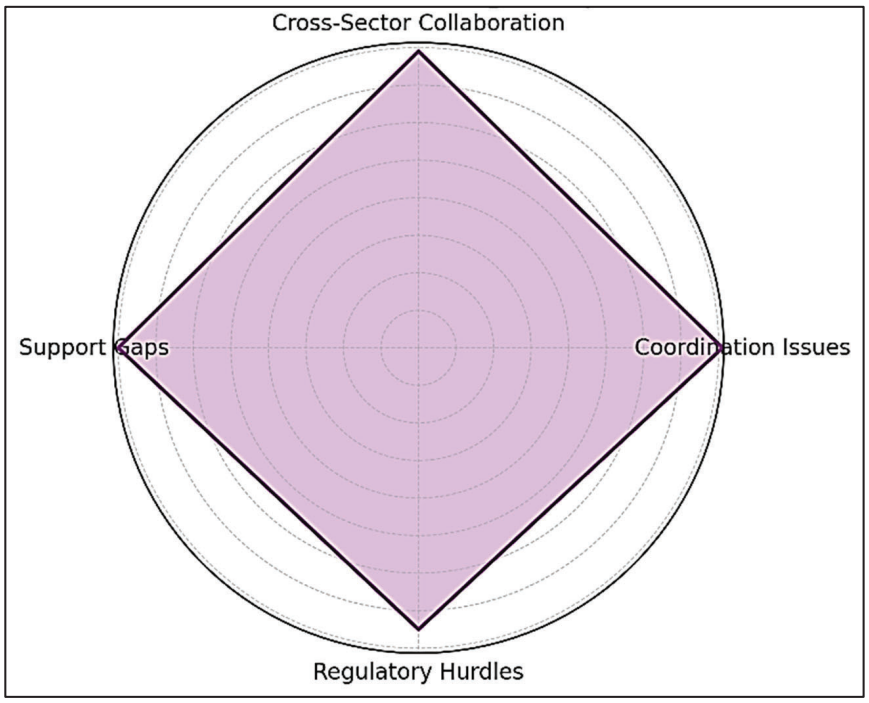

Fig. 8: Governance barrier sub-categories impact score on SSC development

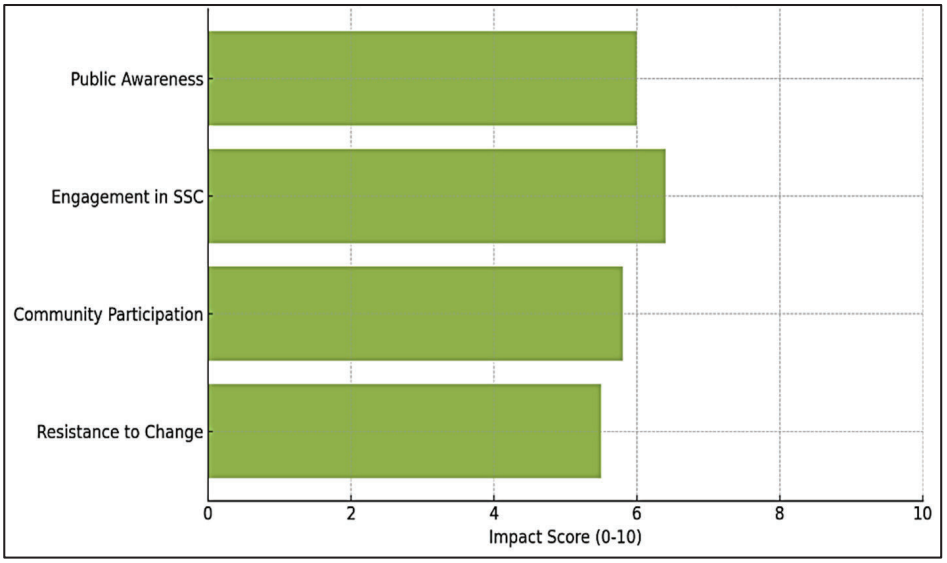

Fig. 9: Social awareness barrier sub-categories impact score on SSC development

and data-sharing practices, which are integral to SSC functionality. This study's novelty lies in identifying the specific cultural challenges in Doha, where public trust in technology and data-sharing practices may conflict with societal expectations around privacy.

Environmental barriers

Environmental barriers in Doha's harsh climate, particularly related to energy consumption for cooling and water scarcity, are well-documented challenges. This study adds to the existing body of knowledge by

Fig. 10: Heatmap in SSC development

highlighting the unique environmental obstacles faced by SSC projects in desert climates, such as the high costs of maintaining green spaces and infrastructure in an arid environment (Yousif *et al*., 2022). The study's novel contribution is in its exploration of tailored solutions, such as solar-powered cooling systems and water-saving technologies that could mitigate some of the environmental challenges specific to Doha's context.

Regulatory barriers

Regulatory barriers are a critical issue in Doha, with the study pointing out the lack of SSC-specific policies and the restrictive nature of current data protection laws. Previous studies have discussed regulatory challenges in emerging economies, but this research extends those findings by emphasizing how the absence of clear policies on SSC technologies, such as smart grids and autonomous vehicles, contributes to delays and inefficiencies (Santamouris *et al*., 2018). The study's innovative approach lies in its detailed exploration of how regulatory gaps impede innovation, providing valuable insights for policymakers in Doha and other cities facing similar challenges. The six barriers identified in this study align with those found in previous research, its contribution lies in the specific context of Doha and its comprehensive exploration of how economic, technological, governance, social, environmental, and regulatory barriers interact to hinder the development of SSCs. By including diverse stakeholder perspectives, this study offers a more nuanced understanding of these barriers and provides actionable insights for overcoming them.

Heatmap in SSC development

The heatmap provides a visual representation of how different stakeholders perceive the severity of various barriers to SSC development. The heatmap provides a visual representation of how different stakeholders perceive the severity of various barriers to SSC development in Doha (Fig. 10). The stakeholder perceptions of various barriers to SSC development in Doha reveal distinct priorities across different groups are

1. Economic barriers are viewed as the most severe by the government (4.5), indicating significant concerns about financing, investment, and the return on investment in SSC projects. The private sector also ranks economic barriers highly (4.0), citing profitability, risk, and market uncertainties as key

Table 2: Barriers and Solutions in SSC Development Using PLS-PM Analysis

Barrier Category	Proposed Solution	Expected Impact
Economic	Public-Private Partnerships	Reduced financial burden on government, increased innovation and expertise from private sector partners
Technological	Investment in ICT and Green Technologies	Improved digital infrastructure, enhanced cybersecurity, greater capability to manage environmental constraints
Social	Community Awareness and Engagement Programs	Increased public support and engagement. reduced resistance to SSC projects
Governance	Establishment of SSC Coordination Body	Better inter-departmental collaboration, and streamlined decision-making increased project management efficiency
Environmental	Use of Climate-Specific Technologies	Reduction in cooling costs, sustainable water use, better adaptation to harsh environmental conditions
Regulatory	Development of SSC-Specific Legal Framework	Streamlined approvals, reduced legal challenges, increased ability to implement and manage SSC initiatives seamlessly

challenges. While economic barriers are important for all stakeholders, the community, academia, and NGOs tend to prioritize other barriers more, reflecting varying concerns based on their roles.

2. Technological barriers are considered most severe by academia (4.5), likely due to the need for continuous innovation and adaptation to rapidly evolving technologies (Ma *et al*., 2021). The government also views technological barriers as significant (4.0), particularly in terms of the need for supportive policies and infrastructure to facilitate the adoption of new technologies. The private sector and NGOs, while acknowledging technological barriers, place greater emphasis on other challenges such as governance or regulatory issues.

3. Social barriers are seen as the most severe by the community (4.0), emphasizing challenges in public acceptance, social equity, and community engagement. The government also acknowledges these issues (3.5), focusing on the importance of communication, public awareness, and social impact assessments (Manikas *et al*., 2022). However, private sector stakeholders and academia tend to prioritize other barriers more, reflecting a broader focus on economic and technological concerns.

4. Governance barriers are considered the most critical by the government (4.0), emphasizing challenges like bureaucratic inefficiencies, regulatory obstacles, and policy inconsistencies. The private sector also sees governance as a key challenge (3.5), emphasizing the need for a clear and stable regulatory environment (Mandeli 2019). The community and NGOs, while recognizing governance issues, seem to focus more on other types of barriers, particularly social and environmental concerns.

5. Environmental barriers are seen as most severe by NGOs (4.0), who are concerned with sustainability, climate change, and environmental impact assessments. The government shares this view (3.5), with a focus on the importance of robust environmental regulations and sustainable development practices (Luthra *et al*., 2016). The private sector and academia, though recognizing environmental challenges, place less emphasis on them compared to governance or technological barriers.

6. Regulatory barriers are perceived as the most severe by the private sector (4.0), emphasizing the need for simplified regulations and streamlined procedures. The government also ranks regulatory barriers as significant (3.5), with a need for regulatory reform and better coordination across agencies (Lee *et al*., 2014). Community members and academics, however, tend to prioritize other barriers, reflecting their different concerns and roles in the SSC development process.

From Fig. 10, it may be observed that by mapping the responses of urban planners, policymakers, tech experts, and academics, the heatmap highlights key areas where stakeholders agree on the challenges to be addressed and where their perceptions diverge. Ma *et al*. (2021) emphasize the role of IoT in waste management and the associated challenges, which may be reflected in the heatmap as a significant issue for tech experts, who are more likely to experience the technical difficulties of implementing such systems. The heatmap may reveal that financial constraints, including limited funding for infrastructure and

innovation, are perceived as a significant challenge across urban planners, policymakers, and tech experts (Albreem *et al*., 2023). This is likely to resonate strongly with urban planners and policymakers, who must balance the need for sustainable urban growth with Doha's unique environmental context. By analyzing this heatmap, researchers can better understand how each group prioritizes the barriers to SSC development in Doha, facilitating more targeted interventions that address the specific concerns of each stakeholder group. This visual tool also underscores the complex, multi-dimensional nature of SSC development, where different barriers impact stakeholders in varying ways, emphasizing the need for a coordinated, cross-disciplinary approach to overcome these challenges.

Partial Least Squares Path Modeling

PLS-PM's suitability for SSC research stems from its ability to handle both reflective and formative measurement models, which are critical for understanding the various constructs involved in SSC development. Table 2 describes various barriers to SSC development that are addressed through targeted solutions. These solutions are expected to have significant impacts, including enhanced collaboration, reduced financial burdens, and improved public engagement.

Reflective models measure constructs such as citizen engagement, technology readiness, or policy effectiveness, where the observed indicators reflect the latent variable. Formative models, on the other hand, measure constructs where the indicators contribute to the formation of the latent variable, such as economic development, technological readiness, or environmental resilience (Santamouris *et al*., 2018). Given that SSCs involve a combination of both types of constructs, PLS-PM provides flexibility in modeling these complex relationships. PLS-PM is an invaluable tool for analyzing and addressing the multifaceted barriers to SSC development. By providing a comprehensive, data-driven understanding of the interrelationships between economic, technological, social, and governance factors, PLS-PM allows researchers to identify the most significant challenges and prioritize solutions. Santamouris *et al*., (2018) highlighted environmental resilience as a critical factor, showing a formative relationship with a coefficient value of 0.60, reflecting its role in driving long-term sustainability. This study differs from previous research by incorporating a more holistic framework that integrates both direct and indirect impacts of economic, governance, technological, and environmental barriers while emphasizing the interplay between these factors in urban ecosystems. Additionally, it highlights the dynamic interdependencies between governance and other barriers, offering deeper insights into their combined influence on SSC outcomes. In this study, the application of PLS-PM highlighted the centrality of financial and governance barriers, providing a strategic roadmap for addressing the obstacles to SSC success. The results align with previous findings that economic and governance factors have both direct and indirect effects on SSC performance (Santamouris *et al*., 2018). The flexibility and sophistication of PLS-PM make it an indispensable technique in SSC research, particularly when dealing with complex urban systems that require multidimensional analyses to foster sustainable urban growth. By capturing the intricate relationships between various barriers, PLS-PM not only aids in identifying root causes but also helps design targeted interventions for achieving sustainable smart cities.

Reliability and validity

In the context of SSCs, it is essential to ensure the reliability and validity of the strategies being implemented. This involves evaluating the effectiveness of proposed solutions through a combination of policy recommendations and expected outcomes. Table 3 summarizes key recommendations, their descriptions, and expected outcomes, with relevant studies supporting the need for these solutions.

To ensure the reliability and validity of these recommendations, various studies have highlighted the importance of these strategies in overcoming the unique challenges faced by SSCs. Similarly, Ahmad *et al*., (2024) highlighted cyber security risks within SSC environments, suggesting the development of specific regulatory frameworks to mitigate risks associated with data-sharing and infrastructure management. Public engagement is also critical, as Meijer and Bolívar (2016) noted that community awareness and adoption are crucial to overcoming resistance to smart city initiatives, aligning with the proposed recommendation for public education

Table 3: Key recommendations, their descriptions, and expected outcomes in SSC development

Policy Recommendation	Description	Expected Outcome
PPPs	Collaborate with the private sector to fund and implement SSC projects	Increased funding, accelerated project rollout, access to private sector expertise
SSC-Specific Regulatory Framework	Develop laws and policies that support SSC infrastructure and data-sharing requirements	Streamlined project approval, legal support for data-driven systems, and reduced regulatory hurdles
Community Awareness Programs	Initiate public education campaigns, workshops, and forums	Increased public awareness, higher citizen engagement, and improved acceptance of SSC initiatives
Investment in Green Technologies	Focus on technologies suitable for desert climates, e.g., solar-powered cooling and water-saving systems	Cost-effective solutions for environmental challenges, reduced dependency on non-renewable resources
Enhanced Governance and Coordination	Establish a dedicated SSC governance body to oversee and coordinate projects	Improved inter-agency collaboration, accountability, and consistency in SSC policy implementation

programs. Finally, Ma *et al*. (2021) focused on the need for enhanced governance and coordination to tackle the complexities of waste management in smart cities, which can be supported by a dedicated SSC governance body, ensuring streamlined decision-making and effective project implementation.

Comparison of SSC initiative in Doha and Abu Dhabi

The comparison of SSC initiatives between Doha and Abu Dhabi highlights notable disparities in key areas, emphasizing the need for targeted improvements in Doha (Fig. 11). From Fig. 11, it may be observed that Abu Dhabi's higher score in the regulatory framework (4 compared to Doha's 3) reflects its more streamlined legal environment, facilitating smoother implementation of SSC projects. Public awareness in Doha (2.5) also lags behind Abu Dhabi (3.5), underscoring the need for enhanced education and engagement strategies to gain citizen support for smart city initiatives. Technological readiness presents a significant challenge, with Doha scoring 2.8 against Abu Dhabi's 4.2, reflecting the latter's superior digital infrastructure and adoption of emerging technologies. Additionally, Abu Dhabi's public-private partnerships (PPP) model scores 4.5 compared to Doha's 3.5, demonstrating its ability to leverage private sector resources for SSC development. Razmjoo *et al.,* (2021) highlight that effective PPPs are essential in overcoming barriers, with Abu Dhabi utilizing these models to boost technological integration. Wei *et al.,* (2021) report that cities with effective PPP frameworks score an average of 3.8 for technological adoption and sustainability, with Abu Dhabi surpassing this global benchmark, further emphasizing the importance of such collaborations in smart city development. To achieve comparable progress, Doha must prioritize regulatory reforms, increase public awareness, invest in technological upgrades, and foster robust PPP frameworks. These measures are crucial for Doha's sustainable urban growth and SSC advancement. Doha's path to becoming an SSC faces unique challenges rooted in its hydrocarbon-based economy and rapid urbanization. Transitioning to a knowledge-driven economy requires substantial structural change, which has been a critical obstacle (O'Neill and Green, 2021). Unlike Abu Dhabi, which has more modern urban infrastructure, Doha needs significant upgrades before advanced SSC technologies can be introduced. This study highlights the importance of a phased approach, first strengthening foundational infrastructure before deploying advanced systems, a challenge less pronounced in Abu Dhabi. Environmental factors, such as high temperatures and water scarcity, complicate SSC initiatives in Doha. The city faces challenges in cooling infrastructure and sustainable water management, requiring tailored solutions like solar-powered cooling systems. The study contributes by addressing these specific climate-related barriers and proposing innovative solutions that are not extensively covered in broader research.

A comparative analysis of SSC initiatives in Doha and Abu Dhabi reveals differences in key areas. Regulatory Frameworks show both cities are progressing, but Abu Dhabi leads in developing SSC-specific policies. Doha's lack of such policies hampers the adoption of smart technologies like autonomous vehicles, a novel insight of this study. Public Awareness is higher in Abu Dhabi, reflecting more investment in

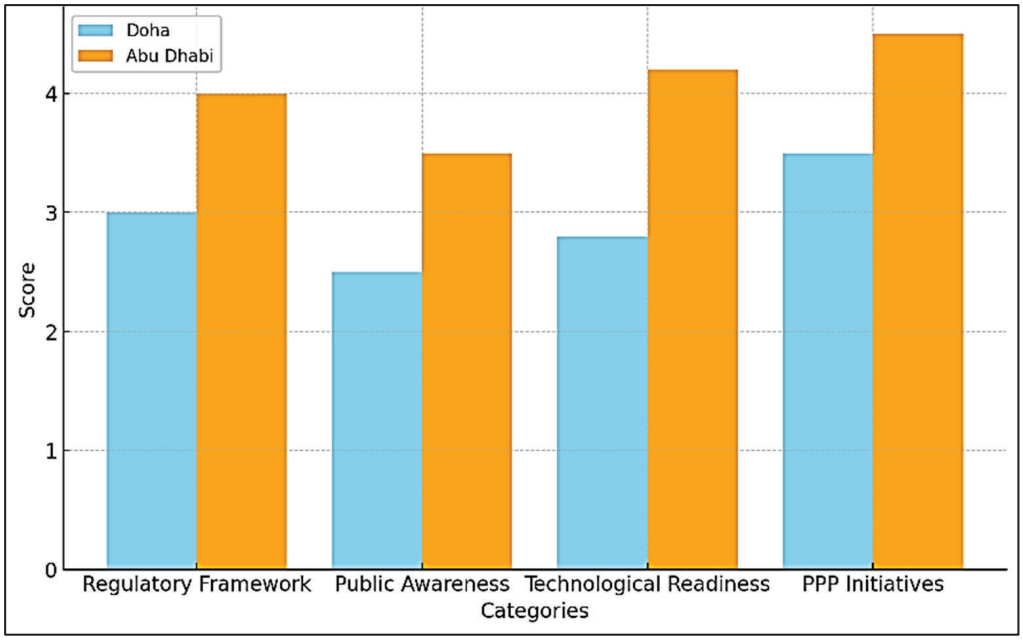

Fig. 11: Comparison of SSC initiatives between Doha and Abu Dhabi

public education, while Doha faces cultural barriers related to data-sharing and trust, as noted by Wuni *et al.,* (2023) in the context of industrialized construction projects, where public trust and awareness play a key role in the successful implementation of technology. The study uniquely addresses these barriers by linking cultural factors to public awareness of SSC adoption. Regarding Technological Readiness, Abu Dhabi's advanced digital infrastructure gives it an edge, whereas Doha struggles with technological literacy and infrastructure gaps, which are crucial challenges identified in Yousif *et al.,* (2022) in the context of construction industry readiness, highlighting that technological gaps can delay or hinder the integration of modern technologies into existing systems. This study emphasizes the need for digital literacy investments to overcome these challenges. Both cities excel in Public-Private Partnerships (PPP), with Abu Dhabi slightly ahead, supporting the view that PPPs are essential for SSC success. This study compares PPP models in both cities and suggests ways for Doha to enhance these partnerships. While Doha and Abu Dhabi share common challenges in SSC development, this study's novelty lies in its detailed exploration of Doha's specific barriers, such as its economic structure, infrastructure needs, and cultural factors. By offering tailored recommendations, it provides a roadmap for overcoming obstacles and advancing SSC initiatives in the region.

Comparison of SSC development barrier in Doha and Abu Dhabi

The comparison of SSC development barriers between Doha and Abu Dhabi underscores distinct challenges faced by each city (Fig. 12). From Fig. 12, it may be noted that economic barriers are significantly higher in Doha (9) compared to Abu Dhabi (7.5), reflecting Doha's greater reliance on hydrocarbon revenues and the higher costs associated with transitioning to a diversified knowledge economy. Technological barriers are equal (8 for both cities), suggesting shared challenges in upgrading infrastructure and integrating advanced SSC technologies. Governance issues are slightly more pronounced in Doha (8) than in Abu Dhabi (7), indicating a need for streamlined decision-making and enhanced inter-departmental coordination in Doha. Social barriers, including public awareness and cultural acceptance, are higher in Doha (6.5) compared to Abu Dhabi (6), highlighting the need for more robust community engagement programs. Environmental challenges show a similar pattern,

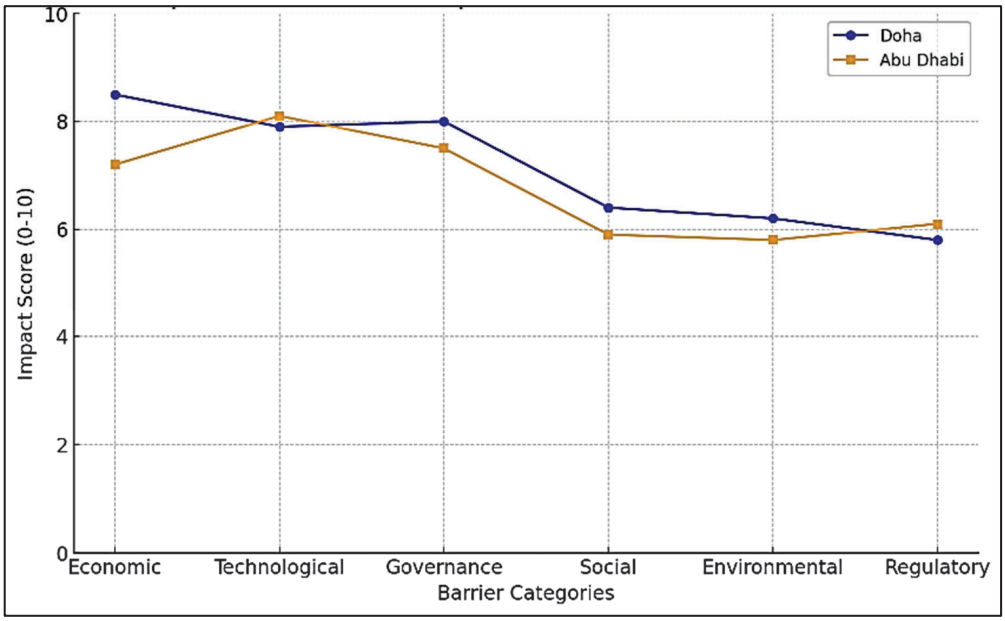

Fig. 12: Comparison of SSC development barriers between Doha and Abu Dhabi

with Doha scoring 6 against Abu Dhabi's 5.5, reflecting the unique environmental conditions in the region, such as heat and water scarcity. Regulatory barriers are identical (6), suggesting that both cities face comparable challenges in creating supportive legal frameworks for SSC implementation. This analysis highlights Doha's need to address economic and governance barriers as priorities while also tackling shared challenges in technology, environment, and regulations.

The comparison of SSC development barriers in Doha and Abu Dhabi reveals several key insights, with both cities facing similar challenges but with varying degrees of impact. Technological Barriers were rated as the highest in both cities, with Doha scoring 8.5 and Abu Dhabi 8, highlighting the shared difficulty in keeping up with technological advancements and integration into urban infrastructure. This is consistent with the observation that both cities are grappling with the need to upgrade and modernize their ICT systems to meet the demands of sustainable smart city development. Technological readiness is crucial for SSC success, and while both cities have made progress, they face similar obstacles in implementing cutting-edge technologies that will shape their future urban landscapes. Regulatory and Governance Barriers were also significant in both cities, with ratings ranging from 6 to 7. This reflects challenges such as bureaucratic inefficiencies, inconsistent policies, and unclear regulatory frameworks that slow the pace of SSC development (Rana *et al*., 2019). In both Doha and Abu Dhabi, regulatory environments need to be streamlined, and governance structures need to be strengthened to foster more agile decision-making and policy implementation. These barriers are a common theme in urban transformation efforts, especially when transitioning from traditional systems to smart, sustainable urban frameworks. Economic and Social Barriers were rated somewhat lower, suggesting that while they are important, they are not as critical as technological and governance challenges (Randeree and Ahmed, 2019). Economic barriers, such as the need for substantial investment and the transition from a hydrocarbon-based economy to a knowledge-driven one, remain a concern, but they were considered less urgent than technological or regulatory issues (O'Neill and Green, 2021). Social barriers, such as public awareness and acceptance of smart city initiatives, were similarly rated lower, indicating that while public engagement is necessary, it is not as pressing as the need for infrastructural and technological development. Environmental Barriers were rated the lowest, reflecting the perception that while environmental sustainability

remains a significant consideration, it does not pose as immediate a challenge as other factors like technology or governance (Alsaeed *et al*., 2022). From the comparison it may be noted that both cities share common barriers to SSC development, Doha appears to face slightly higher technological and governance challenges, while Abu Dhabi is slightly ahead in terms of regulatory readiness and public awareness. The findings underscore the need for both cities to focus on digital infrastructure, regulatory reform, policy coherence, and capacity building to address these barriers effectively. By doing so, both cities can overcome their respective challenges and accelerate their journey towards becoming fully SSC.

Contextual challenges in Doha

Doha's transition to an SSC faces several local challenges:

1. Reliance on a hydrocarbon-based economy: Doha's economy, largely dependent on hydrocarbons, requires significant structural changes to transition to a knowledge-driven economy central to SSCs. This shift demands policy reforms, workforce development, and a focus on technology and innovation (O'Neill and Green, 2021).

2. Pressure from rapid urbanization: The city's rapid urbanization places strain on existing infrastructure, requiring upgrades before SSC technologies can be implemented. A phased approach is necessary to first enhance foundational systems before introducing advanced smart technologies.

3. Environmental challenges: Extreme heat and water scarcity in Doha necessitate energy-efficient cooling and advanced water management solutions. Technologies like desalination and wastewater treatment are essential to ensuring sustainable urban development.

4. Phased approach: A gradual, phased approach to SSC development is crucial. Strengthening core infrastructure (e.g., energy, transport) must precede the integration of advanced smart technologies such as AI and smart grids.

5. Technological and societal adaptation: Successful SSC adoption also requires societal engagement and public education. Raising awareness and addressing concerns about data security and privacy are critical for ensuring citizen acceptance and participation.

Addressing these challenges will allow Doha to develop a sustainable, technologically advanced urban future.

Recommendations

This study recommends fostering public-private partnerships, adapting regulatory frameworks, promoting community engagement, and investing in green technologies to overcome Doha's SSC barriers. Additionally, strengthening governance and coordination across departments is crucial for successful SSC implementation. Based on these identified barriers, the study suggests the following policy recommendations for Doha's transition to an SSC:

1. Fostering public-private partnerships (PPPs): Encouraging PPPs can help Doha attract foreign investment and leverage private sector expertise to accelerate the development of SSCs. Collaborative projects between government and private firms, particularly in ICT infrastructure, can help distribute financial burdens and foster innovation (Mirzaee and Sardroud, 2022).

2. Developing SSC-specific regulations: Regulatory frameworks should be tailored to support SSC development, including policies that incentivize renewable energy, establish data-sharing protocols, and protect data privacy. Clear SSC-specific policies will streamline project approvals, build stakeholder trust, and enhance overall project efficiency.

3. Promoting community engagement and awareness: Initiating community programs can increase public understanding and acceptance of SSC technologies. Workshops, information campaigns, and public forums can address privacy concerns, raise awareness of the benefits of SSCs, and encourage active citizen participation (Hammar *et al*., 2011).

4. Investing in green technologies for resource management: Doha should prioritize investments in green technologies that are well-suited for its desert climate. Solutions such as solar-powered cooling, efficient water recycling systems, and drought-resistant landscaping can help manage environmental challenges and enhance sustainability in SSC development (Lee *et al*., 2014).

5. Enhancing governance mechanisms: Improving coordination across government agencies can streamline SSC projects, reducing delays caused by bureaucratic complexity. Establishing an SSC governing body to oversee initiatives will

ensure alignment, accountability, and efficient implementation across various departments (Chu *et al*., 2018).

These recommendations address Doha's unique challenges by focusing on key areas such as public-private partnerships, regulatory frameworks, community engagement, and green technologies. They aim to create a strong foundation for SSC initiatives, ensuring successful implementation through effective governance, digital infrastructure, and sustainable solutions that enhance public trust, quality of life, and environmental resilience.

Future scope of the study

Future research on Doha's transition to an SSC should focus on tracking the long-term impacts of SSC projects, comparing Doha's progress with other GCC cities, and exploring emerging technologies for better governance and sustainability. Studies on citizen-centric design, climate adaptation, economic models, and evolving policies will also be crucial for optimizing SSC development. The key focusing areas are as follows.

1. Longitudinal analysis: Track the long-term progress and outcomes of SSC projects, assessing the impact of policy and technological advancements on sustainability, citizen engagement, and economic growth.

2. Comparative studies across GCC cities: Compare SSC development in Doha with other GCC cities to identify shared challenges, opportunities, and best practices for accelerating urban transformation.

3. Integration of emerging technologies: Investigate how technologies like AI, blockchain, and IoT can enhance governance, security, and efficiency within Doha's SSC framework.

4. Citizen-centric design: Explore participatory urban planning to improve community involvement and address citizens' needs, especially regarding privacy, inclusivity, and equitable resource access.

5. Environmental impact and climate adaptation: Focus on developing solutions for resource management in Doha's extreme climate, such as new green technologies for water and energy conservation.

6. Economic models and funding mechanisms: Study financial models, especially Public-Private Partnerships (PPPs), to assess the feasibility and impact of funding mechanisms for SSC projects.

7. Policy and regulatory evolution: Examine how Doha can evolve its policies and regulations to support technological innovations and global competitiveness in SSC development.

These research avenues will provide valuable insights for Doha's SSC transformation, addressing its unique challenges while enhancing sustainability and innovation. By focusing on long-term impacts, emerging technologies, citizen-centric design, climate adaptation, economic models, and evolving policies, researchers can offer actionable strategies to refine development, improve community engagement, ensure environmental resilience, and overcome financial barriers, ultimately supporting Doha's transition to a sustainable and smart city.

CONCLUSION

This research identifies key barriers hindering Doha's transition into an SSC, including economic limitations, technological readiness, governance challenges, and social awareness. Economic barriers, such as high infrastructure costs, reliance on imported technologies, and limited funding, pose significant challenges for implementing and maintaining the advanced ICT systems necessary for SSCs. Technologically, Doha's infrastructure is not fully equipped to meet the demands of SSC technologies, and there is a need to upgrade digital systems and enhance technological literacy among residents and administrators. Governance issues, like overlapping authorities and bureaucratic inefficiencies, further complicate SSC development, necessitating streamlined regulations and clearer accountability. Social awareness also plays a critical role, as public understanding and trust are essential for the adoption of SSC initiatives. Additionally, environmental barriers, including water scarcity and energy consumption, add to the complexity of SSC development in Doha. To overcome these challenges, future research should focus on developing tailored strategies, including fostering public-private partnerships, regulatory reforms, and technological innovations. Investigating the socio-economic impacts of SSC development will be crucial for ensuring equitable access to services and enhancing public participation. By addressing these barriers, Doha can advance its vision of becoming a leading SSC hub in the region. The study highlights the distribution of key barriers to SSC development in Doha: economic

(25%), technological (20%), social (20%), governance (15%), regulatory (10%), and environmental (10%). Economic barriers are the most significant, followed by technological challenges such as data security and infrastructure gaps. Social barriers stem from limited public awareness and cultural concerns, while governance issues involve bureaucratic inefficiencies. Regulatory barriers relate to outdated policies, and environmental barriers focus on climate-related issues. Stakeholder perceptions reveal varying views on these barriers, with the government and private sector seeing economic barriers as most severe, while academia emphasizes technological challenges. The community prioritizes social barriers, and governance issues are critical for both the government and the private sector. Environmental concerns are most severe for NGOs, and regulatory barriers are a key concern for the private sector. When comparing SSC development in Doha and Abu Dhabi, the study reveals significant differences. Doha lags in regulatory frameworks (Doha 3, Abu Dhabi 4), public awareness (Doha 2.5, Abu Dhabi 3.5), and technological infrastructure (Doha 2.8, Abu Dhabi 4.2). Abu Dhabi also outperforms Doha in public-private partnerships (Doha 3.5, Abu Dhabi 4.5). Additionally, Doha faces more significant economic (Doha 9, Abu Dhabi 7.5) and governance (Doha 8, Abu Dhabi 7) barriers, primarily due to its reliance on hydrocarbons and bureaucratic inefficiencies. Both cities share technological (8) and regulatory (6) challenges. Doha also faces higher environmental (Doha 6, Abu Dhabi 5.5) and social (Doha 6.5, Abu Dhabi 6) barriers, highlighting the need for tailored solutions. Addressing economic and governance barriers should be a priority for Doha as it seeks to advance SSC development and close the gap with Abu Dhabi.

AUTHORS CONTRIBUTIONS

D. Padi contributed to the conceptualization, data collection, methodology, and drafting of the manuscript, while C. Thangavelu supervised the research, provided critical revisions, and ensured the overall integrity of the study. Both authors reviewed and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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PUBLISHER NOTE

ABBREVIATIONS	DEFINITION
GCC	Gulf Cooperation Council
ICT	Information and Communication Technology

IoT	Internet of Things
PLS-PM	Partial Least Squares Path Modelling
PLS-SEM	Partial Least Squares Structural Equation Modelling
PPPs	Public-Private Partnerships
SEM	Structural Equation Modelling
SSC	Sustainable Smart City
SSC	Sustainable Smart Cities

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CASE STUDY

Designing a human resource management model to satisfy the tribes (case study: Iran Nomads Affairs Organization)

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ABSTRACT

BACKGROUND AND OBJECTIVES: The current research aims to design a desirable model of human resource management to attract the satisfaction of tribes and provide a descriptive model that illustrates how the functions of human resource management are formed through various processes such as recruitment, promotion, performance evaluation, service compensation, and enhancing the capabilities of managers and employees in the organization of Iranian tribes with a customer-oriented approach.

METHODS: First, the dimensions of the concept of human resource management with a customer-oriented approach were extracted through reviewing documents, materials, and library studies. Then, the most important dimensions and influential factors were identified through interviews with 18 experts using a judgmental sampling method.

FINDINGS: The result of qualitative data analysis included 2 concepts, 9 dimensions, and 64 components presented and explained as a model. The desirable model of human resource management aiming to attract the satisfaction of tribes consists of 9 dimensions (organizing theme) in the form of two comprehensive themes, strategies, processes, and functions of human resources (human resource supply, training and development, service compensation, job analysis, and performance management) and organizational direction (customer-oriented organizational strategy, customer-oriented organizational structure, customer-oriented organizational culture, and two-way communication channels) was designed.

CONCLUSION: Based on the research findings, to attract the satisfaction of the tribal community and improve communication with the tribal leaders, focusing solely on the human resource system is not sufficient. Instead, all aspects of the human resource environment should be aligned with the functions of human resources and the orientation of tribal leaders.

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INTRODUCTION

Customer satisfaction and loyalty have become fundamental topics for any service or manufacturing organization today. A satisfied customer, as a member of the organization, directly contributes to the development and sustainability of the organization in a way that the opinions of the customer influence the organization's decisions and the establishment of a system for collecting feedback and suggestions from customers, leading to increased effectiveness of expected services and greater responsiveness. Customer satisfaction is a focal point in most organizations' annual reports, yet the number of organizations that have succeeded in this path is very few (Lina, 2022; Naini, Santoso, Andriani, Claudia, & Nurfadillah, 2022). According to researchers' findings, designing and implementing structures, processes, and systems that are desirable to create customer satisfaction are among the most important challenges for governmental organizations (Maria & Ilias, 2020). The lack of commitment from senior managers to ensure customer satisfaction, the absence of a clear and formal definition of the organization's strategy to meet the needs of clients, the failure to embed customer-centricity in the organizational culture, the existence of conflicts between managers' actions and their statements regarding the importance of clients, the disregard for the voice of customers, and the lack of communication between clients and organization employees are considered the most significant barriers to achieving customer-centricity (Madhani, 2020). In the public sector, Human Resource Management (HRM) Human Resource (HR) management faces three major challenges:

1. Coordination between HR subsystems and functions,

2. Alignment of HR subsystems with other organizational systems,

*3. Alignment and coherence between HR policies and organizational strategies (*Hans, 2021*).*

Theoretical foundations

Strategic human resource management examines the relationship between HRM and strategic management, as well as the need for human capital the development of process capabilities, and the ability to carry out activities efficiently (Ren and Jackson, 2019). HRM is one of the elements enabling an organization to remain competitive in turbulent conditions (I Gede Riana *& et al*., 2020, Anwar & *et al.,* 2020). The effective practice of HRM makes competent and innovative employees contribute to achieving organizational objectives (Rustiawan, I. Gadzali, S. S. & *et al*., 2023, Kshiroda Kumar Sahoo 2024). Studies examined the subtle points of the empirical experience of human resource management functions in the public sector and identified issues related to human resource management in the Iranian public sector as follows: unstable and personal structure, abolished job description, dual standards in recruitment, imbalance between wages and employee performance, lack of a regular career path, general training programs instead of specialized ones, imbalance between organizational strategy and human resource management, deceitful knowledge management, lack of alignment in human resource systems, and the challenge of unworthy employees (Aghaz, Sheikh, & Amirkhani, 2017; Berman, Bowman, West, & Van Wart, 2021). The success and effectiveness of human resource management depend on various underlying factors such as organizational structure, culture, leadership, and others. Analyzing HRM human resource management or proposing a model requires attention to these underlying factors. Past research has not paid much attention to these factors or has examined them in a general manner without a deep understanding of their components (Abdulfatai, 2021). Based on the findings of research in the Municipality of Tehran, the relationship between strategic human resource management subsystems; including employee recruitment, supply and adjustment system, performance management system, human resource development system, service compensation and reward system, job analysis and design system, talent and succession management system and employee relations and innovation management system approved (Amani S, Mosakhani M, Daneshfard K, 2021). In addition, other contextual factors such as communications and infrastructure also impact human resource management aimed at satisfying superiors (Mohiuddin, Hosseini, Faradonbeh, & Sabokro, 2022; Swanepoel, Erasmus, & Schenk, 2008), but they have not been addressed in past research. Several models have been designed and presented in the field of HRM; however, existing

models lack a specific direction. General human resource management, without any specific orientation, does not have sufficient desirability to meet the needs of the audience (Dhillon, Smith, & Dissanayaka, 2021). Most of the models presented below suffer from generalization, causing human resource managers to face ambiguity and confusion during planning, evaluation, and control. Since human resource management plays a significant role in achieving employer-centric goals, the lack of a suitable HRM model in government organizations with an employer-centric approach is considered a fundamental problem and challenge for these organizations. This situation leads HR managers to make incorrect decisions, failing the employer-centric approach (Dhurup, Surujlal, & Kabongo, 2016; Thevanes & Opatha, 2022).

Literature review

The Global Leadership and Organizational Behavior Effectiveness (GLOBE) study examined how cultural differences influence leadership practices in 62 countries. The findings showed that cultural values significantly influence the characteristics of leaders and their effectiveness, underscoring the need for culturally responsive leadership development programs (Moreno, 2020). Hofstede's research has examined how cultural dimensions influence workplace behavior. For example, countries with high individualism are likely to have employees who value personal achievement, while countries with high collectivism may prioritize team success. Human resource professionals can leverage these insights to develop culture-relevant management strategies (Hofstede, Hofstede, & Minkov, 2014). In a study titled Differentiating Human Resource Management Practices in the Public Sector, Knies *et al.,* (2022) showed that human resource management practices aimed at equal opportunities are used more in the public sector than in the private sector. However, welfare management, as well as career development and management practices, are now used either equally by public and private organizations or even more in the private sector than in the public sector (Knies, Borst, Leisink, & Farndale, 2022). In a study titled "Investigating the Relationship between Human Resource Management, Employee Engagement and Organizational Performance in Federal Public Service Organizations in Ethiopia," Tensay & Singh (2020) showed that there is a positive and significant relationship between human resource management, employee engagement, and organizational performance. In addition, employee engagement partially mediated the relationship between human resource management and performance. Regarding the impact of individual human resource practices, the present study showed a positive and differential impact of human resource practices on engagement and performance, although the impact is smaller than the combined impact of human resource practices. In addition, autonomy was identified as an important driver of engagement and performance. This result contributes to the discussion of human resource management performance (Tensay, Singh, 2020). The findings of the research conducted to investigate the effect of knowledge-based human resource management on the sustainable performance of employees with the mediating role of psychological empowerment of human resources show that knowledge-based human resource management has a significant effect on the sustainable performance of employees and psychological empowerment of human resources, and psychological empowerment of human resources has a significant effect on the sustainable performance of employees, and finally, knowledge-based human resource management has a significant effect on the sustainable performance of employees with the mediating role of psychological empowerment of human resources (Hamzavi, H & *et al.,* 2024). Therefore, understanding the existing research gap and considering the theoretical foundations and research background, it can be concluded that a comprehensive model covering the dimensions and components of human resource management aimed at satisfying tribal chiefs is not available. Existing models in previous research lack a strategic orientation and solely focus on satisfying employees and achieving desirable organizational outcomes. Moreover, the initial identified components do not encompass all aspects of HRM centered on tribal chiefs, being rather general and lacking sufficient details. This current research, relying on both quantitative and qualitative data analysis, aims to present a native model for human resource management in tribal affairs organizations that fully aligns with existing capacities and new requirements. Given the aforementioned points,

this research seeks to answer the question: What is the desired model of human resource management aimed at satisfying tribal chiefs in the tribal affairs organizations of Iran? The findings of this research play a significant and influential role in designing developmental programs throughout various processes such as recruitment, promotion, performance evaluation, service compensation, and enhancing the capabilities of managers and employees to achieve a high level of continuous performance. Hence, there is a necessity for implementing this research due to the existing research gap and the researcher's concern, utilizing field findings and information gathered from relevant experts to design a human resource management model focused on satisfying tribal chiefs. The present study was carried out in 2024 in Iran to design an optimal model of human resource management to satisfy the nomads. This study aims to present a descriptive model that shows how human resource management functions are formed during different processes of recruitment, promotion, performance evaluation, service compensation, and the ability of managers and employees in Iran's nomadic affairs organization with a customer-oriented approach.

MATERIALS AND METHODS

Survey design and data collection

In general, the research method was applied in this qualitative study. Qualitative research, by its nature, conducts a deep and comprehensive study on the phenomenon under study, namely "customer-centric HRM." Qualitative research relies on primary sources for data collection. A common feature of various types of this research is the analysis of unstructured data aimed at identifying, categorizing, and extracting concepts based on the study of texts or expert opinions. Therefore, the main tools for data collection in qualitative research are interviews and library studies. Activities such as observation, interviews, and extensive participation in research activities each assist the researcher in obtaining firsthand information about the research topic. Thus, in the present study, we have endeavored to use the collected descriptive, analytical, and categorized information to achieve the following objectives:

A. Identifying the components and elements of the HRM*-model in the Iran Nomads Affairs Organization.*

B. Identifying the content elements of the HRM *model in the Iran Nomads Affairs Organization.*

Statistical population, place, and time of research

The present study was conducted in Tehran from January to July 2024. The research statistical society in the documentation sector includes all laws and upper-level documents related to *HR* development, including the National Service Law and other relevant regulations. Data collection was conducted in the expert data section through semi-structured interviews with 18 university and executive experts, including university professors, HR opinion leaders, managers, and policy implementers using a judgmental sampling method. After analysis, an optimal HRM–model was designed to satisfy the stakeholders. All interviewees had high academic degrees and were directly related to research and executive topics in the human resources field. It is worth mentioning that interviews continued until no new data, perspectives, or features were presented regarding the research topic. Based on this; after interviewing 14 experts, the responses of the subsequent experts were similar to the previous samples until the eighteenth sample where repetitive content was found, and data saturation was achieved with 18 samples.

Analytical framework

Considering that the appropriate method for collecting research data is the textual study (text of library documents and interview transcripts), the content analysis method was used as a strategy. Content analysis is a research tool used to determine the presence of certain words, themes, or concepts within some given qualitative data (i.e., text). Using content analysis, researchers can quantify and analyze the presence, meanings, and relationships of certain words, themes, or concepts (Mayring, P. 2014). Table 1 shows how to identify the basic, organized, and comprehensive themes. Subthemes were extracted from the interview text, and then merged and themes were identified. It was analyzed using the content analysis method and used the MAXQDA 11 software.

RESULTS AND DISCUSSION

Based on the research method, in the first stage, the basic themes were extracted from the interviews, and in this regard, 64 basic themes were identified from the key points of the texts. In the next step, based on the

Table 1: How to identify the basic, organized, and comprehensive themes

Comprehensive theme	Theme	Sub-theme	The text of the interview
Strategies, processes, and functions of human resources	Compensation for services	Collective payment based on the organization's customer-oriented performance	"For employees to take responsibility, we must use a combination of customer-oriented evaluation indicators and financial incentives based on customer-oriented performance."
		Compensation for services based on merit	"We must define the desired attitude, skills, and behaviors to meet customer needs to determine the basis for recruiting and hiring, training, performance management, and service compensation."
	Performance management	Determining performance indicators in line with customer needs	"To evaluate the performance of the employees, the evaluation indicators should be in line with the expectations of the customers and we should use the customers as an evaluation source."
		Performance evaluation based on competence	"First, we have to design the human resource competency model to support the organization's customer-oriented values. In the next step, let's link this competence model to the evaluation of the employees' performance".
	Training and improvement	Determining educational goals in line with the needs of customers	"To improve the satisfaction of the clients, the organization should spend a lot of money on training and improving the employees establishing a good relationship with the client should be supported by training, performance management, and service compensation."
		Educational needs assessment of employees based on customer needs	"The training of employees and managers should be based on the analysis of annual training needs. Training courses should be designed and presented based on the needs of employees and customers."

categories obtained from combining and summarizing the basic themes, 9 organizing themes have been described. In the next step, based on the categories obtained from the combination and summarization of the themes of the organizer, 2 comprehensive themes have been described, which are given in the form of Table 2. By using the network of obtained themes, the human resource management model was obtained to satisfy the nomads in the organization of nomadic affairs of Iran. The findings of the present research showed that the human resources management model to satisfy the nomads in Iran's nomadic affairs organization includes 2 concepts (comprehensive theme), 9 dimensions (organizing theme), and 64 components (basic theme).

As mentioned, the orientation of the organization has four dimensions: customer-oriented strategy, customer-oriented structure, customer-oriented culture, and strengthening two-way communication channels. Each of these dimensions has several components, and in the following, the role of each of these requirements and their relationship with other dimensions and components of the human resources management model in Iran's nomadic affairs organization will be discussed with the approach of obtaining the satisfaction of the nomads. The strategy of the organization is considered an organizational directional decision for aligning goals, strategy, and processes of human resources. The organization's strategic plan has a direct impact on customer satisfaction by influencing the direction, goals, strategy, and processes of human resources (Loeppke *et al.,* 2015). The client-centered approach must be clearly defined in the statement of mission, vision, goals, values, and strategy of the organization. In other words, in line with the requirements of the central client, the strategy of the organization should be developed in the direction of the client's needs and honor the client (Knies, Borst, Leisink, & Farndale, 2022). Customer-oriented structures are considered a necessary condition for realizing the organization's goals, but they are not considered a sufficient condition. The existence of structures related to clients is essential to obtaining client satisfaction (Aktar & Pangil, 2018). In general, if the employees are motivated and capable, but if the job satisfaction of the employees is not possible within the organization due to the lack

Table 2: Identification of the basic, organized, and comprehensive subjects

Comprehensive theme	Theme	Sub-theme
Strategies, processes, and functions of human resources	Providing human resources	Accuracy of job requirements for selection
		Making customer orientation the most important priority for employee selection
		Extensive initial training in line with customer needs
		Customer-oriented competencies as the basis for recruitment and hiring
		Maintaining a realistic proportion of the number of organizational jobs in line with customer needs
		Employer branding and its impact on successful recruitment
	Education and improvement	The importance of clearly identifying goals for human resources in line with customer needs
		Creating and developing job skills and knowledge in line with customer expectations
		Collecting information about customer needs and expectations
		Using modern educational technologies
		Sharing information and knowledge related to customer needs and expectations
		Ensuring the added value of the training course
	compensation plan	Design and implementation of appropriate payment mechanisms based on customer-oriented performance
		Employee rating schemes to evaluate and reward customer-oriented performance
		Individual and collective annual bonuses for customer-oriented performance
		Including consideration of customer demands in the customer-oriented compensation system
		Including consulting services to customers in the customer-oriented compensation system
		Appropriate payment strategy during times of work pressure
		Including positive interaction with customers as a criterion
	Performance Management	Linking performance measures to customer-centric outcomes
		Performance assessment with a meritocracy approach
		More points for people active in satisfying clients
		Setting performance indicators in each department according to its specific goals
		Transparency of performance indicators and two-way interactions between employees and customers
		Measuring employees' efforts in presenting a positive image of the organization to customers
	Job analysis	Analyzing job duties based on customer needs
		Planning to identify new and necessary skills and knowledge in job areas
		Dividing job duties into smaller and more specialized ones
		Dividing job duties according to customer needs
		Defining flexible job descriptions based on customer needs
		Providing job descriptions and qualification requirements that are consistent with professional ethics
Organizational orientation	Customer-centric organizational strategy	Strategic planning with a customer-centric focus
		The need to revise the organization's mission statement and create value beyond customer expectations
		A customer-centric organizational vision that is in line with issues and problems
		Organizational values that are in line with customer-centricity
		The organizational mission's focus on customer-centricity
		The need to align human resources strategy with the organization's strategy in line with customer needs
		The participation of the human resources unit in formulating the organization's strategy in line with customer needs
		Identifying opportunities and commitments in the human resources dimension with a customer-centric approach

Table 2: Identification of the basic, organized, and comprehensive subjects

Comprehensive theme	Theme	Sub-theme
	Customer-oriented organizational structure	The need for documented planning to change the structure and adapt based on the needs of clients Structural flexibility and creating horizontal values in the organization Creating changes in the organizational structure according to the needs created for the organization Designing support processes based on target customers Updating the organizational structure based on customer needs Adapting the structure and customer-centric strategy mutually Appropriateness of the organizational structural conditions for implementing customer-centric strategies
	Customer-oriented organizational culture	Reflecting the importance of customers in the organization's culture Employee awareness of the importance of customer satisfaction Employee belief in their importance to the organization Employee attitude toward the importance of customer satisfaction Employee attitude toward the importance of providing quality services to customers Employee pride in the organization's values and goals Employee belief in the importance of all processes and units of the organization for customer satisfaction Providing superior services to customers as an employee value A culture of accepting mistakes Mutual respect is one of the elements of a customer-oriented culture
	Two-way communication channels	Reflecting customer opinions in organizational decision-making Comprehensive transparency and documentation of how to provide services to customers Need for training in customer relationship skills The role of management in creating good relationships in order to realize a customer-centric strategy Eliminating discrimination between customers Informing employees about customer opinions and perspectives Flexibility in providing services Emphasizing the importance of honoring customers

of proper infrastructure, they will not be able to obtain the satisfaction of the clients. Client-centered structures affect not only the strategies, processes, and functions of human resources but also the clients' results (Wu, Tsai, & Fu, 2013). Also, the informal dimension of the organizational structure affects the satisfaction of clients by facilitating communication and the process of learning and development. Reduction of regulations and removal of redundant instructions will lead to more delegation of authority and proportional to responsibilities and reduction of organizational levels. Without the existence of a binding law, the employees fulfill the requests of the clients in the shortest possible time based on their authority, as a result, the satisfaction of the clients increases. Designing client-centered structures strengthens communication channels with clients and provides identification of their needs (Dello Russo, Mascia, & Morandi, 2018). In connection with the organizing theme of organizational culture, customer-oriented culture should place the customer at the center of its values and goals and can be a supplement to the performance management system by organizing the customer-oriented behaviors of employees. With the expansion of a customer-oriented culture, there is less need for rules, procedures, and control systems. The values and beliefs of employees are considered a motivational structure that is related to the desired and desirable goals of people in different situations. In addition to the functions of human resources, culture also has a significant effect on the direct interaction of employees with customers (Dello Russo *et al.,* 2018). In connection with the organizer's theme of strengthening two-way communication channels, communication

channels facilitate organizational learning and development by strengthening trust. Also, by gathering opinions and experiences and transferring them to employees and clients, provides the tools needed to formulate human resources strategies and processes (Cho & Choi, 2021). Also, by encouraging the participation of employees in the organization in the planning and decision-making process, it facilitates the possibility of designing and improving organizational mechanisms in line with the client's needs (Ehnert, Parsa, Roper, Wagner, & Muller-Camen, 2016). In addition to providing a set of solutions to solve complex organizational problems, two-way communication channels also have a direct impact on the satisfaction of employees and clients. The two-way communication channels with the clients increase the sense of confidence between the organization and the clients, the ability to identify the negative and positive points of the organization, understand the demands of the stakeholders and share information and knowledge. Therefore, it provides the basis for responding to the needs and demands of clients in the best possible way (Arasli, Nergiz, Yesiltas, & Gunay, 2020). Excellent communication with the clients of the organization, accurate and timely information, polling of them, and the like have an impact on the client's understanding of the quality of services (Telles, 2023).

The content of the model drawn in Fig. 1 refers to the strategies, processes, and functions of human resources, which have five components: job analysis, HR–provision, training and improvement, performance management, and comprehensive service compensation. To gain the satisfaction of the client, the human resources management should design and implement the strategy of the organization and the strategy of HRs, the direction, and direction of the main duties of the human resources unit in a way that shows the importance of the client and the possibility of responding positively and favorably to the demands. Provide them and get their satisfaction (Reina & Scarozza, 2021). In connection with the organizing theme of job-oriented and worker-oriented analysis, it affects the functions and processes of human resources and by matching human resources activities with the real needs, it provides the necessary platform for other human resources actions. In addition, the provision of HRs, training and improvement, performance management, and comprehensive service compensation in this model have mutual effects on each other (Najam *et al.,* 2020). When the actions of human resources management are mainly aimed at meeting the interests and expectations of clients and are in line with the goals and strategies of the organization, it draws a clear vision based on the importance of creating desirable customer-oriented values for employees (Cho & Choi, 2021). A job-oriented and worker-oriented analysis is done by identifying the necessary mechanisms in attracting and identifying the human resources that are prone to providing effective services to satisfy the client. The organization's emphasis on recruiting and attracting competent human resources helps to solve the problems of the clients, people are recruited and hired who have the necessary specialized skills, i.e., double job motivation for the satisfaction of the clients, desirable personality traits, knowledge, insight, and professional ethics, the ability to respond to It enables the client's demands (Reina & Scarozza, 2021). Performance-based and fair rewards also strengthen the motivation of employees. Designing jobs with a client-centered approach and increasing job independence also provides the opportunity for employees' innovative behaviors through increasing job involvement (Najam *et al.,* 2020). Customer focus is considered as a basis for planning job descriptions, selecting employees, compensation for services, and so on. Job analysis should be done to respond favorably to the demands of the organization's clients so that in addition to identifying the duties and responsibilities, the competencies needed to establish work interaction and communication with clients are also identified. To improve the return-oriented approach, it is necessary to hire people who have a deep understanding of the needs and expectations of the clients and prepare and facilitate the conditions for training and improvement of the employees in such a way that the expectations of the target clients are realized (Borges, Herter, & Chebat, 2015). Performance management can significantly meet the needs of the organization's stakeholders, and service compensation in line with other HRM-systems is also effective in fulfilling the needs of target customers (Opatha, 2019). First of all, desirable personality traits should be defined to satisfy the demands of clients, the basis for recruitment and employment, training,

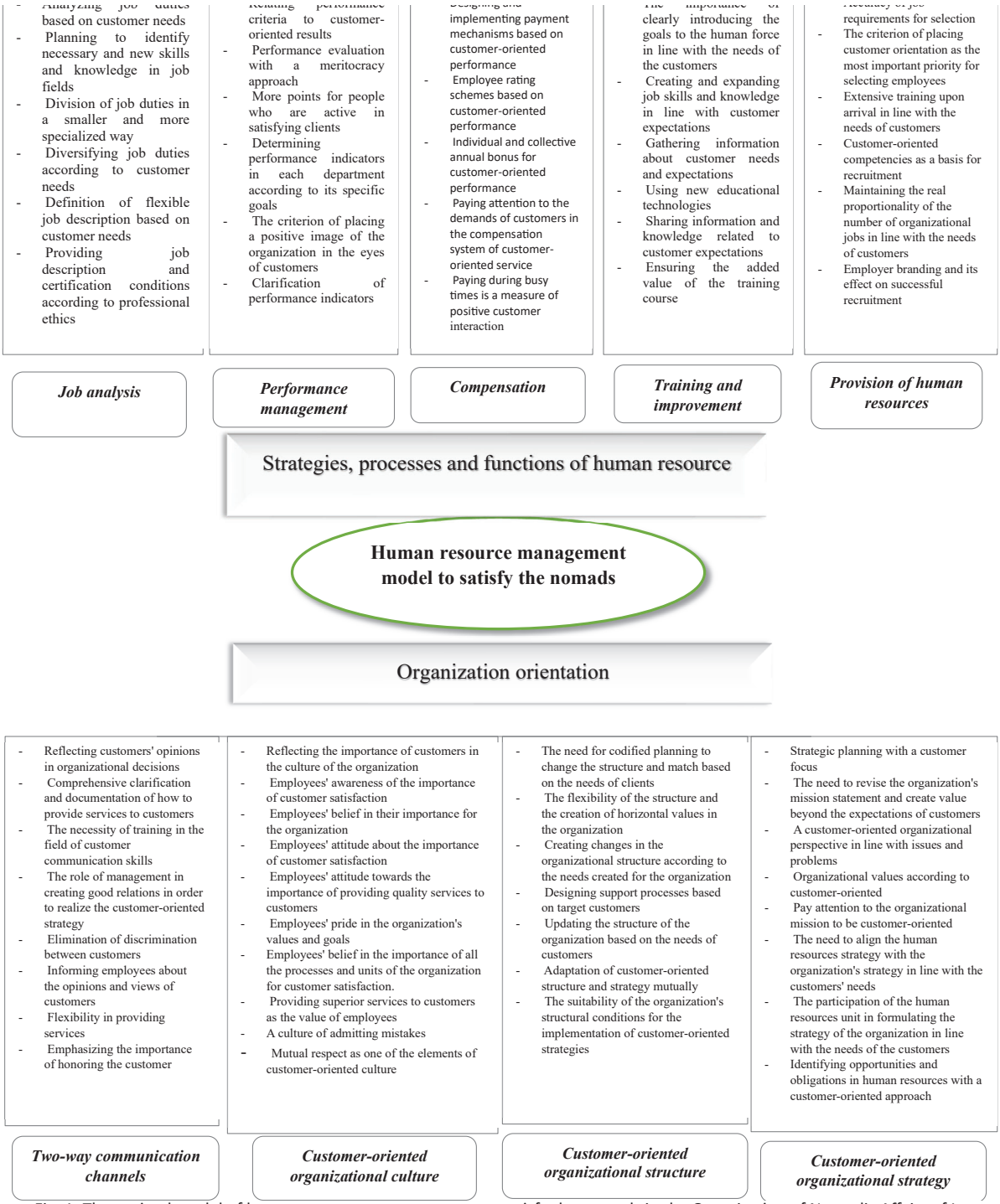

Fig. 1: The optimal model of human resources management to satisfy the nomads in the Organization of Nomadic Affairs of Iran

performance management, and service compensation (Arasli *et al.,* 2020). Organizations can recognize the importance of customer-centricity to employees and include customer-oriented components as one of the competency requirements in the HR meritocracy model (Cho & Choi, 2021). Organizations create a constructive attitude and atmosphere for employees by appreciating the behaviors that lead to the promotion and preservation of people's dignity in the administrative system (Reina & Scarozza, 2021).

Limitation of the present study

The first limitation of our study is that while we asked participants whether performance was a cultural element, we did not explicitly ask them about performance expectations. The second limitation is that the study was conducted in one country and cross-cultural studies would signal similarities and differences.

CONCLUSION

The present study was conducted to design an HRM model with the approach of obtaining the satisfaction of the nomads in the Organization of Nomadic Affairs of Iran. In this sense, a qualitative research approach with a content analysis method was used. According to the findings of the research, the human resource management model in Iran's nomadic affairs organization with the approach of obtaining the satisfaction of the nomads has two main dimensions of the organization's orientation (the relationship between human resources and the nomads) and content (HRs strategies and processes). The orientation of the organization (relationship between HRs–and nomads) has four dimensions: customer-oriented strategy, customer-oriented structure, customer-oriented culture, and strengthening of two-way communication channels. The content of the model refers to the strategies, processes, and functions of HRs, which have five components: job analysis, provision of HRs, training and improvement, performance management, and comprehensive service compensation. The research conducted among the statistical sample shows: First, that customer-oriented human resource management, although it is similar to other HRM-models in terms of its mechanisms, its indicators are fundamentally different from the existing models, which are in the form of Qualitative tables were mentioned under the title of basic themes. According to the findings of the research, human resource management in terms of satisfying the nomads requires external alignment between HR–systems and background requirements such as the strategy and structure of the organization. According to the researchers' findings, designing and implementing optimal structures, processes and systems to create customer satisfaction is one of the most important challenges of public sector organizations (Chan, Thong, Brown, & Venkatesh 2021). The proposed model of the current research emphasizes the interrelationship and coherence between human resource management measures. In the mentioned model, special attention has been paid to the stakeholders of the organization, the influence, and the role of clients as one of the most important stakeholders of the organization. Also, the role of variables including other requirements of the immediate environment of HRM–such as customer-oriented culture, customer-oriented structures, and two-way communication channels are included in the model. The results of a study that was conducted to design a model to explain sustainable human resource management in Iran's government organizations with a sociological approach show that in the causal conditions of individual, group, and organizational components and attention to the organization, in the main phenomenon of participation, Communication and adherence, intervening conditions, internal and external organizational factors, in the context of capacity building, organizational change and planning and in connection with the main strategy of sustainable human resource management measures, human resource information system design, and consequences including individual, organizational and It has been social that is worthy of focus and skills Human resource management is effective (kiani, Rangriz, & Ahmadi, 2022). The final model of research that designing a strategic model of customer-oriented human resources in the Iranian banking system has five main factors including the functions and relationships of customer-oriented human resources, customer-oriented organizational culture, external factors, strategic customer-oriented strategic resources, and customer-oriented human resource results (Marzdashti, Jazani, & Mehrabi, 2022). The mentioned model is aligned with our model in the field of customer orientation. There are also differences compared to other prominent models

in the field of human resources, such as the Michigan, Warwick, Phillips, Harvard, and Guest models. For example, in Gast's model, there is no mention of background factors such as structure, culture, and communication, and its focus is on the realization of organizational goals through the satisfaction of employees. In other words, it lacks an outside-in attitude, that is, it does not pay any attention to the importance of obtaining the satisfaction of external stakeholders and how human resource management affects the results of customers and society (Rezaee, Seyed Javadin, Ganjali, & Abdollahi, 2017). In this research, it has tried to focus all the strategies, processes, and functions of human resources management on the satisfaction of the nomadic community in the first place, unlike the existing models that lack strategic direction and whose goal is only to get the satisfaction of the employees and achieve the desired organizational results. The current research can be the beginning of a new movement in which other aspects of the immediate environment, including the direction of the organization, leadership, infrastructure, culture, and communication, are aligned to satisfy the organization's clients and support this direction. Unlike the previous models, which lack an outward-inward attitude. Finally, based on the findings of the research, it can be said that managers should not have a dimensional view of HRM human resources management, but should have a holistic view. For human resource management to be successful in a customer-oriented way, other aspects of the immediate environment, including the organization's strategy, structure, culture, and communication, must support this orientation. Based on the findings of the research, it is not enough to focus only on the human resources system to improve the relationship with the clients, all aspects of the environment close to the human resources should be aligned with the client-centered orientation. According to the findings of this research, the results of the clients are under the direct influence of the background requirements, i.e., the orientation of the organization, infrastructures, culture, and communications, as well as under the influence of the strategies, processes, and functions of human resources. Therefore, one should not expect favorable results to be achieved just by focusing the strategies, processes, and functions of human resources on the needs of the clients. The proposal of this article, in line with the results obtained, indicates that special attention should be paid to the participation of employees and to create the necessary platforms to gain the trust of employees and include them in organizational decisions so that decisions in the field of sustainable HRM become more visible and to be operational.

AUTHOR CONTRIBUTIONS

A. Hosseinkhani Asl performed the literature review, experimental design, analyzed and interpreted the data, and prepared the manuscript text and manuscript edition. N. Jazani and J. Mehrabi performed the experiments and literature review, compiled the data, and manuscript. All authors contributed to and approved the manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER NOTE

Tehran Urban Research & Planning Centre (TURPC) takes a neutral position about claims on disputed territories, place names, international boundaries, jurisdiction in published maps, and institutional affiliations. TURPC is committed to retracting a paper after its publication if it becomes apparent that there are serious problems in its content, in terms of research and publication ethics (https://www.ijhcum.net/journal/process?ethics).

ABBREVIATIONS (NOMENCLATURE)

HR Human Resource
HRM Human Resource Management

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Review Paper

Advances in community participation strategies: A revisit panacea to strengthen infrastructural provision

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ABSTRACT

The provision of infrastructural services in developing countries like Nigeria has not received adequate delivery in the past decades. This situation is growing increasingly alarming given the present economic downturn, political manipulations, and uncontrolled population increase, especially in the urban areas, which remains a major hindering factor. Communities are undergoing regression in countless facets of development. Community participation in the provision of infrastructure stands as a potential option for the citizens to utilize effectively, rather than depending on the government. Community participation maintains equitable and communal assets in providing a basic need within the community. The government, whose role is to provide the essential infrastructures and basic social amenities, has been overwhelmed and termed incompetent in this aspect. This study aimed to revisit the need for community participation in the provision of infrastructure. The objectives identified potential determinants, especially in Nigeria's situation, limiting the public citizens' involvement. The study adheres to a desk research method. This approach gives access to converge information from available sources, which also includes hand-searching of grey literature and related articles. Study findings revealed a very low level of community participation practices exposed from the few data available in the literature. However, there is a paucity of empirical studies on the hindering glitches towards participation; therefore, this review fills this gap in the literature. Moreover, continuity in the participation process at this time is needed, given the potential embedded in infrastructure provision and quality of life. Recommendations focused on introducing sustainable approaches and tools as a remedial factor in attaining success in community participation.

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INTRODUCTION

Cities in both developed and developing countries serve as a mechanism of growth that provides opportunities in different sectors and levels. Cities provide job opportunities, better healthcare services, academic facilities, enhanced commercial activities, and better infrastructural facilities (Kamau *et al.,* 2021, Orekan, 2015). These available facilities in urban cities stand as a pulling factor responsible for rural-urban migration leading to an increase in population in the cities. The geometric rise in population in urban areas is recently outgrowing the available infrastructures and services (Selod, 2017, Duranton, 2014). The need for adequate and functional infrastructural facilities cannot be overemphasized especially for city dwellers. They are essential components necessary for the adequate growth of towns and cities (Okosun, 2017 and Olugbamila et al., 2020). Developing countries are usually not equipped to cope with the growing demand for the needed infrastructure. This usually results in inadequacy in life survival resulting in urban worries (Kamau et al., 2021). Availability and the quality of city infrastructures are noted to create either positive or negative impacts on the welfare of citizens and economic consistency (Kamau *et al.,* 2021). The deficits in urban infrastructure represent a reflection of complete resource limitations at the city level (Meskerem, 2019, Kamau et al., 2021). The Nigerian environment is plagued with numerous failed public infrastructure projects. Thousands of them are regarded very expensive costing billions for the government to provide and maintain (Abdullahi and Sieng, 2023, Orekan, 2015). The majority of the citizens have been denied access to these basic infrastructures which are needed for daily life existence (Nnamdi, 2016, Micheal and Chathan, 2022). Unfortunately, Nigeria still faces weighty challenges with the awful state of its infrastructures showing grossly inadequate (Umuanna, 2022). These infrastructures range from a power supply, adequate housing, roads and rail lines facilities, water supply, drainage system, and irrigation systems among others. The poor state of some of these infrastructures has created an enormous weight on local and foreign businesses impacting the economy negatively and causing lots of difficulties in accessing markets places because of derelict situation of roads with evidence of portholes and bad drainage facilities (Umuanna, 2022, Asaju, 2023). This situation has resulted in a severe hostile business environment and low productivity affecting livelihood (Hassan and Nor, 2017). Asaju, (2023) pointed out that the investment in infrastructure in the country has remained so insignificant over several years with records of huge deficit. However, studies from the literature equally revealed that the highest investment in infrastructure in Nigeria stands at an estimated amount of $664.00 per capita per annum which constitutes 3% of the national gross domestic product (Asaju, 2023 and Blessing and Peter, 2020). Availability of basic infrastructural facilities is increasing as a delinquent issue, with very little attention and a more prominent situation in some regions (Olufemi, 2014). The major factor lies in the resources needed for the provision of infrastructures that are not readily available. However, political-interest group agitation and lobbying are characterized by nature in democratic governance towards the provision of infrastructural facilities especially in Nigeria (Oladeji, 2021). Other strong reasons accountable for the appalling situation include insufficient funding of infrastructural projects (Umunna, 2022, Olufemi, 2014). Corruption and shoddy contracts have perpetuated deeply in the system denying the citizens access to these vital needs forming a very huge deficiency in the country (Oyedeji 2021, Asaju, 2023). Several scholars have also quoted irregularity in government policies as one of the foremost reasons for infrastructure failure in Nigeria. Inconsistency in policies noted in frequent leadership changes sometimes results in suspension of current projects and programs ending up in abandonment (Nnamdi, 2016). The rising demand for the most essential infrastructures in different regions of the country is increasingly generating the need for different providers to participate in improving the situation (Odunola *et al.,* 2022, Eziyi, 2009). Providers will include both private establishments, Non-Governmental Organizations, and stakeholders. Philanthropist, individual involvement, and community participation effort. Odunola *et al.,* (2022) pointed out that the concerns about infrastructure inadequacy have created a platform for the basic once to be anchored through community participation rather than waiting for government-overwhelmed and politicized provision. The problem lies in continuity, especially with individual members' involvement in participation giving the current economic situation in the country that seems overwhelming. The challenge

ranges from inflation and continuous rise in the cost of items, to poor income that does not match up with household expenses, resulting in general hardship. Engaging sustainable participation practices with the use of justifiable tools will serve as an option for effective community participation. This study is expected to cover this discovered gap in knowledge. The outcome of this review is expected to align with the emphasis on achieving sustainable practices and growth for community participation. This was highlighted recently in the United Nations' Agenda for SDGs with its 17 targets. Among these targets are community participation issues in providing basic facilities necessary for upgrading living conditions (Ugwu and Aruma, 2019). Community participation is a generally accepted concept in the development process, having been recognized as a reform needed for upgrading and improvement. Inyang *et al.,* (2019), George and Natiul, (2020) confirmed that the advocacy of community participation brings a lot of enduring benefits to community people apart from getting the needed things done. The concept harmonizes people together in providing and making important decisions about the environment. It promotes a sense of ownership and control among the people since they are actively involved even with their finances (Kenneth and Matthew, 2023). Therefore, this study aims to assess the advances in community participation strategies as a catalyst to strengthen infrastructural facilities in Nigeria's urban areas.

METHODOLOGY

This review observed a desk research study method. This approach gives access to converge information from available sources, which also includes hand-searching of grey literature and related articles (Havryshko, 2024). Much information from past studies and scientific databases was obtained from journals, articles, and books. The scientific database employed comprises ResearchGate, Science Direct, Google Scholar, and Scopus. The process helped to identify gaps in knowledge for additional contributions. It also aided the reliability and legitimacy of findings. The concluding results were then scanned for relevance upon this selection to the review by screening the abstracts and the titles. The appropriate and related articles were then downloaded and reviewed carefully. This process helped to establish a list of 100 references at the end of the information gathered.

Global view of community participation

Community participation has remained a generally accepted concept and effective terminology in the development and improvement of communities. Its principles and methods all over the world are visible from several policy guidelines adopted in different countries (Mohammed, 2016). Zizipho and Cronje, (2021) stated that communities across the developed countries of the world have successfully employed various forms of community participation initiatives to solve specific needs of the people, which have led to substantial improvements in life quality for the residents. This is usually based on balanced and objective planning and strategies. Strategies adopted include joint community clean-up donations and community fundraising, community outreach programs, community town hall meetings, community health and wellness fairs, and education and literacy programs. Others include community garden maintenance, voluntary firefighters, youth training and mentorship programs, and many others. The success of engaging the community members also demonstrates the power of community participation in addressing pressing societal issues, therefore, deepening democracy at the grassroots (Meskerem, 2019, Ngilambu and Mccubbin, 2017). Community involvement is a reflection of grassroots or bottom-up development projects that are of great advantage to the people whose voices are not easily heard by the government. It is regarded as a global problem-solving mechanism that regulates policies and programs intended to improve the quality of life. It embraces the active engagement of individuals which including men, women, and youths, within a community to solve a problem, regardless of age, status of citizenship, socioeconomic value, political association, religion, or educational qualification, among others (Kenneth and Matthew, 2023). Zizipho and Cronje, (2021) confirmed that community participation occupies an outstanding place in the structure of American society. It is one of the main forces that collectively bring ideas, individuals, and solutions in pursuit of creating better and more comfortable communities, irrespective of individual beliefs and culture. Engagement in community projects helps in mobilizing local resources and

capacity, and the realization of common goals and visions. Similarly, participatory theory presented as part of the Basic Needs Approach to development assumes that participation of community members will make decision-making processes more inclusive to instigate ownership over the development processes, resulting in reliability and sustainability (George and Natiul, 2020). The terms include people-centered development, self-reliance, capacity-building mentality, equality, and empowerment. It grew out of the recognition that the urban poor have undergone much suffering as a result of development (Laura, 2011). It buttresses the fact that everyone needs to be involved in development processes starting from the initiation stage, decision-making, execution, and benefits aspect (Mohammed, 2010). The clearness of this theory is expected to function along with two different dimensions, which are the Social Movement Orientation and Institutional Orientation. The Social Movement Perspective defines participatory theory as a means of mobilizing people to have a say within their community and also eradicate unequal power that affects the distribution of available resources (George and Natiul, 2020).

Community participation in infrastructural provision in Nigeria

The infrastructural facility in a developing country like Nigeria is meant to stand as a strength behind development, economic growth, and stimulants for foreign investors, and thus, remain vital for poverty reduction (Okolie and Udo, 2023). However, the available infrastructure is noted to have fallen below standards regarding quantity and quality, especially within the urban communities (Adejugbagbe, 2020). Several citizens have to rely on other alternative providers that have been described not unreliable, unsafe, costly, and often provided by Self-help Groups (SHGs) for profit purposes. In general terms, infrastructures are supposed to be a non-profit focused project, and both the provision and maintenance ought to be funded with public funds (Okosun, 2017). The most common pointers of insufficient infrastructure delivery in a settlement are the vital ones that include potable water supply, bad roads, and transportation routes, poor environmental sanitation infrastructure, and inadequate health facilities (Arnstein, 2019). All these indicators are almost lacking and inadequate in Nigeria's environment, signalling insufficiency in supply. The failed agenda from the Government to meet the needs of its citizens prompted the demand for different providers' efforts (Okosun and Olujimi, 2019). Table 1 shows the studies on commitment made by providers informed of community participation. These efforts are meant to be encouraged for continuity, as the state of infrastructure seems to be deteriorating speedily in some communities.

Determinant of community participation success

Community participation in the provision of infrastructure is inevitable, especially in developing countries where such vital needs and services are wanted. However, there are several factors influencing its success. Fakere *et al.,* (2018). pointed out that the socioeconomic and demographic factors of participants remain significant in determining the level of success and engagement in a community project. It is vital to recognize the levels and determinants of the community participation process as some determinant factor poses a challenge in realizing the motive behind participation (Adewumi and Deborah, 2021). The following listed points have been discovered to have influenced individuals' involvement in community activities.

Level of education

The impact of educational attainment has been revealed as a critical determinant of why some people are actively engaged and others are not participating in matters affecting the community where they live (Elizabeth Young, 2011 and Farmer, 2017). Educated people are noted to be more inclined to address challenges that affect their immediate environment because they have a better understanding or rather the implications of such challenges seem to affect them more than those with a low level of educational attainment (Elizabeth Young, 2011, Flanagan and Peter, 2010). However, individuals with lesser educational achievement are also assumed to have little stake or input in decisions or policy changes that will improve the community. The reason could be traced to their low-level features such as lesser investment, and low income/wages generating a lack of interest in other activities (Campbell, 2009). Nigeria situation of educational attainment has remained so low for the past several

Table 1: Studies on community participation in Nigeria

Region / State	Level of participation	References
Akure (South West of Nigeria).	• The study assessed community participation in the delivery of environmental sanitation infrastructure in Akure, Nigeria. The result revealed that the community participation role was insignificant in this provision, revealing government effort as the major role (1) (2)	(1) Olugbamila et al., 2020 (2) Adanlawo, 2015. (3) Okosun, 2017 (4) Mailumo et al., 2021 (5) Fakere et al., 2018 (6) Odunola et al., 2022 (7) Veta, 2021 (8) Yusuf et al., 2020 (9) Adesida and Okunlola, 2015 (10) Ofuoku, 2011 (11) Omowunmi and Albert, 2023 (12) James, 2018
Ilawe-Ekiti, (South West of Nigeria).	• The study investigated the participatory role that involved Self-Help Groups in the development of infrastructures. Sources of funds include individual membership contributions, annual fees, and donations from philanthropists and Landlords' associations accounted for 58.8% of the funds raised (3)	
Ekiti State. South West of Nigeria.	• The study examined the progress of infrastructure development associations in the state. The findings exposed many problems, including the low level of participation among the communities, political influence, economic downturn, funding, and logistics hitches (3)	
Jos town, Plateau state. Northcentral	• In this study, the extent of community participation in solid waste management was assessed. The result revealed a lack of commitment and inadequate waste infrastructure. A recommendation was made for a waste management fund to be established among the community members to meet some of the solid waste management facility costs (4)	
Akure/ South Western Nigeria	• The study evaluates the perception of the inhabitants on community participation in infrastructure provision. The result showed that residents are aware of the different forms of participation, but the level of deficiency in social responsibility and participation is very low. (5)	
Ido / Oyo state	• This study assessed the perception of the residents on community involvement in infrastructure improvement. The result revealed the major role executed by community-based organizations within the community is noticeable in serving as the public voice, an aspect vital in communication for effective participation. The research further recommended that citizens should be more committed to their social involvement obligation (6)	
Niger Delta region	• This study sought to investigate factors influencing community involvement in development projects under a Micro Project Program. Borehole water, generator-house, health centers, staff quarters, and markets were the projects executed. Insufficient delegation of authority to the grassroots, lack of communication, and corruption among the community heads, among others, were the major problems. (7)	
Kwara State (Southwestern region)	• This study evaluated community participation in using the organization and attendance at meetings, using financial contribution as a source of fund generation. The result revealed high weighted mean scores of 1.62 and 1.50, respectively, on financial contribution. Also, community participation tended to increase, especially among individuals with higher monthly income, fewer projects' individuals participated in, and higher perceived sustainability of the projects (8)	
Ondo state	• The study examines the impact of rural households' participation in the sustenance of the available infrastructure. facility. The rural households participated through payment of counterpart funds, replacing scratched project parts, providing manual work assistance, securing the project site, fencing of projects, and presence in regular meetings to review projects (9)	

Table 1: Studies on community participation in Nigeria

Region / State	Level of participation	References
Delta state (South, South region)	• The study investigated a community water project that was co-funded by members of the community. This funding was noted to be more highly sustainable than that exclusively funded by governments. The community members were organized through the formation of committees, social groups, and weekly meetings (10)	
South West Nigeria	• The study investigated the effect of ideal community contribution on sustainable development in Southwest Nigeria. The result revealed that the optimum community participation strategy influenced the delivery of primary health care services and other economic development (11)	
Eastern Region, Nigeria	• The study investigated the development of schools to collaborate with proprietors by involving Parents/Teachers Associations, Age groups, Traditional leaders, Village Development Associations, and Religious, Political, and Alumni associations in solving the problems in public schools. The result showed a positive response (12)	

decades. UNESCO report places Nigeria among the 41 countries in the world with high records of illiterate level (Ifijeh *et al.,* 2016). The country is also known among the list countries in the global literacy index with 66% of records ranking 161 out of 184 in the world literacy index (Anthony et al., 2022, Ifijeh *et al.,* 2016). The quality of public education in the county is also degrading rapidly affecting another aspect of the economy. However, cultism, drug use, misconduct, community clashes, violence, armed robbery, human trafficking, kidnapping among others are growing on the increase leading to more illiteracy (Oladele and Afolayan, 2010). Birabil and Ogeh, (2020) pointed out that education attainment remains a basis for growth and progress of any nation. Illiteracy extremely impacts on development and progress of communities. This situation could be the reason behind the low turnout in community participation, especially in the provision of infrastructural facilities. The effects of educational attainment equally result in other complications such as poverty cycle lack of employment and higher chances of poor health (Anthony *et al.,* 2022, Oladele and Afolayan, 2012).

Income inequality

The income level of individuals plays a major role in achieving both participation and participatory success (Aschalew and Teferee, 2016). However, it is assumed that high-income individuals will participate better than the lower-income group (Aschalew and Teferee, 2016). Income inequality at community levels has contributed to success and failure in terms of community participation in development (Laura, 2011). Broadening income inequality in developing countries like Nigeria is a growing challenge of our time. The gap between the rich and the poor is at its peak stage. As most people say, 'the poor are getting poorer while the rich are becoming richer. Akinbobola and Saibu, (2004) pointed out that people are considered poor when their estimated living standard in terms of income level and consumption cannot match up to the poverty line. Poverty is regarded as a condition of deprivation and subjection to a lower living, resulting in reduced health and life expectancy (Akinbobola and Saibu, 2004). This situation makes the lower-income group practically redundant and inactive in community activities. A continuous lack of empowerment capacity restricts their adoption in practically everything (Chimobi, 2010). Educated individuals do not necessarily mean they will be employed. The worst scenario occurring in Nigeria today is that millions of people with higher educational attainment are without a well-paid job. Most of these vibrant youth in these categories are being classified as lower-income earners. These are the people who could have been more relevant in community participation projects.

Unemployment rate

Unemployment factor is a major setback and a critical community participation. A potential 35% of individuals in Nigeria between the ages of 15 and 34 years are termed unemployed (Nnachi and Ugochukwu, 2023). This implies that these categories

of people are readily available to be employed and vigorously seeking work (Olayemi et al., 2023). However, 28% of active youths within the workforce are formally regarded as underemployed, working almost 20–39 hours within a week Federal Ministry of Youth Development (FMYSD, 2022). This situation has grown worse recently with increasing economic downturn, inflation, and increasing population growth when compared with the number of qualified jobs available in the country (Nelson, 2023). Unemployment has negative effects on health (Picchio and Ubaldi, 2023). The physical health of an individual deteriorates when unemployment continues because certain unhealthy behaviors, such as smoking, violence, depression, and unruly behavior tend to set in (Filomena and Matteo, 2023, and Pohlan, 2019). Gaining employment in Nigeria is already skewed to favour those who are highly connected and not based on merit (Nwankwo and Ifejiofor, 2014). Many highly qualified people with evidence of educational attainment are left wandering about and missing out on the income they would have earned to partake in community projects (Dumbili and Nelson, 2022, Dele-Adedeji et al., 2021).

Age Range / Family Size

Age range is considered a significant determinant of participation (Fakere *et al.,* 2018). Several scientists have argued that age factor influences people's participation, especially in local communities. Parks and Kim, (2014) stated that the age group that is mostly active in participation is between 30 – 45 years. Older individuals are also noted to be more actively involved in community meetings and discussion forums. Studies from the literature also revealed that people between the ages of 50 and 74 are more willing to attend community consultations and other engagements (Parks and Kim, 2014). Age was a potential determinant factor in the delivery of community primary healthcare services in the Bayelsa community (Diri and Ighedose, 2024). Younger people may show up nonchalant and ignorant attitude in engaging while old people may be too exhausted to participate (Fakere *et al.,* 2018). However, the young youth are more active and sociable to participate (Diri and Ighedose, 2024). The number of family size is also another factor that tends to impact the level of individual participation (Jacinta *et al.,* 2021). Households with smaller families are usually more willing and active because they have fewer burdens (Hu *et al.,* 2022). However, Studies attested that people with lower family sizes tend to contribute more to development programs because small family size households enjoy better living conditions which impact better understanding and progressive mentality compared to those with higher family sizes (Mohammad, 2010, Aschalew and Teferee, 2016).

Economic challenges

The recently intensified economic crises in Nigeria are giving rise to incessant inflation, loss of businesses, hunger, stive, and violence. This situation tends to worsen and hinder the active involvement of individual participation in community affairs and development (Ovwasa and Onimisi, 2021). The economic condition in any region as well as its centralized system is vital to its sustained survival (Ngwube and Ogbuagu, 2014). Economic activities are growing low with hyperinflation on the increase (Omowumi and Bamidele, 2018). This awkward condition results in low savings, low investment, increase in unemployment, underemployment, restraint in employment, poor salary structure, reduction in consumption rate, and eventually, declining gross domestic product (GDP) (Lanyue *et al.,* 2023). The standard of living is also affected greatly as several homes could no longer accommodate three times feeding as usual, school fees payment, and other essential needs. Social pointers are presently projecting continuous difficult access to food production, health services, clean water, energy, affordable housing, education, and health services among others (Onyekpe, 2022). Prevalent and severe poverty is a growing concern that portrays a lack of clothes, education, food, and other essential basic services. The poor citizens find it difficult to survive because they lack almost all the basic provisions needed for survival (Omowumi and Bamidele, 2018 and Chimobi, 2010). All these economic crises are bound to reduce the extent of individual participation in community development.

Exploring the benefit of community participation

The ineptitude of the government effort and the public sector in providing the necessary infrastructure prompted community members to engage themselves in providing some of these basic needs within their capacity (Abdullah *et al.,* 2014). Participation is a robust concept that differs in its methods and definitions. Its meaning varies

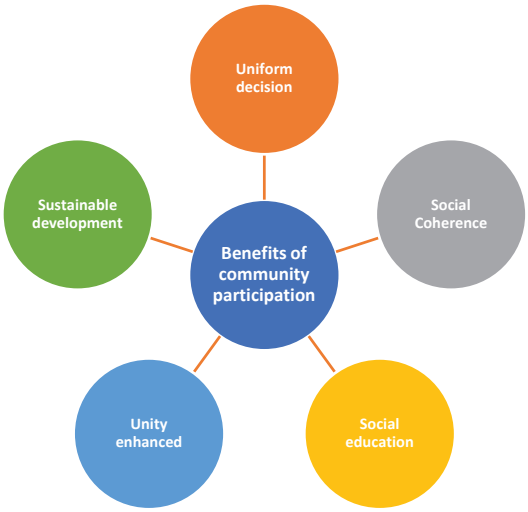

Fig. 1: Benefits involved in community participation.

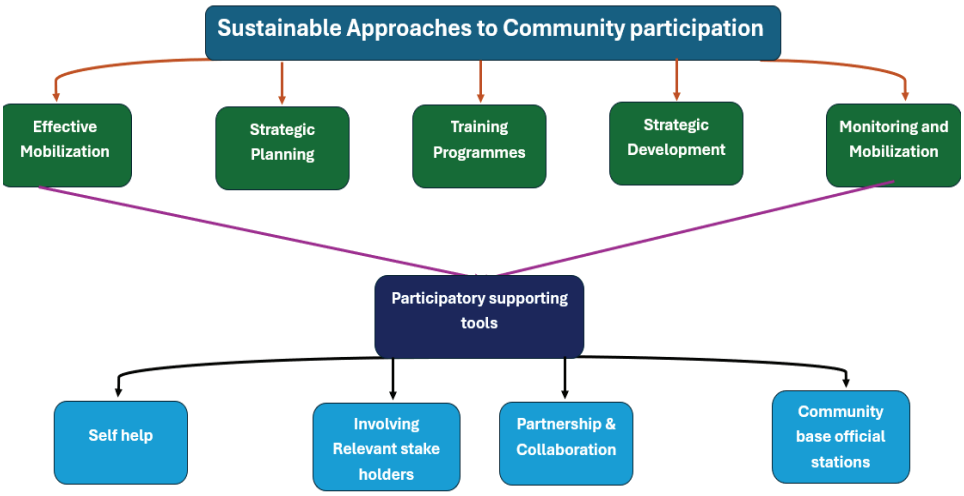

Fig. 2: Sustainable approaches and supporting tools to enhance community participation

depending on the context of use or occurrences. From a general context, it can be regarded as a principle, while for other occurrences it is a practice or an end in itself (Kleemeier, 2000, Musa and Ifatimehin, 2011). The merit of its principles lies in freewill participation. Chimobi, (2010) defined participation as an avenue to prepare the citizens and also improve their ability. It is content that determines decisions on how the community can be better and impact itself (Odunola *et al.,* 2022). However, the advocacy of community participation believes that it brings a lot of enduring benefits to community people apart from getting the needed things done (Yusuf *et al.,* 2020). The concept of community participation harmonizes people together in providing and making important decisions about their environment (Omowunmi and Albert, 2023). This is because the government is failing to spread resources in the areas of providing the needed infrastructural facilities, such as good roads, electricity (transformer), educational institutions, potable water, and primary health care services, among others (Omowunmi and Albert, 2023). Community participation promotes a sense of ownership and control among the people since they are actively involved even with their finances (Kenneth and Matthew, 2023). Fig. 1 revealed other

benefits embedded in community participation.

Sustainable participatory approaches to community participation

Improving our environment and residential communities remains crucial in the general context of the sustainability goal of the SDGs (Ibimilua and Ayiti, 2024). However, achieving this development will involve community members fully participating. This aspect must be stimulated despite several hindering situations generating an obstacle to deter active participation (Kobani 2022, Olaleye, 2019). Sustainable development is engineered from the need to preserve the environment and natural resources to meet the demand for the present and the future (Ibimilua and Ayiti, 2024). Securing the growth and improvement of human culture is also pertinent (Dokubi, 2021). Fig. 2 revealed several approaches and supporting tools that can promote effective, sustainable participation in development within a community. Among these approaches are summarised under five subheadings.

Effective mobilisation

Effective mobilization is one major tool for stimulating people to take action toward engaging in the sustainability of community development projects (Olaleye, 2019; Kobanu & Alozie, 2019). It accommodates briefing and updating community members on the need and the importance of the project development. It is a factor that must be reckoned with in promoting participation. Mobilization is a tool to create opportunities to encourage discouraged, deprived, underprivileged, marginalized, and poor individuals (Ovwromoh *et al.,* 2023). The individuals in this category hold lesser satisfactory of consciousness in terms of the development that is required to improve their livelihood prospects. Therefore, it is indispensable to organize mobilization avenues for them. It encompasses creating awareness in the community in terms of the needs, building and promoting community organizations, generating policies and measures towards achieving the desired agenda, and building empowerment opportunities among the people (Dokubi, 2021). Mobilization is also noted as a significant aspect of improving economic development, especially in developing countries like Nigeria (Olaleye, 2019; Ugwu and Aruma, 2019). The United Nations Organization describes mobilization as a process that involves the combined effort of the people themselves in building a resilient community that is self-dependent in providing most of their basic needs (Olaleye, 2019).

Strategic planning

Planning is an essential requirement in attaining the scale of participation. It is known as a tool that bridges the gap between the present and the future (Chukwuemeka and Catherine, 2017; Olaleye, 2019). Planning also focuses on the attainment of goals and objectives. Adequate planning accommodates resource planning and management, fund sourcing, events, and task management (Ovwromoh *et al.,* 2023). It gives access to gather ideas and opinions from different people, especially when meetings are organized (Ovwromoh *et al.,* 2023). Most developing countries have set up Community-Based Planning Committees, which involve engaging community members in the planning process. This was designed to promote and encourage individuals to participate in community activities (AICDD, 2018). The process follows an orderly analysis among the local community people who participate in planning community development and intervention programs (AICDD, 2018). It also involves disseminating the action plan, monitoring, and evaluating the process to achieve the overall aim. The benefits of planning include supporting community engagement and enhancing the validity of the project. it improves expectations because community members are well-informed. First-hand information is conceived because the communities are carried along. Progress can easily be monitored and manipulations can be prevented (Zanudin *et al.,* 2021).

Training programmes

Organizing training sessions and networks is a useful component of community engagement. It is built upon the philosophy of providing a new and reachable way to bring people to participate in the things that will benefit their lives and the community at large (Ovwromoh *et al.,* 2023). Ewelum and Mbara, (2015) pointed out that with the training exercise, community members would be prepared with adequate information and skills

for better involvement in community issues. Training of community members is categorically required to bridge the gaps between demand and the scale of preference. It determines actions to be considered and deficiencies that will be dropped for effective task performance. Ovwromoh *et al.,* (2023) explained that training programs organized for individuals who are actively involved in community participation resulted in a huge success. The aim was to develop certain skills and abilities that will enhance their capabilities to carry out their roles and activities in a convenient manner. Both formal and informal training activities should be incorporated through group leaders to enhance communication and fund donations that will sustain community projects (Ewelum and Mbara, 2015; Ovwromoh *et al.,* 2023).

Strategy Development

Strategies are known as policies, tactics, approaches, and schemes that are vital to carrying out different tasks and assignments (Ovwromoh *et al.,* 2023). These approaches to community participation vary in different countries and regions depending on socioeconomic and political circumstances (Chitambo *et al.,* 2002). For instance, developed countries have adopted strategies such as assessment of problems and community needs using science-based data, setting priorities based on urgent needs, implementation, and evaluation at different stages (Chitambo *et al.,* 2002). Most recent strategies adopted involved individual participation, committee, and representative approaches.

Monitoring and evaluation

Monitoring and evaluation are observed as imperative features that must be put into procedures in community participation, including the execution of other responsibilities and activities (Elikana & Hamidu, 2020). Haldane *et al.,* (2019) pointed out that most organizations and groups generate policies and procedures that are needed for monitoring and evaluation. The major reason behind monitoring and evaluation is to recognize the faults and discrepancies and ensure better measures are needed to bring about improvements (Alqahtani *et al.,* 2015). When monitoring and evaluation take place, the individuals can generate adequate awareness in terms of barriers and challenges that take place in the accomplishment of tasks.

Participatory supporting tools toward sustainability

Self-help support

The role of self-help involvement is now unavoidable as all hope in waiting for government intervention on infrastructural provision is proving abortive. This situation seems to generate severe damage to sustenance and environmental quality. Self-reliance is understood as an attitude that develops from the deep taught of taking responsibility towards reaching out to society's needs (Lester, 2022). The role of self-reliance is evident in the ambiance of sustainable development. The major aim is to provide a remedy to societal challenges within a given capacity and not a continuation exercise or to become self-sufficient and exclusive (Lester, 2022). Etienne, (2000) stated that this trend is mostly used by public and social workers to accomplish a given task. The key mechanisms of this progressive system allow more participative initiatives that will help identify pressing needs to be anchored as self-reliance (THP, 2016). It supports a fight against over-reliance and dependency on the government that limits the silencing capacity of poor citizens (Lester, 2022). This approach can be adopted in specific areas in Nigeria where people have been marginalized in terms of infrastructural provision.

Involvement of relevant stakeholders

The involvement of stakeholders such as non-governmental Organizations, private sectors, donors, politicians, church bodies, philanthropists, and institutional bodies in development projects is widely acceptable as a vital component of the process. This will be engineered from the community members informing of a written document, proposals, or a visit to any relevant choices. Stakeholders' participation is noted to have yielded a better result and management in terms of providing resources and financing for any projects (Zwane and Matsiliza, 2022). This comes into play when the self-help support system seems weak and unachievable. Appropriate and well-planned stakeholder engagement programs have subscribed to several successful community development programs (Erevbenagi and Caldwel, 2016). However, stakeholder participation may not also actualize all the intended objectives despite the observed indication of the achievement (Erevbenagi and Caldwel, 2016). Effective communication is vital between the stakeholders and the community leaders to ensure service efficiency and execution of public projects

(Ngilambi and McCubbin, 2017). Zwane and Matsiliza, (2022) pointed out that stakeholders equally have varied interests in providing public services; hence, they render support in reacting to communities' basic needs and also engage in decision-making stages and rendering progress support needed to execute the public project.

Partnership and collaboration

Partnership and collaboration in development also ensure quick and reliable solutions in achieving the set targets. Partnership, collaboration, and other related terms such as alliance, union, networking, cooperation, and workgroup are used to designate an extensive variability of associations and structures (Walid and Cern, 2009). They are also known as groups of organizations with a mutual motive who decide to work together towards a common goal (Judith *et al.,* 2015). That goal could be narrowed in the form of funding or fund sourcing for a specific intervention (Jessica *et al.,* 2021). Efficient partnering machinery can be used to shape an existing partnership and organize line networks of partners with unique roles and obligations (Makwalete *et al.,* 2018). These network systems produce an environment that permits originality, innovations, ideas, and awareness required for the effective delivery of basic needs at the community level. Concerned partners and collaborators engage in meetings to discuss and solve problems with individuals who are often perceived as leaders in the community or social groups (Jessica *et al.,* 2021). Building and maintaining a good partnership is needed for effective community participation in Nigeria's situation.

Community-based organizations

In Nigeria, there are lots of recognized and unrecognized community-based organizations with visible achievements, especially in the area of social amenities provisions, infrastructure reformation, and maintenance (Odunola *et al.,* 2018, Muhammad, 2016). The continuation of these CBOs following their recorded success in helping the communities and improving lives must be encouraged. The community-based groups include women groups, market women groups, youths, peer groups, volunteers, church organizations, social groups, committees, cooperative societies, school volunteers, and sports clubs. They represent different associations that bring people together to socialize and to address major concerns (Mgawanyemba and Dalitso, 2008). These groups generate funds through donations, contributions, fines, and levies as they address each need. Several scholars have argued that tangible community participation happens within community-based organizations because it is within the community and also managed by the community. These groups have better structure; therefore, participation among them is regarded as more intensive and more genuine (Muhammad, 2016). Their smaller group size of people also enhances the action processes, and members are also encouraged to participate more.

CONCLUSION

This review examined the critical importance of infrastructural provision and the need for community participation in this context. This study aimed to revisit the need for community participation in the provision of infrastructure. The objectives identified potential determinants, especially in Nigeria's situation, limiting the public citizens' involvement. The necessity of these provisions arises as a result of countless development regressions in various communities in Nigeria's urban areas are lacking regarding infrastructural availability and the growing economic downturn. The review highlighted the usefulness and the basic reasons behind participation despite the determinant factors that could hinder individuals' responsiveness, given the present situation in Nigeria's urban areas. It is worth noting that a lack of infrastructure and ineffective development are attributed to the non-applicability of optimum community involvement. The non-participation or engagement of individuals within communities tends towards greater challenges and deterioration of life, especially when basic services necessary for life survival are lacking. Therefore, community members should not relent efforts. The major postulation is that the exertion from community members can support the improvement of the environment and the quality of life of the people by making available the basic infrastructures that will support life. The element of ideal community participation should be accepted as an absolute tool that augments development/community projects. Community members should be equipped not as beneficiaries of development programs but rather, become relevant stakeholders with an important

role to play in providing basic needs. The success of community participation in developing countries such as Nigeria will depend wholly on utilizing sustainable approaches, considering the present situation of severe economic downturn affecting both family income and expenses. The sustainable approach to participation will require the active effort of members in planning, organizing, and adopting several strategies that will generate funds rather than relying on self-funding / donations. The various sustainable tools and approaches should be utilized to the fullest to achieve success. A dodged, continuous, and determined effort by community members can solve challenges, including basic needs such as health care centers, schools, water provisions, transformer provision for electrification, and drainage facilities.

AUTHOR CONTRIBUTION

G.U. Fayomi performed the literature review. O.P. Akinpelu conceptualized the research and reviewed the literature content. E.K. Onyari supervised the research.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS (NOMENCLATURE)

SDGs Sustainable Development Goals

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REVIEW PAPER

Investigation of atmospheric corrosion risk mitigation processes for urban structures: Effective strategies for sustainable development

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ABSTRACT

Atmospheric corrosion poses a significant challenge to steel structures in urban environments, severely impacting their safety and durability. This paper examines effective processes for mitigating atmospheric corrosion risk and suitable strategies for sustainable development. One of the most important and effective methods for combating corrosion, particularly atmospheric corrosion in polluted cities like Tehran, is the use of protective coatings. These coatings, such as epoxy and polyurethane, act as barriers against moisture and harmful agents, preventing damage to structures. Additionally, cathodic protection techniques are explored as an effective means of preventing electrochemical corrosion. By utilizing sacrificial anodes, these techniques significantly reduce the detrimental effects of corrosion. The selection of appropriate materials, considering economic costs and availability, also plays a crucial role in minimizing corrosion risk. For instance, the use of stainless steel and corrosion-resistant alloys can enhance structural performance under harsh conditions. Furthermore, design requirements and the reduction of vulnerabilities in structures must be considered to extend their lifespan. The results indicate that incorporating these strategies into urban planning and design can enhance the durability of metal infrastructure, contributing to a safer and more sustainable urban life. These measures not only help preserve investments but also improve the quality of life for citizens.

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INTRODUCTION

Urban metal infrastructures play a vital role in the functionality of modern cities like Tehran, being utilized everywhere from transportation networks to public services. However, one of the greatest threats to these infrastructures is corrosion processes, particularly atmospheric corrosion in polluted urban environments, especially in steel structures essential for safety and durability. If not properly managed, atmospheric corrosion can lead to high repair costs, unsightly appearances of structures, increased maintenance needs, and even catastrophic failures. As urban environments continue to evolve and face new challenges such as climate change, pollution, and increasing traffic, the importance of effective corrosion management strategies becomes increasingly evident(Chen *et al.,* 2022; Fang *et al.*, 2022; Kumar*et al.*, 2023, Meziane *et al*., 2019). In today's world, protecting urban infrastructures like metal structures is crucial for economic stability, public safety, and quality of life. While steel structures are strong and durable, they are susceptible to various forms of corrosion due to exposure to environmental factors such as moisture, salt, and pollutants like carbon monoxide and sulfur dioxide, which increase the acidity of the environment. This vulnerability necessitates a proactive approach to corrosion management that goes beyond traditional maintenance practices. This paper explores practical and effective strategies for addressing corrosion in steel structures, particularly in the highly polluted environment of Tehran.(Nicoletti *et al.*, 2022; Reinoso-Burrows *et al.*, 2023). Various protective methods, including corrosion-resistant coatings, are of paramount importance, especially for steel structures. These methods must not only be economically viable but also applicable to existing structures. Coatings such as epoxy and polyurethane are recognized as effective options in this regard. They serve as barriers against moisture and harmful agents, preventing damage to the structures (Zhang *et al.,* 2023). In addition to protective coatings, cathodic protection techniques play a crucial role in corrosion management. These techniques utilize sacrificial anodes to prevent electrochemical corrosion, providing an additional protective layer for critical infrastructure. The selection of suitable materials is also particularly important; using stainless steel and corrosion-resistant alloys can significantly reduce risks in challenging environments. It is worth noting that given the challenges present in large urban and industrial environments, adopting proactive approaches and utilizing modern technologies in corrosion management is essential. These measures not only help preserve investments but also extend the lifespan of structures and enhance public safety. Therefore, combining various protective methods with appropriate material selection can serve as an effective strategy for combating corrosion in steel structures(Sundaram *et al.*, 2023; Jasiulewicz-Kaczmarek *et al.*, 2023). Moreover, design considerations and related requirements are vital in reducing corrosion risk. Establishing regular inspection and maintenance programs to identify potential issues before they escalate into serious problems is crucial. These proactive measures not only contribute to extending the useful life of steel structures but also ensure that urban infrastructures remain safe and reliable. By integrating these strategies into urban planning and design processes, the durability of infrastructure can be significantly enhanced, contributing to more sustainable urban living. As cities continue to grow and expand, prioritizing corrosion management to address the challenges it presents and mitigate corrosion risks becomes essential. Thus, collaboration among engineers, urban planners, and policymakers can create a future where urban environments thrive despite the challenges posed by corrosion(Mohammed *et al.,* 2022; Salloum *et al.*, 2017).Modern cities rely heavily on their infrastructure to support essential functions like transportation, communication, and public services. Steel structures, known for their strength and versatility, are a critical part of this framework. However, these structures face a growing threat from atmospheric corrosion, which compromises their safety and durability. This issue is particularly pressing in polluted and industrialized cities such as Tehran, where environmental factors accelerate corrosion, leading to significant repair costs, safety hazards, and negative effects on the city's appearance. Recent studies have explored various aspects of corrosion management, including protective coatings, material selection, and cathodic protection (Chen *et al*., 2022; Fang *et al*., 2022; Nicoletti *et al*., 2022). Despite this progress, limited research has addressed the integration of these methods into comprehensive management strategies

tailored for highly polluted urban environments. Additionally, while new corrosion-resistant materials and coatings have shown promise, their practical application in cities with unique environmental challenges, like Tehran, remains limited. This study aims to bridge this gap by focusing on practical, integrated strategies for mitigating atmospheric corrosion in steel structures, which this research contributes to the development of sustainable infrastructure solutions.However, the novelty of this article focuses on corrosion management and the application of various protective methods to reduce the risk of atmospheric corrosion in steel structures within Tehran, taking into account the city's humidity levels and types of pollutants. It emphasizes the integration of advanced protective measures with proactive maintenance strategies. While existing studies have explored various aspects of corrosion (Sundaram *et al.*, 2023; Jasiulewicz-Kaczmarek *et al.*, 2023, Mohammed *et al.*, 2022; Salloum *et al.*, 2017), such as the effectiveness of coatings and corrosion-resistant materials, there has been limited research on atmospheric corrosion management in industrial cities, as well as its implications for urban planning and sustainable infrastructure development. A key aspect of the study is its emphasis on combining these methods with proactive maintenance strategies to mitigate the risks posed by Tehran's high humidity levels and significant urban pollution. Unlike previous research, which often concentrates on isolated methods or generalized findings, this article provides a tailored approach for industrial cities like Tehran, bridging the gap between existing studies and the specific demands of highly polluted environments. This review article explores the challenges of corrosion in urban steel structures and presents comprehensive strategies for effective management. It begins by discussing the impact of corrosion in polluted urban environments, emphasizing the need for proactive management approaches. Key topics include cathodic protection, the selection of corrosion-resistant materials such as Carbon Fiber-Reinforced Polymers (CFRP), and the role of design considerations in mitigating risks. This study employs a systematic review methodology, rigorously analyzing peer-reviewed articles, case studies, and field reports on urban atmospheric corrosion. By focusing on advanced practical strategies for effective corrosion management. The analysis emphasizes the unique challenges of Tehran's high pollution and humidity, offering a comparative evaluation of these approaches across different conditions. This cohesive framework not only addresses the research problem but also provides actionable insights and tailored solutions for Tehran's specific environmental demands.Key findings highlight the effectiveness of integrating design considerations, material selection, and innovative protective methods in extending the lifespan and enhancing the safety of steel structures, specifically in Tehran. This research, conducted in Tehran in 2023, provides a localized yet impactful contribution to understanding and managing atmospheric corrosion in challenging urban environments.

Corrosion of urban steel structures

Corrosion is a natural phenomenon that leads to the gradual deterioration of metals, primarily resulting from chemical and electrochemical reactions with environmental elements such as moisture, oxygen, and pollutants (Al-ambery *et al.,* 2023; Brown *et al.,* 2018). In Tehran, approximately 75 to 80 percent of air pollution is attributed to vehicles, particularly older and inefficient cars that contribute significantly to this issue. With nearly two million vehicles in the city, many lack the catalytic converters necessary to neutralize harmful gases, resulting in the release of pollutants like nitrogen oxides, carbon monoxide, and particulate matter (Heger *et al.*, 2018). This situation is particularly concerning in urban environments where steel structures are utilized for various applications, including bridges, buildings, and pipelines. The vulnerability of steel to atmospheric corrosion manifests in several different forms, each requiring specific management strategies (Qiao *et al.,* 2022; Mattsson, 1999). Among these forms are uniform corrosion, which leads to even degradation across surfaces; pitting corrosion, characterized by localized damage and the formation of small pits; galvanic corrosion, which occurs when two dissimilar metals come into contact; and stress corrosion cracking, which arises from the combination of tensile stress and a corrosive environment.

Uniform corrosion

This type of corrosion primarily arises from electrochemical reactions that involve environmental elements such as moisture, oxygen, and various

pollutants. When steel is exposed to these elements, oxidation occurs, leading to the formation of rust. This process typically begins when moisture accumulates on the metal surface, creating an electrolyte that facilitates the movement of ions. Consequently, the oxygen present in the atmosphere reacts with the exposed metal, resulting in a gradual reduction of the thickness of the metal structure over time. Several environmental factors significantly influence the rate and severity of uniform corrosion. High humidity levels and the presence of corrosive ions, such as chlorides from saltwater or de-icing agents, can accelerate corrosion processes (Mattsson, 1999; Hwang *et al.*, 2023; Xu *et al.*, 2023). In Tehran, major pollutants include Particulate Matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO). When these pollutants react with moisture, they form acidic compounds that create corrosive environments Eqs. 1 and 2. Environmental factors, such as Tehran's geographical location near the Alborz Mountains, also contribute to the trapping of pollutants, especially during winter months when temperature inversions occur. This phenomenon prevents the dispersion of air pollution and according to Eq. 3, leads to the formation of dense smog Fig. 1 (Heger *et al.*, 2018).

The effects of uniform corrosion typically occur very gradually and subtly. While they may not lead to immediate structural failure, they progressively weaken the material and reduce its mechanical strength. In atmospheric environments, uniform corrosion usually develops at a slower rate compared to aqueous environments; however, it is still influenced by factors such as humidity, temperature fluctuations, and exposure to pollutants. In urban areas, steel structures may be exposed to corrosive agents like sulfur dioxide or nitrogen oxides emitted from vehicles, which can contribute to the formation of acid rain. This acidic precipitation can create a more aggressive environment for the degradation of steel, thereby exacerbating uniform corrosion. Additionally, temperature variations can lead to moisture accumulation on steel surfaces, further intensifying the effects of uniform corrosion (Xu *et al.*, 2023; Liu *et al.*, 2022; Putikam *et al.*, 2018; Xia *et al.*, 2018).

Pitting corrosion

Pitting corrosion is a localized form of corrosion that leads to the formation of small holes or pits in metal surfaces, and it is particularly exacerbated in polluted urban environments like Tehran. The mechanism begins when a protective oxide layer on the metal is compromised, often due to the presence of aggressive ions such as chlorides from atmospheric pollutants or saline conditions (Xia*et al.*, 2023; Zhu *et al.*, 2023; Cui *et al.*, 2023; Li *et al.*, 2022). In Tehran, high levels of humidity combined with pollutants like sulfur dioxide (SO_2) and nitrogen oxides (NO_x) create acidic conditions that further degrade this protective layer (Heger *et al.*, 2018). As chloride ions penetrate the exposed metal, they react with iron to form iron chloride complexes, which can lead to the dissolution of the metal in the pit, perpetuating the corrosion process (Zhu *et al.*, 2023; Cui *et al.*, 2023; Li *et al.*, 2022). The chemical reactions involved in pitting corrosion can be summarized in Eqs. 4, 5, 6, and 7.

$FeO+Cl^- \rightarrow FeCl+OH^-$ (Degradation of Oxide Layer and breakdown of the layer) (4)

$Fe \rightarrow Fe^{2+}+2e^-$ (Oxidation at Anodic Site and Formation of Pits) (5)

$O_2+4e^-+2H_2O \rightarrow 4OH^-$ (Reduction at Cathodic Site) (6)

$Fe^{2+}+2OH^- \rightarrow Fe(OH)_2$ (Formation of Hydroxide in Pit and Pit Growth) (7)

In urban settings like Tehran, where environmental conditions are often harsh due to pollution and humidity, pitting corrosion can lead to significant structural damage if not monitored and managed effectively. The combination of moisture and corrosive pollutants creates an environment conducive to rapid pit formation, which can compromise the integrity of steel structures over time.

Galvanic corrosion

Galvanic corrosion occurs when two dissimilar metals are in electrical contact within a conductive environment, leading to accelerated corrosion of the more reactive metal (anode) while the less reactive metal (cathode) is protected. In polluted urban environments like Tehran, where high levels of humidity and airborne contaminants such as chlorides and sulfates are prevalent, the risk of galvanic corrosion increases significantly. The mechanism

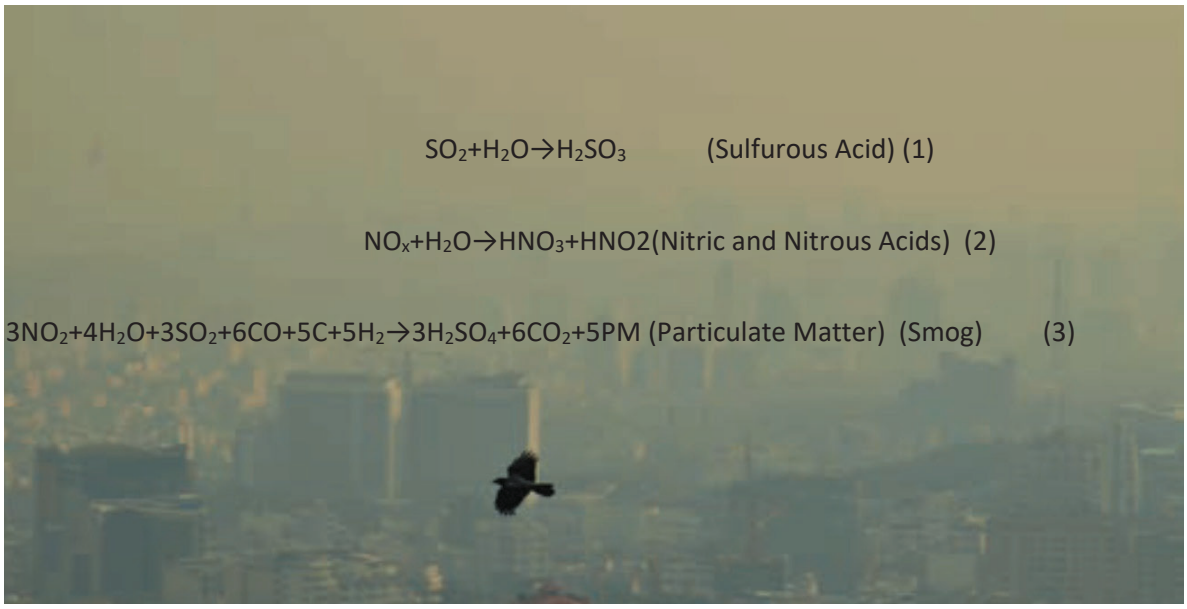

Fig. 1: Schematic of equations illustrating the formation of acidic compounds from pollutants and the impact of environmental factors on air quality and smog formation (Heger *et al.*, 2018)

involves the establishment of an electrochemical cell where the anode undergoes oxidation, releasing metal ions into the electrolyte, while the cathode experiences reduced corrosion due to the protective effect of the anodic reaction (Zhang *et al.*, 2023; Ma *et al.*, 2023). The presence of moisture and pollutants in Tehran's atmosphere plays a crucial role in facilitating galvanic corrosion. High humidity levels enhance the conductivity of electrolytes, allowing for efficient ion transport between dissimilar metals. Pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) can lead to acid formation when combined with moisture, creating an aggressive environment that accelerates corrosion processes (Heger *et al.*, 2018). For example, when aluminum is coupled with steel in a moist environment, aluminum acts as the anode and corrodes preferentially due to its higher reactivity compared to steel. This localized attack can result in significant material loss over time if not properly managed (Ma *et al.*, 2023).

Stress Corrosion Cracking (SCC)

SCC is a significant failure mechanism that occurs when tensile stress interacts with a corrosive environment, leading to the formation of cracks in metals. In polluted urban environments like Tehran, where high levels of humidity and aggressive pollutants such as chlorides and sulfur compounds are prevalent, the risk of SCC is notably increased. The mechanism begins with the presence of tensile stress—either applied or residual—combined with a corrosive medium that can penetrate protective oxide layers on metals. This interaction creates conditions conducive to crack initiation, often at points of high-stress concentration, where microstructural changes occur, leading to rapid crack propagation. In Tehran's atmosphere, environmental factors play a critical role in exacerbating SCC (Jiang *et al.*, 2023; Coréet *al.*, 2018; Yang *et al.*, 2023). High humidity levels provide moisture that facilitates electrochemical reactions, while pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) can create acidic conditions that further corrode the metal. Chloride ions, commonly found in urban pollution from road salts and industrial emissions, are particularly harmful as they can significantly lower the threshold for SCC in susceptible alloys, such as austenitic stainless steels. The combination of these environmental stresses and corrosive agents can lead to unexpected and rapid failures in structural components, making early detection challenging. The effects of stress corrosion cracking can be catastrophic, resulting in sudden

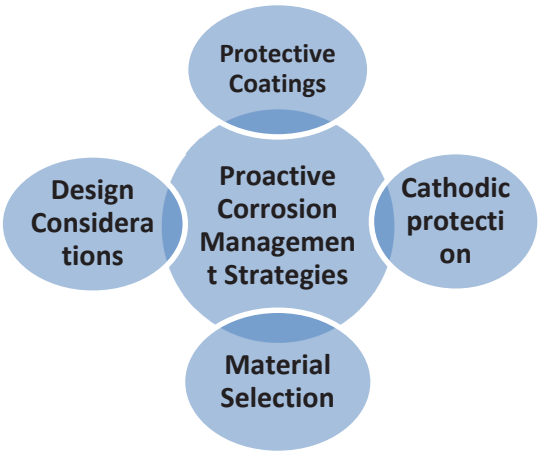

Fig. 2: Overview of proactive corrosion management strategies.

structural failures that pose serious safety risks. Unlike other forms of corrosion that may show visible signs before failure, SCC often remains undetected until it leads to a complete fracture (Coréet *al.*, 2018; Yanget *al.*, 2023). However, understanding these different types of corrosion is crucial for developing effective management strategies tailored to the unique environmental conditions and structural designs found in urban areas.

Proactive corrosion management strategies

Proactive corrosion management strategies are essential for mitigating the adverse effects of corrosion in the polluted atmosphere of Tehran, where high levels of airborne contaminants and humidity exacerbate the degradation of infrastructure. One effective approach involves the selection of corrosion-resistant materials, such as high-alloy stainless steels or coatings that provide a protective barrier against aggressive pollutants like sulfur dioxide (SO_2) and chlorides (Biserova-Tahchieva *et al.*, 2023; Ni *et al.*, 2021; Honarvar Nazari *et al.*, 2021). Additionally, implementing regular monitoring techniques, such as electrochemical impedance spectroscopy, allows for early detection of corrosion-related issues, enabling timely maintenance actions before significant damage occurs. Environmental control measures, including the use of cathodic protection systems and inhibitors to minimize corrosive species in the environment, can further enhance the longevity of metal structures (Biserova-Tahchieva *et al.*, 2023; Ni *et al.*, 2021; Honarvar Nazari *et al.*, 2021; Lazanas *et al.*, 2023; Karabacak *et al.*, 2023). According to Fig. 2, by adopting a comprehensive and proactive approach that integrates these strategies, engineers can significantly mitigate the risk of corrosion-related failures and enhance the lifespan of critical infrastructure in the challenging environmental conditions of Tehran.

Protective coatings

In the polluted atmosphere of Tehran, protective coatings play a crucial role in preventing corrosion of metal structures and components exposed to harsh environmental conditions (Heger *et al.*, 2018; Rahimi *et al.*, 2020). The primary mechanisms by which these coatings function include barrier protection, chemical inhibition, and galvanic (sacrificial) protection. Barrier coatings, such as epoxy and polyurethane formulations, create a physical barrier that isolates the metal substrate from corrosive agents, including moisture and pollutants like sulfur dioxide (SO_2) and chlorides. These coatings are particularly effective in urban environments where exposure to aggressive chemicals is prevalent, as they prevent direct contact between the metal surface and corrosive elements, thereby significantly reducing the rate of corrosion. The selection of appropriate protective coatings is critical in addressing the specific challenges posed by Tehran's environmental conditions (Mattsson,1999; Javaherdashti, 2017; Balachandra *et al.*, 2023). For instance, epoxy coatings are renowned for their

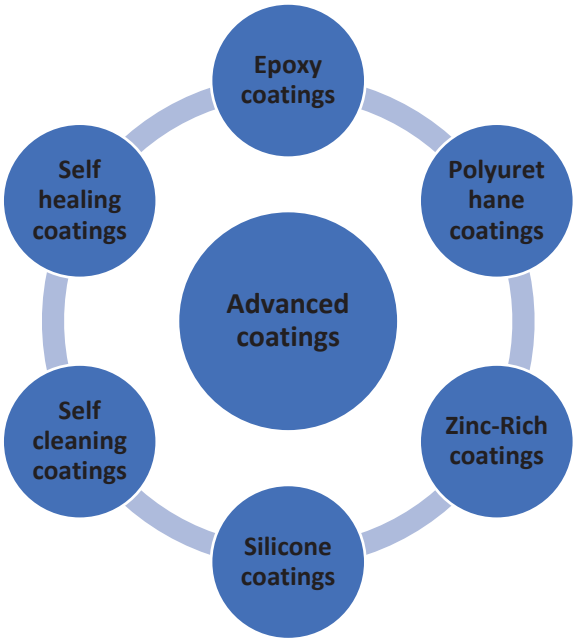

Fig. 3: A view of corrosion-resistant protective coatings suitable for the exterior of urban buildings, which are designed to withstand atmospheric corrosion, particularly under specific climatic conditions and UV exposure.

exceptional adhesion and chemical resistance, making them suitable for industrial applications where metals are exposed to aggressive chemicals and high humidity levels (Balachandra *et al.*, 2023). Similarly, polyurethane coatings offer excellent flexibility and Ultraviolet (UV) resistance, which is beneficial for structures subjected to varying temperatures and sunlight exposure (Xu *et al.*, 2023). Additionally, sacrificial coatings made from zinc or aluminum can provide galvanic protection by corroding preferentially in place of the underlying metal, thus extending the lifespan of critical infrastructure (Nguyen *et al.*, 2023). However, as shown in Fig. 3, several advanced protective coatings can be effectively employed to mitigate corrosion, including, epoxy coatings, polyurethane coatings, zinc-rich coatings, self-cleaning and self-healing coatings.

Epoxy coatings

Epoxy-based coatings are widely recognized for their excellent adhesion, chemical resistance, and durability. They form a robust barrier against corrosive agents, making them particularly suitable for industrial applications where exposure to pollutants like sulfur dioxide (SO_2) and particulate matter is common. The cross-linking nature of epoxy resins provides enhanced mechanical properties, which help withstand the stresses imposed by environmental factors (Balachandra *et al.*, 2023; Zargarnezhad *et al.*, 2021).

Polyurethane coatings

Polyurethane coatings offer superior flexibility and UV resistance, making them ideal for structures exposed to varying weather conditions and direct sunlight. These coatings provide a protective layer that resists moisture penetration and chemical attack, which is critical in Tehran's humid and polluted atmosphere. Their ability to maintain performance over time helps in prolonging the lifespan of metal substrates (Xu*et al.*, 2023; Tian*et al.*, 2023).

Zinc-rich coatings

Zinc-rich coatings provide galvanic protection through sacrificial anode action, where zinc corrodes preferentially to protect the underlying metal. This type of coating is particularly effective in environments with high chloride concentrations, such as those found in urban areas with road salt usage. By utilizing zinc-rich formulations, engineers can enhance the

corrosion resistance of steel structures significantly (Nguyen *et al.,* 2023; Ellingson *et al.*, 2022; Feldmann *et al.,* 2023).

Silicone coatings

These coatings are known for their excellent weather resistance and high-temperature stability, silicone coatings form a flexible and durable barrier on metal surfaces. They are particularly beneficial in harsh environments where extreme temperature fluctuations and moisture exposure are prevalent. Their hydrophobic properties help repel water, thereby reducing the likelihood of corrosion initiation (Zhao *et al.,* 2020; Tao *et al.,* 2023). In the context of Tehran's polluted environment, self-cleaning and self-healing coatings represent innovative solutions to combat corrosion and maintain the integrity of metal structures. Self-cleaning coatings, often based on superhydrophobic or photocatalytic materials, utilize advanced surface chemistry to repel water and contaminants, thereby minimizing the accumulation of dirt, dust, and corrosive pollutants (Cong *et al.,* 2023; Li *et al.*, 2023). For instance, superhydrophobic coatings create a lotus effect, where water droplets easily roll off the surface, carrying away particulate matter and preventing the formation of corrosive layers (Li *et al.,* 2023; Hou *et al.,* 2023). This is particularly beneficial in Tehran, where airborne pollutants can significantly accelerate corrosion processes. Self-healing coatings, on the other hand, incorporate microcapsules or healing agents that can autonomously repair damage to the coating when it occurs. When cracks or scratches penetrate the coating layer, these microcapsules release healing agents that fill in the damaged areas and restore the protective barrier. This mechanism is crucial in environments like Tehran, where the combination of high humidity and pollution can lead to the rapid degradation of protective layers. By maintaining the integrity of the coating, self-healing technologies can significantly extend the lifespan of metal structures exposed to harsh conditions (Shanaghi *et al.*, 2024; Wang *et al.*, 2022; Liu *et al.,* 2022). Both self-cleaning and self-healing coatings provide dual benefits, in that they not only enhance the aesthetic appearance of structures by keeping surfaces clean but also reduce maintenance costs associated with corrosion-related repairs. The implementation of these advanced coatings in Tehran's infrastructure can lead to improved durability and reduced lifecycle costs for critical assets, making them a valuable addition to proactive corrosion management strategies in urban environments.

Cathodic Protection (CP)

CP is a critical technique for mitigating corrosion in metallic structures, particularly in urban environments like Tehran, where pollution levels are high and environmental conditions are challenging. This method involves making the steel structure the cathode in an electrochemical cell by connecting it to a more reactive metal, commonly referred to as a sacrificial anode (Wu*et al.*, 2023; Xu *et al.*, 2024; Goyal *et al.*, 2019; Li *et al.*, 2021).In Tehran, the presence of aggressive pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and chlorides from road salts can significantly accelerate corrosion processes (Heger *et al.*, 2018). By employing cathodic protection, engineers can effectively divert corrosive reactions away from the steel structure, thereby enhancing its longevity and structural integrity. The mechanism of cathodic protection operates on the principle of electrochemical polarization. When a sacrificial anode—typically made from zinc, aluminum, or magnesium—is connected to the metal structure, it oxidizes preferentially, releasing electrons that flow to the cathodic area (the steel). This process reduces the electrochemical potential of the steel, inhibiting oxidation reactions that lead to corrosion (Strebl *et al.*, 2023; Jasim *et al.*, 2023; Martinelli-Orlando *et al.*, 2024; Brenna *et al.*, 2020). In implementing cathodic protection systems in Tehran, several factors must be considered to ensure effectiveness. The design of CP systems should account for soil resistivity, moisture content, and the concentration of aggressive ions present in the environment. Regular monitoring is essential to assess the performance of sacrificial anodes and to ensure that they are adequately protecting the steel structures. Additionally, advancements in CP technology, such as Impressed Current Cathodic Protection (ICCP), can be utilized for larger or more complex structures requiring continuous protection against corrosion (Strebl *et al.*, 2023; Jasim *et al.*, 2023; Mgbemena *et al.*, 2023). However, to optimize cathodic protection systems in the polluted atmosphere of Tehran, several strategies can be implemented that address both environmental challenges and

technical considerations. Given the high levels of airborne pollutants, such as sulfur dioxide (SO_2) and chlorides, which accelerate corrosion processes, it is essential to select appropriate sacrificial anodes that can effectively counteract these aggressive agents. For instance, using zinc or aluminum anodes with enhanced corrosion resistance properties can provide better protection for steel structures exposed to harsh conditions (Strebl *et al.*, 2023; Jasim *et al.*, 2023; Mgbemena *et al.*, 2023; Tamhane *et al.*, 2022; Guo *et al.*, 2024). Regular monitoring and maintenance of cathodic protection systems are also crucial in Tehran's environment. Employing advanced monitoring techniques, such as remote sensing and electrochemical impedance spectroscopy, allows for real-time assessment of the system's performance and the condition of sacrificial anodes. This proactive approach enables timely replacement of anodes before they become ineffective, ensuring continuous protection against corrosion. Also, to optimize cathodic protection systems using green plants in the polluted environment of Tehran, several strategies can be employed.

Phytoremediation

Utilizing plants that can absorb and accumulate heavy metals and other pollutants from the soil can help improve the surrounding environment of cathodic protection systems. Plants such as willows and poplars are known for their ability to uptake contaminants, which can reduce the corrosive effects of pollutants on metal structures (Zeng *et al.*, 2023; Priya *et al.*, 2023).

Green infrastructure

Integrating green roofs and vertical gardens into urban designs can enhance air quality by filtering airborne pollutants. These green spaces not only provide aesthetic benefits but also create a microclimate that can reduce the overall corrosive impact of environmental factors on cathodic protection systems (Chico-Fernández *et al.*, 2022; Yang *et al.*, 2023).

Natural Barriers

Planting trees and shrubs around critical infrastructure can act as natural barriers against wind and airborne pollutants, thereby reducing the exposure of cathodic protection systems to corrosive agents. This natural shielding can help prolong the effectiveness of cathodic protection measures (Osman *et al.*, 2022; Lim*et al.*, 2023; Brueckner *et al.*, 2022; Dąbrowska *et al.,* 2016).

Biodiversity promotion

Encouraging biodiversity through the planting of various native species can create a more resilient ecosystem that supports overall environmental health. A diverse plant community can enhance soil quality and reduce erosion, contributing to a more stable environment for cathodic protection systems (Simkin *et al.*, 2022). By integrating cathodic protection with other corrosion management strategies—such as protective coatings and environmental controls—engineers can significantly enhance the durability of critical infrastructure in Tehran's challenging atmospheric conditions.

Material selection

Selecting appropriate materials is critical for effective corrosion management, especially in environments like Tehran, where high levels of air pollution and humidity significantly accelerate corrosion processes. Some materials suitable for the pollution conditions in Tehran are illustrated in Fig. 4, and the following detailed discussion outlines key materials commonly used for their corrosion resistance, along with their mechanisms and applications relevant to the harsh conditions prevalent in Tehran.

Stainless steel

Stainless steel is one of the most widely used corrosion-resistant materials, primarily due to its chromium content, which forms a passive oxide layer that protects the underlying metal from corrosion. For instance, 304 and 316 stainless steels are commonly employed in construction and infrastructure projects. Grade 316, with its higher molybdenum content, offers enhanced resistance to pitting and crevice corrosion, making it suitable for applications exposed to chlorides, such as coastal structures and urban environments where road salts are prevalent (Bailey *et al.*, 2023; Zhao H*et al.*, 2023; Sun *et al.,* 2022). In Tehran's polluted atmosphere, these grades can withstand aggressive agents like sulfur dioxide (SO_2) and particulate matter.

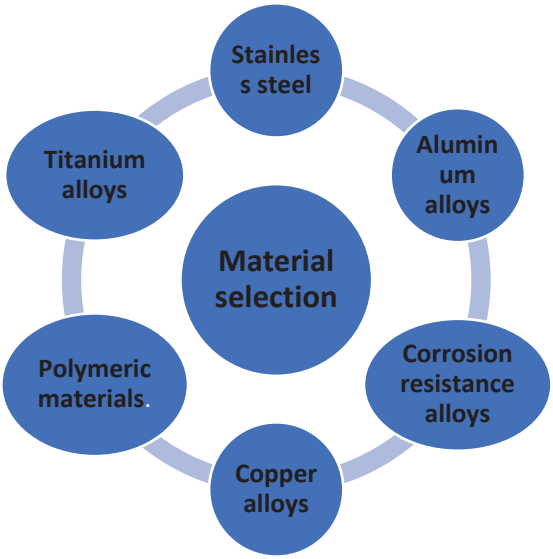

Fig. 4: Materials suitable for the pollution conditions in Tehran, which are appropriate for constructing structures that are resistant to atmospheric corrosion.

Aluminum alloys

Aluminum is naturally resistant to corrosion due to its ability to form a protective oxide layer upon exposure to air. Alloys such as 5052-H32 exhibit excellent corrosion resistance and are lightweight, making them ideal for applications in the automotive and aerospace industries (Ni *et al.*, 2021; Bhowmik *et al.*, 2021). The anodization process can further enhance their protective properties by thickening the oxide layer, thereby increasing resistance to corrosive elements (Balamurugan *et al.*, 2023). In Tehran, aluminum is particularly useful in architectural applications where aesthetics and performance under pollution are critical.

Corrosion-resistant alloys (CRAs)

These alloys are specifically designed for extreme environments. For example, Inconel 625, a nickel-chromium alloy, provides exceptional resistance to pitting and SCC. It is often used in chemical processing equipment and marine applications due to its ability to withstand harsh chemicals and high temperatures (Rebak, 2011; Rodrigues *et al.*, 2023). The unique properties of CRAs make them suitable for critical infrastructure in Tehran that may be exposed to aggressive pollutants.

Copper and copper alloys

Copper exhibits excellent corrosion resistance due to the formation of a protective patina when oxidized. Copper alloys such as bronze (copper-tin) and brass (copper-zinc) are commonly used in plumbing and electrical applications. These materials resist corrosion in various environments, including those containing saltwater or acidic conditions (Shu *et al.*, 2023; Suns et *al.*, 2023; Zheng *et al.*, 2023). In Tehran's urban setting, copper's thermal conductivity also makes it advantageous for renewable energy systems.

Polymeric materials

While metals dominate corrosion-resistant applications, advanced polymers like polypropylene and polytetrafluoroethylene (PTFE) offer significant advantages in corrosive environments. Polypropylene is resistant to a wide range of chemicals and is often used in piping systems where chemical exposure is a concern. PTFE, known for its low friction properties and chemical inertness, is utilized in applications requiring non-stick surfaces or chemical resistance, such as seals and gaskets (Kausar *et al.*, 2022; Zhang *et al.*, 2019).

Titanium alloys

Titanium is renowned for its high strength-to-weight ratio and exceptional resistance to corrosion in aggressive environments. Grades like Ti-6Al-4V are widely used in aerospace applications but are also

Fig. 5: Effective parameters in the design of structures to enhance the durability and lifespan of buildings exposed to corrosive environments.

suitable for chemical processing equipment due to their ability to withstand harsh conditions without significant degradation (Rajan et *al.*, 2022; Gupta *et al.*, 2022). Regular assessments of material performance against evolving environmental factors will further ensure long-term effectiveness in combating corrosion in this challenging urban environment.

Design considerations

In the context of Tehran's polluted atmosphere, effective design considerations are essential for mitigating corrosion risks in infrastructure. According to Fig. 5, the parameters that are effective during the design of structures aimed at enhancing the durability and lifespan of buildings exposed to corrosive environments are shown and summarized as follows:

Design for effective drainage

Incorporating effective drainage systems is crucial to prevent water accumulation, which can exacerbate corrosion. For example, designing roofs with a minimum slope of 2% ensures that rainwater flows toward drainage outlets, significantly reducing the risk of stagnant water pooling on surfaces (Pragati *et al.*, 2023). Similarly, using sloped surfaces on structural elements can facilitate runoff and minimize moisture retention.

Avoiding crevices and traps

Designers must minimize narrow crevices that can trap moisture and debris. For instance, using continuous welds instead of bolted connections can eliminate potential water traps. In applications like facade systems, ensuring that joints are designed with smooth transitions helps prevent water accumulation and reduces the likelihood of localized corrosion (Li *et al.*, 2023).

Access for maintenance

Providing easy access to all parts of a structure

is essential for regular inspection and maintenance activities. For example, integrating removable panels or access ladders into designs allows maintenance crews to reach critical areas without extensive dismantling. This facilitates timely inspections and maintenance of protective coatings or cathodic protection systems (Jasiulewicz-Kaczmarek *et al.*, 2023; Gnedenkov *et al.*, 2023).

Ventilation

Adequate ventilation within enclosed spaces helps reduce humidity levels and promotes drying after exposure to moisture. For example, incorporating vents in basements or utility rooms allows for airflow that can help mitigate the conditions conducive to corrosion, especially in areas where moisture may accumulate (Abd Wahab *et al.*, 2019).

Corrosion allowance

When designing components susceptible to corrosion, incorporating a corrosion allowance into material thickness calculations provides an additional safety margin against material loss over time. For instance, if a steel beam is expected to experience significant exposure to corrosive elements, increasing its thickness by 1-2 mm can compensate for anticipated wear due to corrosion (Feyissa *et al.*, 2022; Chauhan *et al.*, 2018).

Integration of protective coatings

The application of protective coatings should be considered during the design phase. For example, specifying epoxy or polyurethane coatings on steel surfaces enhances their resistance to moisture and corrosive agents. Ensuring proper surface preparation before coating application is critical for achieving optimal adhesion and performance (Guo *et al.*, 2023; McCarron *et al.*, 2022).

Avoiding dissimilar metal contacts

Careful consideration must be given to avoid galvanic corrosion by minimizing contact between dissimilar metals within the structure. For instance, if aluminum components are used alongside steel structures, insulating materials should be employed at contact points to prevent electrochemical reactions that could lead to accelerated corrosion (Zhang *et al.*, 2023).

Environmental considerations

Understanding local environmental conditions—such as air quality, humidity levels, and potential sources of contamination—is vital for effective design. Designers should assess these factors when selecting materials and designing structural elements to ensure long-term performance against corrosion (Méndez *et al.*, 2023; Waqas *et al.*, 2023). However, simple design elements, such as inclined surfaces for drainage and avoiding narrow crevices that trap moisture, can enhance the resilience of steel structures.

Effective corrosion management strategies for urban infrastructure: case studies and best practices

Corrosion management is a critical aspect of maintaining urban infrastructure, particularly in environments exposed to aggressive conditions. Numerous case studies illustrate successful strategies that have been implemented to mitigate corrosion risks. One effective approach is the use of duplex coating systems, which combine different types of coatings to provide superior protection against corrosive elements. For instance, hot-dip galvanized steel can be coated with a polymeric top layer, such as epoxy or polyurethane (Shah *et al.*, 2023). This combination not only enhances corrosion resistance but also extends the maintenance cycle significantly. The synergistic effect of these coatings can lead to service lives that are 1.5 to 2.5 times longer than that of each coating used independently, as demonstrated in various infrastructure projects across coastal cities where salt exposure is prevalent. Another innovative strategy involves the use of CFRP in conjunction with traditional materials. CFRP is recognized for its high strength-to-weight ratio and excellent corrosion resistance, making it an ideal choice for reinforcing structures in corrosive environments. For example, in the rehabilitation of aging bridges, CFRP sheets have been applied to strengthen steel girders while reducing overall weight (Gaugel *et al.*, 2016; Sohail *et al.*, 2021). This application not only enhances structural integrity but also minimizes the risk of corrosion-related failures, thereby prolonging the lifespan of the bridge without significant increases in maintenance costs. The integration of advanced monitoring technologies has also proven essential in effective corrosion management. Real-time monitoring systems equipped with sensors can provide continuous data on structural health, allowing for timely interventions

before significant damage occurs (Yang *et al.*, 2015). For instance, the use of fiber optic sensors embedded within concrete structures has enabled engineers to detect early signs of stress and corrosion, facilitating proactive maintenance strategies. This approach has been successfully implemented in various urban infrastructure projects, including tunnels and elevated highways, where environmental conditions can lead to rapid deterioration. When comparing the results of this study with previous research, it becomes clear that combining multiple strategies—such as advanced coatings, CFRP reinforcements, and real-time monitoring systems—creates a more effective and comprehensive approach to managing corrosion. Earlier studies often focused on individual solutions, like applying protective coatings or using specific corrosion-resistant materials, without fully exploring how these methods could complement each other. For instance, research by Shah(Shah *et al.*, 2023)highlighted the effectiveness of polymeric and zinc-rich coatings in reducing corrosion. However, it overlooked how these coatings could work synergistically with structural reinforcements like CFRP or be enhanced by real-time monitoring to significantly improve infrastructure durability. This study builds on existing knowledge by showcasing how the integration of these strategies addresses the complex challenges posed by polluted urban environments, such as those in Tehran, offering a more adaptable and resilient solution to corrosion management. Additionally, the research reflects a growing trend toward context-specific and multidisciplinary approaches to corrosion management. Unlike traditional studies that provide broad, generalized findings, this work emphasizes the importance of customizing strategies to fit unique environmental and structural conditions. For example, while CFRP applications have been widely discussed in the context of bridge rehabilitation, their potential when combined with advanced coatings in highly polluted urban settings remains largely unexplored. By addressing this gap, the study not only deepens the theoretical understanding of corrosion mitigation but also highlights the practical advantages of coordinated approaches.However, successful corrosion management strategies involve a combination of innovative materials, advanced coatings, and real-time monitoring technologies. By implementing duplex coating systems, utilizing CFRP for reinforcement, and integrating monitoring solutions, urban infrastructure can achieve enhanced durability and resilience against corrosion. These best practices not only extend the lifespan of critical assets but also contribute to overall safety and cost-effectiveness in maintenance operations.

CONCLUSION

Given the severity of air pollution in Tehran, managing corrosion in urban infrastructure has become a critical priority. Effective strategies, including the use of protective coatings, cathodic protection, and careful material selection, are essential to counter the corrosive effects of pollutants like sulfur dioxide and nitrogen oxides, which can significantly accelerate structural deterioration. To ensure the success of protective coatings, meticulous attention to surface preparation and application methods is vital. Zinc-rich coatings, in particular, are well-suited to Tehran's environmental conditions, offering durable protection against corrosion. Similarly, epoxy and polyurethane coatings provide excellent resistance to moisture and chemicals, while aluminum coatings offer reliable anti-corrosion performance. The application of these cutting-edge technologies has been shown to improve asset longevity by an additional 15-25%, ensuring that critical infrastructure remains reliable under challenging conditions. From a managerial standpoint, the research emphasizes the importance of incorporating corrosion management into urban planning and infrastructure policies. Findings indicate that comprehensive strategies, such as regular inspections and the adoption of advanced materials, can reduce maintenance costs by up to 30%. Policymakers are urged to prioritize investments in real-time monitoring systems to detect early corrosion signs and implement robust regulatory frameworks for material and coating standards. These measures can help cities like Tehran achieve sustainable development goals while ensuring public safety and long-term economic stability.Future research directions include exploring emerging technologies, such as nanomaterials and smart coatings, to enhance corrosion resistance. Investigating the long-term performance of self-healing and self-cleaning coatings under Tehran's environmental conditions could offer practical insights into their application. Additionally, comparative studies across cities with varying pollution levels could further refine global

best practices, providing scalable and transferable strategies for urban infrastructure protection. In conclusion, prioritizing these considerations in the design and maintenance of infrastructure will have a profound impact on cost reduction and quality of life improvements in Tehran. By investing in effective corrosion management strategies, the city can not only safeguard its infrastructure but also foster a more sustainable urban environment for future generations.

AUTHOR CONTRIBUTIONS

A. Shanaghi conducted the literature review, designed the experiments, analyzed and interpreted the data, and prepared the manuscript. A. Farrokhi performed the experimental work, compiled the data, and contributed to the manuscript preparation.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS

PM	Particulate Matter
NO_x	Nitrogen oxides
SO_2	Sulfur dioxide
CO	Carbon monoxide
SCC	Stress Corrosion Cracking
CP	Cathodic Protection
ICCP	Impressed Current Cathodic Protection
CRAs	Corrosion-resistant alloys
PTFE	Polytetrafluoroethylene

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