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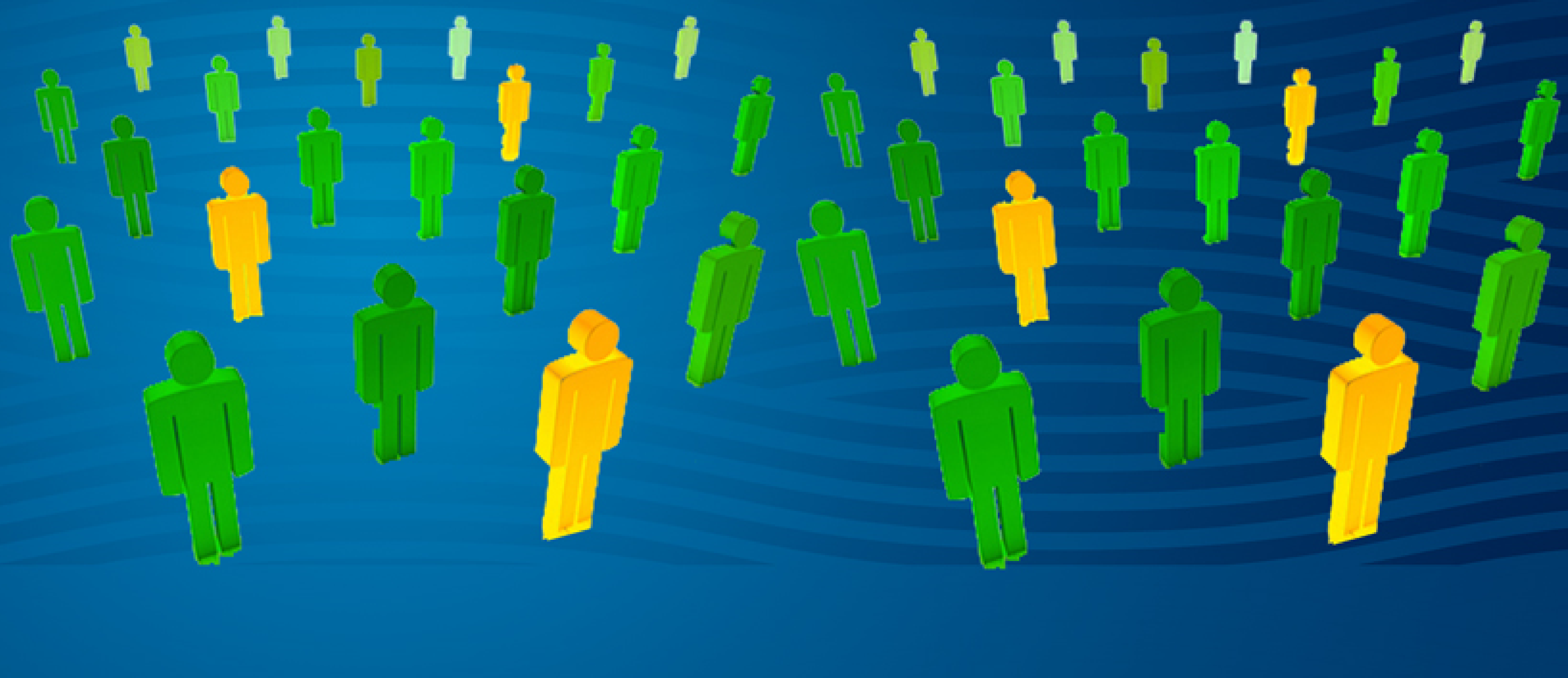

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Email: publisher@ijhcum.net
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Editor in Chief
Professor A. Gholipour
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Managing & Handling Editor
Dr. M. Khodadi
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Page Designer
A. Rezaei Soltanabadi
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ardavanre@gmail.com

Editorial Contact Information
IJHCUM Journal, Khayyam St.,
Building No. 2, Tehran Municipality,
Tehran 1114676111 Iran

Phone: +9821-96015406
Fax: + 9821- 22392096
Emails:
editor@ijhcum.com
ijhcum@gmail .com
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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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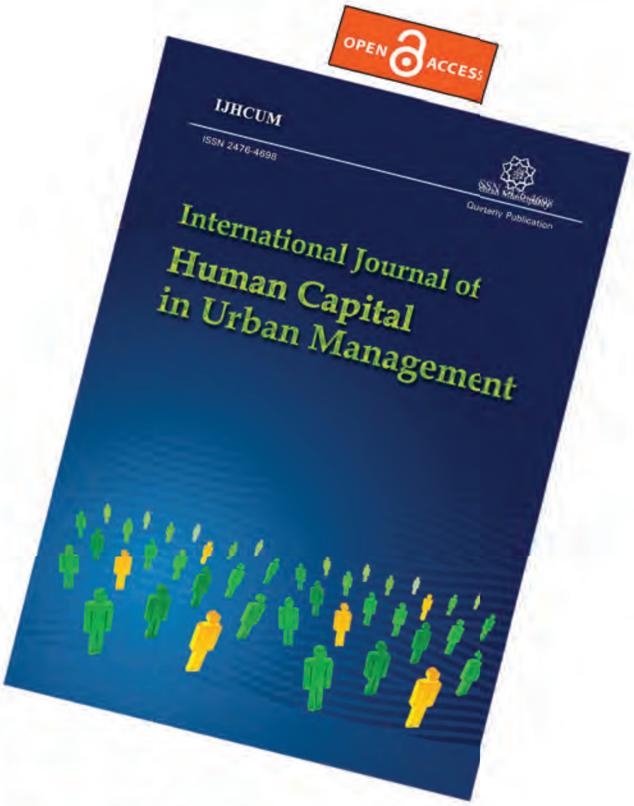

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ORIGINAL RESEARCH PAPER

Utilizing social media to promote responsible tourism: Applying the technology acceptance model and source credibility theory

R. Puengjandum[1], N. Lewis[2], A. Leelasantitham[1,*]

[1]*Technology of Information System Management Division, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand*

[2]*Faculty of Business and Law, Anglia Ruskin University, Chelmsford, United Kingdom*

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ABSTRACT

BACKGROUND AND OBJECTIVES: The rapid growth of social media has significantly influenced tourist behavior, presenting an opportunity to promote responsible tourism. However, limited studies have explored the factors influencing tourists' intention to use social media for responsible tourism. This study integrates the Technology Acceptance Model and Source Credibility Theory to examine key determinants affecting tourists' behavioral intentions.

METHODS: A quantitative research approach was adopted, utilizing an online survey to collect data from 400 Thai tourists using social media. Partial Least Squares Structural Equation Modeling was employed to analyze the relationships between Perceived Usefulness, Perceived Ease of Use, Expertise, and Trustworthiness on the intention to use social media for responsible tourism.

FINDINGS: The results indicate that Perceived Usefulness, Perceived Ease of Use, Expertise, and Trustworthiness all have a significant and positive influence on tourists' intention to utilize social media for responsible tourism. The structural model demonstrated strong explanatory power with a coefficient of determination value of 0.701, supporting the relevance of the proposed framework. These findings highlight the crucial role of social media in promoting responsible tourism and provide valuable insights for developing targeted interventions and awareness campaigns to foster sustainable tourism practices.

CONCLUSION: This study provides empirical evidence supporting the integration of the Technology Acceptance Model and Source Credibility Theory in explaining social media adoption for responsible tourism. This study serves as a foundation for advancing conceptual models and frameworks to support responsible tourism.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
44	5	7

*Corresponding Author:
Email: *adisorn.lee@mahidol.ac.th*
Phone: +66(81)353-1220
ORCID: 0000-0001-6999-8348

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INTRODUCTION

Thailand's tourist industry is regarded as one of the country's primary economic drivers. Tourism is a major service-oriented trade sector closely connected with various production industries. Thailand was one of the top 10 most popular international visitor destinations according to the United Nations World Tourism Organization (UNWTO) (UNWTO, 2021). However, although tourism has created enormous economic benefits, it has been found that promoting the concept of socially and environmentally responsible tourism has not yet become widely popular among Thai tourists (Tourism Authority of Thailand, 2024). According to 2024 data (Fig. 1), Thailand's tourism development index ranks 47th out of 119 countries, 107th in terms of travel and tourism sustainability, and 66th in terms of enabling environment for tourism (World Economic Forum, 2024). If not properly managed, it may lead to negative impacts on tourist attractions in the long term, such as the closure of Maya Bay, Krabi Province, which is caused by the impact of a huge number of tourists that destroy the marine ecosystem and cause the degradation of environmental resources. The decision to close Maya Bay is a proactive action by Thai authorities to restore natural resources (Koh & Fakfare, 2020). In the context that sustainable tourism has become a key issue. The use of technology and social media has played an important role in promoting tourism. Tourism operators utilize technological media to create tourism ideologies, aiming to reach target audiences and motivate people to travel (Leung *et al*., 2013). Presenting engaging and concise content encourages tourists to explore destinations and gain travel inspiration. Examples include recommendations for destinations and activities, eco-friendly travel practices, or travel reviews, which stimulate tourists' desire to travel and allow them to plan trips immediately (Chung & Koo, 2015). Social media has become an essential tool in supporting tourism, leading to studies on its applications in this sector (Singh & Srivastava, 2019; Wang *et al*., 2022). For instance, research has examined the use of social media for trip planning (Cheunkamon *et al*., 2020) and hotel reviews (Bae & Han, 2020). These studies often employ the Technology Acceptance Model (TAM), developed by Davis (Davis, 1989), which was derived from the Theory of Reasoned Action (TRA) by Fishbein and Ajzen (Douglass, 1977). TAM evaluates technology adoption based on users' Perceived Ease of Use (PEoU) and Perceived Usefulness (PU). These factors influence users' Behavioral Intentions (BI) and Actual technology Usage (AU). PU refers to users' perception that technology enhances efficiency or benefits daily life, while PEoU focuses on the ease with which users can utilize the technology (Davis, 1989; Venkatesh & Bala, 2008). The integration of TAM and Source Credibility Theory (SCT) (Hovland & Weiss, 1951) provides a framework for understanding how people engage with sustainable tourism content on social media platforms. TAM offers insights into users' acceptance of technology, while SCT underscores the importance of credibility, expertise, and the appeal of information sources in influencing attitudes and behaviors. Hovland proposed the Source Credibility Theory, which explains the factors that make information from a source influential to its audience (Hovland & Weiss, 1951). Credible sources can foster trust and increase the likelihood of behavioral changes based on their recommendations. Celebrity endorsers have become significant social representatives, with their credibility studied as a key factor influencing consumer attitudes and behaviors (Ohanian, 1990). The theory conceptualizes source credibility in terms of perceived expertise and trustworthiness. Applying this theory in the context of social media helps us understand why content from credible creators, such as travel experts or influencers, has a substantial impact on tourist behavior. Previous research has demonstrated that credible sources have a significant impact on tourist behavior. Their credibility significantly influences the intentions of their audience (Qiu *et al*., 2024), and this is a crucial factor in encouraging responsible behaviors (Qiu *et al*., 2023). Although there is research on the use of social media in tourism, only a few studies have presented the use of social media for sustainable tourism management (Hysa *et al*., 2022) or responsible tourism. The objective of this study is to fill this gap by investigating the factors—source credibility on social media and technology acceptance—that influence tourists' intentions to use social media to support responsible behaviors. The research survey was collected from Thai tourists in 2024. The findings of this research can be applied to the design of social media campaigns that encourage tourists to adopt environmentally friendly practices during their travels while also raising awareness of environmental issues. Additionally, these initiatives support the more general objectives of encouraging a more responsible and sustainable tourism sector.

Literature review

Social media and tourism

Social media plays a crucial part in the tourist sector because it allows consumers to rapidly and efficiently search for, share, and compare information about various destinations. According to the 2024 Thai Tourist Data Survey, Thai tourists often share their experiences from various tourist attractions, including photo spots, scenic spots, restaurants, beverages, hotels, and accommodations. Local activities, including travel routes through social media such as Facebook, and use Facebook as a channel for positive word of mouth, more than 80 percent (Tourism Authority of Thailand, 2024). Zeng and Gerritsen (2014) found that social media plays an important role in various elements of tourism, particularly in information search, decision-making behavior, tourism promotion, and consumer engagement. Leveraging social media is considered an excellent strategy for marketing tourism products. Social media has become a key source of information influencing tourists' decisions regarding destination selection and trip planning. Xiang and Gretzel (2010) discovered that social media is crucial in trip planning, especially via search engines, successfully engaging customer attention. Consumers engage with content on social media by sharing their own experiences in various forms, such as posting stories, comments, photos, and videos. This interactive dynamic gives social media a direct influence on tourists' travel intentions. Social media is not merely a communication platform but also a space where travelers can exchange experiences and inspire others (Kaplan & Haenlein, 2010).

TAM

Davis (1989) proposed the TAM, which integrates fundamental concepts from technology models with the TRA to explain the factors influencing users' acceptance and use of technology. The relationships and components of TAM are shown in Fig. 2. As illustrated in Fig. 2, the model begins by considering external variables that influence users' perceptions, namely Perceived Usefulness and Perceived Ease of Use. If users perceive the technology as beneficial and easy to use, this will positively affect their attitude, leading to behavioral intention and, ultimately, actual technology adoption. In the context of online tourism, TAM has been used to explain tourists' intentions to use various applications and online platforms (Bano & Siddiqui, 2024; Chen & Tsai, 2019; Phaosathianphan & Leelasantitham, 2020). For example, applications for hotel booking or flight ticket purchases that offer convenience and reliable information, as well as the use of social media for tourism-related purposes, such as trip planning, accommodation reviews, and destination recommendations, are effectively captured within the TAM framework, as demonstrated in Table 1.

Table 1 presents studies examining the use of

Fig. 1: Thailand's tourism rankings (World Economic Forum, 2024)

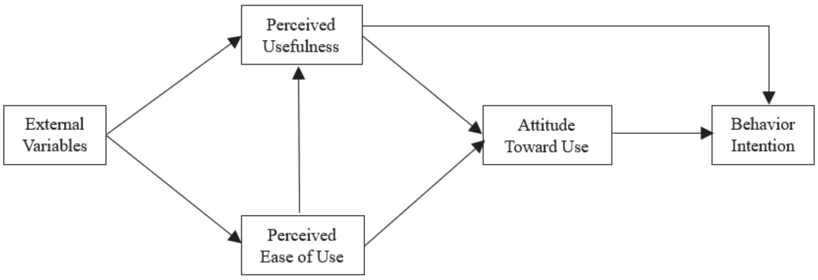

Fig. 2: A schematic of TAM (Davis et al., 1989)

Table 1: Related research about social media in tourism using TAM

Context	Theories	Purpose
Social media for outbound leisure travel (Singh & Srivastava, 2019)	TAM	The utilization of social media by Indian travelers who are traveling abroad.
Generation Y's tourism activity in social media (Kowalczyk-Anioł and Nowacki, 2020)	TAM	Study the factors influencing tourism-related social media activities of Generation Y.
Social media for travel planning (Cheunkamon *et al.*, 2020)	TAM, TPB	The utilization of social media platforms for travel planning.
Online hotel reviews (Bae & Han, 2020)	TAM, Cultural Consonance	Study the factors influencing the acceptance of UGC websites for travel planning among Generation Y.
Short video apps (Wang *et al.*, 2022)	TAM	Explore the factors influencing the intention to use short video apps for travel planning and decision-making.
Short tourism video (Liu *et al.*, 2023)	TAM, SOR	Study the key factors of short videos that influence tourism intention to help develop strategies for tourism destinations.

social media in tourism, employing TAM as the foundational theory to investigate factors influencing tourists' intentions or behaviors when using social media. For instance, one study explored the use of social media by Indian tourists traveling abroad, particularly for leisure purposes, to develop a comprehensive framework encompassing various factors influencing social media usage in the travel process (Singh & Srivastava, 2019). The research utilized Perceived Usefulness and Perceived Ease of Use as key factors, as these user perception factors significantly influence users' intentions or acceptance of technology.

SCT

SCT, proposed by Hovland, explores how the credibility of a source influences the decision-making and behavior of its audience (Hovland & Weiss, 1951). Source credibility refers to the positive attributes of a message source that impact the audience's acceptance of information. Messages delivered by credible presenters tend to have a significant influence on the beliefs, opinions, attitudes, and behaviors of recipients (Amos *et al.*, 2008; Kang & Namkung, 2019). Source credibility comprises two main factors: trustworthiness, which refers to the audience's perception of the source as honest and reliable, and expertise, which denotes the audience's recognition of the source's knowledge and competence in the subject matter being presented (Ohanian, 1990). Research in the tourism context indicates that credible sources, such as tourism influencers who possess expertise and trustworthiness, can enhance tourists' intentions to travel (Dedeoglu, 2019; González-Rodríguez *et al.*, 2022; Qiu *et al.*, 2024). Social media amplifies the role of credible sources, such as influencers and tourism experts, by allowing them to influence tourists' behavior and improve confidence in destination choosing.

Hypothesis

This study is grounded in the integration of the TAM and SCT to investigate the factors influencing tourists' behaviors and Intentions to use social media to support responsible tourism (IU), as illustrated in Fig. 3.

PU

PU represents the level to which users believe that technology can improve their performance, as defined in TAM by Davis (Davis, 1989). For example, users who perceive that social media platforms make it easier and faster to access information or plan their trips are more likely to accept and use these platforms. Research by Doanh et al. (Doanh *et al*., 2022) highlights that perceived usefulness positively impacts users' intentions to adopt technology. Therefore, a hypothesis is proposed:

H1: PU positively influences the intention to use social media for responsible tourism.

PEoU

PEoU represents the level to which people believe that technology is simple and uncomplicated. It is a key factor in TAM and can be defined as the perception that social media platforms are straightforward to use and reduce the complexity of accessing information and making decisions (Davis, 1989). This construct has been widely used in numerous studies, which consistently demonstrate that ease of use significantly influences the intention to adopt technology (Doanh *et al*., 2022; Joo & Sang, 2013). Accordingly, a hypothesis is proposed:

H2: PEoU positively influences the intention to use social media for responsible tourism.

EX

EX refers to the level of knowledge and proficiency of a source, which is perceived as credible and capable of providing accurate and valuable information (Hovland & Weiss, 1951). In the scope of social media, users tend to trust information from expert sources, such as travel experts or influencers, as this information enhances their confidence in choosing destinations (Ohanian, 1990). Expertise has been extensively studied and is shown to influence the attitudes, inspiration, intentions, and behaviors of users (AlFarraj *et al*., 2021; Nguyen *et al*., 2025; Yılmazdoğan *et al*., 2021). Based on this, a hypothesis is proposed:

H3: EX of the source positively influences the intention to use social media for responsible tourism.

TR

TR refers to the perception that a source is sincere, honest, and reliable in presenting information (Hovland & Weiss, 1951). The credibility of a source significantly impacts customer behavior, especially within the field of social media. When users perceive a source as trustworthy, their intention to follow recommendations, especially when planning travel, can increase (Amos *et al*., 2008). Numerous studies have utilized trustworthiness as a factor and have found that it significantly impacts users' attitudes,

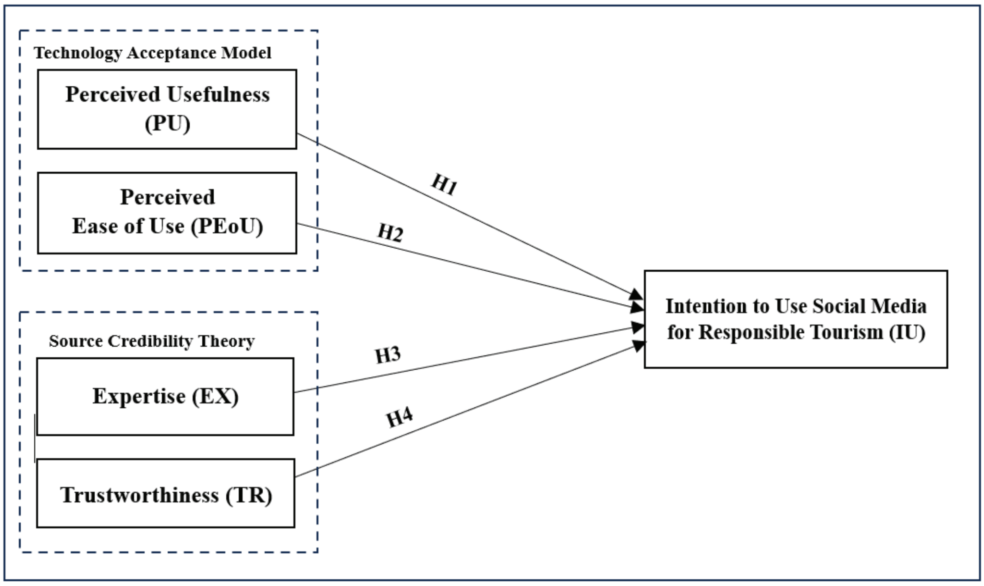

Fig. 3: Proposed research model

intentions, and behaviors (AlFarraj *et al.*, 2021; Nguyen *et al.*, 2025; Yılmazdoğan *et al.*, 2021). Based on this, a hypothesis is proposed:

H4: TR of the source positively influences the intention to use social media for responsible tourism.

MATERIALS AND METHODS

Sampling and data collection

The data collecting method uses an online questionnaire via Google Forms, distributed through social media to collect information from a sample of 400 Thai visitors who are active social media users. The questionnaire was developed based on TAM and SCT and consisted of three sections, with a total of 15 selected questions, as shown in Table 2.

The first section focused on general information related to demographic characteristics. The second section included questions about key factors: Perceived Usefulness, Perceived Ease of Use, expertise, trustworthiness, and the intention to use social media. The third section comprised open-ended questions, allowing respondents to provide additional opinions and recommendations. Responses were measured on a 5-point Likert scale, with 1 representing "strongly disapprove" and 5 representing "strongly agree." Additionally, before conducting the main testing, the quality of the research instrument was assessed through a pilot test. The evaluation employed the internal consistency method using Cronbach's alpha coefficient, which should not be lower than 0.7. The questionnaire utilized in this study received approval from the Center for Ethics in Human Research at Mahidol University, with the reference number COE No. MU CIRB 2025/001.0301 Before the questionnaire could be used to collect data, this approval was required.

Data analysis

Statistics are utilized in research to investigate causal correlations. SmartPLS was utilized to conduct the study with the Partial Least Squares Structural Equation Modeling (PLS-SEM) method. The analysis

Table 2: The measuring items in the questionnaire

Construct	Items	Question	Source
Perceived Usefulness	PU1	You have received useful information about responsible tourism via social media.	(Davis *et al.*, 1989; Qiu *et al.*, 2023)
	PU2	Using social media enhances followers' understanding of responsible tourism.	
	PU3	Social media helps support decision-making in selecting responsible tourism activities more effectively.	
Perceived Ease of Use	PEoU1	You feel that accessing information about responsible tourism through social media is easy.	(Davis *et al.*, 1989; Qiu *et al.*, 2023)
	PEoU2	You feel that using social media to share content about responsible tourism is simple.	
	PEoU2	Learning how to use social media to view and share content about responsible tourism is easy for you.	
Expertise	EX1	You believe that travel influencers on social media are knowledgeable about tourist destinations.	(Ayeh, 2015; Qiu *et al.*, 2023)
	EX2	You believe that travel influencers on social media often research and learn from sources about responsible tourism.	
	EX3	You believe that travel influencers on social media often provide useful information about destinations.	
Trustworthiness	TR1	You believe that travel influencers on social media would not present themselves as experts if they lack sufficient knowledge.	(Ayeh, 2015; Qiu *et al.*, 2023)
	TR2	You believe that travel influencers on social media express their opinions about tourism honestly.	
	TR3	You believe that travel influencers on social media present tourism information with sincerity.	
Intention to Use social media for responsible tourism	IU1	I expect to use social media to share content about responsible tourism in the future.	(Chung *et al.*, 2015; Venkatesh *et al.*, 2003)
	IU2	I plan to share posts or information about reducing environmental impacts through social media in the future.	
	IU3	I expect to use social media to access reviews and information about responsible tourism in the future.	

includes two main types: measurement model evaluation and structural model analysis (Hair Jr *et al*., 2023)

RESULTS AND DISCUSSION

Demographic characteristics

Data was gathered from a sample of 400 Thai tourists utilizing social media, as indicated by the survey. Table 3 summarizes the results, including the demographic characteristics of the respondents, categorized into four groups: gender, age, education, and monthly income.

The data in Table 3 shows that the respondents included 98 males and 302 females, representing 24.5% and 75.5% of the respondents, respectively. The largest number of respondents were aged 25 to 34 years, representing 39.8% of the sample. Notably, respondents aged 18 to 24 years and those over 55 years comprised similar proportions, representing 6.8% and 7.8%, respectively. Regarding education, the majority of respondents had either completed or were pursuing a bachelor's degree, representing 78.5% of the sample. In terms of income, the largest group reported a monthly income of 30,001–50,000 baht, representing 53.3%, followed by those earning 15,000–30,000 baht, representing 31.8% of the respondents.

Measurement model

The assessment of the variables' quality was performed according to the criteria outlined in the measurement model, considering Composite Reliability, Cronbach's α, and Average Variance Extracted (AVE), as shown in Table 4. The analysis results revealed that the Composite Reliability values for each latent variable ranged from 0.793 to 0.935, meeting the required threshold of no less than 0.7. Similarly, Cronbach's α values ranged from 0.718 to 0.875, also conforming to the specified criteria. Moreover, the AVE values ranged from 0.617 to 0.940, exceeding the minimum threshold of 0.5. The survey items used to assess quality showed outer

Table 3: Summary of participants' demographic characteristics

Variables	Categories	N	% of Responded
Gender	Male	97	24.2%
	Female	303	75.8%
	Total	400	100
Age	18-24	27	6.8%
	25-34	159	39.8%
	35-44	111	27.8%
	45-54	72	18%
	Over 55	31	7.8%
	Total	400	100
Education	Undergraduate	3	0.8%
	Bachelor	314	78.5%
	Master	79	19.8%
	Doctorate	4	1%
	Total	400	100
Income	<15,000	20	5%
	15,000 - 30,000	127	31.8%
	30,001 – 50,000	213	53.3%
	50,001 – 70,000	35	8.8%
	>70,001	5	1.3%
	Total	400	100

loading values between 0.711 and 0.959, meeting the minimum threshold of 0.7, indicating strong correlations between the indicators and the latent variables. The reliability of the survey items for measurement in this study was confirmed to meet the specified criteria.

Table 5 presents the results of the Fornell-Larcker criterion-based discriminant validity assessment. The square roots of the AVE for each construct are shown by the bold diagonal values, whereas the off-diagonal

Table 4: Internal consistency, reliability, and convergent validity

Constructs	Items	Outer Loading	Cronbach's α	Composite Reliability	AVE
	PU1	0.778			
Perceived Usefulness	PU2	0.711	0.718	0.793	0.617
	PU3	0.876			
	PEoU1	0.923			
Perceived Ease of Use	PEoU2	0.946	0.856	0.874	0.873
	PEoU2	0.912			
	EX1	0.859			
Expertise	EX2	0.871	0.816	0.820	0.730
	EX3	0.832			
	TR1	0.923			
Trustworthiness	TR2	0.959	0.875	0.935	0.940
	TR3	0.901			
	IU1	0.914			
Intention to Use social media for responsible tourism	IU2	0.926	0.819	0.822	0.847
	IU3	0.891			

Table 5: Fornell-Larcker criterion

Construct	IU	PEoU	PU	EP	TR
IU	0.920				
PEoU	0.678	0.934			
PU	0.706	0.595	0.786		
EP	0.709	0.639	0.470	0.854	
TR	0.706	0.571	0.667	0.710	0.941

Table 6: Hypothesis testing

Hypothesis	Relationship	Tourist (N=400)					
		Coefficient (β) (>0.1)	p-value (<0.05)	t- value (>1.96)	VIF (<5.00)	Q^2	Supported
H1	PU -> IU	0.357	0.000	9.716	2.120	0.629	Supported
H2	PEoU -> IU	0.178	0.000	3.726	2.086		Supported
H3	EX -> IU	0.337	0.000	7.704	2.490		Supported
H4	TR -> IU	0.128	0.000	3.639	2.838		Supported

values represent the correlations between the constructs. The findings indicate that the square root of the AVE for each construct exceeds its correlations with other constructs, thereby verifying discriminant validity.

Structural model

The structural model was assessed by the Bootstrap approach. Multicollinearity was assessed by the Variance Inflation Factor (VIF), revealing that the causative variables remained below the threshold of 5 (Hair, 2014). The significance of the path coefficients was assessed by analyzing p-values and t-values according to predefined criteria: a t-value greater than 1.96 (at a 5% significance level), 2.58 (at a 1% significance level), and 3.29 (at a 0.1% significance level) (Hair, 2014). The findings revealed that H1: PU positively influences the intention to use social media for responsible tourism at a significance level of 0.05 (β = 0.357, t = 9.716); H2: PEoU positively influences the intention to use social media for responsible tourism at a significance level of 0.05 (β = 0.178, t = 3.726); H3: EX positively influences the intention to use social media for responsible tourism at a significance level of 0.05 (β = 0.337, t = 7.704); and H4: TR positively influences the intention to use social media for responsible tourism at a significance level of 0.05 (β = 0.128, t = 3.639). Table 6 and Fig. 4 illustrate the findings of this investigation. The analysis indicates that all hypotheses in the model are supported and reliable for further analysis.

The R-squared (R^2) value serves as a measure of model fit, with specific thresholds to evaluate its acceptability. An R^2 value below 0.19 indicates that the model is deemed unacceptable. Values ranging from 0.19 to 0.33 suggest a low level of acceptability, while values between 0.33 and 0.67 reflect moderate acceptability. An R^2 value exceeding 0.67 signifies that the model exhibits a good level of acceptability. In this study, the R^2 value for the dependent variables was 0.701, surpassing the established minimum threshold. This finding implies that the model effectively captures the patterns in the collected data. Consequently, the analysis confirms that the model achieves a high degree of fit, as shown in Table 7.

Discussion

This study aimed to examine the factors influencing tourists' intention to use social media to support responsible tourism. A conceptual model was developed by integrating TAM, which focuses on Perceived Usefulness and Perceived Ease of Use, with

Table 7: Coefficient of determination (R2)

Constructs	Items	Outer Loading	Cronbach's α	Composite Reliability	AVE
Perceived Usefulness	PU1	0.778	0.718	0.793	0.617
	PU2	0.711			
	PU3	0.876			
Perceived Ease of Use	PEoU1	0.923	0.856	0.874	0.873
	PEoU2	0.946			
	PEoU2	0.912			
Expertise	EX1	0.859	0.816	0.820	0.730
	EX2	0.871			
	EX3	0.832			
Trustworthiness	TR1	0.923	0.875	0.935	0.940
	TR2	0.959			
	TR3	0.901			
Intention to Use social media for responsible tourism	IU1	0.914	0.819	0.822	0.847
	IU2	0.926			
	IU3	0.891			

the SCT, including expertise and trustworthiness, to analyze their effects on the intention to use social media. The findings revealed that all variables significantly impacted tourists' intention to use social media to support responsible tourism. For factors derived from TAM, Hypothesis H1 indicated that PU positively affects tourists' intention to use social media. This aligns with Davis (Davis, 1989), who stated that the perceived benefits of technology stimulate its acceptance and use. Additionally, Chung and Koo (2015) confirmed that social media enhances users' ability to efficiently find tourism-related information. In the area of tourism, this study suggests that when tourists perceive the usefulness of social media for responsible tourism—such as accessing reviews about eco-friendly destinations, activities, or content that enhances understanding and facilitates sustainable travel planning—it effectively increases their intention to use the platforms. Hypothesis H2 demonstrated that PEoU positively influences tourists' intention to use social media. In the area of tourism, travelers find it convenient to search for and share information about responsible tourism through social media, which contributes to greater intention to use these platforms and encourages the sharing of responsible tourism information. These findings align with those of Doanh *et al.*, (2022) and Lin *et al.*, (2020), who emphasized that simplicity and user-friendliness are critical factors in encouraging technology adoption, reducing barriers to information access, and increasing user motivation. For factors derived from the SCT, Hypothesis H3 indicated that EX positively impacts tourists' intention to use social media. This result aligns with studies conducted by

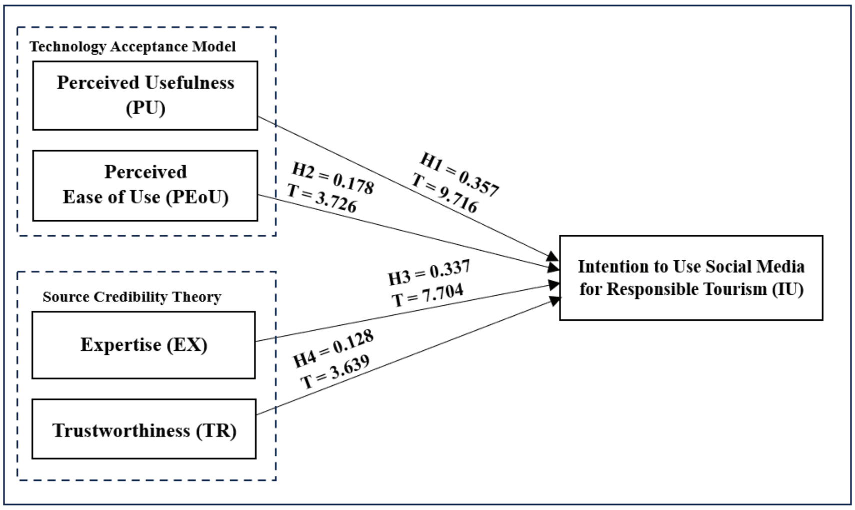

Fig. 4: Model testing results

Fig. 5: Practical recommendations for responsible tourism via social media

Ohanian (1990) and Hovland and Weiss (1951), which highlighted that the expertise of a source enhances its credibility and influences consumer behavior. Similarly, Nguyen *et al.,* (2025) supported the notion that expertise in social media platforms affects tourists' intentions. In this context, travel influencers with expertise can inspire other tourists to create or share environmentally responsible travel experiences on social media, fostering adherence to responsible tourism practices. Hypothesis H4 demonstrated that TR positively affects tourists' intention to use social media. This finding aligns with studies by Ayeh (2015) and Ismagilova *et al.,* (2020), which suggested that the trustworthiness of a source enhances trust and promotes behavioral changes among consumers. In this context, trustworthy influencers help build confidence among tourists, increasing their likelihood of using social media to access or share information about responsible tourism. The results emphasize the important role of social media in encouraging responsible tourism and identifying the factors that affect tourists' intentions.

Recommendations

From the research results, various practical recommendations for digital tourism management can be proposed, which can be applied to communication, digital marketing, and promoting sustainable tourism behaviors via social media effectively and systematically, as shown in Fig. 5. This figure shows four main approaches recommended for promoting responsible tourism behaviors via social media:

(1) using credible sources of information, such as influential experts or certified organizations;

(2) designing useful and motivating content, such as providing knowledge, providing tangible examples, and creative communication;

(3) supporting learning via social media, such as organizing online workshops, short-term activities, or lessons that stimulate environmental awareness;

(4) promoting participation through engaging activities, such as quizzes, campaigns, or online challenges that emphasize real-world actions.

All of these elements work together to create a systematic, positive impact on the behavior of new-generation tourists.

First, the study results indicate that "source credibility" has a significant influence on environmentally responsible tourist behavior, which is consistent with the source credibility theory (Hovland & Weiss, 1951) that explains that highly credible sources can effectively influence recipients' attitudes and behaviors. Credibility consists of two main components: trustworthiness and expertise. When a communicator is perceived as highly credible, they can effectively persuade recipients and bring about changes in opinions (Qiu *et al*., 2024). In addition, those with specialized expertise, such as experienced tourists or environmental experts, are more persuasive and accepted by recipients than individuals without relevant expertise (Ohanian, 1990). Therefore, tourism agencies, governments, and private sectors should focus on selecting content publishers who are both trustworthy and expert, especially those who can convey sustainable tourism experiences and knowledge in an influential and credible manner, such as tourism influencers with hands-on experience, environmental experts, or organizations certified for sustainability. These publishers can positively influence tourists' decisions and behaviors in choosing tourist attractions, activities, and using resources responsibly. In terms of technology acceptance, it was discovered that the intention to use technology is significantly influenced by both PU and PEoU (Davis, 1989; Venkatesh & Bala, 2008). In the case of tourists, using social media to promote tourism is an effective communication channel. According to the 2024 Thai Tourist Behavior Survey (Tourism Authority of Thailand, 2024), the most influential source of information on travel decisions and the most influential stimulus for travel decisions is social media, especially Facebook and TikTok. Therefore, those who play a role in producing online content should design and present content that is consistent with the format that users can easily access, communicate clearly, and present the benefits that viewers will receive from participating in sustainable behaviors, such as having a deeper travel experience, helping to conserve natural resources, and participating in local communities. At a strategic level, government agencies and tourism organizations should develop public communication approaches using social media channels, creating campaigns or campaign activities that use influencer content, short videos, or content that uses narrative storytelling techniques to inspire and raise awareness about the impact of irresponsible tourism behavior and present practical alternatives such as reducing waste, choosing environmentally friendly activities, and supporting local businesses.

Future work

This research focuses on developing a conceptual model to study tourists' intentions to use social media for responsible tourism, serving as an important starting point for establishing a novel guideline framework, as proposed in Leelasantitham (2024). Based on the approach in this study, the new framework comprises three key components: the development of a conceptual model, the creation of a conceptual framework, and the implementation of these concepts through technology handling. These components can be applied in future research to extend the findings into practical applications and create societal and economic impacts. This is particularly relevant for raising awareness, leveraging technology to support environmentally responsible behaviors in tourist destinations, and establishing new learning frameworks for sustainable tourism.

CONCLUSION

This study investigates the factors influencing tourists' intention to use social media for responsible tourism by integrating the conceptual frameworks of the TAM and SCT. The purpose of this study is to understand tourists' social media behavior in the digital era. The study combines factors from TAM, including Perceived Usefulness and Perceived Ease of Use, with factors from SCT, such as expertise and trustworthiness of the information source, which play a crucial role in shaping users' intentions and behaviors. The findings reveal that all variables positively influence tourists' intention to use social media. This research's model demonstrates strong validity and offers a robust explanation of tourists' intention to use social media. Furthermore, the results provide useful implications for stakeholders in the tourism business. For instance, they can guide the development of campaigns that emphasize simple access to information and building trust through credible influencers. Social media can also be leveraged to foster engagement and support sustainable tourism. Finally, this research contributes to the foundational knowledge for developing future tourism strategies aimed at promoting environmentally responsible tourism and effectively addressing the needs of digital-age travelers.

AUTHOR CONTRIBUTIONS

R. Puengjandum performed the conceptualization, literature review, and wrote the original draft. N. Lewis provided guidance on the research design, data collection, and data analysis. A. Leelasantitham supervised the research and assisted in conceptualizing, data collection, data analysis, and reviewed as well as edited 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 authors have witnessed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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)

R^2_{adj}	Adjusted coefficient of determination
R^2	Coefficient of determination
AVE	Average Variance Extracted
COE	Certificate of Exemption
EX	Expertise
IU	Intention to Use social media for responsible tourism
N	Sample size
PEoU	Perceived Ease of Use
PLS-SEM	Partial Least Squares Structural Equation Modeling
PU	Perceived Usefulness
p-value	Probability value
Q^2	Predictive relevance
RMSE	Root Mean Square Error
SCT	Source Credibility Theory
SOR	Stimulus-organism-response theory
t- value	Test statistic value
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
TR	Trustworthiness
TRA	Theory of Reasoned Action
UNWTO	United Nations World Tourism Organization
VIF	Variance Inflation Factor
β	Coefficient

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ORIGINAL RESEARCH PAPER

Climate crisis and cultural heritage management

L. Akbarishahabi

Department of City and Regional Planning, Faculty of Architecture, Design and Fine Arts, Cappadocia University, Nevşehir, Türkiye

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ABSTRACT

BACKGROUND AND OBJECTIVES: Climate change poses significant threats to cultural heritage sites, particularly coastal regions. This study focused on the Side Ancient City in Antalya, Türkiye, examining the impacts of sea-level rise, coastal erosion, extreme temperatures, construction, and earthquakes on its historical and archaeological integrity. Unlike previous studies, this study employed a holistic risk analysis framework.
METHODS: The study integrated a literature review, field observations, GIS-based spatial analysis, and comparative case studies to assess Sides' vulnerability to climate-induced hazards. This multi-method approach enabled a more precise evaluation of risks affecting key historical structures.
FINDINGS: Sid has experienced magnitude 5-6 earthquakes in the last 120 years, a 4.45% loss of green areas in 15 years, and a 20-fold increase in built-up area, rising from 0.84% in 1953 to 16.8% in 2010 over 57 years. The average temperature increased from 17.1°C (1979) to 18.5°C (2023).
Climate change is projected to raise the sea level on the Side coast by 2-2.2 meters. Despite its tourism significance, local-scale visitor data is lacking.
CONCLUSION: The study proposed a multi-faceted adaptation strategy to mitigate risks, including coastal defence measures, improved drainage systems, climate-resilient restoration materials, and seismic retrofitting of vulnerable structures. Additionally, it recommended policy reforms and tourism management strategies to support conservation efforts. The research offered a transferable model for protecting coastal archaeological sites from climate-induced and seismic hazards by aligning site preservation with broader climate adaptation frameworks. The study contributed to global heritage conservation by highlighting the urgent need for proactive and interdisciplinary approaches to safeguard cultural landmarks against accelerating environmental change.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
68	11	5

*Corresponding Author:
Email: *leila.akbarishahabi@kapadokya.edu.tr*
Phone: +903843535009
ORCID: 0000-0002-0547-7874

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INTRODUCTION

Cultural heritage sites symbolize human history and identity, yet they face escalating threats from environmental and human-induced stressors. Among these, the climate crisis has emerged as a dominant force, reshaping landscapes, destabilizing ecosystems, and accelerating the deterioration of ancient structures. The growing complexity and unpredictability of environmental conditions now demand a rethinking of how we assess, protect, and manage these fragile heritage landscapes, particularly in vulnerable coastal zones. The planet's climate has changed over time, but the 0.6°C rise in global temperature during the 20th century marks the most significant increase in the last 1,000 years. According to the IPCC, human activities especially greenhouse gas emissions and land use changes are the main drivers of warming over the past 50 years. The current rate of emissions is unprecedented in 20,000 years and is fuelled by unequal, unsustainable consumption and production patterns across regions and populations (UNESCO, 2007; IPCC, 2023a). Climate change impacts natural, societal, and cultural systems, including World Heritage sites, by causing physical damage such as soil degradation, deterioration of archaeological remains, moisture damage to historic buildings, and biological infestations. Extreme weather events like floods, storms, erosion, and desertification further threaten the long-term preservation of these heritage sites (Vyshkvarkova & Sukhonos, 2023; UNESCO, 2007). Fig. 1 shows some impacts of climate change on cultural heritage.

Fig. 1 illustrates how climate change threatens cultural heritage through environmental and biological risks, including moisture and temperature shifts, sea-level rise, wind, pollution, desertification, and biological impacts. These lead to flooding, heatwaves, material decay, and invasive species, ultimately endangering the structural integrity and preservation of heritage sites. Table 1 lists climate change impacts on cultural heritage according to researchers.

Climate change threats such as sea-level rise, coastal erosion, acidification, and salt weathering endanger coastal heritage sites by causing corrosion, material degradation, and structural weakening. Biodeterioration, freeze-thaw cycles, and soil temperature changes accelerate decay, while extreme weather events inflict severe damage. These risks underscore the urgent need for climate-adaptive strategies to protect vulnerable heritage sites. Table 2 shows some historic areas in danger and developed

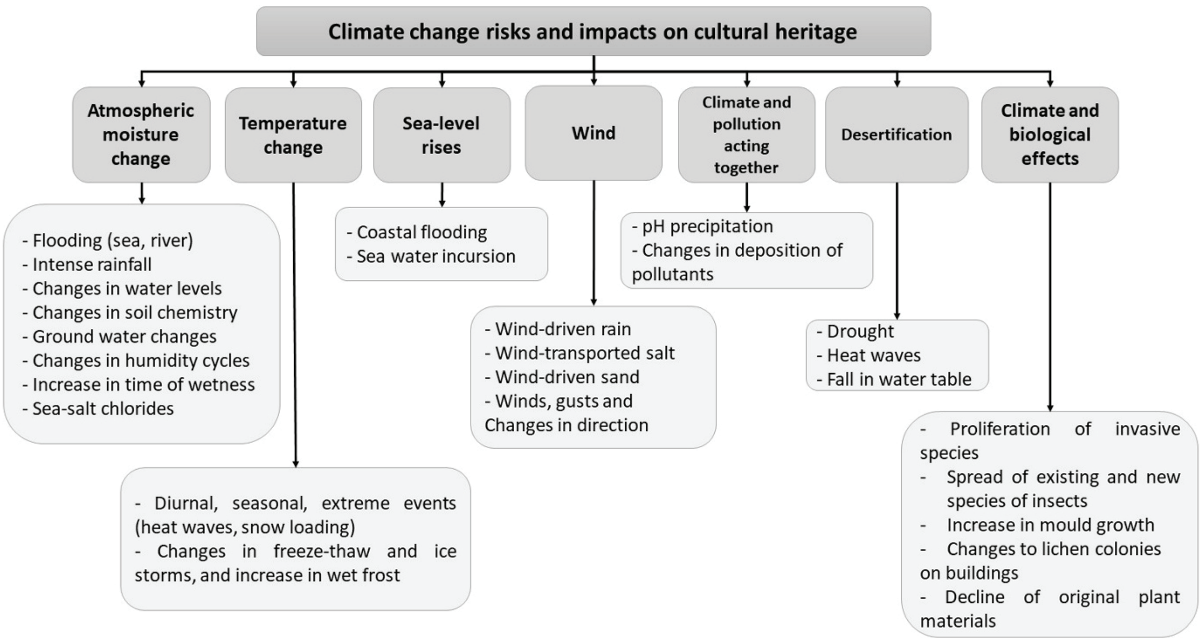

Fig. 1: Impacts of climate change on cultural heritage (UNESCO, 2007).

Table 1: Climate change and cultural heritage

Impacts	Literature
Sea-level rise, Coastal Erosion, and Flooding	(Carbognin *et al.*, 2010; P. Daly *et al.*, 2022; García Sánchez *et al.*, 2020; Maragno *et al.*, 2023; Marzeion & Levermann, 2014; Reimann *et al.*, 2018)
Changing of Sea Temperature	(Harkin & Westley, 2020; Isaak *et al.*, 2012; Willems & Schaik, 2017)
Acidification of Sea Water	(Harkin & Westley, 2020; Willems & Schaik, 2017)
Crystallization and Salt weathering	(Charlo, 2000; Menéndez, 2018; Ruiz-Agudo *et al.*, 2011; Vyshkvarkova & Sukhonos, 2023)
Biodeterioration and Architectural Impacts	(Bienvenido-Huertas *et al.*, 2021; Dias *et al.*, 2023; Hedayatnia *et al.*, 2021; Pires *et al.*, 2022; Prieto *et al.*, 2020; Silva *et al.*, 2020; Sitzia *et al.*, 2023)
Freeze-Thaw Cycle	(Sesana *et al.*, 2018, 2021; Vyshkvarkova & Sukhonos, 2023)
Soil Temperature	(Asano *et al.*, 2023; Bradford *et al.*, 2019; Menberg *et al.*, 2014)
Archaeological Sites	(C. Daly, 2011; Grossi *et al.*, 2007; Heilen *et al.*, 2018; Hollesen, 2022, 2023)
Severe Climate Events	(Sesana *et al.*, 2018, 2021)

adaptation-mitigation strategies to protect them.

Kapsomenakis *et al.,* (2023) warn that climate change and seismic activity increasingly threaten 244 UNESCO heritage sites in the Mediterranean. Their study reports a sharp rise in extreme heat-up to 50 additional hot days annually, and identifies Italy, Greece, and Türkiye as high-risk seismic zones. Coastal sites in these countries, including Cyprus, are particularly vulnerable, prompting the development of a Mediterranean-wide protection plan to address these escalating risks. (Kapsomenakis *et al.*, 2023). To protect heritage sites, key measures include coastal defences like sea walls, natural barriers, and erosion control to counter rising sea levels. Enhanced conservation through regular maintenance, monitoring, and climate-resilient materials is also crucial (Sabbioni *et al.*, 2010; Sesana *et al.*, 2021). According to recent research, vegetation greening has a cooling influence on air temperature both locally and globally (Liu *et al.*, 2022; Yu *et al.*, 2022). Policy and decision-makers require quantitative data on heritage risks to set risk thresholds and develop adaptation strategies. A coherent assessment methodology is needed to evaluate tangible and intangible heritage damage. Filling these gaps enables prioritized interventions, effective planning, and resource allocation (Bonazza & Sardella, 2023). While recent studies have examined the vulnerability of cultural heritage sites like Venice (Faranda *et al.*, 2024) and Petra (Abdalhaleem *et al.,* 2024), there remains a lack of integrated, site-specific, and data-driven assessments that account for both environmental and anthropogenic pressures on heritage sites. There is a lack of integrated, site-specific climate risk analyses, particularly for complex conservation sites like Side Ancient City, where archaeological, natural, and urban conservation sites. This study addresses that gap by proposing a holistic approach combining comparative analysis with similar examples, field observation inputs, GIS, and risk assessment. The findings aim to support climate-resilient conservation not only for Side but also as an interdisciplinary and transferable model for other vulnerable heritage sites. By emphasizing interdisciplinary risk modelling and policy integration, this research contributes to the emerging field of climate-resilient heritage management, offering both methodological innovation and practical relevance. This study aims to develop a holistic climate risk assessment framework for Side Ancient City by integrating comparative site analysis, field observations, GIS-based spatial analysis, and risk modelling, and answer the following questions:

1. *What are the primary climate-induced threats to the Site Ancient City?*
2. *How do these threats compare with similar sites?*
3. *What integrated conservation strategies can enhance the site's resilience?*

The methodology includes a literature review, field analysis at Side, examination of similar sites under risk, and a detailed risk analysis. This study examines the climate change risks threatening the Side Ancient City in Türkiye in 2024, focusing on material decay, structural vulnerabilities, and natural hazards like floods and storms. Using a site-specific, probabilistic risk assessment, it integrates

Table 2: Historic sites in danger and developed adaptation-mitigation strategies

Risks & Impacts	Adaptation & Mitigation Strategies
Venice, Italy	
Venice faces significant risks from rising sea levels and increased flooding, exacerbated by climate change. The frequency of "Acqua Alta" (high water) events has increased, threatening the city's unique architecture and historic buildings (Faranda *et al.*, 2024).	Faranda *et al.* (2024) examine the MoSE system's effectiveness in reducing Acqua Alta flooding in Venice, analyzing its impact on sea levels and economic damage. Comparing past floods (1966, 2008, 2019), it finds that while MoSE provides protection, additional measures are needed for unprecedented floods, requiring further research and adaptation strategies (Faranda *et al.*, 2024).
Machu Picchu, Peru	
Peru has significant tourist potential due to its landscapes, culture, and geomorphological features. This diversity creates a responsibility for preservation, especially given the risks posed by even moderate climate change scenarios.	The study evaluated solar and wind energy use for a historic site and museums in Peru, finding strong renewable potential but a lack of specific sustainability laws. It emphasized the environmental benefits of renewables and recommended policy enhancements to support sustainable tourism (Calderón-Vargas *et al.*, 2021).
City of Chan Chan, Peru	
The Chan Chan Archaeological Zone is highly susceptible to the impacts of climate change, particularly the extreme climatic events associated with the El Niño phenomenon that affect the northern coast of Peru (UNESCO, n.d).	Following its designation as a World Heritage site in danger, Chan Chan implemented a Master Plan supported by the World Heritage Fund, focusing on El Niño mitigation, water table control, and structural stabilization using both traditional and modern methods. The plan also prioritized documentation, training artisans, and public education. The Ministry of Culture's ENSO program introduced preventive actions, including wall stabilization, protective roofing, and water management (UNESCO, n.d.).
Djenné, Mali	
Djenné, Mali, faces climate-induced threats to its mudbrick architecture, including flooding, material deterioration, and loss of craftsmanship. Economic pressures drive the use of modern, unsustainable materials, while climate change accelerates urbanization and challenges restrictive conservation policies (Brooks *et al.*, 2020).	The study highlights the importance of preserving both tangible and intangible heritage, noting that cultural practices are as vulnerable as physical sites to climate change. It calls for greater awareness and the integration of heritage preservation into climate policy to prevent irreversible cultural loss (Brooks *et al.*, 2020).
Stonehenge and Avebury, United Kingdom	
Murphy *et al.*, (2013) identify 22 risks to heritage sites, including erosion from tourism, livestock, and extreme weather, flooding at Avebury, vegetation changes affecting conservation, wildfire threats, and damage to species like lichens on monuments *(Murphy et* , 2013).	The report underscores the need for regular monitoring, strategic responses, and adaptive measures to protect sites' Outstanding Universal Value. It advises incorporating these actions into updated World Heritage Site Management Plans, with ongoing reviews to address changing climate conditions (Murphy *et al.*, 2013).
Petra, Jordan	
Petra faces major climate risks such as flash floods, drought, and storms, which endanger its archaeological structures and the local economy reliant on tourism and agriculture (Abdalhaleem *et al.*, 2024)	The study advocates combining local knowledge with scientific data to strengthen Petra's resilience to climate change. Under a moderate emissions scenario, it projects moderate risk by 2060, highlighting the need for proactive and sustainable adaptation measures to safeguard its cultural and natural heritage (Abdalhaleem *et al.*, 2024)
Pyramids of Giza, Egypt	
The Giza pyramid complex, including the Great Pyramids and the Sphinx, faces structural damage and material decay from natural aging, human activity, and rising groundwater levels linked to urbanization and irrigation, increasing the risk of limestone deterioration (Hemeda & Sonbol, 2020).	The research emphasized the need for structural interventions and effective management to conserve the Giza site. It also discovered a large original hill beneath the pyramids and stressed controlling urbanization's impact on rising groundwater levels (Hemeda & Sonbol, 2020).
Greek Theatre of Dionysus in Athens	
The Ancient Greek Theatre of Dionysus in Athens faces climate change threats, including material degradation from humidity, corrosion, and vegetation growth, as well as structural damage from soil erosion, landslides, heatwaves, and heavy storms (Nastou & Zerefos, 2021).	Suggested strategies focus on energy efficiency, humidity control, and resilience enhancement, integrating climate adaptation into heritage management. The approach emphasizes proactive conservation, continuous monitoring, community involvement, and a sustainable framework to protect cultural heritage from climate change (Nastou & Zerefos, 2021)

field observations, GIS analysis, and comparative case studies to provide a comprehensive evaluation. The study proposes integrated adaptation and mitigation strategies, such as physical interventions, policy measures, and community-based initiatives to enhance Side's resilience. By bridging climate science and heritage conservation, it offers practical solutions and serves as a model for protecting historic urban sites from climate change. The study begins by identifying the vulnerability of the Side Ancient City to climate change, setting out its aim to develop integrated conservation strategies. It then poses key research questions about climate-induced threats, comparisons with similar sites, and resilience-enhancing solutions. The methodology includes a literature review, field analysis at Side, risk analysis, and comparison with other at-risk heritage sites. Based on this, the paper proposes adaptation and mitigation strategies such as coastal protection, improved drainage, structural resilience, protective measures, tourism management, and sustainable policies. The findings are synthesized in the results

Fig. 2: Location of Side

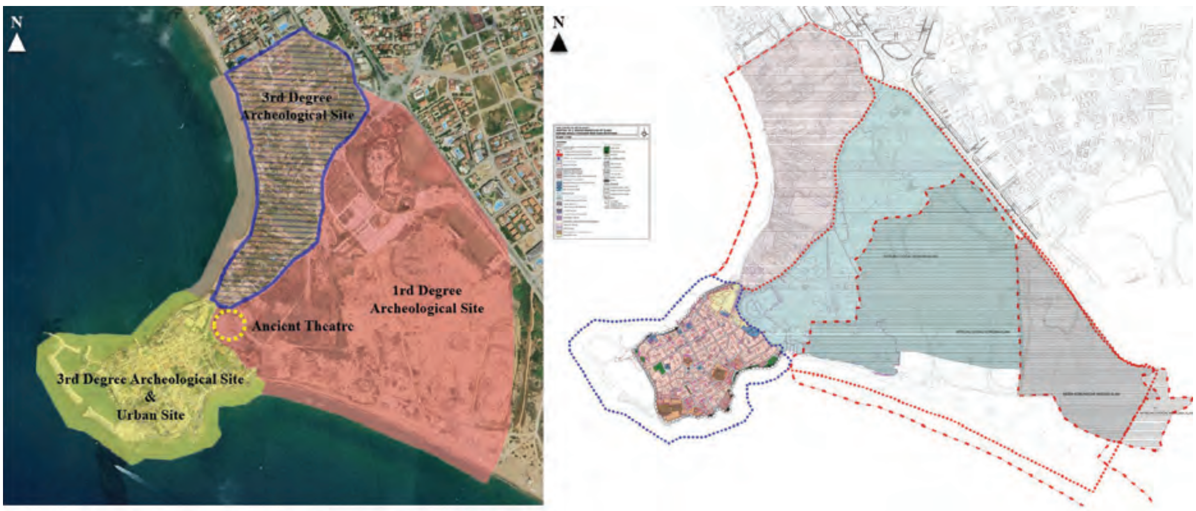

Fig. 3: 2024 Site conservation plan

and discussion sections, and practical and theoretical implications are highlighted, emphasizing similarities and differences with the literature. Finally, in the conclusion, the study's contributions, suggestions for future studies, and the study's limitations are presented.

MATERIALS AND METHODS

Side Ancient City

Asia Minor, a peninsula now largely corresponding to modern-day Türkiye, was a significant region in ancient times known as Anatolia. It played a key role in the Greek and Roman periods, particularly in Ionia along the central western coast. After the decline of Mycenaean society, Greeks, especially Ionians, began settling in the area around 1000 BC, establishing important city-states like Miletus, Samos, Chios, and Ephesus. Between 750 and 550 BD, Greek colonization expanded further, with cities positioned along major trade routes, boosting their prosperity (Sacks, 2005; 5). The Side, located in Asia Minor (modern-day Türkiye), is an archaeological treasure with a rich history that spans several civilizations. Today, Side is located in Antalya Province in the Manavgat District of southern Türkiye, near the Mediterranean coast. It lies approximately 75 kilometres east of Antalya's centre (Fig. 2).

Side, an ancient city in Eastern Pamphylia, is located near the Melas River. Its name, meaning "pomegranate", appears in various regions, including Pamphylia, Pontos, and Greece. Though its founding date is uncertain, ancient sources link it to Cymeans from Aeolia, while archaeological evidence suggests Late Hittite origins. Eusebius dates its establishment to 1405 BC. Unlike many ancient cities, Side experienced minimal migration or colonization, preserving its local cultural identity (Alanyalı, 2011; Alanyalı & Yurtsever, 2020). Side gained independence in the late Hellenistic period, later becoming a Roman administrative centre and naval base. It flourished in the Early Byzantine period and was eventually abandoned after the Seljuk conquest (13th century). In the late 19th century, Turkish families from Crete resettled the area, naming it Selimiye Village, and later reverted to Side. Archaeological excavations, led by Arif Müfid Mansel since 1947, uncovered key Late Antique and Byzantine monuments. Recent research focuses on the bishop's complex and urban integration during the Byzantine era, offering new insights and a conservation model for Anatolia (Altun, 2020; Elam, 2020; Soykal Alanyalı, 2017). Despite its designation as a 1st-degree archaeological site in 1990, Side faced rapid, unplanned development driven by tourism, delaying conservation and enabling illegal construction. Preservation efforts later aimed to integrate Ottoman rural architecture with archaeological heritage. The approved 2014 Conservation Plan focused on protecting traditional structures, preventing illegal building, involving the public, advancing excavations, and safeguarding both tangible and intangible heritage (Altun, 2020; Büyüksural & Sağıroğlu Demirci, 2023). To improve the 2014 Conservation Plan and better accommodate the historical area's spatial needs, revision work began in 2022. Following spatial analyses and stakeholder discussions, the updated plan was approved in 2024. Fig. 3. illustrates the 2024 Conservation Plan. Fig. 3. shows the ancient city of Side, highlighting areas with different levels of archaeological significance. The 1st Degree Archaeological Site (red area) includes key historical features like the Ancient Theatre and is under strict protection. The 3rd archaeological Sites (yellow and blue areas) are less sensitive but still hold archaeological value, with parts integrated into urban sites.

Earthquake

Side, located on Türkiye's southern coast, has historically faced natural disaster risks due to its geographical and environmental conditions. Archaeological records indicate earthquake impacts in the Antalya region, including the collapse of monumental structures in ancient cities like Termessos, Rhodiapolis, Perge, Selge, and Phaselis. Other earthquake-related effects included fires, toxic gas releases, water system failures, tsunamis, and the submersion of settlements (AFAD, 2022). Fig. 4 shows the distribution of earthquakes greater than 5 Mw from 1900 to the present.

Fig. 4 is color-coded with circles of different sizes and colors to represent the seismic activity in the Antalya province between 1900 and 2021. Blue circles for magnitudes between 5 and 6 are seen in the Manavgat district, where Side Town is located. According to the current earthquake zones of Türkiye, Side is located in the 2nd-degree earthquake zone. In these regions, ground acceleration is expected to be between 0.30 and 0.40 g. The most intense earthquakes are expected in 1st-degree regions (AFAD, 2022).

Sea level rise and coastal erosion

Side is located on the Mediterranean coast. Fig. 5 shows the risk levels of cultural heritage on the Mediterranean coast against climate change impacts. The coastal area where Side is located is shown in the red box in Fig. 5. According to the legend of this map, the Side region is at a high risk of sea rise. In possible cases, the sea level in this region may rise between 2 and 2.2 meters. This means the region is at risk from rising sea levels. The proximity of the coastal heritage like Apollo Temple to the sea presents significant challenges in the face of climate change (Fig. 6). Rising sea levels, coastal erosion, and intensified storms pose severe threats to the Apollo Temple, risking flooding, structural collapse, and accelerated material decay due to saltwater intrusion, temperature rise, and humidity changes. Shifting coastal landscapes further undermine site stability. Effective preservation requires physical barriers, better drainage, potential artifact relocation, and comprehensive risk assessment and mitigation strategies.

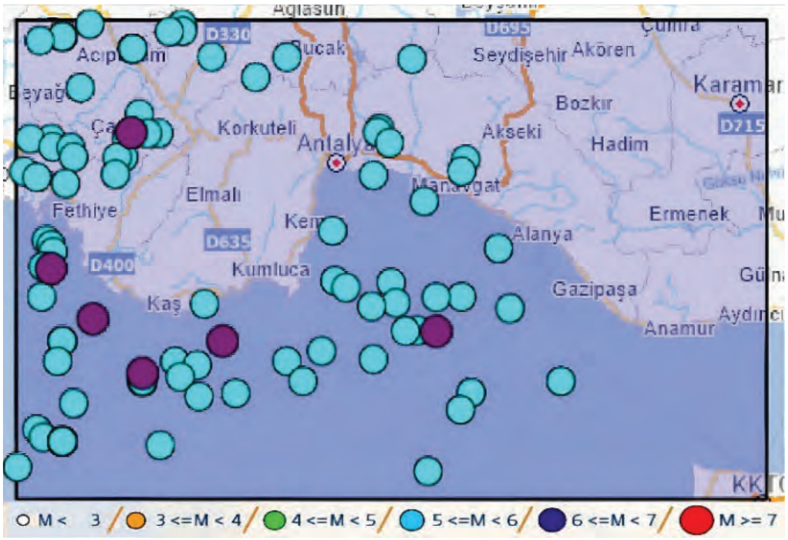

Fig. 4: Distribution of Earthquakes Greater than 5 Mw Affecting Antalya, 1900-2021 (AFAD, 2022).

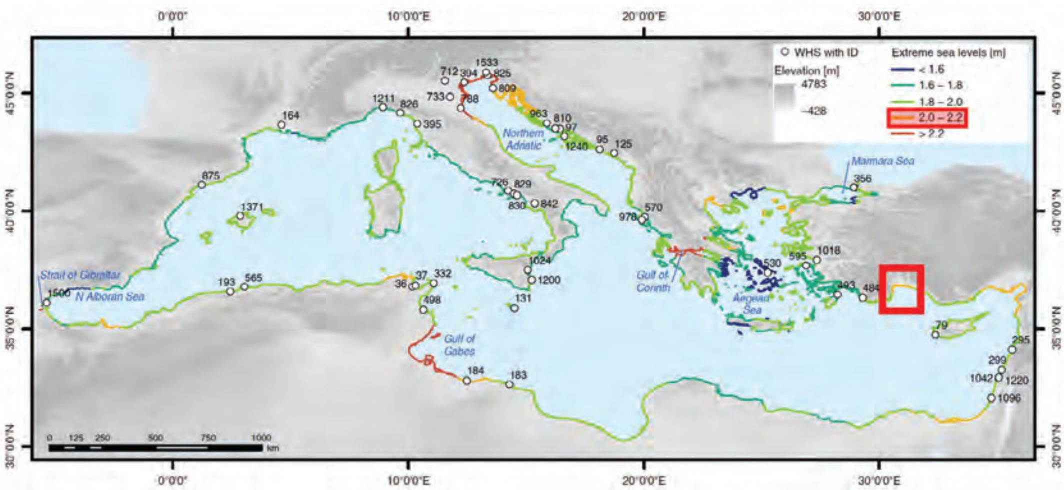

Fig. 5: Risk levels of cultural heritage on the Mediterranean coast (Reimann et al., 2018).

Vegetation

At this stage, the temporal change in the green area ratio within the section encompassing both urban and archaeological sites of the region was analysed. For this purpose, aerial photographs taken in June 2009 and June 2024 were compared (Fig. 7). Using the GIS software, green area pixels were extracted from raster data, and area calculations were performed. The analysis revealed that the green area ratio was 15.57% in 2009 and 11.12% in 2024, indicating a decrease of approximately 4.45% over the 15 years. This decline is likely attributable to multiple factors, including changes in precipitation patterns and increased drought conditions associated with climate change, as well as the implementation of inadequate urban development and environmental policies.

Urbanization

An examination of Side's urbanization process reveals a rapid increase in new structures over the past years, primarily driven by tourism development (Güven Ulusoy, 2014: 75). Fig. 8 illustrates the structural changes in the ancient city of Side in recent

Fig. 6: Vulnerability of coastal heritage

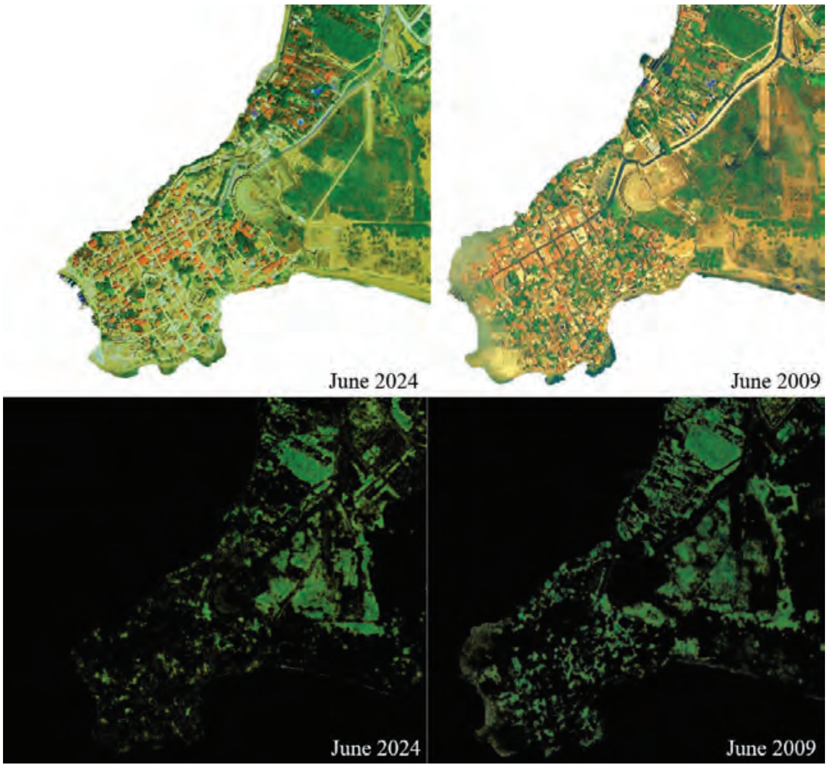

Fig. 7: Change in vegetation

years. A Void-Solid Analysis was conducted on raster data utilizing GIS software. The results indicate that the built-up area ratio was 0.84% in 1953, 4.5% in 1975, 15% in 1992, and 16.8% in 2010, demonstrating a nearly 20-fold increase in construction activity over 57 years. This rapid urban expansion has led to inevitable environmental impacts, which remain a pressing concern today.

Exposure to the sun and high temperatures

Climate change and rising temperatures are closely linked, with higher global temperatures being one of the most evident consequences of climate change. The Side Historic Site's direct exposure to the sun and high temperatures can accelerate the degradation of its ancient stone materials due to UV exposure and thermal expansion, which may lead to cracking and weakening of the structure (Fig. 9). The average temperature in Side, which was 17.1°C in 1979, has risen to 18.5°C by 2023 (meteoblue, 2023). Harsh environmental conditions deteriorate the site's microclimate, threatening its historical landscape. Protecting ruins like the Temple of Apollo requires shelters, shade structures, vegetation, and moisture control systems to reduce heat, wind, and sun exposure. Using reflective materials, regular monitoring, and adaptive management ensures long-term climate resilience in conservation.

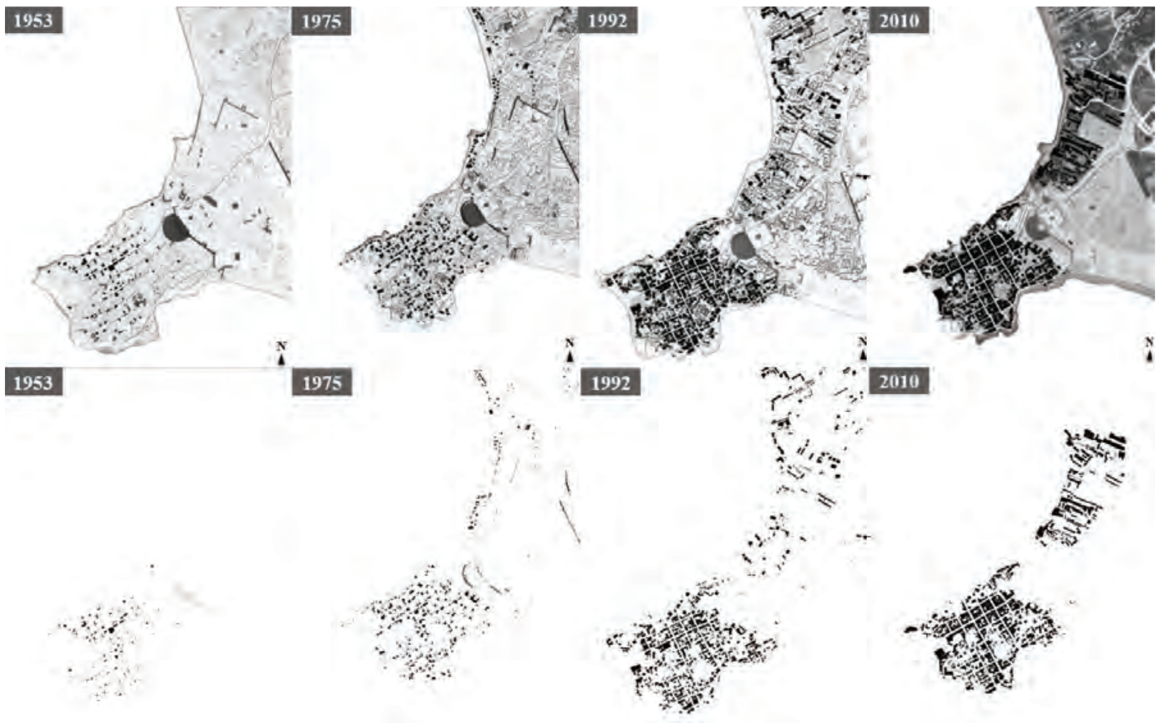

Fig. 8: Urban development of Side between 1953 and 2010

Fig. 9: Exposure to the sun

Accessibility and materials

Accessibility challenges at the site include cobblestone roads, which create instability for wheelchairs, walkers, and strollers, and a lack of ramps, smooth transitions, and handrails, making navigation difficult for individuals with mobility impairments. Narrow pathways and raised curbs further restrict movement. Improving these aspects would enhance accessibility. Environmentally, cobblestones are durable and recyclable, offering some sustainability benefits (Fig. 10). Cobblestone and brick pavements contribute to the Urban Heat Island Effect (UHIE) by absorbing and retaining heat, making cities hotter during heat waves. Their production and transportation also have a high carbon footprint, especially when not locally sourced. Additionally, their impermeability increases rainwater runoff, worsening urban flooding risks, which are escalating due to more frequent extreme weather events (Arora *et al.*, 2023; Logan, 2021). Moreover, climate change impacts like extreme heat can damage such pavements, leading to higher maintenance costs. To mitigate these issues, using cool or permeable pavements and prioritizing sustainable, low-carbon materials in construction to enhance climate resilience urban planners and designers *(Li et al.*, 2013; Santamouris, 2013).

Covering archaeological sites with glass roofs

Covering archaeological sites with glass roofs offers a way to protect them from climate change impacts, but it also comes with certain challenges (Fig. 11). Glass roofs help protect ancient structures from rain, wind, UV exposure, and temperature fluctuations while enhancing the visitor experience. However, in Side, condensation caused by trapped heat and humidity has led to concerns about accelerated degradation. To avoid the greenhouse effect, microclimate design must balance insulation, shading, and ventilation, use UV-treated, reflective glass, and regulate air exchange to maintain a stable environment (Carbonara, 2019).

Over-Tourism

Over-tourism indirectly amplifies climate change impacts through factors such as rising travel demand, air pollution, and an increased carbon footprint (Dodds & Butler, 2019; Peeters *et al.*, 2018). According to MATOB (Manavgat Tourism Hoteliers and Operators Association) 2023 data, Side hosts a total of 295 hotels, 45,211 rooms, and 102,454 beds. However, specific data on visitor numbers and tourism revenue for Side is unavailable. In 2023, Manavgat district received 7,112,462 visitors, generating $7,013,318 in tourism revenue (MATOB, 2023). The study highlights a significant gap in detailed and reliable data regarding Side Ancient City's tourist capacity, daily visitor numbers, and revenue, emphasizing the need for comprehensive tourism monitoring

Fig. 10: Accessibility and materials

Fig. 11: Covering archaeological sites with glass roofs

and reporting. Over-tourism causes overcrowding, environmental degradation, and infrastructure strain, driving loss of local identity and increased pollution. Solutions include tourist taxes, visitor caps, and tourism management strategies. Sustainable tourism management and collaboration are crucial for balancing economic benefits and environmental degradation with long-term sustainability (Dodds & Butler, 2019; Seraphin *et al.*, 2018). In places like Side, managing tourist numbers and adopting sustainable tourism practices are essential to balancing the economic and cultural benefits with the need to protect the environment and local community.

RESULTS AND DISCUSSION

Risk analysis of side effects

This section details the risk analysis of the site in Antalya, focusing on both natural and artificial factors that could threaten the site. Table 3 presents the risks, descriptions, and impacts.

Table 3: Risk analysis of side effects

Risk	Description	Impact
Sea Level Rise and Flooding	Rising sea levels, exacerbated by global climate change, pose a significant risk to low-lying areas of the site. Flooding could damage or submerge parts of the city, especially during storm surges or extreme weather events.	Physical damage to the ruins, erosion of foundational soils, and potential long-term inundation of parts of the site.
Coastal Erosion	The Side's coastal location makes it highly vulnerable to erosion from rising sea levels and increased wave action due to climate change. Over time, this erosion threatens the structural integrity of ancient ruins, especially the Temple of Apollo near the shore.	Loss of structural stability, increased risk of collapse of coastal ruins, and potential loss of archaeological artifacts.
Earthquakes	Climate change indirectly increases seismic risks by melting glaciers, thawing permafrost, and altering sea levels, which destabilize fault lines and soil structures (Turner *et al.,* 2023). Türkiye’s UNESCO heritage sites face rising threats from extreme heat, wildfires, earthquakes, and sea level rise, especially in the western and southern regions. As a high-risk seismic zone, earthquakes could worsen climate-induced damage (Kapsomenakis *et al.,* 2023). Antalya is located in a seismically active region. Earthquakes pose a significant threat to the ancient structures in Side, which were not built to withstand seismic activity.	Structural damage or collapse of buildings, loss of historical integrity, and potential endangerment of visitors and staff.
Temperature Extremes and Freeze-Thaw Cycles	Temperature extremes and fluctuations cause thermal expansion and contraction, leading to cracks and structural weaknesses in stone materials. The freeze-thaw cycle further accelerates damage to stone surfaces and mortar joints.	Cracking and fragmentation of stone structures, leading to long-term deterioration and increased need for conservation efforts.
Drought and Vegetation Loss	Prolonged droughts from climate change can reduce vegetation, destabilize soil, and increase erosion, which accelerates ruin degradation.	Increased soil erosion, loss of protective vegetation, and exposure of foundations and ruins to additional weathering.
Urban Development and Construction Activities	Urban development and construction in Antalya pose risks to the site by causing ground vibrations, pollution, and altered water drainage, potentially compromising the structural integrity of the ruins.	Structural damage from ground vibrations, pollution-related stone deterioration, and increased risk of flooding due to altered drainage patterns.
Tourism Pressure	High tourist traffic at Side accelerates wear and tear, with foot traffic, physical contact, and vandalism worsening ruin degradation. Overcrowding also increases safety risks and maintenance demands.	Physical wear on paths and structures, potential structural damage from unauthorized access, and increased maintenance and repair costs.
Inadequate Conservation and Maintenance Practices	Insufficient conservation, lack of funding, and poor restoration efforts can worsen site damage, while inadequate maintenance increases vulnerability to natural degradation and climate impacts.	Accelerated deterioration of ruins, loss of historical authenticity due to inappropriate restoration, and potential safety hazards for visitors.
Mismanaging Visitor	Poor visitor management and a lack of supervision can lead to vandalism, graffiti, and physical damage. Inadequate signage and barriers allow access to fragile areas, worsening site deterioration.	Damage to the site’s visual and structural integrity, loss of historical and cultural value, and increased costs for repairs and restoration.

Comparison of climate change risks: literature review and Side case study

A structured comparison of climate change risks between example heritage sites (Table 2) and sites (Table 3) is presented below (Table 4). This comparative analysis aims to contextualize the vulnerabilities of Side within the broader framework of global heritage conservation challenges.

The Side Ancient City faces severe climate and human-induced threats, including sea-level rise, erosion, seismic risk, extreme weather, and rapid urbanization. Unlike other heritage sites like Venice and Machu Picchu, it lacks adequate flood defences, visitor regulations, and strong conservation policies, making it especially vulnerable. These challenges highlight the urgent need for adaptive and mitigation strategies to ensure its long-term preservation.

Adaptation and mitigation strategies

Climate change strategies include mitigation, which reduces greenhouse gas emissions to limit impacts, and adaptation, which minimizes risks from extreme weather while leveraging potential benefits. Both approaches work together to address short-term effects and ensure long-term climate resilience (NASA, n.d.). Adaptation strategies focus on adjusting social, environmental, and economic systems to minimize the negative effects of climate change. These include enhancing infrastructure resilience to withstand extreme weather, developing drought-resistant crops, improving water conservation, and building flood defences along coastlines. Mitigation strategies aim to reduce greenhouse gas emissions by transitioning to renewable energy, improving energy efficiency, sequestering carbon, and promoting sustainable implementations and transportation reforms. Combining both adaptation and mitigation is essential for long-term climate resilience, requiring efforts from governments, businesses, and individuals (IPCC, 2023b). Table 5 shows adaptation and mitigation strategies developed in this study for the protection of Sides from climate change impacts.

Table 4: Comparison of climate change risks: similar heritage sites and Side

Category	Similar Heritage Sites (Table 2)	Side (Table 3)	Key Observations
Sea-Level Rise & Flooding	Venice, Petra, Djenné, Stonehenge and Avebury, Chan Chan	Severe risk: flooding threatens ruins and foundational erosion	Both share flooding concerns, but Side lacks large-scale flood control (e.g., Venice MoSE)
Coastal Erosion	Venice, Giza, Petra, Chan Chan	High risk due to coastal proximity (e.g., Temple of Apollo)	Similar erosion issues, but Side's unique archaeological value makes it more fragile
Earthquake Risk	Italy, Greece, and Türkiye are identified as high-risk seismic zones, where earthquakes could exacerbate climate-related damage to Mediterranean cultural heritage sites (Kapsomenakis et al., 2023). These zones need urgent adaptation strategies.	Side Ancient City is located in the south of Türkiye and the Mediterranean region, and is at risk of earthquakes.	Earthquake risk is a challenge for Side, requiring seismic-focused adaptation
Temperature Extremes & Freeze-Thaw Cycles	Greek Theatre of Dionysus	Thermal expansion and freeze-thaw cycles cause stone cracking	Both sites experience stone degradation
Drought & Vegetation Loss	Petra, Stonehenge, and Avebury	Prolonged droughts increase erosion and expose ruins	Side faces greater vegetation loss risks due to its coastal-arid environment
Urban Development & Construction	Venice (tourist-driven construction impact), Giza (construction vibrations, urban sprawl)	Urban expansion alters water drainage, and pollution effects	Both face urbanization risks
Tourism Pressure	Machu Picchu	High visitor traffic causes physical wear and structural stress	Tourism impacts are a shared concern. Side lacks controlled visitor management like Machu Picchu
Inadequate Conservation Practices	Giza (mismanagement of restoration projects), Djenné, Chan Chan	Lack of consistent conservation efforts threatens site integrity	Similar conservation challenges

Table 5 presents a comprehensive framework for climate adaptation and mitigation strategies for Side, covering coastal defence, water management, structural resilience, tourism regulation, green initiatives, and policy advocacy. While it effectively integrates nature-based solutions, technological monitoring, and sustainable tourism, several areas require improvement. Coastal defines strategies that should incorporate hybrid solutions like living shorelines to prevent erosion without disrupting natural sediment transport. Water management should address drought risks alongside flooding by incorporating rainwater harvesting and drought-resistant landscaping. Structural resilience measures should include seismic retrofitting, particularly for earthquake-prone regions such as Türkiye, Italy, and Greece. Sustainable tourism strategies need regulatory mechanisms like visitor caps and

Table 5: Adaptation & mitigation strategies

Adaptation & Mitigation Strategies		
Category	Strategy	Description
Implement Coastal Defence Mechanisms	Construct Sea Walls and Utilize Natural Defences	Develop artificial structures and enhance natural features to prevent coastal erosion
	Beach Restoration	Replenish sand and other natural materials to preserve beach areas
Upgrade Water Drainage and Management Systems	Strengthen Drainage Networks	Improve infrastructure to handle stormwater and prevent flooding
	Rainwater Collection and Control	Introduce systems for capturing and managing rainwater efficiently
Strengthen and Restore Structures	Apply Climate-Resilient Building Materials	Use durable materials that withstand climate extremes
	Routine Upkeep and Inspections	Conduct regular maintenance and checks to ensure long-term stability
Provide Protective Shelters	Temporary and Permanent Refuge Solutions	Offer shelters for immediate or long-term protection against extreme weather
	Shade and Windbreak Installations	Install coverings and barriers to guard against harsh environmental conditions
Enhance Monitoring and Early Warning Systems	Deploy Environmental and Climate Sensors	Set up devices to monitor climate changes and environmental conditions
	Install Early Warning Mechanisms for Severe Weather	Ensure communities receive timely alerts about extreme weather events
Manage Landscapes and Prevent Erosion	Apply Erosion Control Methods	Implement strategies to prevent soil erosion in vulnerable areas
	Promote Sustainable Landscaping Practices	Use eco-friendly techniques and materials to maintain landscapes and minimize environmental impact
Promotion of Sustainable Tourism	Visitor Management Plans	Implementation of strategies to reduce visitor impact and promote sustainable tourism practices.
	Educational Campaigns	Initiatives to raise awareness and educate the public on climate change impacts and sustainable actions.
Energy-Efficient Infrastructure and Practices	Renewable Energy Use	Adoption of clean energy solutions to reduce carbon emissions in energy consumption.
	Sustainable Building Practices	Application of eco-friendly construction techniques to reduce environmental impact.
Carbon Offsetting and Green Initiatives	Tree Planting and Reforestation	Initiatives to offset carbon emissions and restore natural ecosystems through tree planting.
	Green Roofs, Pavements and Walls	Installation of vegetative systems on buildings to improve insulation and reduce heat effects.
Collaboration with Climate and Heritage Organizations	Partnerships with Research Institutions	Collaborations aimed at developing innovative climate and heritage preservation strategies.
	Engagement with Local and Global Communities	Active participation in community efforts to address climate challenges.
Policy Advocacy and Integration	Advocacy for Climate-Responsive Policies	Promotion of policies aligned with climate action to protect heritage sites.
	Integration into Climate Action Plans	Inclusion of heritage preservation strategies in broader climate mitigation plans

controlled access to mitigate Over-Tourism impacts. The green initiatives section would benefit from incentives for sustainable practices around heritage sites, such as tax benefits for eco-friendly businesses. Additionally, policy advocacy should align with global frameworks, including UNESCO's Climate Action Plan and the Paris Agreement, ensuring international coordination in heritage conservation. Strengthening these areas will enhance the practical applicability of the strategies, making them more effective in safeguarding cultural heritage against climate and seismic threats. This study presents a comprehensive, site-specific climate risk assessment of Side Ancient City in Türkiye, integrating environmental, seismic, and anthropogenic threats. The results confirm that the Side faces complex, overlapping risks, such as sea-level rise, coastal erosion, earthquakes, extreme temperatures, drought, vegetation loss, over-tourism, and insufficient conservation measures, many of which are exacerbated by the absence of flood defences and poor tourism management. Unlike prior studies that address single threats in isolation, this research employs a layered vulnerability model combining GIS analysis, field observation, and comparative global heritage data, advancing scholarly understanding of site-specific diagnostics. A critical synthesis with existing literature reveals key parallels with heritage sites like Venice, Petra, Giza, and Machu Picchu in terms of environmental stressors and management challenges. However, Side's lack of adaptive infrastructure and controlled visitor access renders it particularly fragile. However, unlike Petra or Machu Picchu, where structured tourism management exists, Side suffers from a lack of regulated visitor flow and monitoring—a critical gap also noted in research on over-tourism's impact on heritage (Dodds & Butler, 2019; Peeters *et al.*, 2018). The study reveals a novel dimension by addressing green space loss and its implications for microclimate regulation, a factor often overlooked in heritage climate studies. Vegetation cover has declined by 4.45% in Side over the past 15 years, exacerbating urban heat island effects and increasing surface-level erosion risks. While Liu *et al.,* (2022) and Yu *et al.,* (2022) affirm the cooling and stabilizing benefits of vegetation, this study demonstrates how such loss can compound heritage vulnerability in coastal settings. Another important point of synthesis involves seismic threats. While the literature identifies Türkiye as a high-risk seismic zone (Kapsomenakis *et al.,* 2023), few studies offer integrated seismic and climate assessments at the site level. This study advances by linking probabilistic seismic data with climate-induced degradation pathways such as thermal expansion and freeze-thaw cycles (Vyshkvarkova & Sukhonos, 2023). In terms of mitigation, existing literature often proposes isolated strategies—such as protective barriers or climate-resilient materials—but lacks the integrated, site-adapted, and multi-scalar approach offered here. This research develops a model of adaptation and mitigation strategies (Table 5) that align physical interventions (e.g., drainage systems, seismic retrofitting) with policy actions (e.g., sustainable tourism management, community engagement), following the interdisciplinary calls from Bonazza & Sardella (2023) and Sesana *et al.* (2021). In conclusion, this work significantly advances the literature by:

- Providing an integrated, GIS-informed risk assessment model;
- Comparing the sides' vulnerabilities within global case studies;
- Offering a robust set of practical and policy recommendations;
- Shifting heritage conservation discourse from generalized risk awareness to proactive, site-based adaptation planning.

This work moves the discussion forward from generalized vulnerability assessments to localized, actionable frameworks, bridging the gap between theoretical models and practical heritage management.

CONCLUSION

This study presents a significant theoretical contribution by introducing an integrated, site-specific framework that assesses climate, seismic, and anthropogenic risks to heritage sites, addressing a key gap in the literature where such threats are typically examined in isolation. Unlike traditional approaches that analyse risks in isolation, this research synthesizes environmental, urban, and structural vulnerabilities into a unified model. The model combines GIS analysis, probabilistic risk assessment, and global comparisons, offering a scalable and transferable approach to understanding vulnerability and resilience in complex heritage landscapes like Side Ancient City. Managerially, the study provides actionable recommendations, such as coastal defence systems, seismic retrofitting, improved drainage infrastructure, and sustainable tourism regulation, while emphasizing the importance of community engagement and cross-sector collaboration in policy implementation. This model is particularly relevant for Mediterranean heritage zones increasingly exposed to environmental hazards. For future research, the model should be tested in other geographic contexts, integrated with real-time environmental monitoring, predictive modelling to enhance risk forecasting, and expanded to explore socio-economic aspects such as community resilience, equity in tourism, and cost-benefit analyses of intervention strategies. Lastly, future studies can test the applicability of this framework within national policy systems and international agreements (e.g., UNESCO's World Heritage Climate Action Plan or the Paris Agreement) to inform global heritage governance under accelerating environmental change. This study's main limitations include the absence of detailed visitor data for Side Ancient City, limited generalizability due to its single-site focus, lack of real-time environmental monitoring, uncertainties in long-term climate projections, and insufficient detail on seismic retrofitting measures. These constraints reduce the precision and broader applicability of the findings. Other researchers can address these limitations by collecting real-time environmental and tourism data, applying the methodology to multiple heritage sites for broader validation, using advanced climate modelling tools, and collaborating with engineers to develop site-specific retrofitting solutions.

AUTHOR CONTRIBUTIONS

L. Akbarishahabi performed the conceptualization, literature review, methodology, data collection, data analysis, manuscript preparation, and final 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.

ABBREVIATIONS (NOMENCLATURE)

BC	Before Christ
C	Celsius
ENCO	El Niño Southern Oscillation
g	Typical range of earthquake acceleration
GIS	Geographical Information Systems
IPCC	Intergovernmental Panel on Climate Change
MATOB	Manavgat Tourism Hoteliers and Operators Association
MoSE	Modulo Sperimentale Elettromeccanico
Mw	Moment Magnitude
UHIE	Urban Heat Island Effect

UNESCO	United Nations Educational, Scientific, and Cultural Organization
UV	Ultraviolet

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ORIGINAL RESEARCH PAPER

Modeling sediment transport and assessing erosion and sedimentation status in the Haraz River watershed based on the ecosystem services concept

A. Chahkandi, G. R. Nabi Bidhendi*, B. Malekmohammadi

Department of Environmental Engineering, Faculty of Environment, University of Tehran, Tehran, Iran

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ABSTRACT

BACKGROUND AND OBJECTIVES: Effective river basin management requires understanding sediment transport dynamics and their impact on ecosystem services to mitigate soil erosion and sedimentation. This study emphasizes the novel integration of the ecosystem services framework into sediment transport modeling using the Integrated Valuation Ecosystem Services and Tradeoffs Sediment Delivery Ratio model. The Haraz River basin, a critical watershed in northern Iran, faces significant erosion and sedimentation problems due to steep slopes, sporadic vegetation, and intensive land use. This study aimed to model sediment transport and assess erosion and sedimentation dynamics within the basin using the Integrated Valuation of Ecosystem Services and Tradeoffs Sediment Delivery Rate model, focusing on ecosystem services, particularly sediment retention and delivery.
METHODS: The Integrated Valuation of Ecosystem Services and Tradeoffs Sediment Delivery Rate model was applied to the Haraz River Basin, using high-resolution land use maps, a Digital Elevation Model, and field-calibrated parameters. The study quantified soil erosion and sediment export at pixel and sub-watershed levels. The analysis considered key factors such as rainfall erosivity, soil erodibility, slope length, land cover, and management actions to estimate sediment dynamics and identify critical erosion hotspots.
FINDINGS: The results showed considerable spatial variability in sediment transport and retention across the catchment. Subwatershed 2 had the highest soil erosion potential (13,016,268 tonnes) and sediment export (1,992,277 tonnes), primarily due to steep slopes and limited vegetation cover. In contrast, sub-catchment 5 had the lowest erosion potential (60,721 tonnes) and sediment export (9,328 tonnes) due to effective land management and favorable land cover conditions. The values for erosion control and sediment retention illustrate the crucial role of vegetation in mitigating soil loss and reducing sediment input into rivers.
CONCLUSION: This study highlights the complex interplay between natural and management factors in regulating erosion and sediment dynamics. Integrating Sediment Delivery Ratio modeling with an ecosystem services framework provided actionable insights for prioritizing erosion control measures in high-risk areas and improving sediment retention. Management strategies that include vegetation restoration, land use optimization, and sediment control barriers are recommended to improve watershed sustainability in the Haraz Basin.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
39	10	2

*Corresponding Author:
Email: *ghhendi@ut.ac.ir*
Phone: +982161113167
ORCID: 0000-0001-9930-9080

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INTRODUCTION

The sustainable management of river watersheds is critically important for maintaining both ecological integrity and providing vital ecosystem services (Andualem *et al.*, 2023), (Balist *et al.*, 2022a), (Rodriguez *et al.*, 2023). Sediment transport, a fundamental process within river systems, has a substantial impact on several ecosystem services, including water quality, aquatic habitat, and flood protection (Fang *et al.*, 2024; Slosson *et al.*, 2021; Malekmohammadi *et al.*, 2023). However, anthropogenic activities and climate change are altering sediment dynamics and leading to increased erosion and sedimentation in many river basins worldwide (Owens *et al.*, 2020), (Zebardast *et al.*, 2023), (Sadeghi *et al.*, 2021); this requires a comprehensive understanding of the interplay between sediment transport, erosion, sedimentation, and the resulting impacts on ecosystem services. The Sediment Delivery Ratio (SDR) is a significant indicator for managing water catchment areas. It indicates the proportion of sediment generated from land surfaces that is ultimately transported to a particular river or river system point. Understanding sediment dynamics, erosion processes, and their impact on ecosystem services and water resources is fundamental. Increasingly, researchers and practitioners are adopting ecosystem services frameworks to analyze and model sediment dynamics due to their holistic approach, which integrates environmental, social, and economic dimensions (Schröter *et al.*, 2014; Costanza *et al.*, 2017). This study aims to model SDR in a watershed using the Integrated Valuation of Ecosystem Services and Tradeoffs model (InVEST), which explicitly incorporates ecosystem services to assess sediment transport and deposition processes. Sediment delivery processes are closely tied to land-use practices, soil conservation, and hydrological dynamics within a watershed. High sediment loads can lead to several adverse consequences, such as reservoir siltation, reduced water quality, habitat degradation, and increased treatment costs for drinking water (Pimentel *et al.*, 1995). Understanding SDR provides insights into erosion hotspots and helps prioritize areas for conservation interventions (Borrelli *et al.*, 2017). Moreover, sediment transport affects ecosystems' provisioning, regulating, and supporting services, underscoring the need to study SDR from an ecosystem services perspective (Dominati *et al.*, 2010). The ecosystem services concept provides a structured approach to evaluate the benefits humans derive from ecosystems, such as clean water, fertile soils, and flood regulation (MEA, 2005). Sediment dynamics directly influence multiple ecosystem services. For instance, regulating services, including soil retention and water purification, are impacted by sediment transport and deposition patterns. Similarly, cultural services, such as recreational fishing and aesthetic values of water bodies, may be degraded by excessive sedimentation (Posthumus *et al.*, 2010). Integrating SDR modeling within the ecosystem services framework enables a comprehensive understanding of how land-use changes, climate variability, and conservation efforts affect these services. Sediment Transport Modeling: Empirical sediment rating curves (Tabarestani *et al.*, 2022), (Guo *et al.*, 2002), and physically-based sediment transport models will be used to estimate sediment loads. The selection between these methods will depend on the availability of data on sediment grain size distribution and the characteristics of the river bed. The InVEST model is frequently used for assessing ecosystem services and their tradeoffs. It includes a suite of models that estimate the biophysical and monetary values of ecosystem services, including the SDR model, which predicts sediment retention and delivery based on land use, topography, and climate inputs (Hamel *et al.*, 2015), (Balist *et al.*, 2021). The SDR module of InVEST combines GIS-based spatial analysis with process-based algorithms to evaluate sediment retention and identify priority areas for erosion control (Hamel *et al.*, 2015). The model is particularly useful in watersheds with complex land-use patterns, where it can support decision-making for sustainable land and water resource management. Despite significant progress in SDR modeling, several challenges remain. First, the accuracy of SDR predictions depends on the precision and resolution of input data, like land use maps (Balist *et al.*, 2022b), soil properties, and precipitation patterns (Hamel *et al.*, 2017). Second, existing models often do not fully account for sediment processes' temporal variability and spatial heterogeneity, which can lead to uncertainties in predictions (Tedesco *et al.*, 2020). In addition, more empirical studies are needed to validate model results under different environmental conditions and management scenarios (Fu *et al.*, 2011). This study addresses the above challenges by applying the InVEST SDR model to a specific watershed to evaluate its effectiveness in capturing sediment dynamics within an ecosystem services framework.

This study aims to

(1) Quantify sediment retention and delivery using the InVEST SDR model,

(2) Analyze spatial patterns of sediment transport,

(3) Assess the impact of sediment dynamics on ecosystem services,

(4) Provide land-use planning recommendations.

This study contributes to the growing literature on sustainable watershed management by integrating SDR modeling with the ecosystem services approach. It provides actionable insights for policymakers, land managers, and conservationists seeking to balance ecological and socio-economic objectives. The paper's structure follows: The methodology section describes the study area, data collection, and modeling approach, including applying the InVEST SDR model. The results section presents the spatial patterns of sediment delivery and retention and their implications for ecosystem services. The significance of the findings is discussed in the context of watershed management and ecosystem services, including limitations and future research directions. The conclusion summarizes the key findings and provides recommendations for sustainable management practices.

MATERIAL AND METHODS

Study region

The study region is located in the southern part of Mazandaran Province, within the political boundaries of Amol County and the Haraz River Basin. The watershed spans 200,051 hectares, with a perimeter of 296.062 kilometers. The basin's minimum elevation is 200 meters, while its maximum elevation reaches 5,600 meters. All rivers within the basin ultimately flow into the Haraz River. Notable rivers include Akhn Sar, Shirkalarud, and Namarestagh. Significant elevations in the basin include Mount Damavand, the highest peak in the region, as well as Shim Kuh and Mount Imamzadeh Qasem. Major settlements within the Haraz watershed include Polour, Nashel, Tiran, Rineh, Kandovan, Ab Esk, Gazanak, Baijan, Balghalm, and others. Fig. 1 illustrates the position of the Haraz study area in Mazandaran Province and the entire country. The Haraz River Basin has a humid to semi-humid climate, with an average annual precipitation of approximately 850 mm, most of which occurs in the fall and winter seasons. Mean annual temperature ranges from 5°C in the highlands to 18°C in lower elevations. The dominant vegetation

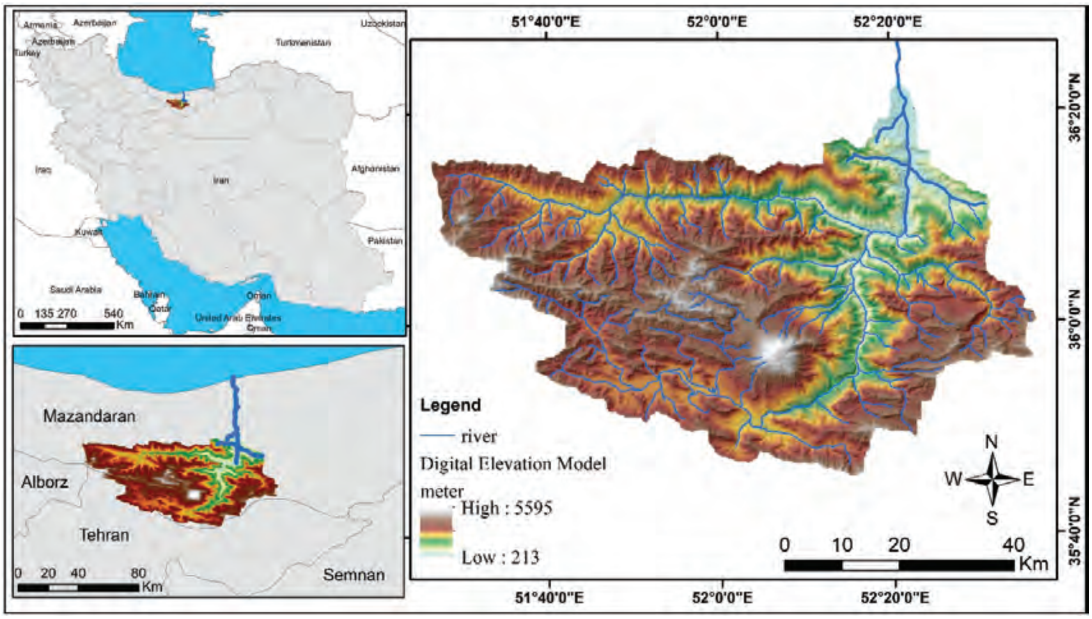

Fig. 1: Location of the study area

types include pasturelands, natural rangelands, and forests, particularly in the northeastern parts of the basin.

Methods

Sediment delivery

The SDR module is a spatially unambiguous model that aligns with the input Digital Elevation Model (DEM) resolution. It estimates the annual soil loss for each pixel and subsequently determines the SDR, quantifying the fraction of eroded soil that reaches the stream. Once sediment enters the stream network, it is assumed to be transported directly to the catchment outlet, as in-stream processes that could modify sediment loads are not considered in this model. Originally introduced by Borselli et al. (2008), this approach has gained increasing recognition in recent studies (e.g., Cavalli *et al*., 2013; López-Vicente *et al*., 2013; Sougnez *et al*., 2011). For more details, refer to the user manual section titled differences between the InVEST SDR model and the original approach by Borselli *et al.,* (2008).

Land use/land cover (LU/LC) data were obtained from ESRI land cover 2024. The DEM was derived from the Shuttle Radar Topography Mission (SRTM) with a 30-meter resolution. Rainfall erosivity data (R-factor) were calculated using long-term monthly rainfall data (1990–2020) obtained from the Iran Meteorological Organization (IRIMO).

Annual soil loss

The annual soil loss for a given pixel (*i*), denoted as *uslei* (expressed in tons per hectare per year), is determined using the Revised Universal Soil Loss Equation (RUSLE). (RUSLE1 - Renard *et al*., 1997):

$$usle_i = Ri \cdot Ki \cdot LSi \cdot Ci \cdot Pi \tag{1}$$

where

- Ri is erosivity of rainfall (units: MJ·mm(hectare per hour per year)−1),
- Ki is the erodibility of soil (units: ton·hectare·hour(MJ·ha·mm)−1),
- LSi is the factor of slope length-gradient (unitless)
- Ci is the factor of cover management (unitless)

Additionally, *Pi* represents the support practice factor, which accounts for the effects of conservation practices in reducing soil erosion (Renard *et al*., 1997; see also Bhattarai and Dutta, 2006). This factor is dimensionless. The *LSi* factor, which accounts for the influence of slope length and steepness on erosion, is derived using the method proposed by Desmet and Govers (1996) for a two-dimensional surface:

$$LS_i = S_i \frac{(A_{\{i-in\}} + D^2)^{m+1} - A_{i-in}^{m+1}}{D^{m+2} \cdot x_i^m \cdot (22.13)^m} \tag{2}$$

where

- The parameter *Si* represents the slope factor of grid cell *i*, computed as a slope gradient function. In this context, *s* denotes the percentage slope, while ϑ represents the slope angle in degrees (Renard *et al*., 1997).

$$S = \begin{cases} 10.8 \cdot \sin(\theta) + 0.03, & where\, s < 9\% \\ 16.8 \cdot \sin(\theta) - 0.50, & where\, s \geq 9\% \end{cases}$$

The parameter Ai−in represents the contributing area (m²) at the inlet of a grid cell, which is derived using the Multiple-Flow Direction (MFD) method. This approach distributes flow across multiple downslope directions, providing a more accurate representation of surface runoff and soil erosion processes.

- D is the linear dimension of the grid cell (m)
- *xi* represents the aspect mean, weighted by the proportional outflow from grid cell *i*, as determined using the MFD algorithm. It is calculated by

$xi = |\sin \alpha_i| + |\cos \alpha_i|$

- where α_i Represents the radian angle for direction d, and P denotes the proportion of total outflow from cell i in direction d.
- -m is the length exponent factor in the RUSLE.

The maximum slope length is limited to 122 meters to prevent overestimating the LS factor in heterogeneous landscapes, though this Threshold can be adjusted as a user-defined parameter (Desmet and Govers, 1996; Renard *et al*., 1997). The length exponent *m* in the LS factor is derived from the traditional Universal Soil Loss Equation (USLE), as explained by Oliveira *et al*. 2013).

$$m = \begin{cases} 0.2 & where\ \theta \leq 1\% \\ 0.3 & where\ 1\% < \theta \leq 3.5\% \\ 0.4 & where\ 3.5\% < \theta \leq 5\% \\ 0.5 & where\ 5\% < \theta \leq 9\% \\ \beta/(1+\beta) & where\ \theta > 9\% \end{cases}$$

$$\beta = \frac{sin\theta / 0.0896}{3sin\theta^{0.8} + 0.56}$$

SDR

Step 1: Calculation of the Connectivity Index (IC)

Following the methodology proposed by Borselli *et al*. (2008), the model first calculates the IC for each pixel. This index quantifies the hydrological connection between sediment sources (i.e., eroded material from the landscape) and sediment sinks (such as streams). A higher IC value indicates a stronger connection, meaning that a greater proportion of sediment from an upstream pixel is transported to a downslope sink, for example, a stream. Strong connectivity is typically observed when the flow path between sediment sources and sinks is steep, short, or sparsely vegetated. Conversely, lower IC values correspond to areas with dense vegetation and gentler slopes, where sediment transport is less efficient. The *IC* is determined by two key factors:

1- The upslope contributing area (Dup)

2- The flow path distance to the nearest stream (Ddn).

Suppose the upslope area is extensive but has a gentle slope and dense vegetation (reflected in a low USLE C factor). In that case, *Dup* will be lower, indicating a reduced likelihood of sediment reaching the stream. Similarly, if the downslope flow path to the stream is long, characterized by low slopes and substantial vegetative cover, *Ddn* will also be low, further limiting sediment transport. IC is calculated as follows:

$$IC = log_{10}\left(\frac{Dup}{Ddn}\right) \quad (3)$$

Threshold values for slope (Sth) and cover-management factor (Cth) are applied in the computation of Dup and Ddn. To prevent infinite values in the IC, a lower bound is established.

An upper bound is imposed on the slope to minimize distortions caused by excessively high IC values in steep areas. These constraints help control extreme values and ensure more accurate sediment connectivity calculations (Cavalli *et al*., 2013).

$$Sth = \begin{cases} 0.005 & for\, S < 0.005 \\ S & for\, 0.005 \leq S \leq 1 \\ 1 & for\, S > 1 \end{cases} \quad (4)$$

$$Cth = \begin{cases} 0.001 & for\, C < 0.001 \\ C & otherwise \end{cases} \quad (5)$$

Dup is the upslope component defined as:

$$Dup = \bar{C}_{th}\bar{S}_{th}\sqrt{A} \quad (6)$$

$\bar{C}_{th}$ represents the average thresholded C factor for the upslope contributing zone, while $\bar{S}_{th}$ denotes the average thresholded slope gradient of the upslope study area (expressed in m/m). *A* corresponds to the upslope contributing area (measured in m²), delineated using the Multiple-Flow Direction (MFD) algorithm. The downslope factor (*Ddn*) is determined as follows:

$$D_{dn} = \sum_i \frac{d_i}{C_{th,i}S_{thi}} \quad (7)$$

Here, d_i represents the length of the flow path across the *i*-th cell, determined based on the steepest downslope direction (measured in meters). The parameters *Cth,i* and *Sth,i* correspond to the thresholded cover-management factor and slope gradient for the *i*-th cell. Like the upslope component, the downslope flow path is derived using the MFD algorithm.

Step 2: Calculation of the SDR

The SDR for a specified pixel *i* is determined based on the IC using the following approach (Vigiak *et al*., 2012):

$$SDR_i = \frac{SDRmax}{1+\exp\left(\frac{IC_0 - IC_i}{k}\right)} \quad (8)$$

SDRmax represents the maximum theoretical SDR, which is adjusted to an average value of 0.8, as

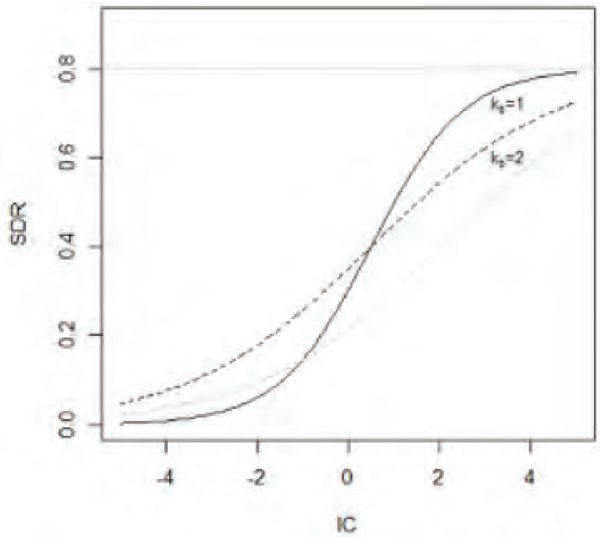

Fig. 2: Relationship between the SDR and the IC (Hamel et al., 2015)

suggested by (Vigiak *et al*., 2012). The parameters IC0 and k serve as calibration factors that shape the relationship between SDR and the IC, which follows an increasing function. The influence of IC0 and k on SDR is demonstrated in the following representation:

The maximum SDR is fixed at SDRmax 0.8. The influence of calibration is demonstrated by setting kb=1 and kb=2 (represented by solid and dashed lines, respectively), while IC0=0.5 and IC0=2 are shown using black and grey dashed lines, respectively.

Sediment export

The sediment export from a given pixel *i*, denoted as *Ei* (measured in tons/hectare /year), represents the portion of eroded sediment from that pixel that ultimately reaches a stream. It is calculated using the following equation:

$$E_i = usle_i \cdot SDR_i \tag{9}$$

The total exported sediment from the catchment, represented as *E* (in tons per hectare per year), is considered as the sum of the sediment transported from all pixels that reach the stream. It is expressed using the following equation:

$$E = \sum_i E_i \tag{10}$$

If relevant data are available, they can be used for calibration or validation with other sediment sources.

Sediment downslope trapping

This model also quantifies the sediment trapped, deposited, or reserved along the downslope flow path from its source. This represents eroded and exported sediment from a pixel but does not ultimately reach the stream. Understanding the spatial distribution of trapped sediment enables users to assess the net sediment change at a pixel level (either a gain or loss), which can be useful for land degradation assessments (Sadeghi *et al*., 2014). Eq. 9 describes sediment export to the stream from pixel *i*. The remaining component in the mass balance equation derived from the USLE accounts for the sediment that does not reach the stream. This loaded sediment must be retained somewhere along the landscape before reaching the stream and is demarcated as follows:

$$E_i^{'} = usle_i \left(1 - SDR_i\right) \tag{11}$$

Since the SDR inherently considers the downslope flow path and biophysical attributes that influence sediment filtration into the stream, the sediment export from a pixel (*Ei*) account for these factors. Consequently, the downslope movement of the remaining sediment flux (*Ei'*) can be modeled independently from *Ei*. To achieve this, the following assumptions about how SDR and sediment export (*Ei*) behave across a landscape are made:

Property A: SDR increases monotonically along a downhill flow path

As sediment moves downslope, SDR values increase progressively since the distance to the stream decreases. However, in some cases, a downslope pixel may have the same SDR value as an upslope pixel. When this occurs, it indicates that no on-pixel sediment trapping occurs along that step.

Property B: All non-exported sediment flux on a boundary stream pixel is retained at that pixel. If a pixel (*i*) drains directly into a stream, no further downslope filtering of *Ei* occurs. Since *Ei* is the inverse of *Ei'*, this means that the upslope sediment flux (denoted as *Fi*) must have been completely retained on that pixel. Based on these two properties, the amount of *Ei* trapped within a pixel must be a function of:

- The absolute difference in SDR values between pixel i and the downslope pixel(s) it drains into and
- The proximity of the downslope pixel's SDR value to 1.0, indicating how close it is to a stream pixel.

These dynamics can be represented through a linear interpolation of the SDR value difference between pixel *i* and its downslope counterpart relative to the difference between pixel *i*'s SDR and the theoretical highest downslope SDR value of 1.0. Formally, this relationship is expressed as:

$$dTi = \frac{\left(\sum_{k\in\{directly\ downslope\ \ from\ i\}} SDRk \cdot p(i,k)\right) - SDRi}{1.0 - SDRi} \quad (12)$$

T represents the process of sediment trapping, while *d* in *dTi* denotes a delta difference, indicating the change in sediment trapping. The term *p (i, k)* refers to the proportion of flow from pixel *i* to pixel *k*. This notation is designed to conceptually resemble the derivative of Ti to emphasize the rate of change in sediment trapping.

- In the case of Property A (where downslope $\left(\sum_{\in\{directly\ downslope\ \ from\ i\}} SDRk \cdot p(i,k)\right) = SDRi$
- When dT=0, it signifies that no portion of F is retained on the pixel.
- In the case of Property B, where the downslope SDR equals 1 (indicating a stream pixel), dT = 1, meaning that the remaining F is retained on the pixel.

Next, we express the amount of sediment flux trapped on each pixel along the flow path by expressing dT as a weighted function of upslope flux.

$$Ti = dTi \cdot \left(\sum_{j\in\{pixels\ that\ drain\ to\ i\}} Fj \cdot p(i,j) \right) \quad (13)$$

Here, *Fi* represents the sediment export flux from pixel *i* that fails to reach the stream. This flux is quantified as follows:

$$Fi = (1 - dTi) \cdot \left(\left(\sum_{j\in\{pixels\ that\ drain\ to\ i\}} Fj \cdot p(i,j) \right) + Ei' \right) \quad (14)$$

Ecosystem service indicators

The landscape's potential ecosystem service of erosion control is evaluated through two approaches:

Avoided erosion – These measures how vegetation helps prevent soil erosion at the pixel level. In other words, it evaluates the value of vegetation in minimizing erosion from occurring in the first place. This metric is useful for quantifying the ecosystem service in terms of local soil loss prevention and is calculated as:

$$AERi = RKLSi - USLEi \quad (15)$$

AERi represents the avoided erosion on pixel i, calculated as the difference between RKLSi and USLEi. This difference reflects the benefit of vegetation and effective land management practices, as RKLS corresponds to USLE without considering the C (cover) and P (practice) factors.

Avoided export – This metric quantifies vegetation's role in reducing erosion at the pixel level and trapped sediment transported from upslope areas, preventing it from reaching a river downstream. Essentially, it represents the total retained sediment on a pixel. Avoided export is a key indicator of the ecosystem service value from the perception of downriver water users and is computed as follows:

$$AEXi = (RKLSi - USLEi) \cdot SDRi + Ti \quad (16)$$

AEXi represents the total sediment retention on a pixel, accounting for both on-pixel erosion control and sediment trapped from upslope sources. By capturing this sediment, the landscape helps reduce the total sediment exported to streams. Similar to avoided erosion, the difference between RKLSi and USLEi highlights the role of vegetation and effective land management actions in preventing erosion. By multiplying this difference by the SDRi, the model quantifies the portion of erosion initiated from that pixel that does not reach a stream. Finally, Ti represents the sediment from upslope areas retained on pixel i, preventing further transport into a stream.

RESULT AND DISCUSSION

The elevation map of the Haraz River Basin (Fig. 3) indicates that the lowest elevation in the region is 213 meters, located at the basin's outlet. In comparison, the highest elevation is 5,595 meters, corresponding to Mount Damavand. Consequently, the elevation difference within the basin exceeds 5,000 meters.

Fig. 4 represents the rainfall erosivity factor (R) in the watershed, a key component of the RUSLE.

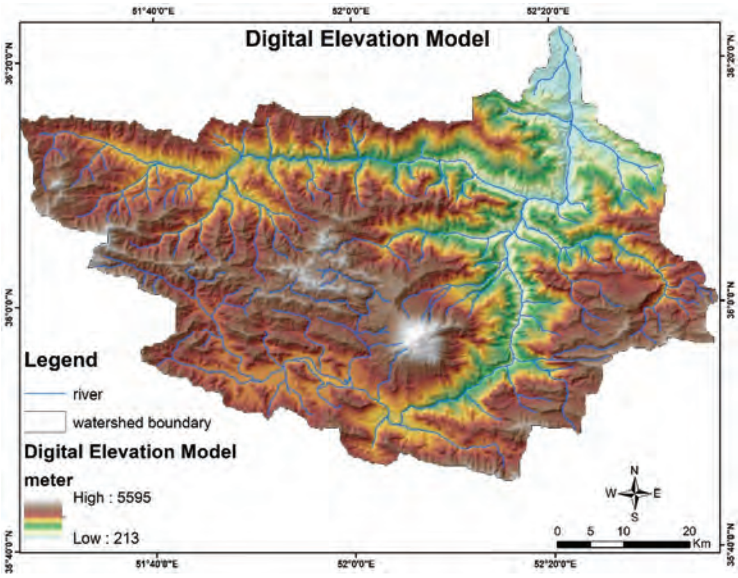

Fig. 3: DEM of the study area

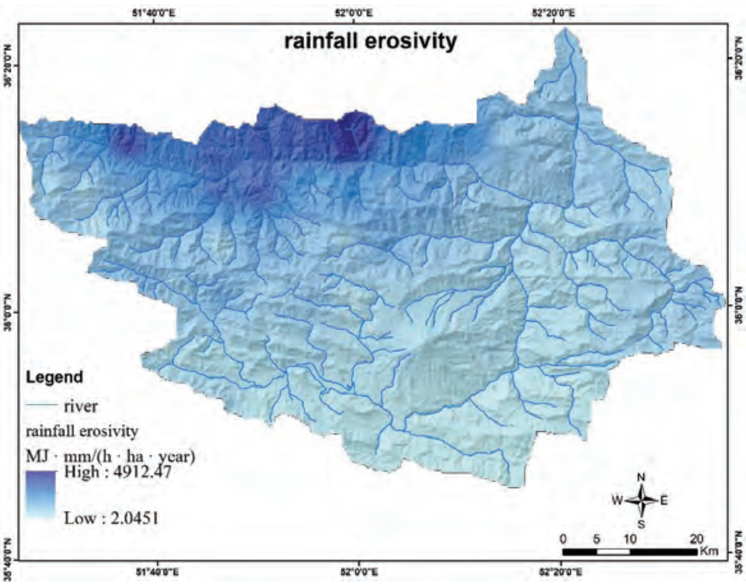

Fig. 4: Rainfall erosivity in the study area

Rainfall erosivity measures precipitation's potential to cause soil erosion and is expressed in units of MJ·mm/(h·ha·year). The values of this factor range from 2.0451 (indicating the lowest erosivity, shown in light blue) to 4912.47 (indicating the highest erosivity, shown in dark blue). Areas with high precipitation erosivity, shown in dark blue, are mainly located in the northern sections of the catchment area. Intense, energy-rich rainfall makes these areas more susceptible to significant soil erosion. In contrast, regions with low rainfall erosivity are mainly located in the central and southern parts of the watershed (shown in light blue), where rainfall is less intense and less erosive.

Fig. 5 illustrates the soil erodibility factor (K), which quantifies soil susceptibility to erosion under standardized conditions. The values of this factor range from 0.0206 (for low erodibility, represented by lighter colors) to 0.0378 (for high erodibility, represented by darker colors) and are measured in t-h-ha/(ha-MJ-mm). Soil erodibility depends on soil texture, organic matter content, permeability, and structure. The darker areas on the map, concentrated in certain regions, represent soils with higher erodibility, i.e., they are more susceptible to erosion when exposed to rainfall or surface runoff. These areas are likely to have sandy or silty textures, low organic matter content, and poor structure, making them less resistant to detachment and transport by water. In contrast, the lighter areas indicate soils with lower erodibility, potentially more stable and less prone to erosion due to higher clay content, improved soil structure, or greater organic matter content.

Fig. 6 represents the distribution of land use and land cover in the study area, calculated and analyzed based on the dataset and the total area (404,500 hectares). The results show that pastureland, which occupies 89.93% of the total area (equivalent to 363,675.6 hectares), is the predominant land use type and is vital for maintaining the ecological balance in the region. Forests, which account for 6.54% (26,459.64 hectares), are mainly located in the northeastern parts of the area and contribute significantly to the protection of soil and water resources. In contrast, barren lands and built-up areas constitute 2.37% (9,588.24 hectares) and 1.28% (5,181.12 hectares) of the total area, respectively, representing regions susceptible to erosion and urban development. Agricultural lands cover only 0.24% (990.72 hectares), indicating limited agrarian activities in the region. Surface water, which accounts for 0.11% (427.68 hectares), is mainly distributed along the river network and reflects the spatial distribution of water resources. Snowpack accounts for the smallest share

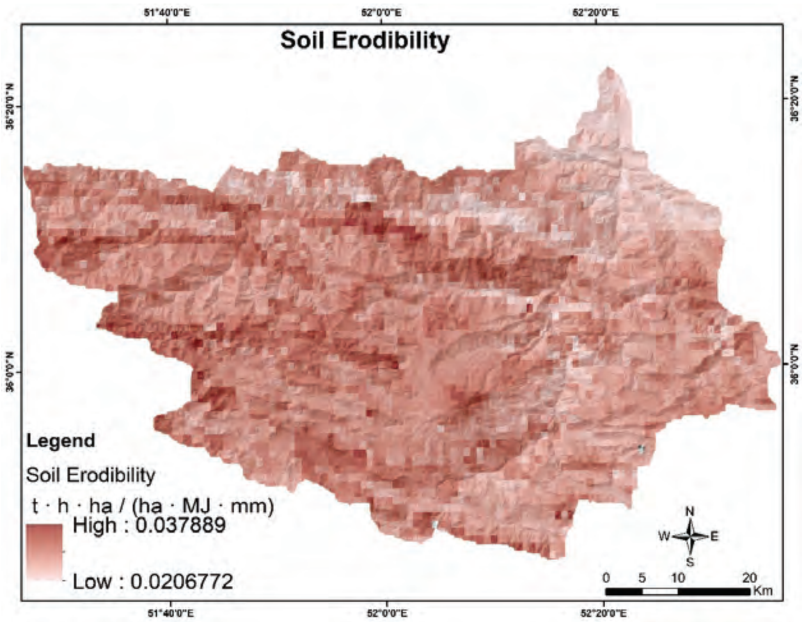

Fig. 5: Soil erodibility in the study area

at 0.03% (110.16 hectares) and is observed at higher elevations. This analysis revealed that grasslands and forests are important components of the regional ecosystem. At the same time, wastelands and croplands require special management to mitigate erosion risks and ensure ecological sustainability. The spatial distribution provides valuable information for managing the region's natural resources, preserving soil and water, and sustainable planning.

Lucode 1:

USLE_C = 0: Represents water bodies. USLE_P = 0.1: Indicates strong erosion control measures have been implemented, significantly reducing the risk of erosion.

Lucode 2:

USLE_C = 0.01: This type of land cover (e.g., forests or protected vegetation) has the highest capacity to prevent soil erosion. USLE_P = 0.8: Some management practices are applied but are less effective compared to Lucode 1.

Lucode 3:

USLE_C = 0.25: Indicates moderate susceptibility to erosion, likely associated with agricultural lands or disturbed areas. USLE_P = 0.85: Basic erosion control measures are in place with moderate effectiveness.

Lucode 4:

USLE_C = 0.05: Represents low susceptibility to erosion, possibly indicative of areas with partial vegetation cover or artificial lands. USLE_P = 1: No erosion control measures have been implemented.

Lucode 5:

USLE_C = 0.7: High susceptibility to erosion, likely representing barren or poorly managed agricultural lands. USLE_P = 1: No erosion control measures are implemented, increasing erosion risk.

Lucode 6:

USLE_C = 0: Indicates no contribution to soil erosion, likely representing snow-covered areas or permanent covers. USLE_P = 1: No need for erosion control measures.

Lucode 7:

USLE_C = 0.02: Very low susceptibility to erosion, possibly representing managed rangelands or semi-

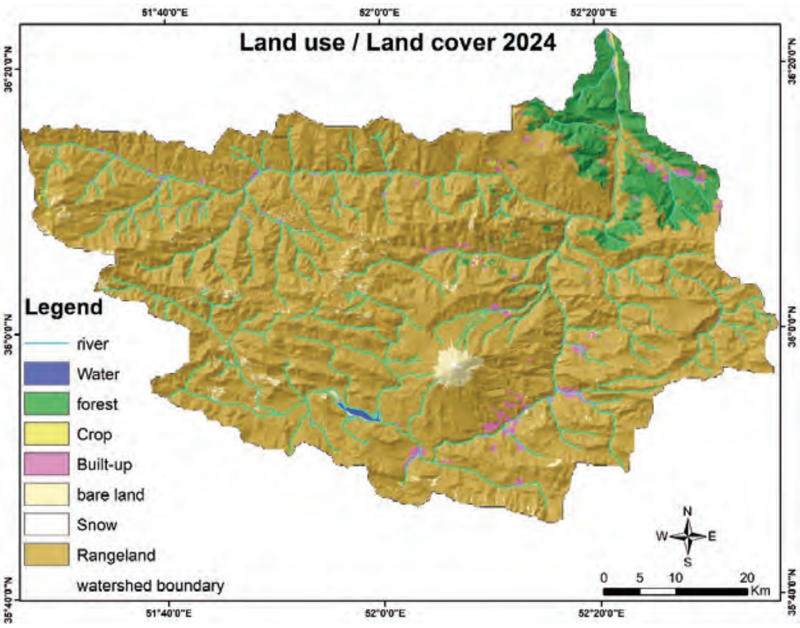

Fig. 6: Land Use and Land Cover (LU/LC) Map of the Haraz River Basin. This figure displays the spatial distribution of major land cover types, including pasturelands, forests, and barren areas. Understanding LU/LC distribution is essential for identifying erosion-prone zones and evaluating their contribution to sediment export and retention within the watershed.

natural lands. USLE_P = 0.9: Basic erosion control measures are present but are not highly effective (Table 1).

The flow accumulation threshold in this study was determined using a flow direction map extracted from the DEM. The Threshold was calculated using the formula Threshold = 0.01 to 0.05 × Maximum Flow Accumulation, resulting in a flow accumulation threshold of 300. The Borselli K parameter is a dimensionless factor used in Eq. 8 of the SDR model. This parameter is critical for determining sediment transport efficiency within the watershed and determines the sediment movement from the hillslopes into the stream network. The default value of this parameter is 2, but it can be changed depending on the specific characteristics of the watershed or calibration requirements. Accurate determination of the Borselli K parameter improves the model's performance and ensures realistic sediment delivery predictions. The Borselli IC0 parameter is another dimensionless factor used in Eq. 8 of the SDR model. It plays a significant role in modeling the relationship between the efficiency of sediment transport and the distance the sediment travels. The default value for this parameter is 0.5, but it can be changed depending on the particular characteristics of the watershed or calibration requirements. Careful determination of this parameter is crucial for improving model accuracy

Table 1: Biophysical properties of that LULC class

lucode	usle_c	usle_p
1	0	0.1
2	0.01	0.8
3	0.25	0.85
4	0.05	1
5	0.7	1
6	0	1
7	0.02	0.9

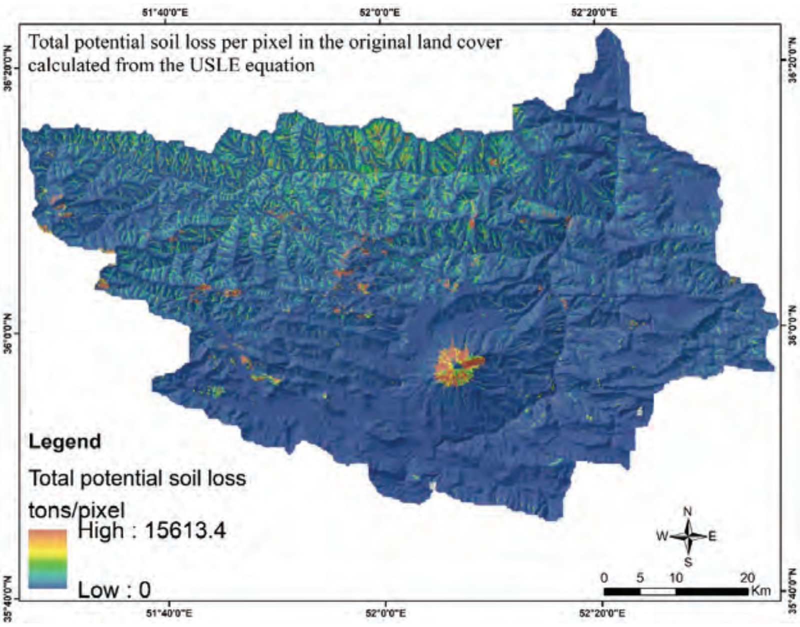

Fig. 7: Total potential soil loss in the study area (based on the USLE equation)

and more realistic sediment transport predictions. The maximum SDR value (required, dimensionless) represents the upper limit of the SDR that a pixel can have. This value is used in Eq. 8 and depends on soil texture. Specifically, it is demarcated as the portion of surface soil particles smaller than coarse sand (1,000 microns) (Vigiak *et al.*, 2012). This parameter can be calibrated in advanced studies. The default value is 0.8, but it can be adjusted depending on the soil characteristics of the study area. Proper selection of this parameter is critical for improving model precision and sediment transport predictions. The maximum L value (required, dimensionless) represents the maximum permissible value for the LS factor's slope length parameter (L). All L values that exceed this limit are limited to the specified maximum. The default value for this parameter is 122, but reasonable values given in the scientific literature range from 122 to 333 (Desmet and Govers, 1996; Renard *et al*., 1997). Appropriate adjustment of this parameter is crucial for accurately calculating the LS factor and its impact on soil erosion predictions. It can be modified based on the topographic characteristics of the study area. In this study, a maximum L value of 200 was used. Fig. 7 illustrates the total soil erosion potential for each pixel in the primary land cover, calculated using the USLE equation. This potential incorporates the C and P factors and represents soil erosion for land under specific land use/ cover conditions. As observed, the erosion potential in this scenario ranges from 0 to 15,613 tons per hectare.

Fig. 8 illustrates the total exported sediment from any pixel and delivered to the stream network. The sediment export ranges from 0 to 3,871 tons per hectare. This map shows the total sediment exported per pixel (in tons/pixel) across the watershed. Sediment export values range from 0 tons/pixel (low sediment export, shown in blue) to 3,871 tons/pixel (high sediment export, shown in red). Areas with the maximum sediment export are condensed as local hotspots, especially on steep slopes or in regions with sparse vegetation. Red and orange critical areas indicate zones where erosion contributes significantly to sediment input into the rivers. In contrast, a remarkable area of the watershed, shown in blue and green, has low sediment export due to well-constructed soil conditions and effective sediment retention. This map depicts the spatial variability of sediment export and emphasizes the importance of implementing erosion control actions in high-risk areas to reduce sediment production and its downstream impacts.

Fig. 9 below depicts the total exported sediment for any sub-watershed. This map illustrates the

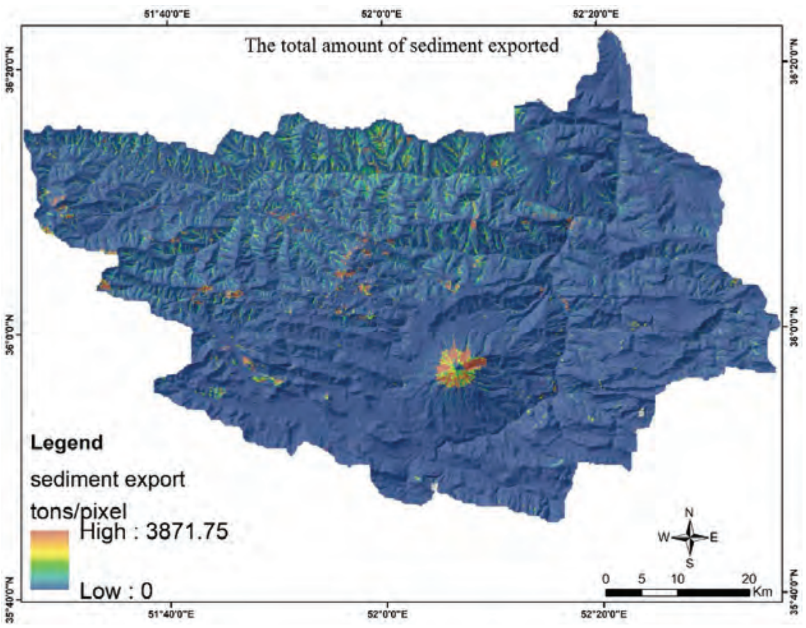

Fig. 8: Total sediment export in the study area

amount of sediment delivered to streams from each sub-watershed in the basin, measured in tons per sub-watershed. Sub-watershed 2, with a total sediment export of 1,992,277 tons, displayed in dark red, has the highest sediment export. This is likely due to steep slopes or intensive land use in this area. In contrast, sub-watershed 5, with a total sediment export of 9,328 tons, shown in blue, has the lowest sediment export, indicating effective soil management or favorable land and vegetation conditions. Other sub-watersheds exhibit varying sediment export levels, with moderate values observed in sub-watersheds 1, 4, and 7 (depicted in green and yellow) and higher values in sub-watersheds 6, 8, and 9 (depicted in orange). Overall, this spatial distribution identifies critical areas requiring management interventions to reduce erosion, particularly in sub-watershed 2, while highlighting the sustainability of practices in sub-watershed 5.

Fig. 10 illustrates the sediment delivery rate across nine sub-watersheds, ranging from 3.27 tons/hectare to 42.79 tons/hectare. Sub-watershed three, marked in red, exhibits the highest sediment delivery rate (42.79 tons/hectare), indicating severe soil erosion. Steep slopes, sparse vegetation, or intensive land-use activities likely cause this condition. Other sub-watersheds with high sediment delivery rates include sub-watersheds 6, 7, and 9, highlighted in orange. These areas may face similar erosion challenges and require soil conservation actions. Sub-watersheds 1 and 4, represented in blue, show the lowest sediment delivery rates (3.27–3.64 tons/hectare). These areas likely feature low slopes, better vegetation cover, or more effective soil management practices. These sub-watersheds can serve as models for implementing conservation strategies in high-risk areas. Sub-watersheds 8 and 5 have moderate sediment delivery rates (3.88–7.99 tons/hectare), indicating balanced conditions where moderate erosion risks coexist with some natural or human-induced controls. The northern sub-watersheds, such as sub-watershed 3, and the southern sub-watersheds, including 6, 7, and 9, are more vulnerable to erosion. In contrast, central and eastern sub-watersheds, such as 1, 4, and 5, demonstrate lower sediment delivery rates. This analysis highlights critical areas requiring erosion control measures and provides insights into leveraging the conditions in low-erosion sub-watersheds to mitigate risks in high-erosion zones.

Sub-watershed 2:

The highest USLE_Tot value (13,016,268 tons) indicates that this sub-watershed has the greatest potential for soil erosion. The high value of Sed_

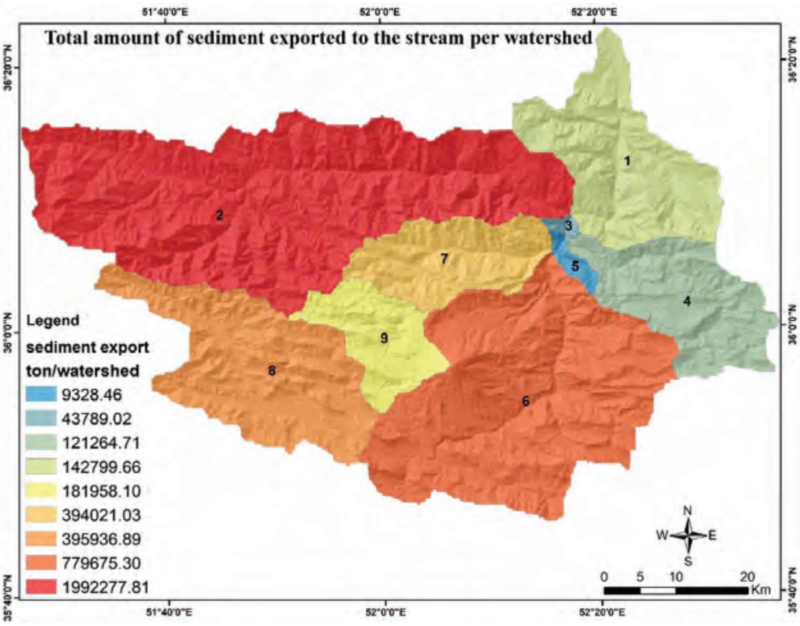

Fig. 9: Total sediment export of each sub-watershed

Export (1,992,277 tonnes) mirrors a huge sediment transport into the rivers, while a substantial part of the sediment (7,467,088 tonnes) is deposited within the sub-basin. The high values of Avoid_Exp and Avoid_Eros showed that vegetation cover is crucial for reducing sediment export and soil conservation (Table 2).

Subwatershed 5:

The lowest USLE_Tot value (60,721 tonnes) and Sed_Export value (9,328 tonnes) reflect minimal erosion and sediment transport. Because of its natural or managed characteristics, this subwatershed generates and exports significantly less sediment, indicating its stability.

Sub-watershed 7:

A relatively high Sed_Export value (394,021 tons) and significant deposited sediment (1,784,968 tons) show that this sub-watershed plays an important role in sediment transport to streams. However, it also retains a considerable portion of sediment within its boundaries. This analysis provides a comprehensive understanding of sediment dynamics and the role

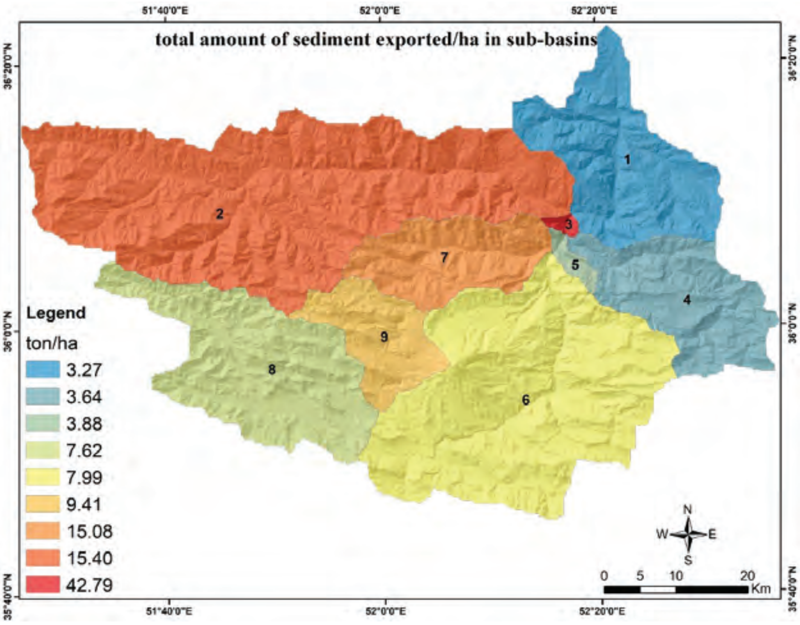

Fig. 10: Sediment Export of each sub-watershed (ton/ha)

Table 2: Erosion and sediment in each sib-watershed

ws_id	usle_tot	sed_export	sed_dep	avoid_exp	avoid_eros
1	1065043.58	142799.66	674584.72	8795877.75	75351901
2	13016268.06	1992277.87	7467088.04	62749964.5	517662540
3	178137.16	43789.02	87910.14	470086.66	2211622.25
4	830865.47	121264.7	473293.12	5415447.13	40070433.5
5	60721.23	9328.46	47877.05	523386.1	3129602.5
6	3444148.2	779675.3	2467061.01	9793981.85	49756400.88
7	2198022.09	394021.04	1784968.44	11303677.5	62681980
8	2210906.43	395936.89	1369691.46	6644613.52	49522931.06
9	1049863	181958	922308	2920707	14631887

of management practices in reducing soil erosion. Sub-watersheds with high USLE_Tot and Sed_Export values (e.g., Sub-watershed 2) require more intensive management interventions to control erosion and reduce sediment transport. In contrast, sub-watersheds with lower values (e.g., Sub-watershed 5) exhibit greater stability and can serve as reference areas for planning sustainable management strategies.

Sedexport (units: tons per watershed): Represents the total exported sediment to the stream within a watershed. This value should be compared with the observed sediment loading at the watershed outlet. Understanding the hydrologic regime of the watershed and the involvement of overland/ sheetwash sediment in total sediment yield aids in adjusting and calibrating the model. (Derived from Eq. 10, with the sum calculated over the watershed area).

Usletot (units: tons per watershed): Denotes the total potential soil loss within any watershed, estimated using the USLE formula. (Calculated as the sum of USLE values from (1) over the watershed area).

Avoidexp (units: tons per watershed): Represents the total avoided sediment export in the watershed, calculated as the sum of AEXi values from (16) over the entire watershed area.

Avoideros (units: tons per watershed): Refers to the total avoided of local erosion avoided within the watershed, obtained by summing AERi values from (15) across the watershed.

Seddep (units: tons per watershed): Indicates the total sediment deposited within the watershed that does not reach the stream. This is determined by summing Ti values from (13) across the watershed area.

Our findings on sediment retention variability align partially with Borrelli *et al.,* (2017), who noted that land cover, especially vegetation, significantly reduces soil erosion at the global scale. However, unlike Borrelli's global models, our study incorporates high-resolution local inputs and topographic heterogeneity, revealing more granular spatial differences across sub-watersheds, particularly between sub-watersheds 2 and 5. This contrast underscores the value of detailed ecosystem service-based assessments at the local level. The identified sediment retention hotspots not only play a critical role in reducing sediment delivery to streams but also contribute significantly to various ecosystem services. By trapping sediments before they reach water bodies, vegetated areas help decrease turbidity and limit the transport of sediment-bound pollutants, thereby enhancing water purification and improving downstream water quality. Moreover, sediment control structures and natural vegetation increase soil infiltration and reduce surface runoff, which supports flood regulation and helps attenuate peak flows. Additionally, by preserving topsoil and retaining essential nutrients, these areas help maintain soil fertility, contributing to long-term agricultural productivity and the ecological resilience of the watershed.

CONCLUSION

The results revealed that areas with sharp slopes and sparse vegetation, such as sub-watershed 2, are most at risk of erosion and sediment transport. Contrary to this, sub-watersheds with dense vegetation, such as sub-watershed 5, effectively prevented erosion and sediment transport. These results align with previous studies, such as those by Vigiak *et al.,* (2012) and Borrelli *et al.,* (2017), which introduced vegetation cover and topography as key factors in reducing erosion and sedimentation. Compared to these studies, this study used high-resolution local data, providing a more detailed spatial distribution pattern of erosion and sediment transport. One of this study's strong points is using advanced tools, such as the SDR model, in combination with local data, which allows a more detailed analysis of erosion and sediment dynamics. Compared to similar studies, such as Renard *et al.,* (1997), this study provides a more detailed analysis of local factors, including land use and the spatial distribution of vegetation cover. For example, including land use maps from 2024 and high-resolution DEM data led to more accurate results than generalized models. Furthermore, the results showed that vegetation cover and management practices significantly influence erosion and sediment control. For example, the high values of avoided erosion and export in areas with enhanced protection measures emphasize the effectiveness of these practices. These results are consistent with the work of Desmet & Govers (1996), who stressed that proper land management can significantly reduce erosion. Overall, the results of this study emphasize the complex interplay between natural and management factors in controlling erosion and sediment transport. Overconfirming previous research findings, this study adds value by providing detailed spatial maps and an in-depth analysis of sediment-related ecosystem services. Concisely, management strategies that focus on improving vegetation cover, changing land use, and installing sediment barriers could improve watershed management in the Haraz Basin and serve as a model for similar watersheds. The findings of this study demonstrate the critical influence of topography, vegetation cover, and land management on sediment retention and erosion dynamics across the Haraz River Basin. Areas such as sub-watershed 2, which exhibited the highest erosion and sediment export rates, indicate an urgent need for targeted afforestation, slope stabilization, and erosion control interventions. In contrast, the stability observed in sub-watershed 5 highlights the benefits of effective land management and vegetation cover in mitigating soil loss. These results underscore the potential of integrating ecosystem service assessments with sediment modeling tools like InVEST to inform spatially explicit conservation planning. For future research, incorporating seasonal variability in precipitation and sediment transport could further refine our understanding of erosion processes and support the development of more adaptive, climate-responsive watershed management strategies.

AUTHOR CONTRIBUTIONS

A. Chahkandi performed the Conceptualization, Literature Review, Data Collection, Methodology, Software, and Manuscript Preparation (Writing – original draft). G.R. Nabi Bidhendi and B. Malekmohammadi performed supervision, validation, project administration, and review and edit of the manuscript.

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CONFLICT OF INTEREST

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

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)

DEM	Digital Elevation Model
GIS	Geographic Information System
IC	Connectivity Index
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IRIMO	Iran Meteorological Organization
LU/LC	Land Use /Land Cover
MFD	Multiple-Flow Direction
RUSLE	Revised Universal Soil Loss Equation
SRTM	Shuttle Radar Topography Mission
SDR	Sediment Delivery Rate

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ORIGINAL RESEARCH PAPER

Exploring the pathways to career success: Analyzing the influence of empowering leadership, self-efficacy, and organizational commitment

I. N. Qamari[1], U. Udin[1*], I. B. A. G. Azmi[2], S. H. Wahyuningsih[1], W. P. Sari[1], M. Musoli[3]

[1] Department of Management, University of Muhammadiyah Yogyakarta, Special Region of Yogyakarta, Indonesia

[2] Department of Syariah and Management, Academy of Islamic Studies, University Malaya, Kuala Lumpur, Malysia

[3] Department of Management, University of Aisyiyah Yogyakarta, Special Region of Yogyakarta, Indonesia

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ABSTRACT

BACKGROUND AND OBJECTIVES: Empowering leadership is essential for employee career success as it encourages skill development and facilitates career advancement. The absence of empowering leadership may significantly hinder employee career success within organizations. Thus, this study investigates the potential mediator roles of organizational commitment, self-efficacy, and competence for performance in the relationship between empowering leadership and career success.
METHODS: By employing a quantitative approach, this study examines the proposed model and hypotheses in the coal mining companies in Indonesia. The data are collected from 123 employees working in the coal mining operations in Central Kalimantan, Indonesia, and it is analyzed using SmartPLS 3.3.3 of partial least squares structural equation modeling.
FINDINGS: The results showed that empowering leadership positively and significantly predicts organizational commitment (β = 0.706, t-statistic = 20.182), self-efficacy (β = 0.478, t-statistic = 5.308), performance competence (β = 0.593, t-statistic = 10.561), and career success (β = 0.387, t-statistic = 3.301). However, self-efficacy (β = 0.124, t-statistic = 1.068) and performance competence (β = -0.009, t-statistic = 0.097) have no impact on career success. Organizational commitment (β = 0.253, t-statistic = 4.218) is also discovered to mediate the relationship between empowering leadership and career success.
CONCLUSION: Empowering leadership plays a crucial role in guiding employees toward career success by fostering a strong sense of organizational commitment. This study explores the mediating roles of organizational commitment, self-efficacy, and performance competence, offering insights into how empowering leadership influences career outcomes. The findings advance existing theory by clarifying that while self-efficacy and performance competence are shaped by empowering leadership, they do not directly predict career success. Instead, organizational commitment emerges as the key mediator in this relationship. From a practical perspective, the results highlight the need for organizations to promote empowering leadership by training supervisors to build autonomy and trust. This leadership approach enhances employees' emotional attachment to the organization, thereby supporting their career development. Aligning career advancement initiatives with empowering practices can enhance employee motivation and long-term success.

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*Corresponding Author:
Email: *udin@umy.ac.id*
Phone: +6285343709228
ORCID: 0000-0002-5491-9085

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INTRODUCTION

Achieving Career Success (CS) in organizations is very important for encompassing personal growth and fulfillment of one's aspirations. In today's fast-paced and competitive world, individuals face various challenges on their path to fulfilling careers (Yen *et al.*, 2019). Also, the journey to CS is fraught with challenges and obstacles that require careful navigation. Therefore, embracing continuous learning, nurturing professional relationships, prioritizing mental and physical well-being, and having a clear career plan are essential steps toward achieving lasting success in today's competitive world. Leadership styles (Gohar *et al.*, 2023; Udin and Dananjoyo, 2023), ranging from autocratic and transactional to transformational and Empowering Leadership (EL), may significantly influence an employee's professional journey, including their opportunities, growth, and overall success. Empowering leaders encourages employees' creativity, innovation, and a strong sense of purpose (Syahrul, 2020) to excel in their roles. Employees working under empowering leaders often experience higher commitment and a greater sense of fulfillment, which can significantly contribute to long-term CS. Kim and Beehr (2018), Zhang and Jin (2019), Yulia and Safaatillah (2023), and Dwidienawati *et al*. (2025) found evidence that empowering leaders helps employees increase their subjective CS in an organization. However, Biemann *et al.* (2015) showed that EL is not related to an individual's belief in their ability to successfully achieve goals in their career at the group level. The impact of EL on CS may take time to manifest fully. While EL behaviors may foster employee job satisfaction in the short term, their effects on CS may become more apparent over the long term as employees accumulate skills, experiences, and opportunities within the organization. Also, EL might have a more indirect impact on certain aspects of CS rather than directly affecting tangible outcomes like Organizational Commitment (OC) (Kim and Beehr, 2023), Self-Efficacy (SE) (Eenink, 2022), and Performance Competence (PC) (Lei *et al.*, 2021). As highlighted by Liu *et al.*, (2024), Udin *et al.*, (2025), EL, when viewed through the lens of Self-Determination Theory (SDT), fosters a work environment that fulfills employees' psychological needs for autonomy, competence, and relatedness. This, in turn, enhances SE, PC, and OC, which collectively contribute to career success. Accordingly, this study seeks to fill a gap in the literature by examining the mediating roles of OC, SE, and PC in the relationship between EL and CS. Ultimately, the study's findings could provide valuable insights for organizations aiming to enhance employee CS by understanding the underlying mechanisms through which OC, SE, and PC operate. This study was conducted from July to October 2024.

Literature review

Career success

CS is defined as the achievement of goals within one's professional life (Briscoe *et al.*, 2006), leading to personal fulfillment, financial stability, and recognition within the chosen field. CS often involves a combination of factors such as skill development, hard work, dedication, networking, and seizing opportunities (Haratsis *et al.*, 2015). CS can vary greatly from person to person, as it is subjective (Eva *et al.*, 2020) and influenced by individual values, circumstances, and aspirations (Santilli *et al.*, 2016). Employees can achieve CS by defining specific career objectives and creating a plan to achieve them (Chui *et al.*, 2020). Also, employees need to invest in developing new skills and knowledge relevant to their field (Penn and Lent, 2018) through courses, training, or self-directed learning. By consistently delivering high-quality work and showcasing their expertise, employees may gain recognition within the organization. Additionally, employees can make strong networks with colleagues, industry professionals, and mentors to create opportunities for career advancement. Employee's CS within the organization can be influenced by a variety of factors (Binh and Nguyen, 2020), including self-confidence (i.e., staying confident in the face of challenges and bouncing back from setbacks), leadership potential (i.e., demonstrating initiative, decision-making ability, and strategic thinking leading to the greater responsibility), hard work (i.e., consistently striving for excellence and go the extra mile), communication (i.e., strong communication skills both verbal and written for conveying ideas), and strong commitment (i.e., making contributions that are recognized within the organization).

Organizational commitment

OC refers to an employee's emotional attachment (Allen and Meyer, 1993) and dedication to their organization. OC reflects the extent to which employees identify with the organization's values and goals, and their willingness to exert effort on behalf of the organization (Udin *et al.,* 2023). According to Allen and Meyer (1993), there are three main components of OC, including (a) *affective commitment* (i.e., an employee's emotional attachment to the organization). Employees with high affective commitment feel a strong sense of belonging and often derive satisfaction from their work and feel deeply connected to the organization's mission; (b) *normative commitment* (i.e., an employee's sense of obligation or duty to remain with the organization). Employees with high normative commitment feel a moral responsibility to stay (Betanzos-Díaz *et al.,* 2017), and often due to feelings of reciprocity, gratitude, and indebtedness towards the organization; (c) *continuance commitment* (i.e., an employee's perceived costs associated with leaving the organization). Continuance commitment reflects the extent to which employees believe that the benefits of staying outweigh the potential costs of leaving, such as loss of benefits, financial stability, or seniority. OC is important because it influences employee behavior, attitudes, and performance (Djastuti *et al.,* 2019; Martono *et al.,* 2020). Employees with higher levels of commitment are more likely to demonstrate greater effort, leading to higher CS and better organizational outcomes (Hassona *et al.,* 2021; Udin *et al.,* 2022). Therefore, fostering OC among employees is crucial for building a positive work environment and achieving long-term success.

Self-efficacy

SE refers to an individual's belief in their ability to perform specific tasks or accomplish goals. SE is a key concept in social cognitive theory, proposed by Bandura (1986). SE beliefs influence how people feel, think, motivate themselves, and behave. SE is rooted in the confidence that one has the necessary knowledge, skills, and resources to perform effectively in a given situation. Employees with high SE are more likely to confidently approach challenging tasks (Gunarto *et al.,* 2025), persistence, and resilience. They tend to set ambitious goals, exert effort, and persevere in the face of setbacks (Choi *et al.,* 2021; Domingo *et al.,* 2024). In addition, SE beliefs have significant implications for various areas of life, including performance achievement, CS, and psychological well-being. Employees with high SE are more likely to set challenging goals, persevere in the face of obstacles, and achieve success. Therefore, cultivating SE within an organization is important for personal growth and achievement (Ashfaq *et al.,* 2021).

Performance competence

PC refers to having the necessary skills, knowledge, and abilities to effectively carry out tasks (Spencer and Spencer, 2008) and achieve desired outcomes in a specific role (Wong, 2020). PC encompasses both technical expertise and behavioral competencies required to perform tasks successfully (Kim *et al.,* 2020). The key components of PC include (a) *technical competence* (i.e., related to the specific skills, knowledge, and expertise required to perform tasks within a particular field). It includes proficiency in using tools, technologies, methodologies, and best practices relevant to the job; (b) *functional competence* (i.e., job-specific skills and knowledge necessary for performing tasks related to a specific function or role within an organization). This can include areas such as human resources, marketing, finance, or operations; (c) *interpersonal skill*s (i.e., fostering positive working relationships such as communication, teamwork, collaboration, and conflict resolution) to interact effectively with colleagues, clients, and stakeholders to achieve common goals; (d) *adaptability and flexibility* (i.e., ability to adapt to changing circumstances, priorities, and requirements within their role). Employees demonstrate flexibility, resilience, and a willingness to learn and grow in response to new challenges; (e) *time management* (i.e., the ability to manage time effectively, prioritize tasks, and organize work efficiently to meet deadlines and achieve objectives) (Garcia-Perez *et al.,* 2019). PC is essential for achieving individual and organizational goals (Spencer and Spencer, 2008). Employees with the necessary competencies are better equipped to meet job requirements, contribute effectively to team efforts, and deliver high-quality results (Almusaddar *et al.,* 2018). Therefore, developing and maintaining competence is essential for achieving high performance and contributing effectively to organizational success.

Empowering leadership

Empowering leadership (EL) is a style of leadership that focuses on decentralizing authority (Amundsen and Martinsen, 2015), fostering autonomy, and enabling employees to take initiative and make decisions within their areas of responsibility (Cheong *et al.,* 2016). EL aims to build employee confidence, motivation, and a sense of ownership, ultimately leading to improved performance, creativity, innovation, and job satisfaction (Amundsen and Martinsen, 2015; Guo *et al.,* 2023). According to Arnold *et al.,* (2000), the EL model emphasizes the key principles, including leading by example, coaching, informing/explaining, participative decision-making, and showing concern for followers' welfare. Empowering leaders demonstrate ethical behavior in their actions and decisions. They uphold integrity and honesty, and serve as role models for ethical conduct within the organization (Shahab *et al.,* 2018). Empowering leaders are committed to their followers' professional development and growth (Kim and Beehr, 2023). They provide opportunities for learning, skill development, and career advancement, and offer constructive coaching to support individual progress. Additionally, empowering leaders delegate authority and responsibility to their followers, allowing them to make decisions and take ownership of their work (Ahmed *et al.,* 2022). They provide clear guidelines and expectations while allowing flexibility for individuals to use their judgment and creativity.

Hypotheses development

Impact of empowering leadership on organizational commitment, self-efficacy, performance competence, and career success

EL fosters OC (Kim and Beehr, 2018) by instilling a sense of purpose among employees. Empowering leaders inspires confidence and trust by promoting collaboration and encouraging creativity to create an environment where individuals feel motivated to contribute their best efforts. Consequently, employees develop a strong emotional connection to the organization, leading to higher levels of performance. In summary, EL cultivates a positive organizational environment where employees feel emotionally motivated to achieve common goals, and it has a positive effect on affective OC (Eliyana *et al.,* 2025; Kim and Beehr, 2018; Raziq *et al.*, 2025), SE (Ahmed *et al.,* 2022; Peng *et al.,* 2024), PC, and CS (Dwidienawati *et al*., 2025; Lei *et al.,* 2021; Yulia and Safaatillah, 2023). Thus,

H1: Empowering leadership has a positive and significant impact on career success.

H2: Empowering leadership has a positive and significant impact on organizational commitment.

H3: Empowering leadership has a positive and significant impact on self-efficacy.

H4: Empowering leadership has a positive and significant impact on performance competence.

Impact of organizational commitment on career success

OC significantly influences CS (Semlali and Elrayah, 2022) by fostering a supportive environment for professional growth. Employees who strongly commit to their organization are more likely to invest in their work and strive for excellence. Furthermore, committed employees are more willing to engage in continuous learning and skill development, positioning themselves as valuable assets within the organization. Previous studies show that OC positively impacts career commitment, career satisfaction (Kundi *et al.,* 2021), career growth (Weer and Greenhaus, 2020), and CS (Semlali and Elrayah, 2022). Therefore,

H5: Organizational commitment has a positive and significant impact on career success.

Impact of self-efficacy on career success

SE, the belief in one's ability to accomplish tasks and achieve goals, is critical to CS. Individuals with high SE are more likely to take on challenging tasks (Aymans *et al.,* 2020) and pursue ambitious goals, as they trust their capabilities to succeed. This confidence drives them to persevere in the face of obstacles, enabling them to overcome challenges and reach their objectives. Also, employees with strong SE are more likely to stay focused and engaged, even during difficult times. They actively seek growth opportunities and are open to feedback, using it as a tool for improvement. SE positively influences career optimism (Aymans *et al.,* 2020) and CS (Bhawna *et al.,* 2024). Thus,

H6: Self-efficacy has a positive and significant impact on career success.

Impact of performance competence on career success

Competence is a fundamental driver of CS (Blokker *et al.,* 2019) as it encompasses the skills, knowledge, and abilities necessary to excel in a professional role. Employees who are competent in their field can consistently deliver high-quality work, which leads to recognition and credibility among colleagues (Zaenudin and Widigdo, 2022). Moreover, competence facilitates adaptability and lifelong learning. Employees who continuously develop their skills stay relevant in a rapidly changing job market and can capitalize on emerging opportunities. This adaptability is crucial for sustained career growth. Results of previous studies imply that competence is positively associated with career development (Arifin *et al.*, 2020), career satisfaction (De Vos *et al.*, 2011), and subjective CS (Blokker *et al.*, 2019; Lei *et al.*, 2021). Therefore,

H7: Performance competence has a positive and significant impact on career success.

The role of mediators

EL indirectly influences CS by fostering an environment that supports employee growth, innovation, and engagement. Leaders who empower their employees by granting autonomy, encouraging decision-making, and offering support enhance employees' SE (Cheong *et al.*, 2016; Widianto, 2021) and OC. When employees feel trusted and valued, they are more likely to take initiative and seek opportunities for skill development (Amundsen and Martinsen, 2015). EL nurtures affective commitment by instilling a sense of belonging and alignment with organizational goals, which drives persistence and participation in career-enhancing activities. Through the lens of SDT, empowering leadership also increases employee engagement (Cai *et al.*, 2018; Liu *et al.*, 2024), strengthening dedication and the likelihood of receiving mentorship, coaching, and guidance, key contributors to CS. By entrusting employees with meaningful responsibilities and developmental support, EL enhances SE, encouraging individuals to pursue challenging goals and persist through difficulties, ultimately advancing their careers. Additionally, empowering leaders cultivates inclusive workplaces that support networking and knowledge sharing (Lee *et al.*, 2014), enabling employees to learn from peers, access new perspectives, and explore career opportunities. Through encouragement of decision-making, problem-solving, and innovation, EL promotes skill acquisition and performance development, positioning employees as strong candidates for advancement. Prior research confirms that EL indirectly affects CS through mediators such as job crafting (Kim and Beehr, 2018), OC, SE (Biemann *et al.*, 2015), and PC (Lei *et al.*, 2021). Thus,

H8: Empowering leadership is positively related to career success, mediated by organizational commitment.

H9: Empowering leadership is positively related to career success, mediated by self-efficacy.

H10: Empowering leadership is positively related to career success, mediated by performance competence.

MATERIALS AND METHODS

Participants and procedure

This study was conducted from July to October 2024. The target population of this study was 1,502 employees working in the coal mining operations in Central Kalimantan, Indonesia. Memon *et al.*, (2017) discuss the selection of a sampling strategy based on the objective of the study. When the study aims to test hypothesized relationships and necessitates the selection of a sampling strategy that aligns with the research scope, non-probability sampling may be more appropriate than probability sampling. This way is often chosen when the research involves exploring complex areas where the researchers do not fully understand the population. On the other hand, Rowley (2014) notes that probability sampling requires a complete understanding of the population to create an effective sampling frame. Therefore, the sampling technique in this study uses non-probability sampling with purposive sampling. Sarstedt *et al.*, (2018) noted that non-probability purposive sampling aids researchers in including only suitable participants for the study. This approach allows researchers to select individuals who align with specific criteria relevant to the research objectives, thereby improving the quality of the study's results.

Using a purposive sampling technique, employees aged 20 years or older with a minimum of two years of work experience were selected. Originally, using Google Forms for data collection, 240 employees were sent a Google Forms link to the accessible questionnaires with a request to complete the survey form. One hundred twenty-three valid responses (with a response rate of 51.25%) were received back and are usable for the final data analysis. Table 1 presents the demographic profile of the respondents. The majority were female (71 respondents; 57.72%), while males comprised 42.28% of the sample. This indicates a slightly higher representation of women in the workforce, which may reflect gender trends within the industry. Most participants were between 21 and 30 years old (94 respondents; 76.42%). This suggests that the workforce is relatively young, which may imply a more dynamic and innovative workforce. Younger employees often bring fresh perspectives, adaptability to change, and tech-savviness. In terms

Table 1: Information of respondents

Characteristics	Description	Frequency	Percentage
Gender	Male	52	42.28
	Female	71	57.72
Age	20 years and less	10	8.13
	21 – 30 years	94	76.42
	31 – 40 years	17	13.82
	41 and above years	2	1.63
Work experience	2 years and less	60	48.78
	3 – 5 years	36	29.27
	6 – 10 years	19	15.45
	11 and above years	8	6.5
Level in education	Senior high school	56	45.53
	Bachelor	65	52.84
	Master	2	1.63

of tenure, 60 respondents (48.78%) had less than two years of work experience in their current company, followed by 29.27% with 3–5 years, 15.45% with 6–10 years, and 6.5% with more than 11 years. Regarding educational background, 65 respondents (52.84%) held a bachelor's degree, 45.53% had completed senior high school, and 1.63% held a master's degree. This could indicate that the job roles are accessible to individuals with various educational backgrounds. The small percentage of respondents (1.63%) with a master's degree may suggest that while the workforce is generally educated, higher qualifications are less common in this particular setting.

Construct measurements

EL is measured using a 6-item scale adapted from Ahmad *et al.* (2022). A sample item for EL includes "*My supervisor encouraged me to search for solutions to my problems on the job without getting his/her stamp of approval*."

Three types of commitment (i.e., affective, continuous, and normative) are used to measure OC. A 5-item scale adapted from Rawashdeh *et al.* (2022) is used to measure organizational commitment. A sample item for OC includes "*I feel 'emotionally attached' to this company*."

SE is measured using a 4-item scale adapted from Morandi *et al.* (2022). A sample item for SE includes "*I will be able to successfully overcome many challenges*."

PC is measured using a 5-item scale adapted from Almusaddar *et al.* (2018). A sample item of PC includes "*I have been able to learn interesting new skills on my job*."

CS is measured using a 5-item scale adapted from Ahmad and Nasir (2023). A sample item for CS includes "*I get excited when I think about my career*."

To measure all the items in the proposed research model, a 5-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5) is utilized.

Data analysis

The data of this study was statistically analyzed using SmartPLS 3.3.3 of partial least squares structural equation modeling (PLS-SEM). SmartPLS is a popular software tool researchers use for conducting PLS-SEM analysis in various fields, including business and management studies (Peralta *et al.,* 2019), due to its ability to handle complex models and small sample sizes. Further, SmartPLS is used to analyze relationships between variables, test hypotheses, and assess the reliability and validity of measurement models (Hair *et al.,* 2016).

RESULTS AND DISCUSSION

The present study examines the indicator loadings, Cronbach Alpha (α), and Composite Reliability (CR) of each construct to establish the internal consistency reliability. Also, each latent construct's Average Variance Extracted (AVE) is measured to affirm the convergent validity.

Table 2 illustrates that reliability is acceptable since indicator loadings' values are above 0.60, and α and CR exceed 0.70 (Hair *et al.,* 2016). Indicator loadings above 0.60 generally indicate that the indicator is a good measure of the latent constructs. Further, all constructs' AVE values are above 0.50, exhibiting adequate convergent validity. Hair *et al.* (2016) highlight a valid and reliable measure when a construct's AVE is above 0.50.

Empirical analysis in Table 3 shows the value of the proposed model's discriminant validity. All values of the Fornell-Larcker criterion indicate that the square root of the AVE for each construct is greater than the correlations between the constructs, providing evidence of discriminant validity (Fornell and Larcker, 1981). Although Henseler *et al.* (2015) proposed using the heterotrait-monotrait ratio of correlations (HTMT) as a more reliable method for assessing discriminant validity in PLS-SEM models, the Fornell-Larcker criterion, however, is still used in practice.

The collinearity diagnostics in Table 4 revealed that all Variance Inflation Factor (VIF) values were below the commonly accepted threshold of 5.0 (Hair *et al.,* 2017), indicating no substantial multicollinearity issues. Furthermore, most indicators demonstrated VIF values below the stricter threshold of 3.3, suggesting that common method bias is unlikely to pose a serious threat to the study's validity (Kock, 2015). However, EL4 (VIF = 3.623) slightly exceeds the recommended threshold of 3.3 and should be considered for refinement in future studies.

Table 2: Composite reliability and convergent validity

Constructs	Items	Loadings	Cronbach's Alpha	Composite Reliability	AVE
Empowering Leadership	EL1	0.835	0.910	0.930	0.691
	EL2	0.831			
	EL3	0.830			
	EL4	0.873			
	EL5	0.819			
	EL6	0.796			
Organizational Commitment	OC1	0.816	0.788	0.855	0.544
	OC2	0.709			
	OC3	0.850			
	OC4	0.621			
	OC5	0.666			
Self-Efficacy	SE1	0.758	0.815	0.878	0.643
	SE2	0.802			
	SE3	0.839			
	SE4	0.806			
Performance Competence	PC1	0.809	0.828	0.879	0.593
	PC2	0.761			
	PC3	0.807			
	PC4	0.724			
	PC5	0.747			
Career Success	CS1	0.790	0.827	0.878	0.591
	CS2	0.787			
	CS3	0.784			
	CS4	0.752			
	CS5	0.730			

Fig. 1 and Table 5 show the results of the research model's hypotheses testing. Hypotheses H1, H2, H3, and H4 proposed positive relationships between EL on CS, OC, SE, and PC. The results showed that EL was positively and significantly associated with CS ($\beta = 0.387$, T-Statistic = 3.301, $\rho < 0.05$), OC ($\beta = 0.706$, T-Statistic = 20.182, $\rho < 0.05$), SE ($\beta = 0.478$, T-Statistic = 5.308, $\rho < 0.05$), and was also significantly

Table 3: Discriminant validity (Fornell-Larcker criterion)

Main Constructs	Career Success	Performance Competence	Empowering Leadership	Organizational Commitment	Self-Efficacy
Career Success	0.769				
Performance Competence	0.459	0.770			
Empowering Leadership	0.694	0.593	0.831		
Organizational Commitment	0.681	0.449	0.706	0.738	
Self-Efficacy	0.459	0.621	0.478	0.433	0.802

Table 4: Collinearity statistics

Main constructs	Items	VIF
Empowering Leadership	EL1	3.107
	EL2	3.214
	EL3	2.697
	EL4	3.623
	EL5	2.686
	EL6	2.032
Organizational Commitment	OC1	1.882
	OC2	1.774
	OC3	2.419
	OC4	1.309
	OC5	1.341
Self-Efficacy	SE1	1.477
	SE2	1.771
	SE3	1.870
	SE4	1.994
Performance Competence	PC1	1.852
	PC2	1.718
	PC3	1.967
	PC4	1.657
	PC5	1.773
Career Success	CS1	1.887
	CS2	1.826
	CS3	2.092
	CS4	1.631
	CS5	1.976

associated with PC (β = 0.593, T-Statistic = 10.561, $\rho < 0.05$). Thus, hypotheses H1, H2, H3 and H4 were supported. Further, OC was positively and significantly associated with CS (β = 0.358, T-Statistic = 4.462, $\rho < 0.05$), confirming H5. However, no significant associations in this study were found between either SE and CS (β = 0.124, T-Statistic = 1.068, $\rho > 0.05$) or PC and CS (β = -0.009, T-Statistic = 0.097, $\rho > 0.05$). Therefore, hypotheses H6 and H7 were rejected. To examine the mediation effects of OC, SE, and PC in the relationship between EL and CS, this study performed a mediation test by the methodology outlined by (Zhao *et al.,* 2010). The results revealed that the indirect effect of EL on CS through OC was significant (β = 0.253, T-Statistic = 4.218, $\rho < 0.05$), confirming hypothesis H8. The study's findings indicated that the relationship between EL and CS is significantly mediated by OC. This means that OC plays a crucial role in explaining how EL influences CS. However, the results showed that the indirect effects of EL on CS through SE (β = 0.059, T-Statistic = 1.054, $\rho > 0.05$) and PC (β = -0.005, T-Statistic = 0.093, $\rho > 0.05$) were not significant. Thus, the study's findings did not confirm the mediation effects of SE and PC. Therefore, hypotheses H9 and H10 were rejected. Empirical findings of this study show that EL significantly promotes employees' OC, SE, PC, and CS. These results are consistent with previous studies demonstrating that EL positively influences OC (Eliyana *et al.,* 2025; Kim and Beehr, 2018; Raziq *et al.,* 2025), SE (Ahmed *et al.,* 2022; Peng *et al.,* 2024), PC (Fikri *et al.,* 2023; Khatoon *et al.,* 2024), and CS (Dwidienawati *et al.,* 2025; Lei *et al.,* 2021; Yulia and Safaatillah, 2023). EL grants employees more autonomy and control over their work, allowing them to take initiative and decision-making. This autonomy fosters a sense of ownership and investment in their work, enhancing their commitment to the organization. By granting employees opportunities to make decisions and solve problems, empowering leaders facilitates the continuous development of competence and expertise, leading to a greater sense of accomplishment (Lin *et al.,* 2020). Also, when leaders empower employees to take charge of their tasks, it builds their confidence in their abilities to perform well. This boost in SE encourages employees to take on challenging tasks (Joo *et al.,* 2023) and achieve higher performance levels. Further, empowering leaders show trust in their employees' abilities, which can lead to a positive and supportive work environment. Employees who feel trusted and recognized for their contributions are more likely to contribute meaningfully to their work (Mutonyi *et al.,* 2020). This can lead to career

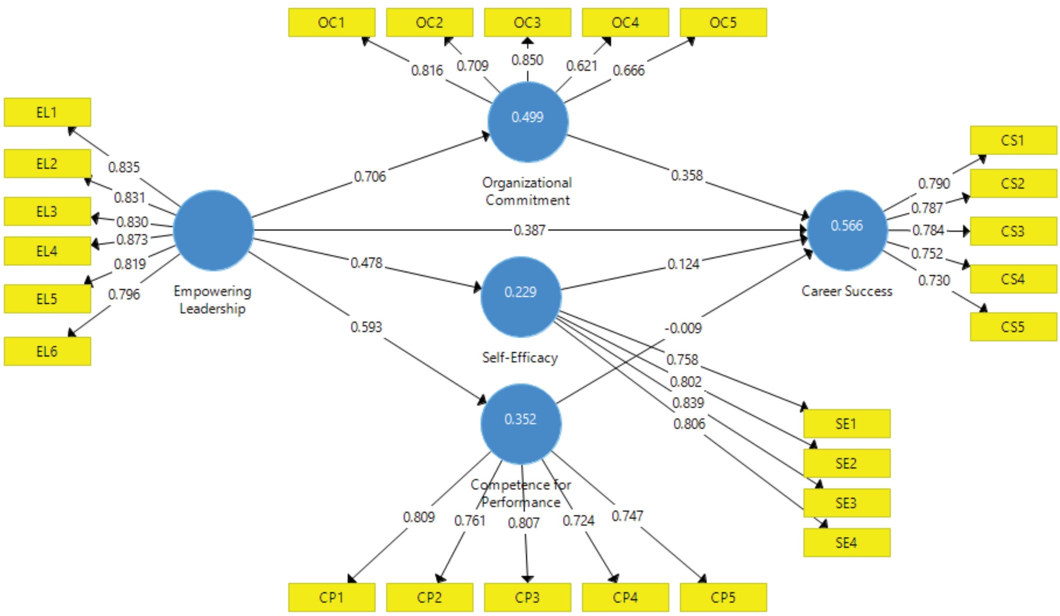

Fig. 1: Conceptual framework

Table 5: Path coefficients

Relationship	β	Standard Deviation	T-Statistics	P-Values	Remarks
Direct Effect					
Empowering Leadership → Career Success	0.387	0.117	3.301	0.001	Supported
Empowering Leadership → Organizational Commitment	0.706	0.035	20.182	0.000	Supported
Empowering Leadership → Self-Efficacy	0.478	0.090	5.308	0.000	Supported
Empowering Leadership → Performance Competence	0.593	0.056	10.561	0.000	Supported
Organizational Commitment → Career Success	0.358	0.080	4.462	0.000	Supported
Self-Efficacy → Career Success	0.124	0.116	1.068	0.286	Rejected
Performance Competence → Career Success	-0.009	0.094	0.097	0.922	Rejected
Indirect Effect					
Empowering Leadership → Organizational Commitment → Career Success	0.253	0.060	4.218	0.000	Supported
Empowering Leadership → Self-Efficacy → Career Success	0.059	0.056	1.054	0.292	Rejected
Empowering Leadership → Performance Competence → Career Success	-0.005	0.058	0.093	0.926	Rejected

advancement and success as employees gain visibility and recognition for their efforts. This study, in contrast to the expectation, found that SE and PC do not significantly promote CS. These results are consistent with previous studies demonstrating that SE (Windayati and Malik, 2023) and PC (Novelya and Karuehni, 2023) have no significant impact on CS. While SE and PC are typically associated with positive outcomes such as increased motivation, creativity, and productivity, their direct impact on CS may be more complex than one might expect. There are several reasons why these variables may not significantly promote CS on their own. CS heavily depends on relationships and networking (Porter *et al.,* 2023). SE and PC may not necessarily translate into successful networking, which is crucial for career advancement. Building networks and maintaining strong social relationships can have a greater impact on CS than individual skills alone. Additionally, highly self-efficacious and competent employees may still struggle with CS if their efforts and achievements are not visible to key decision-makers. Without proper exposure or recognition, their career advancement may be limited. This study revealed that EL positively influences OC, which in turn plays a crucial role in mediating the relationship between EL and CS. When employees feel a strong sense of commitment to their organization, they are more likely to be engaged and dedicated to achieving their career goals within the organization (Semlali and Elrayah, 2022). EL fosters an environment where employees feel trusted and valued. This can enhance their commitment to the organization as they perceive a supportive work culture. When employees are committed to the organization, they are more likely to go beyond their roles, contributing to their CS (Weer and Greenhaus, 2020). Also, empowering leaders often work closely with employees to align organizational goals with personal career aspirations. When employees feel that their personal goals are in harmony with the organization's objectives, their commitment to the organization significantly deepens, providing a solid foundation for CS.

Limitations and future research agenda

The study focuses on coal mining companies in Indonesia, which may limit the transferability of the findings to other industries or cultural contexts. Also, the cross-sectional design of the study may limit the ability to establish causal relationships between EL, OC, SE, PC, and CS. Therefore, longitudinal studies are recommended to explore the long-term effects of EL on OC, SE, PC, and CS. Also, future studies need to compare the effects of EL on CS across different industries, organizational sizes, and cultural contexts to identify potential variations in outcomes. By addressing these limitations and pursuing suggestions for future research, scholars can further enhance valuable insights into EL's role in promoting CS and organizational effectiveness.

CONCLUSION

The results of hypotheses testing in the research model conclude that EL was positively and significantly associated with CS, OC, SE, and PC. Further, OC was also positively and significantly associated with CS. However, no significant associations in this study were found between either SE and CS or PC and CS. In addition, the result of the mediation test indicated that the relationship between EL and CS is significantly mediated by OC. This study offers several theoretical implications that enhance the understanding of workplace dynamics and employee professional development. First, EL fosters trust and reciprocity between leaders and employees (Rai and Kim, 2021), cultivating a positive social atmosphere in which employees feel valued and supported. This environment strengthens OC, which, in turn, motivates employees to exert greater effort and strive for CS. Second, EL often facilitates opportunities for learning, skill development, and career advancement. As employees grow more competent and become valuable assets to the organization, their commitment is reinforced by their increased career investment. This elevated level of OC can ultimately lead to greater opportunities for CS within the organization. This study also provides several practical implications for organizations seeking to foster a supportive work environment and promote employee success. First, organizations should invest in training and development programs for leaders that focus on EL style. By teaching leaders to trust and empower their employees, organizations can foster greater employee autonomy, motivation, and commitment. Second, organizations should establish clear career development and advancement opportunities for employees. EL can support these pathways by encouraging leaders to guide employees toward CS while fostering a strong sense of OC. Third, empowering leaders can enhance performance management by giving employees autonomy and responsibility. This approach can lead to higher levels of employee engagement and commitment, resulting in better performance and overall CS.

AURHOUR CONTRIBUTIONS

I. N. Qamari led the research project, contributed to the development of the methodology, and coordinated the contributions of all authors. U. Udin was responsible for the overall planning and supervision of the study, conducted the literature review, and analyzed and interpreted the data. I. B. A. G. Azmi contributed to the literature review and participated in the review and editing of the manuscript. S. H. Wahyuningsih assisted in data analysis and interpretation. W. P. Sari contributed to the manuscript review and assisted with editing and formatting. M. Musoli supported data compilation and was involved in manuscript editing.

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CONFLICT OF INTEREST

The authors declare that there is no conflict 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, have been completely observed by the authors.

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ABBREVIATIONS

AVE	Average Variance Extracted
CS	Career Success
EL	Empowering Leadership
HTMT	Heterotrait-Monotrait Ratio of Correlations
OC	Organizational Commitment
PC	Performance Competence
PLS-SEM	Partial Least Squares Structural Equation Modeling
SDT	Self-Determination Theory
SE	Self-Efficacy
VIF	Variance Inflation Factor

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ORIGINAL RESEARCH PAPER

Why do green spaces matter for mental health in urban environments?

A. Baitalik[1,*], T. Bhattacharjee[2,3]

[1] *Department of Pure and Applied Sciences, Midnapore City College, Midnapore, India*

[2] *PG Department of Education, Fakir Mohan University, Balasore, India*

[3] *Department of Teacher Education, Yogoda Satsanga Palapara Mahavidyalaya, Palpara, India*

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ABSTRACT

BACKGROUND AND OBJECTIVES: Urban green spaces play a vital role in promoting the mental and physical well-being of city residents. While their benefits are widely acknowledged, understanding how demographic factors and travel behaviors influence this green space usage remains limited. This study aims to explore the relationship between urban green space use, user demographics, and perceived mental health benefits within urban environments.

METHODS: A quantitative survey was conducted involving 420 urban green space users. The study assessed participants' health status, physical activities, and emotional responses using structured questionnaires. Statistical analyses such as Analysis of Variance and Principal Component Analysis were employed to evaluate relationships between variables. All analyses were conducted using the Statistical Package for Social Sciences software (version 27).

FINDINGS: Stress levels were found to be moderate to high, with a mean score of 3.22 on a 5-point Likert scale. Emotional well-being showed a positive correlation with reduced stress, with those experiencing emotional distress reporting higher stress levels (mean score of 4.13). Regular physical activity was associated with lower anxiety levels, with individuals engaging in physical exercise reporting an average anxiety score of 2.85 compared to 4.12 for those with minimal activity. Additionally, emotional health improved significantly, as participants reported higher confidence and peace of mind, with scores increasing from 2.75 to 4.10 after engaging in stress-reducing activities. Demographic factors influenced stress levels, with younger participants (ages 18-25) having a mean stress score of 3.45, compared to older participants (ages 45-60) who reported a mean stress score of 2.89.

CONCLUSION: Urban green space provides a significant mental health benefit by reducing stress and enhancing emotional well-being. This study highlights the critical role of UGS in urban planning for fostering resilience and promoting sustainable community development, aligning with the Sustainable Development Goals.

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*Corresponding Author:
Email: *anirbanbaitalik@gmail.com*
Phone: +91 9932750877
ORCID: 0000-0002-1001-5543

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INTRODUCTION

Urban Green Spaces (UGSs), including parks and gardens, are essential elements of urban environments designed to incorporate vegetation (Hanson *et al.,* 2021). Historically rooted in 18th and 19th-century European gardens, these spaces were initially exclusive to the elite, showcasing elaborate designs like those found in Versailles and Central Park (Loughran, 2020). The industrialization of the 19th century highlighted urban issues such as overcrowding and pollution, prompting advocates for public parks to address these challenges (Platt, 2018). This period birthed expansive public parks, exemplified by London's Hyde Park and the designs of Frederick Law Olmsted (Jones, 2022). The late 19th and early 20th centuries saw the City Beautiful Movement, which prioritized aesthetic values in urban planning, leading to grand boulevards and landscaped parks (Krueckeberg, 2018). The 20th century marked a shift towards accessible recreational spaces for all demographics (Contesse, Van Vliet, and Lenhart, 2018). In recent decades, the focus has increasingly shifted to the environmental benefits of green spaces, highlighting sustainability and ecological preservation (Dushkova and Haase, 2020). Community parks have become vital local gathering places, and the concept of urban green spaces continues to evolve, incorporating adaptive reuse of industrial sites and new technologies for education. These spaces are crucial for enhancing urban life, improving environmental quality, and supporting resident well-being amid urban growth and challenges (Lehmann, 2021). By 2050, seven out of ten people around the world will live in cities (De Neve and Krekel, 2020). This rapid urbanization presents numerous challenges, including increased stress, anxiety, and depression, largely stemming from environmental stressors such as noise, pollution, and social isolation (Rahaman, Kalam, and Al-Mamun, 2023). In this context, the integration of green spaces into urban planning is not merely an aesthetic consideration but a vital component of public health strategy. The benefits of UGSs align closely with the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-Being) and SDG 11 (Sustainable Cities and Communities). Theories such as New Urbanism, Eco-City, Social Capital, and Healthy Cities emphasize their importance in creating vibrant, sustainable urban areas (Giacovelli, 2022). UGSs are crucial for enhancing urban livability by positively affecting the environment, public health, and community well-being. Studies indicate significant mental health benefits, with Houlden *et al.,* (2021) showing that individuals near green areas experience lower psychological distress. This supports the "biophilia hypothesis," which suggests that humans have an inherent connection to nature, enhancing emotional well-being through interactions with green environments (Kellert, Heerwagen, and Mador, 2011). Additionally, Bratman *et al.,* (2021) found that even brief exposure to nature can improve mood and cognitive functioning, highlighting nature's restorative role. Attention Restoration Theory (ART) further explains these benefits, suggesting that natural environments replenish cognitive resources depleted by urban stressors, thereby enhancing focus, creativity, and emotional resilience, all vital for mental health in fast-paced urban settings (Kaplan and Kaplan, 1989). UGSs also promote physical activity, an important factor linked to improved mental health (Callaghan *et al.,* 2021). Kaczynski and Henderson (2007) highlighted that environments conducive to physical activity can lead to reduced symptoms of anxiety and depression. Moreover, Motomura *et al.,* (2024) found that proximity to parks correlates with higher rates of physical activity among residents, further emphasizing the mental health benefits associated with active lifestyles. Social interaction facilitated by green spaces is another key factor in promoting mental health. Parks and community gardens provide venues for socialization, fostering community ties and reducing feelings of loneliness. A study by Ruijsbroek *et al.,* (2017) indicated that stronger social connections, enhanced by communal green spaces, are associated with improved mental health outcomes. UGSs in India, including public parks, botanical gardens, urban forests, and community gardens, are influenced by the historical gardens of Mughal and Rajput rulers (Sharma, Upadhyay, and Chani, 2019). The colonial era established the framework for public parks, while post-independence efforts improved urban living conditions through green area development (Mell, 2018). Current trends emphasize ecological sustainability, native plant species, and community engagement, with initiatives like community gardens gaining traction (Mumtaz, 2021). However, challenges such as maintenance, encroachment, and pollution persist due to rapid urbanization and competing land uses (Turaga *et al.,* 2020). Urban planners are increasingly integrating green spaces into development plans, exploring solutions like green roofs and vertical gardens, supported by initiatives such as the Swachh Bharat Mission and Smart Cities Mission (Shruti, Singh, and Ohri, 2020). Examining local UGSs is crucial for general management, especially as their significance grows amid urbanization challenges and the need for environmental sustainability. The objectives of this study are to investigate the relationship between UGS utilization and perceived stress, emotional responses, and overall mental well-being among urban residents. To achieve these objectives, the research survey was conducted in the residential areas of Midnapore town, West Bengal, India, in 2024.

MATERIALS AND METHODS

Research design

This study employed a cross-sectional research design to investigate the utilization patterns and perceptions of UGS among residents of Midnapore town, West Bengal, India. The design aimed to capture a snapshot of visitor experiences across different times of day, focusing on the morning (5:00 am to 8:00 am) and afternoon (5:00 pm to 7:00 pm) periods, which were identified as peak hours for UGS visits. The research was conducted from March 2024 to May 2024.

Selection of the study area

Midnapore town (Fig. 1) was selected for its diverse urban and semi-urban settings, varied population densities, and unique environmental and health challenges. This localized approach aimed to provide insights into how different types of UGS, including public parks, community gardens, and peri-urban forested areas, contribute to the well-being and recreational needs of its residents. Two UGS locations were selected for primary survey data collection, detailed in Table 1.

Population and sample

The study targeted users of UGS in Midnapore town, West Bengal, India, with a total participant pool of 420 respondents. This diverse population was selected to reflect the town's varied demographics, including different age groups, genders, socio-economic statuses, and educational backgrounds. To gather participants efficiently, convenience sampling was employed, allowing for the rapid recruitment of individuals who frequented UGS during peak visiting hours (morning and evening). This method was chosen for its time and resource efficiency, enabling the collection of genuine experiences in a natural setting while capturing a wide range of user motivations for visiting UGS. Participants were required to be at least 18 years old and to have visited a UGS at least once in the past month, ensuring they could provide relevant insights based on recent interactions. According to the 2011 census data, the total population of Midnapore municipality was 169,264. To determine an appropriate sample size for interviews, Eq. 1 was applied, which considered a 95% confidence level and a 5% margin of error.

$$n = \frac{Z^2.p.(1-p)}{E^2} \tag{1}$$

Where: n is the sample size needed, Z is the Z-score corresponding to the desired confidence level (approximately 1.96 for 95% confidence), and p is the estimated proportion of the population that possesses the attribute in question (assumed as 0.5 to maximize the sample size), E is the margin of error

Table 1: Selected urban green spaces in Midnapore town for primary survey

Name of the UGS	No. of Respondents	Percent	Remarks
Police Line Park (PLP), also known as Sukumar Sengupta Smriti Udyan	196	46.67	Public amusement park with recreational facilities
Tetultala Play Ground (TPG)	224	53.33	Public open space without recreational facilities
Total	420	100.0	-

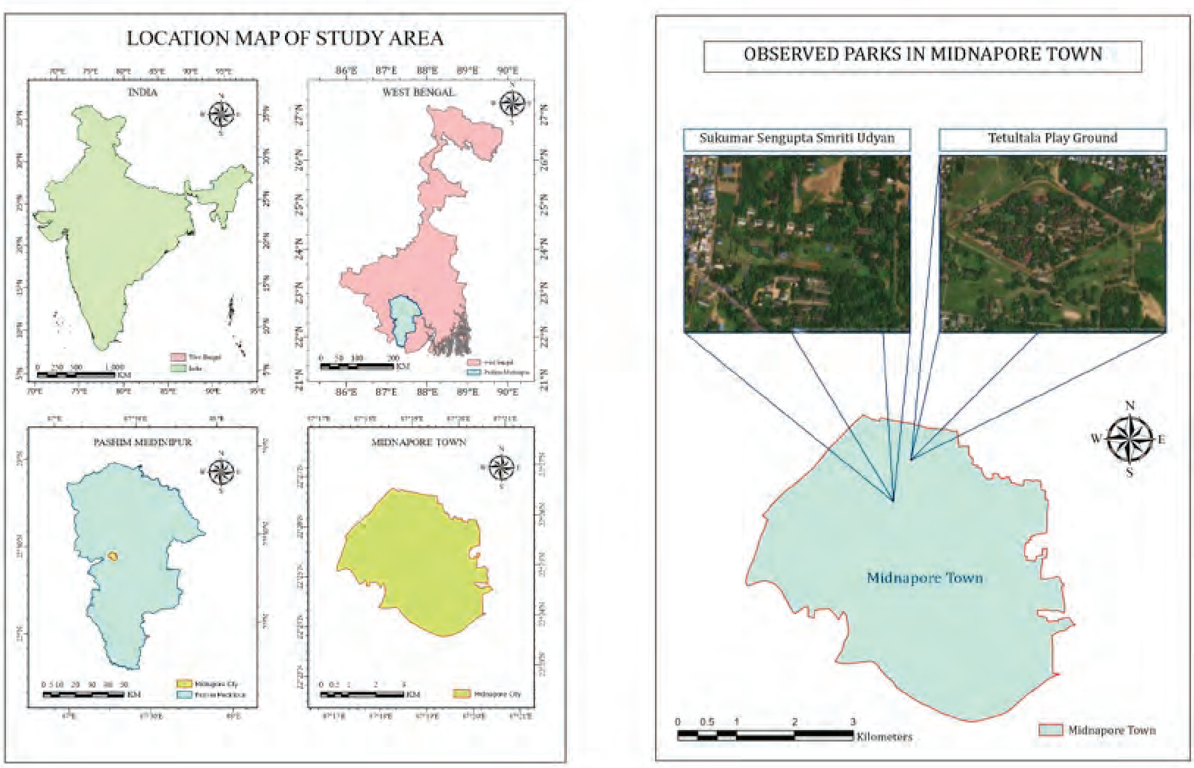

Fig. 1: Geographic location of the observed urban green spaces in the study area

(0.05). Based on this calculation, the sample size required for conducting interviews in the Midnapore municipality was determined to be approximately 385 respondents. Adjustments were made based on specific research goals and conditions, leading to the inclusion of 420 respondents, all of whom were users of urban green spaces.

Data collection methods

The study employed a structured questionnaire as its primary data collection instrument, specifically tailored to measure the mental well-being of UGS users. The first section gathered demographic information, such as age, gender, marital status, educational attainment, household income, and family size, to contextualize the findings. Following this, the questionnaire included a section on travel behavior, where participants reported the frequency of their UGS visits, mode of travel, and travel time, providing insights into how these factors might influence mental well-being. Health metrics were also assessed through self-reported measures of height, weight, and existing health conditions. Crucially, the Perceived Stress Scale, consisting of 10 items measured on a 5-point Likert scale, evaluated the levels of stress associated with UGS experiences.

Reliability and validity assessment

The study rigorously evaluated the reliability and validity of measurement instruments for assessing perceived stress and mental well-being among UGS users. Internal consistency was confirmed with Cronbach's Alpha values of 0.869 for the perceived stress scale and 0.882 for the mental well-being scale, indicating high reliability. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was 0.843, indicating an adequate sample size for factor analysis. Bartlett's Test of Sphericity revealed significant correlations among variables, with a chi-square of 1775.502 ($p < 0.001$), confirming meaningful relationships between constructs.

Data analysis

Data analysis for the study employed several statistical methods to explore the relationship between UGS usage and mental well-being outcomes. Descriptive statistics summarized participants' demographic characteristics and survey responses. One-way ANOVA assessed differences in perceived stress and mental well-being across demographic factors, with significance set at $p < 0.05$. Additionally, Principal Component Analysis (PCA) identified underlying factors related to perceived stress and mental well-being among UGS users.

RESULTS AND DISCUSSION

Socio-demographic profile of the sample respondents

The demographic profile of UGS users, presented in Table 2, reveals a diverse user base predominantly aged 18-30 (41.7%) and over 60 (20.0%), with a majority being male (65.0%). Most respondents identify as Hindu (93.3%) and are married (60.0%), indicating UGS as a family-friendly space. Educationally, many are graduates (31.7%) or have postgraduate degrees (30.0%), suggesting a correlation between education and UGS usage. Employment status is fairly balanced, with 53.3% unemployed, highlighting UGS as a valuable recreational option for job seekers. Income levels primarily fall between 20,001-40,000 rupees (38.3%), indicating UGS's accessibility for lower to middle-income families. Most users reside within the Midnapore Municipality (81.7%) and are homeowners (78.3%), often living in their current residence for over ten years (66.7%), which emphasizes UGS as a significant community asset that fosters engagement and accessible recreation across diverse demographic groups. The demographic profile of UGS users highlights key mental health considerations in urban planning. The prominence of young adults indicates a need for UGS that support their recreational and social activities, which are vital for mental health (Bressane *et al.,* 2024). The higher percentage of male users points to a gender gap, stressing the importance of inclusive environments for psychological well-being. Additionally, the prevalence of married individuals and joint families suggests that UGS are crucial for family-oriented activities, enhancing emotional support and intergenerational bonding, factors important for mental resilience. For many educated yet unemployed users, UGS serve as essential spaces for relaxation and stress relief, underscoring the need for equitable access to these resources (Xiong, Xu, and Zhao*,* 2024).

Travel behavior of the sample respondents

Table 3 reveals key insights into the travel patterns and expenditures of Urban Green Space (UGS) users. A significant majority (73.3%) travel primarily from home, with walking being the predominant mode of transport (53.3%), followed by cycling (31.7%). Most users visit UGS daily (43.3%), and a substantial portion (56.7%) incur no transportation costs for these visits, underscoring the accessibility of these spaces. Travel times are generally short, with 36.7% reaching UGS in under 15 minutes. During their visits, 43.3% spend nothing, while 30% spend between 10-20 rupees, indicating low-cost leisure options. The primary expenditure during visits is on food and beverages (31.7%), but 40% report no spending at all. These findings highlight a trend toward affordable and accessible recreation, emphasizing the role of walkable urban environments and budget-friendly leisure activities in enhancing community engagement with UGS. The findings related to travel behavior to Urban Green Spaces highlight their crucial role in supporting mental health within urban environments. The significant number of users walking to UGS suggests that easy access to these spaces encourages physical activity, which is known to enhance mood and reduce symptoms of anxiety and depression (Maury-Mora, Gómez-Villarino, and Varela-Martínez*,* 2022). Daily visits indicate that UGS serve as essential mental health refuges for urban residents, providing opportunities for relaxation and social interaction, which are vital for emotional well-being (Naghibi, Farrokhi, and Faizi*,* 2024). The low transportation costs and short travel times further enhance the appeal of UGS as an accessible mental health resource, particularly for marginalized communities (Liu, Kwan, and Kan*,* 2021). By facilitating frequent, low-cost access to nature, UGS can help mitigate the stressors associated with urban living, promoting resilience and psychological recovery (Robillard *et al.,* 2023).

Physical health of the sample respondents

Table 4 highlights the health and physical activity profiles of UGS users. A significant 73.3%

Table 2: Socio-demographic profile of sample respondents

Demographic variable	Category	Frequency	Percent
Age group (in years)	Under 18	14	3.3
	18-30	175	41.7
	31-45	70	16.7
	46-60	77	18.3
	Over 60	84	20.0
Gender	Female and others	147	35.0
	Male	273	65.0
Religion	Hindu	392	93.3
	Muslim	21	5.0
	Others	7	1.7
Marital status	Others	168	40.0
	Married	252	60.0
Educational status	Primary	21	5.0
	Upper primary	14	3.3
	Secondary	49	11.7
	Higher secondary	77	18.3
	Graduate	133	31.7
	Postgraduate and above	126	30.0
Employment status	Unemployed	224	53.3
	Employed	196	46.7
Household income (in INR)	Up to 20,000	105	25.0
	20,001-40,000	161	38.3
	40,001-60,000	112	26.7
	60,001-80,000	21	5.0
	Above 80,000	21	5.0
Nature of family	Nuclear	168	40.0
	Joint	252	60.0
Number of family members	3-4	189	45.0
	5-6	161	38.3
	7-8	35	8.3
	Above 8	35	8.3
Residence	Outside Midnapore Municipality	77	18.3
	Inside Midnapore Municipality	343	81.7
Type of residence	Renter	91	21.7
	Homeowner	329	78.3
Duration of ownership/rental (in years)	Less than 1 year	7	1.7
	1-5 years	84	20.0
	5-10 years	49	11.7
	More than 10 years	280	66.7

Table 3: Travel patterns and expenditures of sample respondents:

Travel behaviours	Variable	Frequency	Percent
Origin of travel	Home	308	73.3
	Work	21	5.0
	Shops	14	3.3
	School	14	3.3
	College/University	56	13.3
	Others	7	1.7
	Total	420	100.0
Mode of travel	Walk	224	53.3
	Bicycle	133	31.7
	Drive (motorbike/car)	42	10.0
	Public transportation	14	3.3
	Others	7	1.7
	Total	420	100.0
Frequency of visits	Daily	182	43.3
	Several times a week	119	28.3
	Once a week	91	21.7
	Rarely/Never	28	6.7
	Total	420	100.0
Transportation cost to visit UGS (in INR)	Nil	238	56.7
	Less than 5	28	6.7
	5-10	42	10.0
	10-20	98	23.3
	More than 20	14	3.3
	Total	420	100.0
Travel time to visit UGS (in minutes)	Less than 15 minutes	154	36.7
	15-30 minutes	105	25.0
	30-60 minutes	112	26.7
	More than 60 minutes	49	11.7
	Total	420	100.0
Accompanying persons during the UGS visit	Alone	105	25.0
	Friends	182	43.3
	Partner	70	16.7
	Children	56	13.3
	Others	7	1.7
	Total	420	100.0
Spending per visit to UGS	None	182	43.3
	Less than 10 rupees	21	5.0
	10-20	126	30.0
	21-50	84	20.0
	More than 50	7	1.7
	Total	420	100.0
Primary expenditures during visits to UGS	Nothing	168	40.0
	Food/beverages	133	31.7
	Equipment (e.g., sports gear)	7	1.7
	Entry fees (if applicable)	105	25.0
	Others	7	1.7
	Total	420	100.0

reported no disease history, indicating that UGS may attract healthier individuals, while 26.7% face health challenges, especially diabetes (16.7%) and hypertension (11.7%). Walking is the primary activity for 66.7% of users, underscoring UGS's role in promoting physical activity; however, 35.0% engage in only low to moderate physical activity (30-60 minutes), suggesting room for increased participation. Half of the users' average moderate step counts (501-2000 steps) demonstrate UGS's

Table 4: Status of health and physical activity of UGS users

	Category	Subcategory	Frequency	Percent
Status of health	Disease history	Haven't disease history	308	73.3%
		Have disease history	112	26.7%
	Physical activities at UGS	Walking	280	66.7%
		Jogging	28	6.7%
		Cycling	28	6.7%
		Sports	84	20.0%
	Disease types	No specific diseases	273	65.0%
		Diabetes (Diabetes Mellitus)	70	16.7%
		Blood pressure (Hypertension)	49	11.7%
		Thyroid disorders	14	3.3%
		Arthritis	7	1.7%
		Others	7	1.7%
	Height	Short (4.00 - 5.40 feet)	200	47.6%
		Medium (5.41 - 5.80 feet)	112	26.7%
		Tall (5.81 - 6.20 feet)	108	25.7%
	Weight	Underweight (20 - 54 kg)	153	36.4%
		Normal weight (55 - 69 kg)	217	51.7%
		Overweight (70 - 85 kg)	50	11.9%
	BMI categories	Underweight (mild thinness)	7	1.7%
		Overweight (pre-obese)	35	8.3%
		Obese (Class I)	126	30.0%
		Obese (Class II)	168	40.0%
		Obese (Class III)	84	20.0%
Nature of physical activity	Physical activities at UGS	Walking	280	66.7%
		Jogging	28	6.7%
		Cycling	28	6.7%
		Sports	84	20.0%
	Physical activity duration	Low (30 - 45 minutes)	147	35.0%
		Moderate (60 minutes)	147	35.0%
		High (70 minutes and above)	126	30.0%
	Average step count	Low (0 - 500)	147	35.0%
		Moderate (501 - 2000)	210	50.0%
		High (2001 and above)	63	15.0%

potential for facilitating exercise. Nevertheless, the 40.0% classified as Obese Class II raises concerns about UGS's effectiveness in addressing obesity. Overall, while UGS users generally display a healthy profile, targeted interventions may be necessary to boost activity levels and tackle obesity in this population. The physical health findings among UGS users highlight the critical interplay between mental health and urbanism. While a significant majority of respondents report no disease history, the presence of health issues like diabetes and hypertension underscores the necessity for UGS to promote holistic well-being (Bressane *et al.,* 2024). Regular activities such as walking, engaged in by a notable portion of users, contribute to mental health benefits, including reduced anxiety and improved mood (Keenan *et al.,* 2021). However, the observed low to moderate levels of physical activity indicate an opportunity for urban planners to enhance engagement through targeted programs that encourage active lifestyles within these spaces. Additionally, the prevalence of obesity among users highlights the importance of designing UGS that not only support physical activity but also foster community interactions, which are vital for enhancing self-esteem and mental resilience (Kanelli *et al.,* 2023).

Cognitive and emotional responses related to stress about UGS

The item statistics reveal perceptions and emotional responses related to stress about UGS, categorized into cognitive appraisal and emotional response statements presented in Table 5. Respondents generally reported moderate to high levels of agreement with statements reflecting their cognitive appraisal of stress when in UGS, presented in Table 59. For instance, they expressed feeling confident in their ability to handle problems (Mean = 3.1833, SD = 0.886) and believing they can control irritations better (Mean = 3.0500, SD = 0.992) in these environments. However, there was more variability in feeling overwhelmed (Mean = 2.4667, SD = 1.057) and feeling on top of things (Mean = 3.1167, SD = 1.113). In terms of emotional responses, respondents generally reported positive experiences in UGS. They often felt less anxious and more peaceful (Mean = 3.2167, SD = 1.052) and experienced relief and relaxation (Mean = 3.1833, SD = 1.058) after spending time in

Table 5: Perceptions and emotional responses related to stress about UGS

	Item Statistics			
Perceived stress types	Statements related to perceived stress about UGS	Mean	Std. Deviation	N
Cognitive appraisal of stress statements (Xiong, Xu, and Zhao, 2024)	I feel confident about my ability to handle my problems when I spend time in urban green spaces.	3.1833	.88596	420
	I often feel that things are going my way when I immerse myself in green environments.	3.0167	.94083	420
	I rarely find that I cannot cope with all the things that I have to do when I connect with nature in the city.	2.4667	1.05746	420
	I believe I can control irritations in my life better when I spend time in urban green spaces.	3.0500	.99155	420
	I generally feel that I am on top of things when I engage with greenery in urban settings.	3.1167	1.11326	420
Emotional responses to stress statements (Xu *et al.,* 2024)	I feel less anxious and more at peace when I'm surrounded by green landscapes in the city.	3.2167	1.05152	420
	I often experience a sense of relief and relaxation after spending time in urban green spaces.	3.1833	1.05785	420
	I seldom feel overwhelmed by stress when I immerse myself in the tranquility of urban parks.	2.9500	.82611	420
	I believe that being in nature within the city helps me manage my emotions more effectively.	2.9000	.96205	420
	I rarely feel tense or worried when I take leisurely walks in urban green areas.	2.9500	1.05680	420

The Cronbach's Alpha coefficient of 0.869 indicates a high level of reliability among the items measuring the constructs. The Cronbach's Alpha based on standardized items is 0.867, further confirming the consistency of the measurements.

these settings. However, there was some variability in feeling overwhelmed by stress (Mean = 2.9500, SD = 0.826) and managing emotions effectively (Mean = 2.9000, SD = 0.962) in urban green spaces. Leisurely walks were less consistently associated with reduced tension or worry (Mean = 2.9500, SD = 1.057). The finding that users generally feel confident in managing problems while in UGSs underscores the psychological benefits of natural environments in urban settings. This sense of confidence can be linked to several psychological theories that highlight the restorative effects of nature. Kaplan and Kaplan (1989) propose the "Attention Restoration Theory," which posits that natural environments facilitate mental recovery and enhance cognitive functioning, leading individuals to feel more equipped to tackle life's challenges. Moreover, UGS provides a space for reflection and emotional regulation. Being in nature can promote mindfulness and increase self-awareness, which are crucial for effective problem-solving (Borges *et al.,* 2024). Research indicates that exposure to green environments can reduce cognitive overload and enhance mood, contributing to improved mental resilience (Vella-Brodrick and Gilowska, 2022). This is particularly relevant in urban contexts, where residents often face stressors related to rapid urbanization, noise, and social pressures. Users of Urban Green Spaces report feeling less anxious and more at peace, highlighting the significant emotional benefits associated with natural environments in urban settings. This aligns with the growing body of research indicating that interaction with green spaces can lead to improved mental health outcomes, including reduced anxiety and enhanced feelings of tranquility (Xu *et al.,* 2024). Nature has a unique ability to induce relaxation and mitigate stress. Studies show that exposure to green environments can lower cortisol levels, a physiological marker of stress, promote a sense of calmness, improve overall life satisfaction, and reduce feelings of anxiety among urban residents (McSweeney *et al.,* 2021). The concept of "biophilia," proposed by Wilson (2017), suggests that humans have an innate affinity for nature, and this connection can lead to positive emotional responses when engaging with natural settings. UGS can act as a buffer against urban stressors, offering residents a refuge from the hustle and bustle of city life. The restorative effects of nature can facilitate emotional regulation and promote mental resilience, particularly in densely populated urban areas where individuals may experience high levels of stress (Lencastre *et al.,* 2024).

Factors influencing perceived stress levels: insights from ANOVA analysis

The ANOVA analysis in Table 6 reveals significant factors influencing perceived stress levels among respondents. Age is a key determinant ($F(33, 386) = 14.788$, $p < .001$), with stress experiences varying across age groups. Gender differences are evident ($F(1, 418) = 6.162$, $p = .013$), as males and females exhibit distinct stress levels. Religious affiliation also significantly affects stress perceptions ($F(2, 417) = 11.901$, $p < .001$). Marital status strongly influences stress, with married individuals reporting lower levels ($F(1, 418) = 161.406$, $p < .001$). Educational attainment ($F(5, 414) = 9.866$, $p < .001$) and household income ($F(25, 394) = 17.853$, $p < .001$) are critical factors, indicating that higher education and financial stability contribute to lower stress levels. Family size ($F(8, 411) = 6.765$, $p < .001$) and type of residence ($F(1, 418) = 12.482$, $p < .001$) further influence stress perceptions. Additionally, travel-related factors such as frequency of visits to urban green spaces ($F(3, 416) = 9.195$, $p < .001$) and transportation costs ($F(4, 415) = 4.785$, $p = .001$) significantly impact perceived stress. Finally, health metrics like BMI ($F(49, 370) = 19.275$, $p < .001$) highlight the relationship between physical health and mental well-being, illustrating the complex factors shaping stress perceptions in urban populations. Socio-demographic factors such as age, gender, marital status, educational attainment, and household income significantly affect perceived stress levels among UGS users. Research indicates that marital status enhances psychological well-being; married individuals benefit from social support and companionship, which can buffer stress (Dasgupta *et al.,* 2022). Age also influences stress perception, with younger individuals facing higher stress due to life transitions, while older adults often employ coping strategies (Lyu, Wang, and Fan, 2024). Educational attainment correlates with stress levels, as those with higher education typically have better access to resources, leading to reduced stress (Burger and Strassmann Rocha, 2024). Gender differences are notable, with women often reporting higher stress due to social expectations and coping styles (Giurgiu *et al.,* 2024). Lastly, household income is crucial, as financial stability is linked to lower stress and better access to health and recreational resources (Wdowicka *et al.,* 2024).

Analysis of commonalities in urban green space user perceptions

The commonalities presented in Table 7 offer a nuanced perspective on how urban green space users perceive stress and emotional responses, as analyzed through Principal Component Analysis (PCA). Initially, all survey items start with a commonality of 1.000, indicating complete independence and full variance explanation by each variable. After extraction, the commonalities reveal how closely each item aligns with the underlying factors. For example, statements reflecting confidence and emotional stability, such as feeling capable of handling problems (communality = 0.750) and feeling in control within green environments (communality = 0.800), demonstrate significant retained variance. Conversely, items like rarely feeling overwhelmed by stress (communality = 0.218) indicate weaker alignment, suggesting these may capture more specific or nuanced aspects of the user experience that are less broadly represented by the extracted factors.

The component matrix in Table 8, derived from Principal Component Analysis (PCA) with two extracted components, reveals important insights into how survey statements relate to perceived stress and emotional responses among urban green space users. Component 1, labeled positive engagement and emotional well-being, includes high-loading statements such as "I feel confident about my ability to handle my problems" (.663), "I often feel that

Table 6: ANOVA analysis of factors influencing perceived stress levels

Factors		Sum of Squares	df	Mean Square	F-value	p-value
Socio-demographic factors	Age in years	10701.017	33	324.273	14.788	.000
	Gender	278.405	1	278.405	6.162	.013
	Religion	1034.867	2	517.433	11.901	.000
	Marital status	5338.978	1	5338.978	161.406	.000
	Educational status	2040.592	5	408.118	9.866	.000
	Household income (rupees/month)	10179.433	25	407.177	17.853	.000
	Number of family members	2230.036	8	278.755	6.765	.000
	Type of residence	555.730	1	555.730	12.482	.000
	Nature of family	239.575	1	239.575	5.291	.022
	Duration of ownership/rental of property (years)	13152.767	27	487.140	31.759	.000
Travel behaviours	Origin of travel	3857.170	5	771.434	20.863	.000
	Mode of travel	6041.581	4	1510.395	47.761	.000
	Frequency of visits	1191.830	3	397.277	9.195	.000
	Transportation cost (rupees)	844.906	4	211.226	4.785	.001
	Travel time (minutes)	1257.989	3	419.330	9.741	.000
	Accompanying persons	2668.292	4	667.073	16.781	.000
	Spending per visit	6985.623	4	1746.406	59.504	.000
	Primary expenditures during visits	5289.467	4	1322.367	39.549	.000
Physical health	Diseases types	2514.218	5	502.844	12.502	.000
	Height (feet)	2797.453	17	164.556	4.041	.000
	BMI (kg/m²)	13770.867	49	281.038	19.275	.000

Table 7: Communalities before and after extraction through Principal Component Analysis

Communalities		
	Initial	Extraction
I feel confident about my ability to handle my problems when I spend time in urban green spaces.	1.000	.750
I often feel that things are going my way when I immerse myself in green environments.	1.000	.655
I rarely find that I cannot cope with all the things that I have to do when I connect with nature in the city.	1.000	.434
I believe I can control irritations in my life better when I spend time in urban green spaces.	1.000	.649
I generally feel that I am on top of things when I engage with greenery in urban settings.	1.000	.800
I feel less anxious and more at peace when I'm surrounded by green landscapes in the city.	1.000	.552
I often experience a sense of relief and relaxation after spending time in urban green spaces.	1.000	.598
I seldom feel overwhelmed by stress when I immerse myself in the tranquility of urban parks.	1.000	.218
I believe that being in nature within the city helps me manage my emotions more effectively.	1.000	.585
I rarely feel tense or worried when I take leisurely walks in urban green areas.	1.000	.489
Extraction Method: Principal Component Analysis.		

Table 8: Component Matrix on survey statements related to perceived stress and emotional responses in urban green spaces

Component Matrix[a]		
	Component	
	1	2
I feel confident about my ability to handle my problems when I spend time in urban green spaces.	.663	-.557
I often feel that things are going my way when I immerse myself in green environments.	.774	-.235
I rarely find that I cannot cope with all the things that I have to do when I connect with nature in the city.	.628	-.199
I believe I can control irritations in my life better when I spend time in urban green spaces.	.558	.581
I generally feel that I am on top of things when I engage with greenery in urban settings.	.845	.293
I feel less anxious and more at peace when I'm surrounded by green landscapes in the city.	.731	.134
I often experience a sense of relief and relaxation after spending time in urban green spaces.	.698	.333
I seldom feel overwhelmed by stress when I immerse myself in the tranquility of urban parks.	.440	.157
I believe that being in nature within the city helps me manage my emotions more effectively.	.738	-.202
I rarely feel tense or worried when I take leisurely walks in urban green areas.	.664	-.220
Extraction Method: Principal Component Analysis.		

a. 2 components extracted.

things are going my way" (.774), "I generally feel that I am on top of things" (.845), and "I feel less anxious and more at peace" (.731). These findings indicate that users view urban green spaces as significantly enhancing their confidence, positivity, and emotional calmness. Additionally, items like "I rarely feel overwhelmed by stress" (.440) and "I seldom feel tense or worried" (.664) support this notion, suggesting that reduced stress and relaxation are integral to positive engagement with these environments. Component 2, labeled emotional management and relaxation, includes statements such as "I believe I can control irritations in my life better" (.581) and "I often experience a sense of relief and relaxation" (.333), indicating that users see urban green spaces as beneficial for emotional management and relaxation. However, the statement "I believe that being in nature helps me manage my emotions effectively" (.738) shows a negative loading on Component 2, suggesting that this belief may not align strongly with the emotional management factors identified, highlighting a complex relationship between nature and users' emotional responses.

Integrating UGS into urban planning is essential for community well-being, ecological sustainability, and achieving SDGs. Research shows that UGS significantly enhances mental health by reducing stress and promoting emotional well-being. Notable examples like Central Park in New York City and Griffith Park in Los Angeles provide visitors with rejuvenation and improved mood through activities such as walking and mindfulness (Jacobson, 2017). The Royal Botanic Gardens in Melbourne fosters social interactions, enhancing users' confidence and sense of community belonging (Ward, Truong, and Gray, 2022). Additionally, UGS supports ecological functions like air quality improvement and stormwater management, aligning with SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) (Orsetti *et al.,* 2022). Involving local communities in the planning process encourages ownership and social equity (Grabowski, McPhearson, and Pickett, 2023). Furthermore, developing data-driven smart eco-city models can identify areas needing UGS, ensuring effective resource allocation (Wu *et al.,* 2022). Ultimately, integrating UGS into urban design enhances individual well-being while contributing to ecological and social sustainability.

CONCLUSION

This study addressed the critical research problem of how UGSs influence perceived stress and emotional well-being, focusing on Midnapore town as a representative yet underexamined urban setting. It contributes to theory-building by illuminating the complex interrelationships between UGS, perceived stress, and emotional well-being, offering valuable insights for environmental psychology and urban studies. The study emphasizes the importance of considering demographic, health-related, and environmental variables in understanding mental health dynamics within urban settings. Findings from the study suggest that future theoretical frameworks should integrate such multifaceted determinants to better address the psychological impacts of urban living. From a policy perspective, the study holds significant implications for achieving Sustainable Development Goals, particularly SDG 3 (Good Health and Well-Being) and SDG 11 (Sustainable Cities and Communities). By evidencing that access to and engagement with quality green spaces can alleviate stress and foster emotional resilience, the research reinforces the necessity of embedding UGS into urban planning and governance. Such integration supports not only public health and psychological well-being but also broader goals of inclusivity, environmental sustainability, and community resilience. These insights suggest actionable strategies such as designing inclusive green spaces in densely populated areas, integrating green prescriptions into public health programs, and encouraging participatory planning to reflect community needs. However, the study is limited by its reliance on self-reported data, a cross-sectional design, and a geographically constrained sample, which may not fully capture causal relationships or allow for broader generalization. Future research should incorporate longitudinal approaches, physiological and behavioral indicators of stress, and comparative studies across diverse urban regions to validate and extend these findings. In the long run, urban green spaces emerge as essential infrastructural elements in the pursuit of holistic, sustainable urban development that prioritizes mental well-being.

AUTHOR CONTRIBUTIONS

A. Baitalik performed the literature review and research design, analyzed and interpreted the data, prepared the manuscript text, and manuscript. T. Bhattacharjee performed the literature review, compiled the data, and 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)

ANOVA	Analysis of Variance
ART	Attention Restoration Theory
BMI	Body Mass Index
KMO	Kaiser-Meyer-Olkin
UGS	Urban Green Spaces
PCA	Principal Component Analysis
SDGs	Sustainable Development Goals

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ORIGINAL RESEARCH PAPER

Scenario-based study on preserving residency in historical neighborhoods with an urban acupuncture approach

I. Ghalandarian*, Z. Zavarian Kermani

Department of Urbanism, Faculty of Architecture and Urbanism, Ferdowsi University of Mashhad, Mashhad, Iran

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ABSTRACT

BACKGROUND AND OBJECTIVES: Mashhad, Iran's main pilgrimage city, attracts numerous religious visitors every year. This status led to significant socio-economic and physical transformations, particularly around the holy shrine. The rapid growth of lodging and commercial facilities disrupted the urban fabric, reducing the quality of life for long-term residents. In the southern Samen region, the culturally rich Eidgah neighborhood suffered from neglect, poor planning, and the influx of temporary accommodations, eroding its social and cultural identity. This study aimed to identify key factors affecting residential satisfaction to encourage long-term habitation in the neighborhood.
METHODS: This research was quantitative, critical realism in approach, and grounded in the interpretivism paradigm. It was applied in its purpose, as it focuses on future studies of the Eidgah neighborhood to identify factors contributing to resident displacement and related potential issues. The data for this study were collected using library documents, environmental surveys, observations, and expert group questionnaires. The questionnaires were distributed to experts with prior experience in this urban fabric or other similar historical and deteriorated neighborhoods. The analysis of the questionnaires was conducted using MICMAC software and Scenario Wizard software.
FINDINGS: The questionnaire analysis identified ten key variables as the most influential factors in enhancing residential satisfaction and sustaining habitation. Among these, Adequate security and safety of the environment emerged as the most impactful variable, with an influence score of 498, followed by Length of residence, scoring 488, and sense of belonging, scoring 478. These three variables demonstrated the highest levels of influence on sustaining habitation, underscoring their critical role in residential stability. Based on these findings, the research identified four strategic scenarios for preserving residency in the Eidgah neighborhood.
CONCLUSION: This study demonstrated that multiple factors affect residency preservation, which can vary significantly from one city to another or even from one neighborhood to another. The identified key variables primarily play a prominent role in social-cultural, functional, perceptual, and visual dimensions. Examining these key variables within similar historical contexts can pave the way for more targeted and effective interventions in urban planning, ultimately enhancing residents' quality of life and ensuring sustainability in these areas.

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*Corresponding Author:
Email: *ghalandarian@um.ac.ir*
Phone: +98 915 305 8066
ORCID: 0000-0002-6860-2601

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INTRODUCTION

The processes of rapid urbanization and industrialization have engendered profound socio-ecological transformations, fostering a growing disconnection between humanity and the natural world. This estrangement has negatively impacted urban well-being and resilience, underscoring the urgent need for urban re-naturalization, a pivotal concern in contemporary urban planning discourse (Del Marmol, 2022). As the primary settings for human habitation, cities play an essential role in shaping both the satisfaction and quality of life of their inhabitants. Beyond influencing individual comfort and well-being, the urban environment fundamentally defines social interactions and lifestyle patterns. Consequently, meticulous attention to the design and governance of urban spaces by planners is paramount in advancing the overall quality of urban life (Khani Zadeh and Razavi an, 2016). Historical urban districts, emblematic of the organic and incremental evolution of cities, increasingly confront serious challenges arising from incongruous urban design approaches and structural deterioration. These problems erode residential satisfaction, exacerbate intra-urban migration, and amplify social conflicts (Abidin *et al.*, 2019). Within this framework, the Eidgah neighborhood of Mashhad, a site of notable cultural and historical significance, has been subjected to damaging and poorly coordinated urban interventions. Ineffectual strategies in comprehensive and detailed urban plans, particularly the uncontrolled influx of pilgrims and the proliferation of accommodation facilities, have resulted in the ongoing presence of transient, non-local populations in the area (Forouhar and Forouhar, 2020). This scenario has weakened the neighborhood's social fabric, generated a pervasive sense of alienation, and diminished the overall quality of life for residents. The longstanding local population, deeply rooted in the neighborhood's historical milieu, now struggles with heightened dissatisfaction and insecurity. To confront these multifaceted challenges, the innovative framework of "urban acupuncture" has been introduced. This approach advocates for the strategic and focused use of minimal interventions to address critical neighborhood needs, fostering equilibrium and long-term sustainability. The urban acupuncture methodology prioritizes the preservation of cultural and social identities, aiming to stave off further degradation of the urban fabric (Manouchehri *et al.*, 2022). Complementing this, scenario planning provides urban planners with essential tools to identify key variables influencing the neighborhood's trajectory and to evaluate potential future scenarios. By doing so, it supports more informed decision-making amidst environmental and socio-economic uncertainties. This study aimed to identify effective scenarios for enhancing residential satisfaction and supporting the sustained presence and long-term residency of the local population in the Eidgah neighborhood of Mashhad. To achieve this goal, two key research questions were examined:

(1) What are the key variables influencing residential satisfaction in this neighborhood?

(2) What urban acupuncture-based strategies can contribute to developing an optimal scenario for preserving residency in historical and deteriorated neighborhoods?

Accordingly, this research analyzed the fundamental weaknesses and immediate challenges present in the deteriorated fabric of the neighborhood and sought to propose practical urban regeneration strategies that do not require extensive interventions or large-scale investment. The primary focus of this study was on improving movement networks, enhancing residents' quality of life, strengthening social interactions, and preserving the cultural and historical identity of the neighborhood. Additionally, by utilizing the urban acupuncture approach and scenario planning, this study introduced targeted and cost-effective interventions on a micro-scale in specific areas of the neighborhood. It is important to note that while residential satisfaction is acknowledged as a vital component of neighborhood well-being, this study does not treat it as a sufficient condition for population retention. Rather, it aims to identify which specific variables most strongly contribute to satisfaction, so they can be used to formulate effective scenarios that enhance residential quality and support long-term settlement. Meanwhile, it considers compensatory factors such as economic instability or life-course events that may trigger displacement even under otherwise favorable conditions. Lastly, this study provides urban policymakers with a scientific and actionable roadmap, enabling them to implement strategic measures to ensure the social and environmental sustainability of this valuable urban fabric. To achieve these objectives, a survey was conducted in 2024 across residential areas of the Eidgah neighborhood in Mashhad City.

Urban acupuncture

Urban renewal has experienced the evolution of new approaches within the past couple of years, among which urban acupuncture has attracted more attention as a new approach-particularly where massive planning becomes clumsy or meaningless (Lerner, 2014; Apostolou, 2015; Welsovsky, 2021). On the principles of traditional Chinese medicine, urban acupuncture applies small-scale and concentrated actions to promote bigger city redevelopment (Khaing et al., 2025). The term "acupuncture" is derived from the Latin words acus (needle) and pungere (to puncture), and it is a medical treatment that involves the insertion of needles into specific points on the body to stimulate healing and cure various diseases (Manouchehri *et al*., 2022). In classical Chinese medicine, acupuncture entails the deliberate insertion of fine needles at precise anatomical points to restore balance in the body's vital energy (Qi), thereby enhancing overall health and well-being (Wang and Xiong, 2017). Translating this ancient theory to urban contexts, the concept of 'urban acupuncture' was first proposed by Marco Casagrande, a Finnish architect. This paradigm conceptualizes the city as a living organism whose optimal functioning depends on the harmonious circulation of energy among its components. Disruptions to this equilibrium—akin to blockages in the human body—require targeted interventions to restore balance and order (Wesołowski, 2021). Urban acupuncture thus advocates for selective, small-scale interventions as a sustainable and cost-effective solution to complex urban challenges. Lerner's interpretation of this approach underscores the significance of simplicity, efficacy, and affordability in designing interventions that meet the short-term needs of both urban cores and peripheries. This methodology strives to deliver practical, scalable solutions tailored to a variety of urban scenarios (Harjoko, 2009). Fundamentally, urban acupuncture seeks to "unblock" energy pathways within a city's essential arteries, facilitating the gradual regeneration of larger urban systems through localized, minimally invasive interventions. These solutions are inherently adaptable to both pre-existing and newly developed urban landscapes. They prioritize creativity, innovation, and active community participation while allowing for diverse applications depending on the specific context (Mahdianpour *et al*., 2019). Casagrande describes urban acupuncture as a collaborative engagement with the city's "collective mind," metaphorically framing it as a process of transforming neglected spaces into productive landscapes that foster regeneration and growth. Similarly, Gordon Matta-Clark emphasizes the importance of recognizing and working with the "destructive layers" embedded within the built environment as a fundamental step in this approach (Salman and Hussein, 2021). This paradigm not only proposes the possibility of healing urban spaces but also highlights the potential for achieving social cohesion and ecological balance through carefully planned, calibrated interventions. Urban acupuncture has been implemented in numerous cities worldwide, often as a response to the limitations of conventional large-scale urban planning (Apostolou, 2015). Its minimal-intervention strategy has emerged as a defining characteristic of 21st-century urbanism, reflecting a nuanced understanding of contemporary urban growth and development needs. Notably, this approach has proven effective in addressing the multifaceted challenges of modern cities, particularly in rapidly urbanizing post-industrial Asian contexts (Khaing *et al*., 2025). Apart from its theoretical basis, urban acupuncture possesses several practical advantages in contemporary urban design. One of its key strengths is that it can provide immediate and effective outcomes without the need for mass-scale intervention. With its ability to reduce costs significantly and decrease reliance on external investors, the method offers a viable alternative instead of conventional urban regeneration techniques (Welsovsky, 2021). Unlike large-scale redevelopment plans, which entail high-level demolition and heavy financial investments, urban acupuncture operates through focused, localized interventions that generate minimal disturbance to the cityscape with maximum effects (Raoufi and Shieh, 2023). The limitation of this method is that the effect stays localized in specific neighborhoods or urban districts with minimal spillover effects on the adjacent areas (Apostolou, 2015). And yet another significant advantage of urban acupuncture is its emphasis on bottom-up, community-driven interventions, rather than the traditional top-down approach to urban management. Such a participatory model promotes greater creativity, flexibility, and responsiveness to local needs, which enhance efficiency as well as long-term sustainability (Cutieru, 2020). But for such interventions to work in the first place, there must be close coordination with municipal authorities, particularly local governments and city councils. In the absence of such alignment, the likelihood of project ineffectiveness is heightened, which can undermine the desired urban renewal efforts (Welsovsky, 2021) It should be noted that various large-scale interventions have been made to bring social, physical, and economic regeneration to this neighborhood; however, none have been able to solve its problems Urban acupuncture presents a particularly viable alternative strategy for neighborhood revitalization, capable of enhancing environmental quality and living conditions without requiring massive capital investments or extensive interventions. This approach stands in marked contrast to conventional urban regeneration methods, which typically involve comprehensive, resource-intensive, and protracted implementation processes. The fundamental distinction lies in their respective operational paradigms: while traditional urban renewal relies on demolition and reconstruction, urban acupuncture emphasizes adaptability, community engagement, and rapid implementation. Grounded in systems theory and tactical urbanism principles, this methodology employs precisely targeted, low-cost interventions to achieve disproportionate impacts on urban dynamics and regeneration (Sherafati *et al*, 2024). Various case studies have demonstrated the effectiveness of urban acupuncture in different urban contexts. For example, a study on the historical fabric of Baghdad showed that urban acupuncture can serve as a practical alternative to traditional urban renewal methods, particularly in areas where large-scale interventions are challenging due to financial and structural constraints. This research highlights that a range of actions can be implemented at different scales, from localized modifications in buildings and land uses to the enhancement of street furniture and public spaces, all contributing to the gradual revitalization of the urban fabric and the improvement of residents' quality of life (Al-Hinkawi and Al-Saadi, 2020).

Principles of urban acupuncture

Numerous scholars have proposed various principles within urban acupuncture. The most frequently cited and widely regarded principles in this area include the following:

1. *Defining Diseased Points*: This foundational principle, introduced by Maurice, involves identifying problematic points or areas within the urban body, typically characterized by low energy or energy flow disruption (Salman and Hussein, 2021).

2. *Immediate action*: This principle addresses the prolonged timeframe often associated with planning processes. Lerner emphasizes the need for a "spark" to initiate the process (Manouchehri *et al*., 2022; Salman and Hussein, 2021; Davoodpour and Delshad, 2013; Raoufi and Shieh, 2023).

3. *Citizen participation*: Given the diverse and often valuable perspectives of the community, involving local citizens in decision-making can lead to innovative solutions and multifaceted outcomes (Manouchehri *et al*., 2022; Mahdianpour *et al*., 2019; Salman and Hussein, 2021).

4. *Comprehensive approach*: All interventions should integrate economic, environmental, infrastructural, historical, and political elements. According to Parsons, a singular focus cannot ensure intervention success (Manouchehri *et al*., 2022; Salman and Hussein, 2021; Raoufi and Shieh, 2023).

5. *Small-Scale Interventions*: Urban acupuncture employs localized yet impactful interventions that release or unblock stagnant energy flows within urban areas (Manouchehri *et al*., 2022; Raoufi and Shieh, 2023).

6. *Contextualization*: Urban experiences bridge the connection between the body and material civilization. Lerner and Casagrande emphasize the wealth of localized resources, such as Treasure Hill in Taiwan, advocating for energy restoration over destruction, thus revitalizing regions (Manouchehri *et al*., 2022; Mahdianpour *et al*., 2019; Salman and Hussein, 2021).

7. *Flexibility*: Urban acupuncture avoids rigid structure and absolute authority, accommodating evolving variables and emerging needs over time (Manouchehri *et al*., 2022).

8. *Catalytic processes*: As urban acupuncture addresses diverse energy flows, social, economic, cultural, and more, the approach entails catalysts

that foster systemic change (Manouchehri *et al*., 2022; Mahdianpour *et al*., 2019).

9. *Ease of Implementation*: Compared to other urban renewal strategies, urban acupuncture requires less effort and is more straightforward to execute (Manouchehri *et al*., 2022).

10. *Network development*: Much like acupuncture views the human body as a nervous system to be manipulated point by point, urban acupuncture seeks to develop a network of urban points that release energy (Manouchehri *et al*., 2022; Mahdianpour *et al*., 2019).

Foresight in urban planning

Foresight, or futures studies, systematically examines potential, probable, and preferable futures, including underlying worldviews and myths (Inayatullah, 2013). Over the last five decades, the field has evolved from predicting to shaping alternative and desirable futures on both collective and individual levels. Wendell Bell posits that foresight aims to explore and evaluate potential, probable, and preferable futures to discern what can and should happen (Gharayagh-Zandi, 2015). As a transdisciplinary field, foresight seeks to uncover possible futures and construct desired ones by emphasizing human aspirations. The primary goal of foresight is to enhance awareness of future options, help navigate transformative changes, and design ideal paths forward (Lang, 2016). Various methods used in foresight include:

Delphi method: The Delphi method, a qualitative technique relying on indirect and structured interaction, organizes expert opinions to achieve consensus through systematic questionnaires (Lang, 2016; Gharayagh-Zandi, 2015; Amer *et al*, 2013).

Environmental scanning: This involves gathering information about external environments to understand organizational conditions, adapt to rapid changes, create favorable futures, and facilitate management performance evaluations (Gharayagh-Zandi, 2015).

Scenario Planning: This method examines alternative futures through detailed, internally consistent descriptions of possible outcomes, helping decision-makers confront uncertainty and expand strategic outlooks (Puglisi, 2001).

This research applies foresight with an emphasis on scenario planning, elaborating further on this approach. In this study, residential satisfaction is further operationalized as a subjective yet measurable evaluation of how well the living environment meets residents' physical, social, and psychological needs. It is influenced by both objective factors, such as safety, access to services, and environmental quality, and subjective elements, including personal expectations and lived social experiences.

Moreover, while residential satisfaction may contribute to residential stability, this relationship is not assumed to be linear or causal. Some residents may choose to remain in their neighborhoods despite dissatisfaction, due to emotional ties or economic limitations, while others may relocate despite being satisfied, due to job changes or life circumstances. Therefore, in this study, residential satisfaction is considered as one of several influential factors rather than the sole determinant affecting residents' decisions to stay in or leave the neighborhood.

Literature review

An extensive body of research has investigated the determinants of residential satisfaction. The literature demonstrates that these studies typically examine the complex interplay between environmental, social, and economic factors and their collective influence on inhabitants' satisfaction with their living environments. Residential satisfaction is generally operationalized as a composite measure reflecting the degree to which one's housing situation fulfills physical, psychological, and social needs. As summarized in Table 1, numerous seminal studies in this field have established various measurement scales, methodological approaches, and key variables that continue to inform contemporary investigations.

The following sections categorize and critically analyze these studies to identify major trends and gaps in the literature.

Individual and social determinants

Several studies have emphasized the importance of personal and social characteristics in shaping residential satisfaction. For instance, Park and Kang (2022) and Ghaforian and Hesari (2016) identify variables such as age, education, marital status, socio-economic class, community ties, and neighborhood safety as critical influences. These findings underscore that demographic and psychosocial elements such as a sense of belonging, neighbor relations, and social

Table 1: Literature review related to residential environment satisfaction and preservation

Number	Author	Research Scale	Research Methodology	Variables
1	Chen *et al.,* 2022	Region	Library-based - Survey and Analytical	individual property, social and building density in the area, easy access to destinations, distance to public transport, safety and security, and access to green spaces.
2	Park and Kang, 2022	City	Applied - Survey	Education level, gender, religion, marital status, type of residential area, type of housing species, transportation, proximity to relatives, health status, economic class of individuals, and duration of residence.
3	Farajpour Basar *et al.,* 2021	residential complexes	Descriptive - Survey	dimensions of the housing unit, ceiling height of the units, number of units in the complex, building form, dimensions and size of shared spaces, layout of internal spaces, layout of external spaces and landscaping, external spatial amenities, connectivity of external spaces.
4	Borgoni *et al.,* 2021	City	Applied - Survey	unit type, building density, proximity to daily services and public transport, access to green spaces, natural views, environmental safety, housing costs, proper lighting, efficient waste systems, and resident demographics such as age, gender, education, and marital status. Other aspects include housing ownership, vibrancy, shared space diversity, duration of residence, and a sense of belonging.
5	Rish Sefid Noshabadi and Belaskoui, 2020	residential complexes	Descriptive - Analytical	Social bonds, sense of belonging, duration of residence, collaboration of institutions, economic factors, transportation, access to services, aesthetic features, pollution, and proper wastewater disposal systems.
6	Noori Imani *et al.,* 2019	Neighborhood	Descriptive-Analytical and Survey-Based	Access to bus stations, parking, benches, mechanized waste collection bins, paved paths, housing lighting conditions, environmental cleanliness, water features, cleanliness of surroundings, lighting systems for pathways, commercial and service signage, and the architecture of existing buildings.
7	Akbariyan Ronizi *et al.,* 2017	City	Applied - Survey	Access involves the availability of green spaces, essential services, leisure facilities, and public transport. Social factors include security, a sense of attachment, urban aesthetics, and air quality. Housing focuses on maintenance costs and systems quality, while public services address waste disposal, city beautification, pathway conditions, and adequate street lighting.
8	Wang and Cao, 2016	Neighborhood	Descriptive – Analytical and Survey - Document-based	Household income, neighborhood safety, attractive appearance, presence of interaction among neighbors, proximity to work, low crime rate, closeness to shopping centers, religious and cultural buildings, low vehicle traffic in neighborhood streets, adequate lighting, economic status of individuals, availability of green spaces
9	Byun and Ha, 2016	Neighborhood unit	Descriptive - Analytical	Key factors include ventilation and lighting, access to hospitals and welfare facilities, cultural amenities like parks and playgrounds, public transportation, parking convenience, educational institutions, safety and security, environmental cleanliness, effective waste disposal, privacy preservation, disaster preparedness, neighborly relationships, on-site facility management, and length of residence in the neighborhood.
10	Khani Zadeh and Razvian, 2016	Neighborhood	Analytical – Descriptive and Applied - Developmental	Neighborhood satisfaction is influenced by factors such as housing quality, average income, duration of residence, and access to amenities like green spaces, urban services, and public transportation. Other key aspects include the quality of pathways, effective waste disposal systems, and maintaining privacy and visual permeability.

Continued Table 1: Literature review related to residential environment satisfaction and preservation

Number	Author	Research Scale	Research Methodology	Variables
11	Ghaforian and Hesari, 2016	Neighborhood	Meta-analysis	Individual factors: Age, life stage, gender, ethnicity, marital status, socio-economic status, and education. Social Factors: Community attachment, public safety, social interactions, social class homogeneity in local communities, and duration of residence in the neighborhood. Physical Factors: Public services and facilities, recreational and public spaces, the pleasant appearance of the environment, congestion and quietness, cleanliness, and maintenance.
13	Tabi Masrur and Rezaei Moayed, 2015	residential complexes	Descriptive - Analytical	Access includes green spaces, essential services, public transport, and parking availability. Social factors cover vibrancy, safety, tranquility, urban aesthetics, pollution levels, and citizen participation. Housing structural quality, design, facilities, and maintenance costs. Public services address waste management, beautification, pathway conditions, and street lighting.
14	Bonaiuto and Fornara, 2014	City	Descriptive – Analytical and Survey - Document-based	Building aesthetics, building density, external connectivity to the city, presence of green spaces, safety, environmental hygiene, pollution, access to various services, and activity diversity.
15	Jansen, 2014	Neighborhood	Library-based - Survey and Analytical	Number of rooms, living space dimensions, type of housing ownership, type of housing (apartment or villa), type of design, housing location (city center, suburbs, outside the city), neighborhood vibrancy, duration of residence.
16	Aulia and Ismail, 2013	City	Library-based - Survey	Accessibility features, housing quality, proximity to the workplace, income characteristics, residential amenities, proximity to public transportation, housing type, neighborhood status, and security.
17	Liu, 1999	City	Descriptive – Analytical and Survey - Document-based	Physical comfort, health, safety, functional compatibility, psychological comfort, privacy, security, space preservation, and activity diversity.
18	Carp and carp, 1982	Neighborhood unit	Descriptive - Analytical	Proximity to services, crime rates, noise pollution, proximity to services and facilities.

interactions can significantly affect how residents perceive their living environment.

Physical and environmental characteristics

Other scholars have focused on the physical attributes of housing and the built environment. Farajpour Basar *et al*., (2021) and Byun and Ha (2016) examined aspects such as building layout, ventilation, lighting, parking, and access to welfare facilities. These studies highlight the relevance of spatial configuration and environmental comfort in achieving residential satisfaction. Similarly, Akbariyan Ronizi *et al.,* (2017) and Bonaiuto and Fornara (2014) incorporate factors like aesthetics, cleanliness, pollution levels, and lighting, showing that visual and sensory experiences are integral to the perceived quality of residential spaces.

Mixed and context-specific approaches

Several studies have adopted a more holistic perspective by integrating social, physical, and infrastructural dimensions in their analysis of residential satisfaction. For example, Borgoni *et al*. (2021), Tabi Masrur and Rezaei Moayed (2015), and Noori Imani *et al.* (2019) propose comprehensive frameworks that encompass variables such as access to public transportation, availability of green spaces, provision of urban services, diversity of activities, and residents' length of stay. These components are particularly significant in historical or transitional neighborhoods, where various dimensions of satisfaction converge and interact.

Comparative observations

A comparative review reveals several important patterns. Firstly, while access to essential services and infrastructure such as green spaces, lighting, and waste management systems is consistently highlighted across many studies, only a limited number (e.g., Rish Sefid Noshabadi and Belaskoui, 2020; Wang and Cao, 2016) explore the role of emotional and cultural attachments in shaping residential satisfaction. Secondly, research conducted at the city level often focuses on broader urban attributes such as connectivity and environmental pollution (e.g., Aulia and Ismail, 2013; Liu, 1999). In contrast, neighborhood-scale studies place greater emphasis on factors such as social cohesion, personal safety, and local mobility (e.g., Khani Zadeh and Razvian, 2016).

Research gap

Despite the diversity in approaches, few studies have specifically addressed residential satisfaction in historical neighborhoods experiencing socio-spatial transition. Moreover, the integration of scenario-based methodologies and localized strategies such as urban acupuncture is largely absent from the current body of literature, particularly within the Iranian urban planning context. This study seeks to fill this gap by focusing on the Eidgah neighborhood of Mashhad, combining empirical findings with scenario-based planning and small-scale intervention models to enhance urban livability and residential stability. For a more detailed analysis, the frequency of the extracted components was examined in Table 1, and the results were presented in Table 2. This analysis aids in identifying the components that have the highest frequency and significance in related studies. The selected components, based on their frequency and importance, were used as the primary criteria in the process of measuring and designing the questionnaire.

In the next step, variables with the highest frequency have been identified as priority variables. These variables, due to their significant repetition and relevance in the research literature and prior analyses, play a pivotal role in the research process. As a result, they have been purposefully integrated into the primary measurement tool of the research, a questionnaire based on the Cross-Impact Matrix to evaluate their interrelationships with greater precision. Some of these variables have been consolidated to facilitate transparency and simplify analysis, enabling a more comprehensive and organized assessment. Through this approach, variables influencing residential satisfaction were identified and categorized into key dimensions, including morphological, structural, functional, socio-cultural, environmental, perceptual, visual, managerial, and economic. Detailed information on these variables is presented in Table 3.

MATERIALS AND METHODS

Data collection method

This study adopts a mixed-methods approach combining quantitative and qualitative data within a critical realism framework. At the philosophical level, the study is informed by the principles of critical realism, which acknowledges that urban phenomena can be explored empirically but are also shaped by underlying structural conditions and social interactions. This philosophical stance is highly appropriate to the study's application of expert-based judgments and scenario-led planning. In practical terms, the research is applied in nature, as it focuses on future-oriented planning for the Eidgah neighborhood. The objective is to identify the underlying causes of residential outmigration and to explore urban acupuncture strategies aimed at enhancing residential satisfaction and improving urban livability. To ensure content validity, the research questionnaire was reviewed by 22 experts. The criteria for selecting these experts included:

(a) research activity in academic journals or authorship of books,

(b) teaching experience in the relevant field, and

(c) familiarity with the study area, along with professional experience in this and other similar historical and deteriorated neighborhoods, which enhances the applicability of the findings to comparable contexts.

Due to predefined constraints, the study could not incorporate a larger pool of experts, but efforts were made to prioritize quality over quantity. The experts effectively identified the strengths and weaknesses of the questionnaire, and after implementing the necessary revisions, the final version was approved by all participants. Throughout this process, three key validation questions were examined: Is the developed instrument aligned with the concept intended by the researcher? Does the instrument measure only the intended concept? Are the developed instruments sufficient for measuring the intended concept? Following the expert review, the extracted variables were confirmed to be well-aligned with the research objectives and possessed sufficient validity. Hence, it can be said that the research questionnaire is reliable enough, and the data received is genuine. Further,

Table 2: Examination of the frequency of influential components on residential satisfaction

Dimensions	Variables	Khanizadeh and Razavian 2016	Farajpour Basar and 2021 Colleagues	Akbarian Ronizi and 2017 Colleagues	Taki Masror and Rezaei 2015 Moeid	2016 Ghafourian and Hesari	2020 Rish Sefid Noushabadi	Noori Imani and Colleagues 2019	and Abraham Carp Frances 1982	1972 Menchik, M	2022 Se-Won Kang Park	2022 Qi Chen and Yibo Yan	2007 Adriaanse, C C M	M. Bonaiuto 2013	Abdul Majid Ismail 2013	2016 Byun and Ha	1999 A.M.M. Liu	2016 Cao and Wan	2013 Aulia and Ismail	2017 Bonaiuto and Fornara	2014 S.J.T. Jansen	2021 Bergoni, R	Frequency
Morphological	The aesthetic appeal of building facades and surroundings.																						3
	Proper orientation of buildings against wind and sunlight.																						1
	Building form aesthetics.																						4
	Architectural quality and design of facades and spaces.																						6
structural	Amenities in residential complexes (ventilation, etc.).																						7
	Physical attributes of housing units (number of rooms, unit size, building density, material durability).																						13
	Harmony with the surrounding fabric.																						1
Functional	Accessibility to urban facilities and infrastructure.																						2
	Activity diversity.																						8
	Mixed land use.																						3
	Variety in communal spaces.																						2
	Access to public transportation, urban road networks, and parking.																						16
	Access to local services.																						12
Socio-Cultural	Safety and security.																						13
	Vitality.																						7
	Privacy (absence of overlooking).																						7
	Residents' personal characteristics (education level, age, gender, occupation).																						8
	Social interactions and participation among neighbors.																						5
	Homogeneity of social classes.																						2
	Familiarity and satisfaction with neighbors.																						4
	Length of residence in the area.																						7
Environmental	Access to green spaces.																						12
	Absence of pollution (noise, air).																						7
	Lack of natural or man-made hazards.																						1

Table 3: Variables influencing residential satisfaction and housing preservation

Dimension	Indicator	Variable
Morphological	Quality of facade design	Aesthetics and proportions of the facade
	Network connectivity	Visual permeability
		Physical permeability
Structural	Housing complex amenities	Appropriate materials for the texture
		Prop ventilation in units
		Building density (number of floors on the land)
Functional	Accessibility to service centers	Access to public transport stations
		Access to the urban network
		Access to parking
		Access to local services (supermarket, health center, primary school)
	Functional mix	Existence of activity diversity
Socio-Cultural	Social security	Adequate security and safety of the environment
		Vitality of the environment
		No overlooking
	Social relations	High social participation (residents with each other and with institutions)
		Familiarity and satisfaction with neighbors
	Individual characteristics of residents	Age
		Education level
		Length of residence in the area
Environmental	Greenery	Access to green space
	Environmental cleanliness	Proper waste and sewage disposal
		Noise and acoustic pollution
Perceptual	Environmental awareness	Sense of belonging
		Adequate lighting
Visual	Visual appeal	View and landscape
		Aesthetic of the buildings and environment
Managerial	Environmental monitoring	Level of control and supervision over spaces
	Extent of intervention in the area	based on a conservative approach
		based on a rational approach
		used a conservative approach
Economic	Economic ability	Level of income of residents
		Housing maintenance costs (monthly fee, repair costs)
	Housing ownership	Type of housing ownership (tenant or homeowner)

to measure the reliability of the questionnaire, the test-retest method was used because half of the questionnaires were received six months after the data collection was first done. The reliability test gave a 0.78 coefficient, which, being greater than 0.7, indicates that the questionnaire reflects acceptable reliability.

Study area

The area of interest is located adjacent to the central district of Mashhad and occupies a 60-hectare portion of the Samen region. The Eidgah neighborhood, due to its strategic location within the religious vicinity of the Holy Razavi Shrine, has consistently been influenced by numerous changes. This strategic position has led the neighborhood to be continually subjected to top-down development policies and plans. Such changes, which have primarily been implemented without regard to the actual needs of the residents and the neighborhood's fabric, have resulted in the gradual deterioration and decay of this valuable, old area. The proposed project, with an approach based on "Acupuncture Urbanism," aims to examine and present scenarios for preserving residency in the Eidgah neighborhood of Mashhad, with particular emphasis on preventing the migration of residents from this deteriorating area. The location of this study area within the city of Mashhad is shown on Fig. 1.

Fig. 1: Geographic location of the study area; (a) Samen region, (b) Eidgah neighborhood

Table 4: Key factors influencing residential preservation and their potential future values

Component	Abbreviation	Component	Abbreviation
No overlooking	Overlook	Familiarity and satisfaction with neighbors	NeighborSat
Aesthetics and proportions of the facade	FacadeProp	Age	ResAge
Visual permeability	VisPerme	Education level	EduLevel
Physical permeability	PhysPerme	Length of residence in the area	ResidTime
Appropriate materials for the texture	MatSuit	Access to green space	GreenAcc
Proper ventilation in units	VentUnits	Proper waste and sewage disposal	WasteDisp
Building density (number of floors on the land)	BldDensity	Noise and acoustic pollution	NoisePoll
Access to public transport stations	TransitAcc	Sense of belonging	Belonging
Access to the urban network	UrbanNet	Adequate lighting	Lighting
Access to parking	ParkAcc	View and landscape	ViewLand
Access to local services	LocalServ	Aesthetics of the buildings and environment	Budapest
Existence of activity diversity	ActDivers	Level of control and supervision over spaces	SpaceCtrl
Adequate security and safety of the environment	SafeEnv	The level of income of residents	IncomeLvl
Environmental Vitality	EnvVital	Housing maintenance costs	HousMaint
High social participation	SocPartic	Type of housing ownership	OwnType

RESULTS AND DISCUSSION

This study is based on three key steps. In the first step, a questionnaire was designed to analyze balanced cross-impact effects. This questionnaire was developed using the key variables identified in the previous section and was distributed among a group of experts and specialists familiar with the study subject, particularly those with experience working in this context or other similar historic and deteriorated neighborhoods. After collecting the responses, the interrelationships among variables were analyzed using MICMAC software, and the key variables were extracted through the Cross-Impact Matrix (CIM). This structural analysis enabled the evaluation of the degree of influence and dependency among variables, ultimately identifying the critical factors affecting residential retention in the Eidgah neighborhood. In the second step, potential scenarios for each of the key variables were defined under three distinct conditions: desirable, continuation of the current state, and undesirable, with each scenario assigned a specific code. In this classification, the desirable state represents a positive transformation and improvement of existing conditions. The undesirable state reflects a negative trajectory and worsening conditions. The continuation of the current state (ongoing trend) indicates the persistence of present conditions without any significant change. For example, the "Environmental Vitality" variable was categorized into the following scenario states: Desirable state: Increased active public presence in public spaces. Undesirable state: Absence of people in public space and increased insecurity. Continuation of the current state: Limited public presence in certain public spaces. After defining the occurrence states of each key variable, the coded data were input into Scenario Wizard software, which applies the Cross-Impact Balance Analysis (CIBA) method to assess the interdependencies between different states and generate coherent and compatible scenarios. In the third step, targeted strategies based on the urban acupuncture approach were formulated for the optimal scenario, guiding urban planners and designers toward alternative, low-intervention solutions. This step underscores the notion that, instead of relying on large-scale, disruptive interventions, many urban challenges can be effectively addressed through small-scale social and physical initiatives that promote gradual, community-driven, and sustainable transformations.

Step 1: Identifying key uncertainties using MICMAC software

In this step, the identified variables were input into the MICMAC software to evaluate their degree of influence and interdependence. The key variables were then identified. To this end, an impact evaluation matrix was designed based on the identified variables and was provided to stakeholders and specialists familiar with the study area. They used their knowledge of the area to assess the cross-impact effects of the variables. The relationships between these variables were examined. Thus, a structural analysis of the variables was obtained in the form of a CIM, which examines the influence of row variables on column variables. Row variables are influential, and column variables are influenced. In this part, the relationship between N variables in an N*N matrix was examined by stakeholders and experts familiar with the area, and the scoring system is as follows:

- *Zero: No impact*
- *One: Weak impact*
- *Two: Moderate impact*
- *Three: Strong impact*

Table 4 summarizes the abbreviations of each of the components derived from Table 3, which are the inputs for the MICMAC software.

It should be mentioned that the variables influencing residential satisfaction are at different conceptual levels. Some variables, such as sense of belonging and social participation, are subjective and abstract and are defined based on individual experiences and psychological perceptions. Yet, others, such as access to green spaces or street lighting, are objective characteristics of the built environment and are measurable. Therefore, in assessing their impact, it is important to differentiate between these levels of conceptualization. Subjective variables invite interpretive and qualitative measures, whereas objective variables are more appropriately evaluated by quantitative and standardized processes. This distinction was deliberately built into developing scenario-based strategies: intangible factors, such as a sense of belonging, were addressed through socially focused and participatory interventions, and physical factors, such as access to basic services, were addressed through physical and infrastructural solutions. Note, however, that the MICMAC analysis does not distinguish variables based on their conceptual nature, whether abstract, subjective, or objective. All the variables are considered solely based on their degree of influence and dependence within the system. It enables a holistic, system-based understanding of the variables regardless of their ontological status. In the MICMAC framework, variables are categorized into four quadrants according to their levels of influence and dependence: Quadrant I (Influence Variables): These variables exert a high degree of influence while maintaining low dependence on others. They serve as key drivers of the system's structure and dynamics. Quadrant II (Relay Variables): These variables exhibit both high influence and high dependence, reflecting points of instability that transmit effects across the network. Quadrant III (Dependent Variables): These are highly reactive variables, characterized by high dependence and low influence. Their behavior is shaped by other elements in the system. Quadrant IV (Autonomous Variables): With low influence and dependence, these variables are marginal and exert little impact on the overall system dynamics (Siti *et al.,* 2024). As visually depicted in Fig. 2, these classifications illustrate the spatial and functional distribution of variables within the systemic framework. In the subsequent scenario formulation phase, the strategies were tailored to match the conceptual nature of each variable, whether social, physical, environmental, or perceptual, ensuring their contextual appropriateness, feasibility, and effectiveness in addressing the distinct challenges of the neighborhood.

According to Fig. 2, the key variables influencing residential retention and enhancing satisfaction in the Eidgah neighborhood can be classified into four categories. The strategic variables in Quadrant I hold significant importance, as they possess a strong potential to shape the neighborhood's structure while remaining independent of variables in other quadrants. These variables are referred to as key variables. Furthermore, analyzing the strategic variables in Quadrant II is essential to identify additional priorities that can be implemented more rapidly. Consequently, variables from both Quadrant I and Quadrant II are incorporated into the scenario-building process. Fig. 3 shows the output from the MICMAC software, indicating variables such as adequate security and safety of the environment, the Length of residence in the area, sense of belonging, Environmental Vitality**,** access to the urban network, adequate lighting, high social participation, access to green space, level of control and supervision over space and access to local services. In total, these ten variables, which have the highest degree of influence, are incorporated into the scenario-building process.

Fig. 4 illustrates that the variable (security and safety of the environment) has the greatest influence on other variables within the system under study, while Fig. 5 shows that the variables (existence of activity diversity and adequate security and safety of the environment) exhibit the highest degree of dependency on other variables in the system.

Step 2: Developing scenarios

This step includes two stages:

In this stage, the potential outcomes for each of the key components are defined and entered into the Scenario Wizard software. This software utilizes a 30×30 matrix, incorporating evaluations scored between -3 and +3. This approach ensures that both

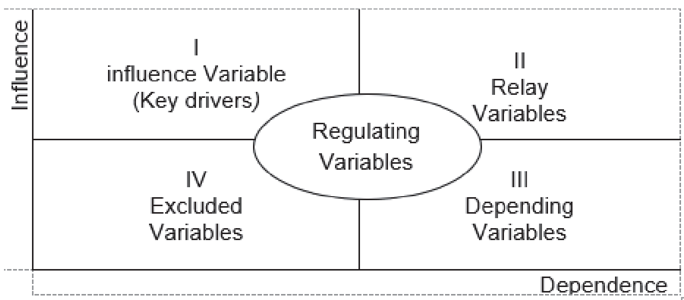

Fig. 2: Variable equalization in MICMAC (Hakim et al., 2023)

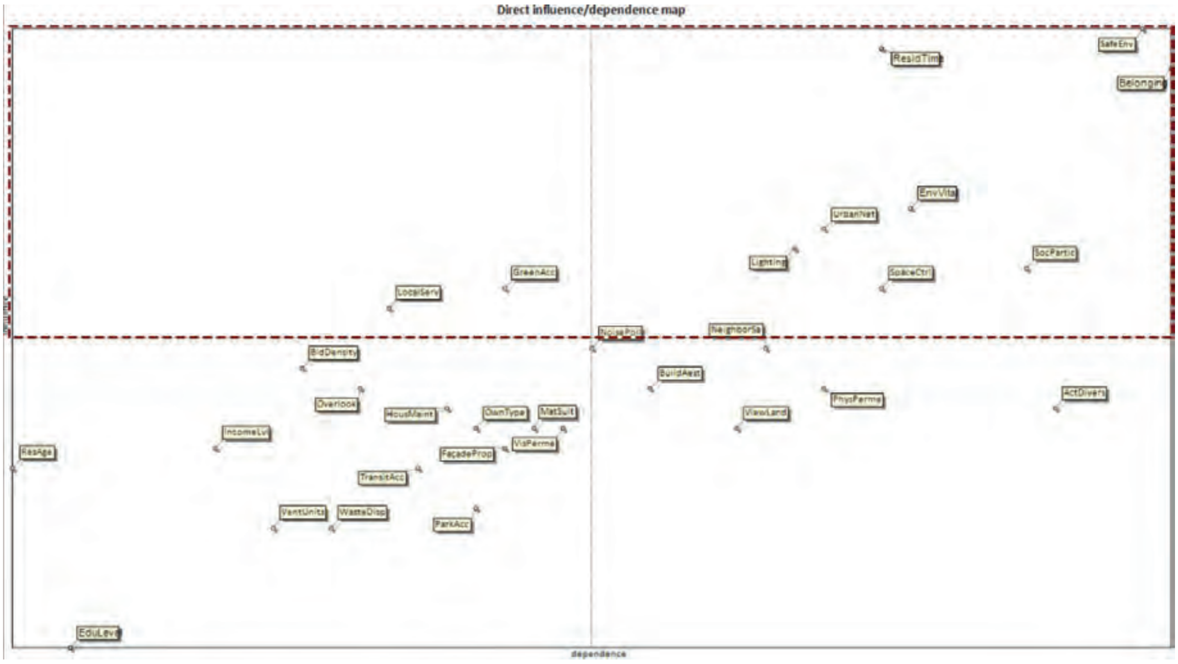

Fig. 3: Direct influence–dependence of variables affecting residential preservation

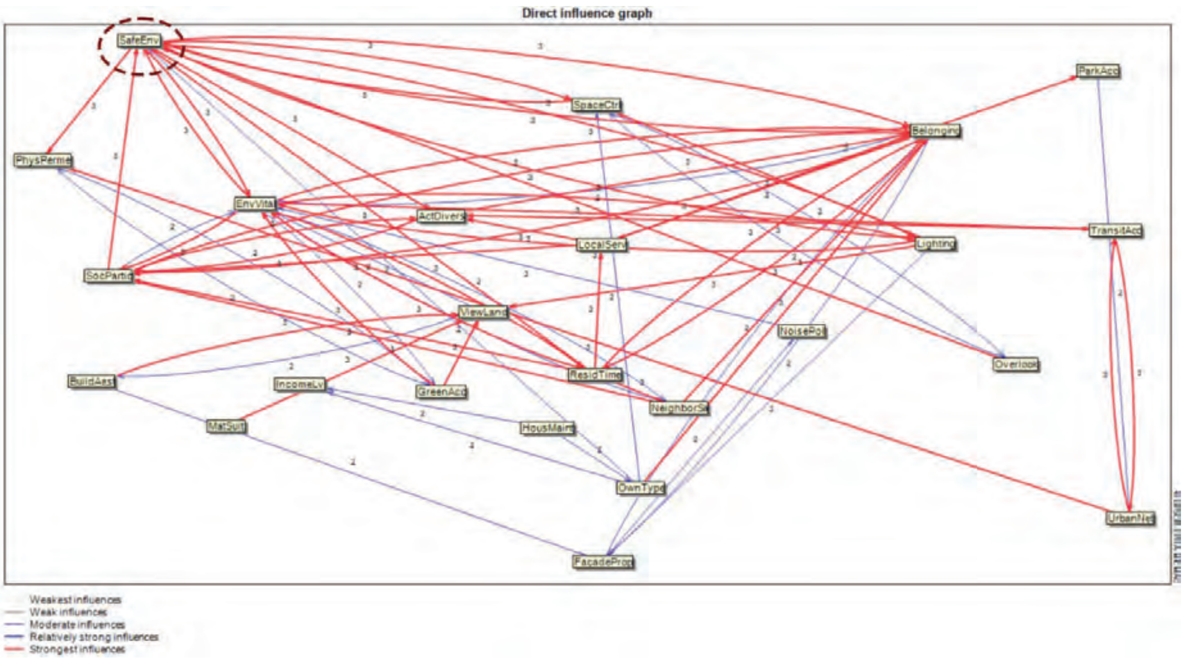

Fig. 4: Direct influence–dependence graph of variables affecting residential preservation

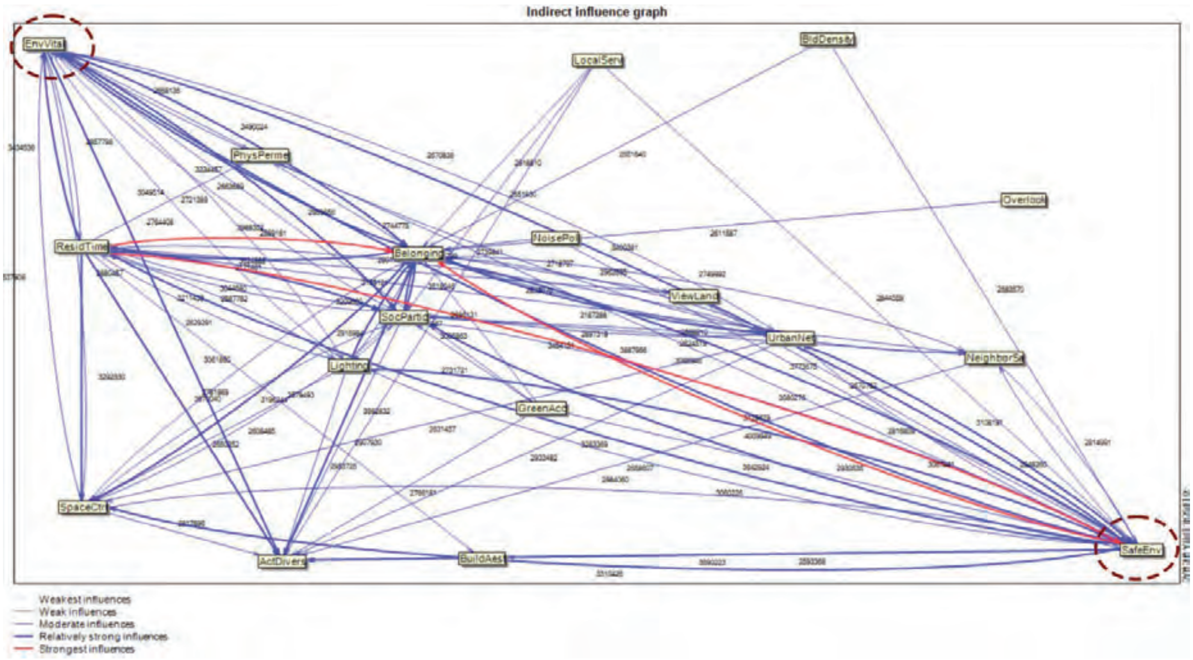

Fig. 5: Indirect influence–dependence graph of variables affecting residential preservation

positive and negative impacts are fully considered. The central question posed in this matrix is as follows: "If scenario 1A of key factor A occurs in the future, what effect will it have on the occurrence or non-occurrence of scenario 2B of key factor B?". The possible outcomes for the key variables, along with their respective codes, are presented in Table 5. This stage helps identify the interdependencies between different scenarios and lays the groundwork for more in-depth analyses in subsequent phases.

Stage 2: In this stage, the key factors are rated on a scale from -3 to +3 based on their reinforcing or limiting effects on each other. Fig. 6 shows the Cross-Impact Balance Matrix (CIBM) after standardization, where the direct impact of each condition on the others is indicated. By analyzing the matrix using the CIBA in the Scenario Wizard software, desirable, undesirable, and intermediate scenarios (continuation of the current trend) are identified. Fig. 7 shows the scenario output in the Scenario Wizard software, known as the scenario dashboard. In this dashboard, desirable scenarios are marked in green, undesirable scenarios in red, and intermediate scenarios (continuation of the current trend) in yellow. Scenario number 3 is identified as the optimal scenario, as it has the highest number of desirable occurrences (green color).

As mentioned earlier, the output of this process is presented as a "Scenario dashboard," which is shown in Fig. 7. The table illustrates four broad scenarios that have been classified following the analysis and evaluation undertaken. Scenario 1, which is an unwanted scenario, illustrates the cases where circumstances in the neighborhood deteriorate and the quality-of-life declines because of inefficient management or interventions. Scenarios 2 and 4, which are the intermediary scenarios, illustrate the sustained continuation of existing trends and conditions, considering the neighborhood's situation without effecting extreme alterations but with improvements to some extent. Scenario 4, as the ideal scenario, represents the best and most optimized possible situation in which all the necessary conditions for improving the neighborhood and preserving residences are provided. Each of these scenarios is further

Table 5: Key factors influencing residential preservation and their potential future values

Row	Factor Code	Key variables	Row	Code of Conditions	Possible Condition
1	A	The length of residence	1	A1 (Desired)	Increased residential satisfaction and maintenance of habitation
			2	A2 (ongoing trend)	Continuation of resident outflow from the area
			3	A3 (Undesirable)	Increase in resident migration out of the area
2	B	Vitality	4	B1 (Desired)	Increased active public presence in public spaces
			5	B2 (ongoing trend)	Continuation of limited public presence in certain public spaces
			6	B3 (Undesirable)	Absence of people in public spaces and increased insecurity
3	C	Sense of belonging	7	C1 (Desired)	Growing sense of neighborhood belonging and local identity.
			8	C2 (ongoing trend)	Gradual decline in neighborhood belonging.
			9	C3 (Undesirable)	Lack of sense of belonging and loss of local identity
4	D	Safety and Security	10	D1 (Desired)	High security and full control in the neighborhood
			11	D2 (ongoing trend)	Relative security with specific controls
			12	D3 (Undesirable)	Lack of security and increased crime in the neighborhood
5	E	Lighting and illumination	13	E1 (Desired)	Complete lighting in all streets and public spaces at night
			14	E2 (ongoing trend)	Moderate lighting in some public spaces at night
			15	E3 (Undesirable)	Darkness in streets and public spaces at night
6	F	Access to local services	16	F1 (Desired)	Full access to services in all areas of the neighborhood
			17	F2 (ongoing trend)	Limited access to services in some areas of the neighborhood
			18	F3 (Undesirable)	Lack of local services in most areas of the neighborhood
7	G	Level of control and oversight of spaces	19	G1 (Desired)	Social supervision and comprehensive control over all spaces
			20	G2 (ongoing trend)	Limited supervision over some spaces
			21	G3 (Undesirable)	Lack of effective social control and supervision, leading to increased violations
8	H	High social participation	22	H1 (Desired)	Extensive resident participation in social and cultural decisions.
			23	H2 (ongoing trend)	Limited participation, restricted to certain groups.
			24	H3 (Undesirable)	Social apathy and declining neighborhood involvement.
9	I	Access to green space	25	I1 (Desired)	Broad and adequate access to high-quality public green spaces.
			26	I2 (ongoing trend)	Green spaces exist but lack proper facilities or maintenance.
			27	I3 (Undesirable)	Insufficient green spaces lead to environmental degradation.
10	J	Access to the urban network	28	J1 (Desired)	Quick and easy access to public transportation and urban network.
			29	J2 (ongoing trend)	Access is available but hindered by delays, congestion, or limited coverage.
			30	J3 (Undesirable)	Difficulty in accessing public transportation and weaknesses in the urban network.

	A			B			C			D			E			F			G			H			I			J		
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	I1	I2	I3	J1	J2	J3
The length of residence																														
Increased residential satisfaction and maintenance of habitation				6	3	-9	6	-6	0	3	0	-3	0	3	-3	-3	0	3	0	-3	3	3	0	-3	4	1	-5	3	0	-3
Continuation of resident outflow from the area				-2	4	-2	-6	3	3	-4	-1	5	-6	3	3	-3	-3	6	-6	3	3	-1	-4	5	-4	2	2	1	1	-2
Increase in resident migration out of the area				-6	3	3	-5	1	4	-3	-3	6	-5	-2	7	-3	3	0	-7	2	5	-3	0	3	-7	2	5	0	0	0
Vitality																														
Increased active public presence in public spaces	-1	-1	2				6	0	-6	6	3	-9	0	3	-3	1	1	-2	6	3	-9	3	3	-6	2	2	-4	3	-3	0
Continuation of limited public presence in certain public spaces	-4	2	2				-6	3	3	-4	-1	5	-5	4	1	-2	1	1	0	0	0	-6	6	0	1	1	-2	0	0	0
Absence of people in public spaces and increased insecurity	-8	4	4				-11	4	7	-11	4	7	-8	1	7	-5	1	4	-8	4	4	-7	2	5	3	0	-3	-4	2	2
Sense of belonging																														
Growing sense of neighborhood belonging and local identity.	3	0	-3	9	-3	-6				3	6	-9	5	2	-7	1	-2	1	6	0	-6	5	-1	-4	1	1	-2	1	1	-2
Gradual decline in neighborhood belonging.	-5	1	4	4	-5	1				-4	2	2	0	0	0	2	-4	2	-7	2	5	0	-3	3	-1	2	-1	-1	2	-1
Lack of sense of belonging and loss of local identity	-8	1	7	-8	4	4				-11	4	7	-4	-1	5	-1	2	-1	-9	3	6	-9	3	6	-2	1	1	-2	1	1
Safety and Security																														
High security and full control in the neighborhood	9	-6	-3	10	-2	-8	6	-3	-3				2	-1	-1	-1	2	-1	4	4	-8	3	-3	0	2	-1	-1	2	-1	-1
Relative security with specific controls	1	-2	1	1	4	-5	-2	1	1				-3	0	3	-3	3	0	3	3	-6	3	0	-3	-1	2	-1	-3	0	3
Lack of security and increased crime in the neighborhood	-5	4	1	-9	3	6	-9	3	6				-2	1	1	-5	1	4	-10	5	5	-9	3	6	-1	-1	2	-2	1	1
Lighting and Illumination																														
Complete lighting in all streets and public spaces at night	1	1	-2	6	3	-9	5	-1	-4	5	5	-10				3	3	-6	5	-1	-4	3	6	-9	2	-1	-1	2	2	-4
Moderate lighting in some public spaces at night	-3	3	0	-1	-1	2	-2	1	1	1	4	-5				1	4	-5	-6	3	3	-3	6	-3	-1	2	-1	1	-2	1
Darkness in streets and public spaces at night	-7	5	2	-9	3	6	-7	2	5	-6	-3	9				-5	-2	7	-6	-3	9	-5	-2	7	-1	-1	2	-5	-2	7
Access to local services																														
Full access to services in all areas of the neighborhood	5	-1	-4	1	4	-5	-1	-1	2	5	-1	-4	1	1	-2				2	-1	-1	1	4	-5	5	-1	-4	5	-1	-4
Limited access to services in some areas of the neighborhood	-3	3	0	1	-2	1	-3	3	0	-2	4	-2	1	4	-5				3	6	-9	-4	5	-1	-2	1	1	-4	2	2
Lack of local services in most areas of the neighborhood	-7	2	5	-8	4	4	-6	6	0	-8	1	7	-3	0	3				-5	1	4	-10	2	8	-4	2	2	-4	2	2
Level of control and oversight of spaces																														
Social supervision and comprehensive control over all spaces	4	-2	-2	3	6	-9	4	-2	-2	5	2	-7	4	1	-5	0	-3	3				0	-3	3	2	-1	-1	3	0	-3
Limited supervision over some spaces	-2	1	1	0	3	-3	-2	1	1	6	0	-6	1	4	-5	0	3	-3				-1	2	-1	-4	2	2	1	1	-2
Lack of effective social control and supervision leading to increased violations	-8	4	4	-11	4	7	-9	3	6	-8	1	7	-9	3	6	-3	-3	6				-9	3	6	-6	-3	9	-6	3	3
High social participation																														
Extensive resident participation in social cultural decisions.	5	-1	-4	6	3	-9	7	4	-11	5	5	-10	5	2	-7	4	4	-8	4	-5	1				2	-1	-1	2	-1	-1
Limited participation restricted to certain groups.	-3	3	0	1	1	-2	-1	2	-1	3	-3	0	-4	5	-1	2	2	-4	-3	6	-3				-1	2	-1	-1	2	-1
Social apathy and declining neighborhood involvement.	-8	4	4	-11	4	7	-5	-5	10	-2	7	-5	-7	-1	8	-6	0	6	-7	2	5				-1	-1	2	-1	-1	2
Access to green space																														
Broad and adequate access to high-quality public green spaces.	6	0	-6	7	1	-8	5	-1	-4	6	3	-9	3	3	-6	5	2	-7	3	0	-3	10	-2	-8				1	1	-2
Green spaces exist but lack proper facilities or maintenance.	-2	1	1	-3	3	0	3	0	-3	3	0	-3	3	0	-3	3	0	-3	-4	2	2	-2	4	-2				0	0	0
Insufficient green spaces leading to environmental degradation.	-7	2	5	-11	4	7	5	-1	-4	-6	-3	9	-6	-3	9	-6	-3	9	-7	2	5	-10	2	8				-3	0	3
Access to the urban network																														
Quick and easy access to public transportation and urban network.	9	0	-9	7	1	-8	2	-1	-1	4	1	-5	2	-1	-1	7	1	-8	8	2	-10	6	0	-6	9	0	-9			
Access is available but hindered by delays congestion or limited coverage.	-3	3	0	2	2	-4	-4	5	-1	-5	4	1	-1	2	-1	-6	6	0	-4	8	-4	1	4	-5	-4	8	-4			
Difficulty in accessing public transportation and weaknesses in the urban network.	-10	2	8	-10	2	8	-5	1	4	-11	4	7	-1	-1	2	-11	4	7	-11	4	7	-5	1	4	-11	4	7			

Fig. 6: CIM after standardization

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 4</th></tr>
<tr><td>The length of residence:
Increase in resident migration out of the area</td><td>The length of residence:
Continuation of resident outflow from the area</td><td colspan="2">The length of residence:
Increased residential satisfaction and maintenance of habitation</td></tr>
<tr><td>Vitality:
Absence of people in public spaces and increased insecurity</td><td>Vitality:
Continuation of limited public presence in certain public spaces</td><td colspan="2">Vitality:
Increased active public presence in public spaces</td></tr>
<tr><td>Sense of belonging:
Lack of sense of belonging and loss of local identity</td><td>Sense of belonging:
Gradual decline in neighborhood belonging</td><td colspan="2">Sense of belonging:
Growing sense of neighborhood belonging and local identity</td></tr>
<tr><td>Safety and Security:
Lack of security and increased crime in the neighborhood</td><td>Safety and Security:
Relative security with specific controls</td><td colspan="2">Safety and Security:
High security and full control in the neighborhood</td></tr>
<tr><td>Lighting and illumination:
Darkness in streets and public spaces at night</td><td>Lighting and illumination:
Moderate lighting in some public spaces at night</td><td>Lighting and illumination:
Complete lighting in all streets and public spaces at night</td><td>Lighting and illumination:
Moderate lighting in some public spaces at night</td></tr>
<tr><td>Access to local services:
Lack of local services in most areas of the neighborhood</td><td>Access to local services:
Limited access to services in some areas of the neighborhood</td><td>Access to local services:
Full access to services in all areas of the neighborhood</td><td>Access to local services:
Limited access to services in some areas of the neighborhood</td></tr>
<tr><td>Level of control and oversight of spaces:
Lack of effective social control and supervision leading to increased violations</td><td>Level of control and oversight of spaces:
Limited supervision over some spaces</td><td>Level of control and oversight of spaces:
Social supervision and comprehensive control over all spaces</td><td>Level of control and oversight of spaces:
Limited supervision over some spaces</td></tr>
<tr><td>High social participation:
Social apathy and declining neighborhood involvement.</td><td>High social participation:
Limited participation restricted to certain groups.</td><td>High social participation:
Extensive resident participation in social cultural decisions</td><td>High social participation:
Limited participation restricted to certain groups.</td></tr>
<tr><td>Access to green space:
Insufficient green spaces leading to environmental degradation</td><td>Access to green space:
Green spaces exist but lack proper facilities or maintenance.</td><td>Access to green space:
Broad and adequate access to high-quality public green spaces.</td><td>Access to green space:
Green spaces exist but lack proper facilities or maintenance</td></tr>
<tr><td>Access to the urban network:
Difficulty in accessing public transportation and weaknesses in the urban network</td><td>Access to the urban network:
Access is available but hindered by delays congestion or limited coverage</td><td colspan="2">Access to the urban network:
Quick and easy access to public transportation and urban network</td></tr>
</table>

Fig. 7: Scenario dashboard

Table 6: Acupuncture urbanism strategies for the Eidgah neighborhood to achieve the ideal scenario

Key Uncertainty	Desired Scenario	Strategy	Number	Acupuncture Urbanism Solutions
Length of Residence	Increased Residential Satisfaction and Preservation	Creating living spaces near work	1	Promoting the "back-to-back living" model: Allowing the blending of living and working spaces, which enhances neighborhood vibrancy and community interaction.
Length of Residence	Increased Residential Satisfaction and Preservation	Creating living spaces near work	2	Developing shared workspaces near residential areas so that individuals can work temporarily without long commutes.
Vitality	Increased Active Presence of People in Public Spaces	Strengthening Participation between Residents, Merchants, and Private Institutions	3	Forming committees composed of residents and merchants to identify and address neighborhood problems and challenges.
Vitality	Increased Active Presence of People in Public Spaces	Strengthening Participation between Residents, Merchants, and Private Institutions	4	Organizing cultural, artistic, and culinary festivals in which both merchants and residents can participate.
Vitality	Increased Active Presence of People in Public Spaces	Strengthening Participation between Residents, Merchants, and Private Institutions	5	Offering incentives like tax discounts, financial assistance, or free advertisements for businesses collaborating with residents.
Vitality	Increased Active Presence of People in Public Spaces	Cultural and Educational Events	6	Establishing cultural and educational centers where residents can teach crafts and souvenirs from Mashhad, preserving cultural values.
Vitality	Increased Active Presence of People in Public Spaces	Cultural and Educational Events	7	Reviving traditional concepts through festivals, exhibitions, and displaying cultural symbols.
Vitality	Increased Active Presence of People in Public Spaces	Mixed Land Use	8	Enhancing nighttime vitality with diverse land uses along main streets.
Vitality	Increased Active Presence of People in Public Spaces	Mixed Land Use	9	Proper distribution of various land uses and open spaces within the neighborhood.
Vitality	Increased Active Presence of People in Public Spaces	Increased Social Interactions	10	Improving the quality and functionality of mosques and centers for cultural, artistic, and leisure activities.
Vitality	Increased Active Presence of People in Public Spaces	Increased Social Interactions	11	Creating public spaces and centers that encourage face-to-face interactions, like mosques and local religious centers.
Sense of Belonging	Increased Sense of Belonging and Local Identity	Urban Facilities Improvement	12	Using diverse colors in urban furniture in parks.
Sense of Belonging	Increased Sense of Belonging and Local Identity	Urban Facilities Improvement	13	Increasing environmental equipment, like waste bins and urban furniture.
Sense of Belonging	Increased Sense of Belonging and Local Identity	Improving Legibility and Creating Local Identity	14	Improving residents' perception through guiding lighting enhances neighborhood identity.
Sense of Belonging	Increased Sense of Belonging and Local Identity	Improving Legibility and Creating Local Identity	15	Upgrading physical appearance and creating a visual identity.
Sense of Belonging	Increased Sense of Belonging and Local Identity	Improving Legibility and Creating Local Identity	16	Enhancing visual identity using valuable elements, plants, unique flooring, creating stepped paths, and mural paintings.
Safety and Security	High Safety and Full Control within Neighborhood	Improving the Legibility of Key Points	17	Improving the condition of abandoned buildings to prevent crime and enhance legibility.
Safety and Security	High Safety and Full Control within Neighborhood	Improving the Legibility of Key Points	18	Defining neighborhood entrances through improved legibility.
Safety and Security	High Safety and Full Control within Neighborhood	Improving the Legibility of Key Points	19	Defining key landmarks, movement paths, intersections, and green spaces for clearer navigation.
Safety and Security	High Safety and Full Control within Neighborhood	Improving Lighting Facilities	20	Preventing dark zones by increasing lighting in key areas.
Safety and Security	High Safety and Full Control within Neighborhood	Improving Lighting Facilities	21	Enhancing lighting in dead-end streets.
Safety and Security	High Safety and Full Control within Neighborhood	Improving Lighting Facilities	22	Using continuous lighting to create visual cohesion in pedestrian spaces.
Safety and Security	High Safety and Full Control within Neighborhood	Enhancing Pedestrian Security	23	Controlling vehicle access using design measures like widening paths, using textured paving, speed bumps, etc.
Safety and Security	High Safety and Full Control within Neighborhood	Enhancing Pedestrian Security	24	Creating pedestrian-only paths to green spaces and neighborhood centers.
Adequate Lighting	Full illumination in all pathways and public spaces at night	Improvement of lighting equipment	25	Improve infrastructure related to lighting and create proper lighting designs.
Adequate Lighting	Full illumination in all pathways and public spaces at night	Improvement of lighting equipment	26	Expand lighting in passageways and communal spaces.

Continued Table 6: Acupuncture urbanism strategies for the Eidgah neighborhood to achieve the ideal scenario

Key Uncertainty	Desired Scenario	Strategy	Number	Acupuncture Urbanism Solutions
Service Accessibility	Complete Access to Services in All Neighborhood Areas	Mixed Land Use	27	Developing sports facilities, shops, schools, healthcare, and green spaces on vacant land to enhance security and access to services.
			28	Creating small local markets.
			29	Balancing service distribution within the neighborhood for easy access.
		Improving Transport Infrastructure	30	Enhancing road access, adding asphalt, and improving taxi and metro lines for better service access.
Control and Monitoring	Social supervision and comprehensive control over all spaces	Social Monitoring by Residents	31	Evaluating neighborhood centers for functionality and performance.
			32	Encouraging residents to interact for increased monitoring.
			33	Organizing police patrols or awareness-building initiatives.
		Enhanced Technological Monitoring	34	Installing surveillance cameras in secluded areas.
High social participation	Extensive resident participation in social cultural decisions.	Local Collaborative Management	35	Establishing neighborhood councils to involve residents in decision-making and planning.
			36	Organizing regular workshops and meetings where residents discuss and propose local improvements.
			37	Encouraging youth participation in urban planning through school and university programs.
Access to green space	Broad and adequate access to high-quality public green spaces.	Improving Urban Green Infrastructure	38	Transforming underutilized areas into community gardens and recreational spaces.
			39	Providing shaded seating areas, exercise facilities, and interactive play zones in parks.
Access to the urban network	Quick and easy access to public transportation and urban network.	Improving Transport Connectivity	40	Creating dedicated bike lanes and pedestrian pathways to key locations.
			41	Improving pedestrian pathways and separating them from vehicular routes through proper paving to ensure comfortable movement for both pedestrians and vehicles.

described as follows:

- *deal scenario (scenario no.3)*

Here, residents are exposed to a high level of security, with illuminated public spaces and streets significantly reducing crimes and enhancing public order. Proximity to important services such as supermarkets, schools, and other daily necessities is evenly distributed around the community, enhancing economic and social diversity while encouraging residents to remain actively occupied in their environments. Universal resident engagement in social and cultural decision-making also further boosts the robust feeling of community, contributing to social cohesion and an enhanced sense of belonging. Tightly maintained high-quality public open space is comfortably within reach, and social contact and improved physical and mental well-being of residents' result. Second, convenient public transport access and efficient links to the wider city network improve mobility, reduce reliance on private cars, and improve connectivity. These all combine with boosting social supervision, levels of resident satisfaction, quality of life, and production of a sustainable and resilient urban society.

- *Ongoing trend (Intermediate) scenario (scenario no.2)*

This scenario reflects the current prevailing conditions in the neighborhood. Security is only partially ensured, with many streets lacking sufficient lighting, especially during nighttime, which contributes to rising crime rates and discourages public presence. Access to basic services is uneven, leading to growing dissatisfaction among residents and diminishing their desire to remain in the area. Community participation is limited and often confined to specific groups, creating divisions and weakening the sense of collective identity. Although green spaces exist, they are poorly equipped or inadequately maintained, reducing their attractiveness and usage. While access to services and transportation is technically available, it is often hampered by delays, congestion, and limited coverage, making everyday life more challenging and diminishing the overall quality of life in the neighborhood.

- *Undesirable scenario (scenario no.1)*

In the undesirable scenario, improper public supervision and management of public spaces result in significant declines in security and rises in criminality. Roads are poorly lit, and access to essential services is low and periodic. These conditions together yield lower public surveillance, higher resident disaffection, and higher propensity for out-migration from the neighborhood. This exodus accelerates the physical, cultural, and social deterioration of the area. Local disinterest becomes widespread, as the disintegration of social bonds and engagement in public activities further increases. Neglect of the environment, along with the absence of green spaces, contributes to the degradation of the ecological and aesthetic value of the area. Moreover, limited public transportation access and inefficiency in the city network hinder the mobility of the residents and their integration with the rest of the city, sustaining the neighborhood's isolation and enhancing its downward trajectory. Analysis of Scenario 3 (Ideal Scenario) reveals that principal subjective and social conditions, such as sense of belonging, social involvement, and space-based control through communities, are in their best forms. This trend emphasizes the importance of enhancing social cohesion and local agency as a component of an integrated strategy for effective physical rejuvenation in the context of historic neighborhoods. The analysis of results anticipates three general situations for the future of the neighborhood: the ideal situation, represented by an improvement in conditions and increasing residential satisfaction; the intermediary situation, where the existing situation is found; and the adverse situation, which relates to aggravating issues and declining living quality. These findings indicate that achieving the best possible scenario requires effective interventions and prudent policymaking aimed at enhancing the quality of life in this area. Worth noting here is that these successes do not always require big-scale intervention in the entire neighborhood, but focused and targeted intervention. This should be a bottom-up approach, with the participation of the residents to encourage more interaction among individuals, strengthen their feeling of belonging to their residential environment, and more effectively solve their genuine needs in the neighborhood. This participatory approach, in addition to reinforcing local identity, ensures interventions are more suited to the needs and aspirations of the community and therefore more sustainable and inclusive in their effects. It is for this reason that this research adopts the approach of "urban acupuncture," which focuses on small-scale but targeted and effective interventions. By promoting micro-scale but impactful projects in key sectors of the locality, this model not only satisfies the real needs of the population but also necessitates incremental positive changes, ultimately resulting in a general improvement in the quality of life in the locality. This observation further suggests that in the specific socio-cultural fabric of Eidgah, cross-linking social relationships and local participation can make more productive physical and infrastructure development possible. Thus, social cohesion and empowerment may not merely accompany urban renewal, they may also help support it. A comparative reflection on the three scenarios reveals that while the optimal scenario provides a holistic vision for urban revitalization, its realization depends on the concurrent fulfillment of multiple interdependent conditions, particularly social cohesion, safety, and access to services. Among these, variables such as "sense of belonging" and "social participation" emerge as pivotal, not merely as outcomes, but as catalysts that influence other dimensions. The ongoing trend scenario, though less favorable, could serve as a foundation for gradual improvements, provided that targeted interventions address their key weaknesses, namely public lighting, participation, and accessibility. The undesirable scenario, on the other hand, illustrates a clear warning of what may transpire if neglect and fragmentation persist. It should be noted that while the Scenario Wizard software offers a systematic framework, the insights derived must be interpreted in the socio-cultural context of the Eidgah neighborhood. Hence, the results are not viewed as deterministic forecasts but as directional guides for informed policymaking. This perspective ensures that strategies remain context-sensitive, actionable, and aligned with the lived realities of residents. It is also worth noting that the scenario results challenge a purely physical or infrastructural approach to regeneration. While factors like lighting and access to services are undoubtedly vital, they appear closely intertwined with social factors such as trust, participation, and a sense of collective responsibility. These conclusions emphasize that policies rooted solely in spatial solutions may fall short if they do not actively engage the social foundation of the neighborhood.

Step 3: Proposed solutions for achieving the ideal scenario

At this stage of the study, after presenting the scenarios for preserving residency in the Eidgah neighborhood, the research proceeds to analyze and propose strategic solutions aimed at achieving the optimal scenario. To strengthen these strategies, findings from similar studies in the fields of urban regeneration, urban acupuncture, and the researcher's expertise have been utilized. This approach facilitates the development of comprehensive and effective solutions grounded in past experiences, scientific analyses, and contemporary urban planning methodologies. These strategies have been formulated through comparative studies, trend analysis, and successful models in urban regeneration and acupuncture urbanism to promote incremental, participatory, and sustainable transformations rather than large-scale, costly interventions. Furthermore, this analytical approach enables the identification of critical urban areas, prioritization of interventions, and formulation of context-sensitive implementation strategies. By integrating empirical data and insights from previous research, these solutions are designed to be both theoretically robust and practically implementable. Ultimately, they provide urban planners and designers with an alternative perspective, demonstrating that significant urban improvements can be achieved with minimal physical intervention, maximizing positive impacts on the urban environment and residents' quality of life. These solutions are outlined in Table 6.

These findings align with the results of Akbariyan Ronizi (2017), who identified factors such as accessibility, social dimensions, physical characteristics, residential units, and public services as influential on residential satisfaction. However, the distinction of the present study lies in its emphasis on identifying influencing components through comprehensive and in-depth analyses, whereas Akbariyan Ronizi's study focused on determining the most significant component from five general categories. Additionally, Tabi Masrour and Rezaei Moayed's (2015) study, which concentrated on residential satisfaction in housing complexes, only examined physical features, while the present study explored a wider range of structural, morphological, perceptual, visual, environmental, managerial, and social factors. The findings of Tabi Masrour's research also underscore the importance of access to diverse services, which aligns with the present study's conclusions. In the same context, Balali Eskuei and Rish Sefid Nosh Abadi (2020) highlighted factors such as the size of the unit, ownership type, and the social role of individuals, which were not identified as key factors in the current study. This discrepancy may stem from differences in the aims and scope of the studies, as their research emphasized personal variables, while the present study took a more structural and collective approach. Furthermore, the findings of Ghaforian and Hasari (2016) categorized influential factors on residential satisfaction into individual, social, and spatial dimensions, recognizing the individual component as the most significant.

However, in the present study, the individual component does not play a central role due to the strategic location of the Eidgah neighborhood as a historical area adjacent to the shrine of the eighth Shiite Imam. This difference arises from the varied approaches to analyzing specific geographical situations and the functions of the studied neighborhood. The results of Noori Imani *et al.,* (2019) align with the components identified in the present study, with variables such as access to shopping centers, green spaces, cleanliness, and adequate lighting for pathways and public spaces recognized as influential on residential satisfaction in both studies. In international studies, Welsovsky (2021) highlighted the impact of temporary artistic interventions on the social and aesthetic transformations of public spaces. While these findings differ from the focus of the current study, which emphasizes social and functional variables, they draw attention to the importance of community perceptions of the living environment. Additionally, Francis and Abraham Krep (1982), and Bion and Ha (2016) emphasized components such as safety, access to services, lighting, and facility management as factors influencing residential satisfaction, many of which align with the findings of the present research. In this regard, the study by Ghalandarian and Goharipour (2023) examines the quality of the urban environment in the renovation process of the Samen district in Mashhad. The study aims to redefine environmental quality across managerial, physical, economic, socio-cultural, and environmental dimensions, analyzing the impacts of interventions on the physical, psychological, and spiritual aspects of urban life. The findings reveal that large-scale interventions driven by economic objectives have led to increased social issues, reduced social interactions, displacement of residents, and changes in the area's cultural identity. The authors conclude that improving the urban environment in historical neighborhoods like Samen requires more than just physical interventions; it must also address social, cultural, and spiritual dimensions. Urban regeneration through public participation and a focus on local values can be an effective strategy to improve residential conditions while preserving cultural and social identity. This study follows a similar approach by identifying key variables influencing residential satisfaction and proposing practical solutions to improve it. These solutions are based on the Urban Acupuncture approach, which emphasizes low-cost, targeted interventions to enhance residential satisfaction and promote long-term habitation in deteriorating urban areas. The results align with previous research, particularly regarding the key factors influencing residential satisfaction. However, the observed differences are primarily due to variations in methodology, sample populations, geographical scope, and the level of participation in urban regeneration processes. These findings can assist policymakers and urban planners in designing targeted interventions to enhance citizens' quality of life and contribute to a more comprehensive model for improving urban environmental quality in historical neighborhoods. In summary, this study provides a thorough analysis consistent with previous research on key variables affecting residential satisfaction. The differences observed are attributed to variations in methodology, sample populations, and geographical scope. Additionally, the proposed framework provides context-specific solutions based on the Urban Acupuncture approach, which provides cost-effective strategies for enhancing satisfaction and promoting long-term habitation in deteriorating urban areas.

CONCLUSION

The historic and central area of Mashhad, Iran's most significant pilgrimage city, is of significant cultural significance because of its historical landmarks and rich religious history. Historically known as the city center and a significant religious area, this region has slowly suffered decline and deterioration, similar to many other historic neighborhoods in Iran. Key drivers for this decline include fragmented and inconsistent urban interventions, along with the rapid expansion of commercial and residential developments, particularly hotels and guesthouses, to accommodate pilgrims and visitors. These developments eroded the district's historic and cultural character, replacing economic objectives with indigenous values and loosening residents' identification with their living environment. Moreover, the disregard for sustainable regeneration resulted in a poorer quality of life and growing discontent among residents, rendering them displaced and further guaranteeing the degradation of the area. In contrast to previous studies that tended to assess satisfaction through generalized or predominantly physical dimensions, this research adopts a more integrated and context-specific approach. By distinguishing between abstract and tangible variables, and aligning potential interventions accordingly, the study offers a framework that is not only theoretically grounded but also pragmatically applicable. While earlier literature (Akbariyan Ronizi, 2017; Tabi Masrur and Rezaei Moayed, 2015; Ghaforian and Hasari, 2016) often emphasized individual or physical factors, this research underscores the catalytic influence of collective and perceptual dimensions, particularly in fostering long-term preservation of historical neighborhoods. What distinguishes this research is its combination of quantitative structural analysis and qualitative scenario-based strategy development. By embedding these findings within a culturally sensitive and participatory planning framework, it offers not only theoretical clarity but also actionable pathways for revitalizing vulnerable urban fabrics. Scenario analysis using the Scenario Wizard was applied to validate and extend the analytical findings. The results revealed that the most desirable outcomes, such as enhanced safety, increased participation, and improved access, depend on the concurrent realization of multiple conditions. More importantly, the research suggests that a sense of belonging, and participation are not just products of revitalization efforts but are essential prerequisites to successful physical interventions. This justifies the need for bottom-up, participatory urban planning. Responding to this need, the study prescribes targeted interventions based on the Urban Acupuncture approach. In contrast to mainstream large-scale regeneration models, which tend to ignore local contexts and generate unintended consequences, urban acupuncture promotes small-scale, low-budget, but high-impact interventions. These include improving lighting, improving pedestrian paths, creating multifunctional spaces, incorporating native nature, and enabling community participation. Not only do interventions like these enhance physical conditions, but they also restore socio-cultural vitality, encouraging residents to remain and reinvest in their neighborhoods. Highlighted in this research is the necessity of a comprehensive analysis and truthful assessment of determinants of residential satisfaction toward a clearer understanding and more realistic planning for residential environment enhancement. Scenario-based modeling is subsequently used to propose solutions grounded in the Urban Acupuncture theory. Characterized by its minimal, context-sensitive, and participatory intervention, the approach offers an economically effective and rapid method of enhancing residential satisfaction and improving long-term occupation of declining city districts. A detailed examination of variables in diverse contexts allows for the creation of more precise and successful interventions in urban planning and regeneration. While the findings are focused on the Eidgah neighborhood, they are also relevant to other historic neighborhoods that face problems like residents' displacement, urban decay, land use changes, tourist pressure, and loss of cultural identity. If left unaddressed, these issues could contribute to outcomes that have been seen in other declining urban areas. Urban Acupuncture, through incremental realization, participatory approaches, and low-cost intervention, presents an alternative approach to traditional large-scale regeneration methods that have too frequently been costly and ineffective. This approach enables urban designers and planners to bring in certain enhancements such as better lighting, better pavement and sidewalk quality, the availability of multifunctional spaces, the addition of local flora, and more resident participation. Not only do these measures preserve historical and natural factors, but they also aim at restoring social and economic vitality, increasing residential satisfaction, and promoting long-term residency. Finally, this study contributes to theory and practice by bridging conceptual knowledge and practical reality. It demonstrates how scenario-based planning, when coupled with locally grounded, participatory interventions, can guide sustainable urban regeneration in historical areas. Although the Eidgah neighborhood constitutes the primary case study, the proposed model remains applicable to similar urban contexts where heritage, displacement, and urban decay intersect. Future research should continue refining this approach by incorporating dynamic, real-time data and evaluating its long-term impacts. Doing so will enhance its effectiveness in navigating the complex interplay between built form, community identity, and urban resilience.

AUTHOR CONTRIBUTIONS

Z. Zavarian: Data collection, software-based modeling, and manuscript writing.

I. Ghalandarian: Conceptualization (research design), supervision, validation, and manuscript review & 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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ABBREVIATIONS (NOMENCLATURE)

CIBA	Cross-Impact Balance Analysis
CIBM	Cross-Impact Balance Matrix
CIM	Cross-Impact Matrix

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ORIGINAL RESEARCH PAPER

Sustainable aquaculture and urban management: leveraging Tilapia farming for economic and social development

W. Madhyamapurush[1,*], N. Somyarone[1], K. Mairin[2], S. Makkhun[3], K. Ratanasanguanvongs[1], K. Seetapan[3]

[1] *School of Business and Communication Arts, University of Phayao, Phayao, Thailand*

[2] *School of Law, University of Phayao, Phayao, Thailand*

[3] *School of Agriculture and Natural Resources, University of Phayao, Phayao, Thailand*

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ABSTRACT

BACKGROUND AND OBJECTIVES: Sustainable aquaculture offers a promising solution by merging eco-friendly fish farming with urban development strategies. Sustainable aquaculture can enhance food security by adopting innovative technologies and resource-efficient practices while minimizing ecological impact. This research explores the integration of Tilapia farming into urban management strategies in Phayao, Thailand, focusing on its economic and social implications.
METHODS: A structured questionnaire was distributed to 436 Tilapia farmers in Phayao to gather data on farm productivity, income levels, market access, and sustainability practices. The data analysis employed descriptive statistics, t-test, multiple regression analysis, and Return on Investment calculations to assess the financial viability of Tilapia farming and the influence of various socioeconomic factors on production.
FINDINGS: Key variables influencing Tilapia farming include farm size, access to quality feed, market access, pond management practices, water source, and government support. These factors are analyzed to assess their impact on profitability, sustainability, and social development. Results reveal that farm size, access to quality feed, and market connectivity are significant determinants of profitability. Furthermore, policy support and urban infrastructure are crucial to the long-term sustainability of Tilapia farming. This research illustrates how urban-integrated Tilapia farming can stimulate local economies and create careers while decreasing dependence on external food sources. All predictors showed statistical significance, with farm size ($p< .001$), quality feed ($p< .001$), market access ($p< .001$), and government support ($p< .001$) having strong effects. Pond management ($p = .022$) and water source ($p =.041$) had moderate but significant effects.
CONCLUSION: It proposes that Tilapia aquaculture could provide a scalable model for sustainable urban economies, which is useful for creating a framework of aquaculture in urban planning. Tilapia farming strengthens local food networks, enhances livelihoods, and promotes sustainable urban growth, making it a vital aspect of urban sustainability efforts in Phayao and other comparable locations.

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*Corresponding Author:
Email: *warachm@gmail.com*
Phone: +66614944469
ORCID: 0000-0003-4110-0780

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INTRODUCTION

Aquaculture is the fastest-growing food sector in the world and generates half of all seafood for human consumption. The total global fisheries landings have averaged about 90 million tons annually. Aquaculture is the most sustainable source of protein and is anticipated to be critical in addressing the global challenge of feeding over 9 billion people by the year 2050 (Sarker, 2023). Aquaculture is anticipated to generate 109 million metric tons of fish by 2030, representing a 158% increase from 2000 to 2018. Feed consumption in the aquaculture industry has reached essentially 60 million metric tons, with 73.15 million tons expected by 2025 (Othman *et al.*, 2024). Aquaculture has developed as an essential catalyst for global food security and economic development, and Tilapia farming has emerged as a prime instance of a sustainable, cost-effective, and resilient freshwater species (Alsaleh, 2024). Tilapia is recognized as an important source of affordable protein for many emerging nations due to its fast growth potential and resilience to farming practices (Piate *et al.*, 2024). Tilapia farming is a source of nutrition, employment, poverty alleviation, and public welfare. By enhancing aquaculture practices, cultivating skill sets, and producing market access, Tilapia aquaculture can be a significant tool for economic growth and social change (Kardgar *et al.*, 2024). Sustainable aquaculture is gaining recognition as a key driver for local development, with the most talented pathway to create integrated social and economic opportunities with Tilapia farming. This aquaculture species has low production costs and is a powerful intervention to achieve food security, rural trades, and sustainable socio-environmental development (Thompson *et al.*, 2024). The farming of Tilapia can connect aquaculture to urban management, resource planning, or urban agriculture methods to promote more inclusive economic growth, enhance local incomes, and create more resilient communities in Phayao (Abdel-Hady *et al.*, 2024). Aquaculture, particularly Tilapia aquaculture, plays a pivotal role in enhancing the resilience of rural communities to climate and economic uncertainty. By incorporating aquaculture into prevailing localized agriculture systems, farmers have a better capacity to adjust to the variable conditions of the environment and the demands of consumers, which is vital to guarantee a future of food security (Chagwaya and House, 2024). The purpose of this research is to investigate the potential role of sustainable Tilapia farming in promoting local economic growth and community welfare in Phayao, Thailand. The research also intends to integrate features of aquaculture as an industry and associated processes into urban management techniques to encourage equitable local growth.

Related works

Aquaculture, a developing food production technology, raises environmental and social challenges. An investigation analyzed data from 57 global aquaculture systems using aquaculture performance indicators and discovered that economic, social, and environmental effects were often mutually reinforcing (Garlock *et al.*, 2024). However, research found considerable differences in sustainability levels across systems. Some systems' poor performance in specific areas created opportunities for new policy initiatives and investment to align sustainability goals. The findings demonstrated the requirement for additional investment and regulations to tackle aquaculture's environmental, social, and economic implications. Solar energy was employed to power two Integrated Multi-Trophic Aquaculture (IMTA) aquaponics systems that grow Nile Tilapia, African catfish, freshwater mussels, and other vegetables, which were examined by Goda *et al.*, (2024). The IMTA system used solar energy to power ponds, controlling nutrient flow, and gaining biomass for aquatic species, with a 0.90 feed conversion ratio. Rizal *et al.*, (2023) explored the most promising urban farming aquaculture business ideas for food and economic security during the COVID-19 pandemic in Jakarta's suburbs. Data were collected and utilized field surveys, interviews with 200 respondents, questionnaires, and secondary data from the Central Bureau of Statistics. The primary data was analyzed by quantitative descriptive methods and Analysis of Variance (ANOVA), whilst the secondary data was evaluated with graphics. The investigation suggested that Tilapia and catfish business models can encourage food security, whereas manfish, goldfish, guppy, and Siamese fighting fish company models can boost financial well-being. The urban agriculture supervision and aquaculture industry in Jakarta were generally carried out by members of the community who have completed their education through college. Mitra *et al.*, (2023) compared the efficacy and productivity of farms with and without access to open water resources in Bangladeshi Tilapia

Pond aquaculture. According to 311 connections with Tilapia manufacturers, farms with access to open water resources were more effective but less creative than those with incomplete access. The investigation also discovered that production could be raised by 29% and 40% without collective input in places with acceptable and limited water supply, respectively. The research highlighted the consequences of the accessibility of fresh water in Tilapia Pond aquaculture for ecological sustainability and efficiency. Rossignoli *et al.*, (2023) identified the farm-level data from 402 aquaculture producers in Egypt and revealed that variation in production features and techniques had significant effects on the sustainability effectiveness of Tilapia farming systems. The research discovered that yields in monoculture systems were substantially greater than in mixed farming systems, emphasizing the importance of sustainable strengthening of aquaculture systems to fulfill anticipated requirements for fish and aquatic products. A solar-powered oxygen compressor, paired with water electrolysis and fuel cells, was intended to enable sustainable aquaculture and ecosystems (Erdemir and Dincer 2024). The devices utilize Proton Exchange Membrane (PEM) electrolyzers to produce oxygen from water splitting, which was later utilized as a clean fuel in fuel cells stacked to generate power. The technique endeavors to accomplish the United Nations' sustainable development goals by encouraging cleaner aquaculture. The structure has been tested in five impoverished cities, with a 1 MWp solar power plant capable of producing oxygen in each city, attaining 12.2% energy and 66% energy efficiency. The research utilized an online survey to investigate stakeholder perceptions of the aquaculture sector and assess their alignment with scientific data (n = 400). The research suggested that stakeholders in the aquaculture sector have negative perceptions, which were determined by requirements such as geography, occupation, and income. These beliefs include low-quality farmed fish, potential health hazards, and poor-quality water. Fish traders and merchants also add to these concerns. To eliminate these issues, preventive actions were required, such as transparent information, effective communication, regulatory methods, constructive associations, and transparent verification standards. These procedures were critical to the aquaculture sector's long-term viability and consumer health. Elmessery *et al.*, (2025) suggested a technique for feeding control in Recirculating Aquaculture Systems (RAS) based on a Deep Deterministic Policy Gradient (DDPG) reinforcement learning algorithm. The equipment incorporated feeding rate optimization and water quality management to enhance reliability and efficiency. Although opposed to traditional approaches, the DDPG controller achieved higher tracking precision, lower feed consumption, and more operating predictability. It also provided speedier recovery times, more long-term rigidity, and substantial economic benefits. This study aims to evaluate the economic and social contributions of sustainable Tilapia farming and to examine how it can be integrated into urban management strategies to support local development. The research was conducted in Phayao Province, Thailand, between January and November 2024.

MATERIALS AND METHODS

The research employed a standardized questionnaire issued to (n=436) farmers to assess the economic and social benefits of incorporating Tilapia farming into urban management techniques in Phayao, Thailand. It evaluated the profitability, sustainability, and financial viability of sustainable aquaculture operations. The investigation employed SPSS Statistics Version 26 to evaluate data on Tilapia farming profitability, sustainability, and Return on Investment (ROI), with the goal of better understanding its contribution to economic development and urban food system resilience in Phayao.

Profitability analysis

To evaluate the financial performance of Tilapia farming, profitability was assessed using several financial indicators, including total yield, gross income, net profit, and profit margin. The core formula used for determining Net Profit is:

$$Net\ Profit = Total\ Revenue - Total\ Cost$$

Where:

Total Revenue=Quantity Sold × Selling Price per Unit

$$Total\ Cost = Fixed\ Cost + Variable\ Cost$$

Fixed Costs include land, infrastructure, and equipment, while Variable Costs cover feed, labor, utilities, and other recurring expenses. This analysis enables the identification of primary profitability drivers such as production efficiency, input quality, and market access.

Sustainability assessment

Sustainability in Tilapia aquaculture was assessed through a multidimensional framework incorporating ecological, economic, and social indicators. One key metric used was Resource Use Efficiency, calculated as:

$$Resource\,Use\,Efficiency = Fish\,Output\left(kg\right) / Feed\ Input\left(kg\right)$$

The Ecological Footprint was calculated based on land and water use in kilograms of fish produced. Some of the indicators used to measure social sustainability included employment generation, improvement of community livelihoods, and contributions to food security. These metrics helped assess the overall impact of Tilapia farming on sustainable development.

ROI

To understand the financial returns relative to capital invested, ROI was computed using the following formula:

$$ROI\left(\%\right) = \left(Net\,Profit\ /\ Total\ Investment\right) \times 100$$

Total investment includes all capital expenses at the beginning, such as infrastructure, equipment, and fish stocking. This indicator helps to assess the economic efficiency of the farming system and allows for comparisons between different farming models. A higher ROI indicates better financial performance.

Data collection

Research in Phayao, Thailand, analyzed the economic and social impacts of Tilapia aquaculture. Data was collected from 436 farmers, focusing on farming techniques, income generation, market access, and sustainability. This research used structured questionnaires and interviews to gather information on demographics, productivity levels, income, input usage, market links, environmental practices, and government support. The mixed-methods strategy improved data reliability and validity, revealing Tilapia as a potential driver for urban and economic growth. Table 1 shows the total number of Tilapia farmers involved in the research.

Table 1: Characteristics of demographic variables

Demographic Variable	Category	Frequency (n)	Percentage (%)
Age (Years)	18–30	62	14.2%
	31–45	158	36.2%
	46–60	145	33.3%
	>61	71	16.3%
Gender	Male	289	66.3%
	Female	147	33.7%
Education Level	No formal education	35	8.0%
	Primary education	179	41.1%
	Secondary education	142	32.6%
	Higher education	80	18.3%
Household Size	1–3 members	95	21.8%
	4–6 members	248	56.9%
	More than 6 members	93	21.3%
Marital Status	Single	115	26.4%
	Married	321	73.6%
Occupation	Full-time Tilapia farmer	198	45.4%
	Part-time Tilapia farmer	149	34.2%
	Others	89	20.4%

According to the age distribution of the respondents, 14.2% were aged between 18 and 30, and 36.2% were aged between 31 and 45. Of the respondents, 33.3% were between the ages of 46 and 60, and 16.3% were 61 years of age or older. Therefore, most farmers reported that they are in the age range of 31-60, which means it is indicative of active working family members in aquaculture. In terms of gender, 66.3% of respondents were male and 33.7% were female, suggesting that Tilapia farming in the region is predominantly male-driven, though women also play a significant role. Fig. 1 depicts the age and gender-differentiated pie chart. In terms of education, 8.0% of respondents had no formal education, 41.1% had primary education, 32.6% completed secondary education, and 18.3% had attained higher education. Fig. 2 visualizes the relationship between household size and levels of education. This reflects a reasonably educated farming population with the potential for adopting improved practices. Household size: 21.8% of respondents had 1–3 members, 56.9% had 4–6 members, and 21.3% had more than 6 members. Most households were mid-sized, likely contributing to family-based farm labor.

Marital status: 26.4% of respondents were single, and 73.6% were married. The high proportion of

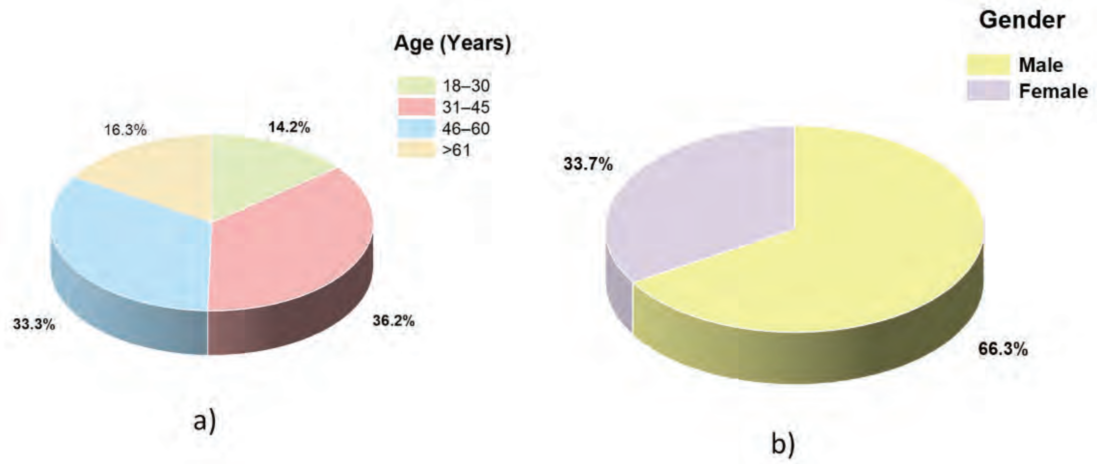

Fig. 1: Graphical representation outcomes of (a) age, (b) gender

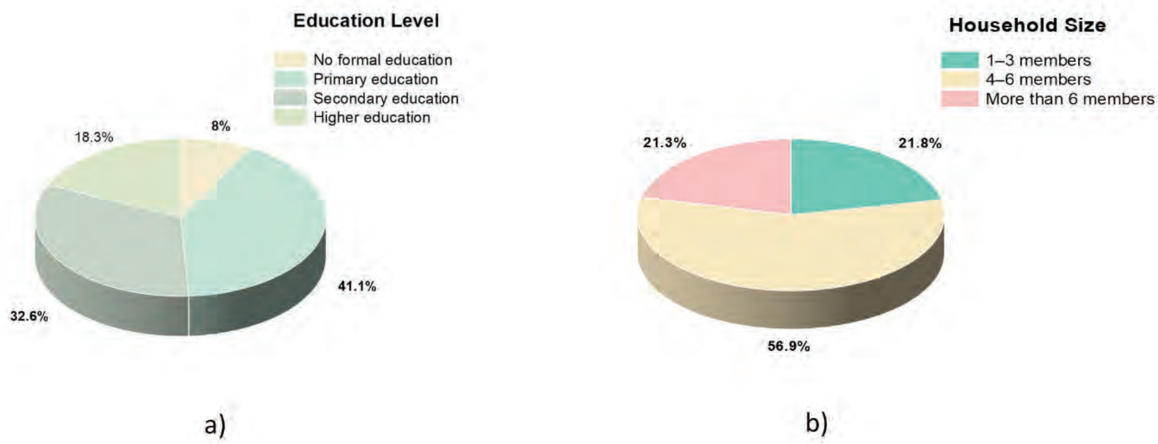

Fig. 2: Graphical representation of outcomes of (a) Educational Level, (b) Household Size

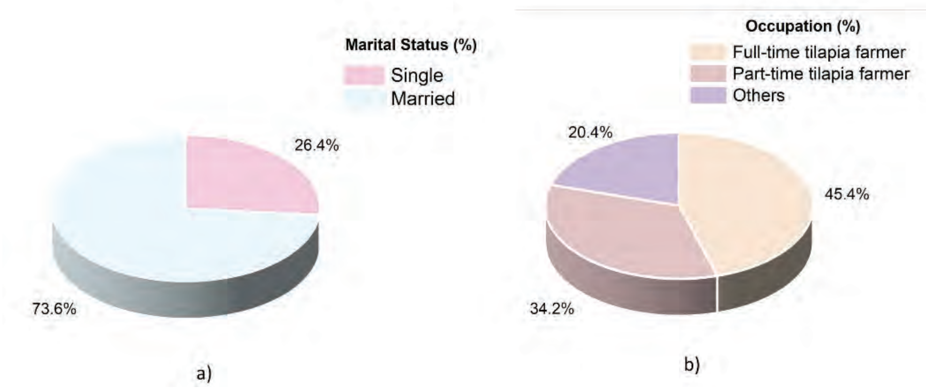

Fig. 3: Graphical comparison of (a) marital status and (b) occupation

married individuals suggests family involvement in farm operations. Occupation: 45.4% of respondents were full-time Tilapia farmers, 34.2% were part-time farmers, and 20.4% reported other non-farming occupations. A visual summary of the association between marital status and occupations is provided in Fig. 3. This indicates that Tilapia farming is a primary livelihood for many, while others supplement it with additional income sources.

Study design

This research occurred in Phayao Province in Northern Thailand, and it focused on the economic feasibility, sustainability practices, and social effects of Tilapia farming, as well as its relationship to urban management systems. The study uses a cross-sectional survey design to determine the economic viability of Tilapia farming, sustainability measures, and social effects of Tilapia farming in Phayao, Thailand. This approach involves generating quantitative and qualitative data from a diverse group of Tilapia farmers at one time. Using structured questionnaires, the study captures critical metrics including farm productivity, income, cost structure, and sustainability indicators, which help analyze how different parameters influence profitability and environmental practices. Additionally, the design integrates qualitative insights from interviews, providing a deeper understanding of social implications such as employment generation and community development. This comprehensive approach allows for an evaluation of the multidimensional impacts of Tilapia farming for the benefit of policymakers and stakeholders interested in improving sustainable aquaculture practices. The investigation was conducted in the chosen location because of its strategic geographic location, agricultural potential, and potential for aquaculture integration.

Evaluation and statistical tools

A combination of statistical and financial procedures is used to examine the obtained data and assess the economic and social viability of Tilapia farming in Phayao. The statistical analysis, IBM SPSS Version 26, is employed to evaluate the Descriptive Statistics, Multiple Regression Analysis, and ROI. Descriptive statistics were utilized to characterize respondents' demographics and sustainable practices. This provided a foundation for understanding the present circumstances and the distributions of key variables. Furthermore, multiple regression analysis assesses the relationships of other variables that could affect farm profitability and productivity. The ROI was examined to measure the return on money spent and the financial feasibility and efficiency of Tilapia farming. These analytical tools assessed the potential of the sector for economic growth, contributing to social development, and potential integration into sustainable urban planning (Akbulut Basar, 2024). To use the combination of statistical and financial procedures in analyzing data obtained from Tilapia farming in Phayao, first, data collection is done using structured questionnaires administered to Tilapia farmers. Once the data is collected, IBM SPSS Version 26 is used for statistical analysis. Descriptive statistics are initially used to summarize and describe the demographics of respondents and their sustainable practices, providing an explicit picture of the current situation and variables' distribution. After this preliminary examination, multiple regression analysis is carried out to check the relationships between factors that could influence farm profitability and productivity. This method helps researchers determine variables such as farm size, feed quality, and market access that largely affect financial results. Simultaneously, the ROI is estimated to determine the financial viability and efficiency of Tilapia farming, considering the returns from investments made.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n + \varepsilon$$

Where:

- Y is the dependent variable (e.g., Net Profit or Productivity),
- X_1, X_2, ..., X_n are independent variables (e.g., Farm Size, Feed Quality, Market Access, etc.),
- β_0 is the intercept,
- β_1, β_2, ..., β_n are the regression coefficients, and
- ε is the error term

RESULTS AND DISCUSSION

This research explores sustainable Tilapia farming for promoting local economic development and community welfare in Phayao, Thailand, and integrating aquaculture industry characteristics into urban management techniques. This research reveals that Tilapia farming has experienced growth and development, with increased production over time. Key farm characteristics, such as size, quality feed, market access, and government support, are key profitability drivers. The economic viability of sustainable Tilapia farming in urban contexts is confirmed by RoI analysis. Larger farms with commercial feed and regional market access maximize return on investment. Government assistance and adequate pond management techniques also increase returns.

Growth of Tilapia farming

Fig. 4 illustrates the goal of the research, which is

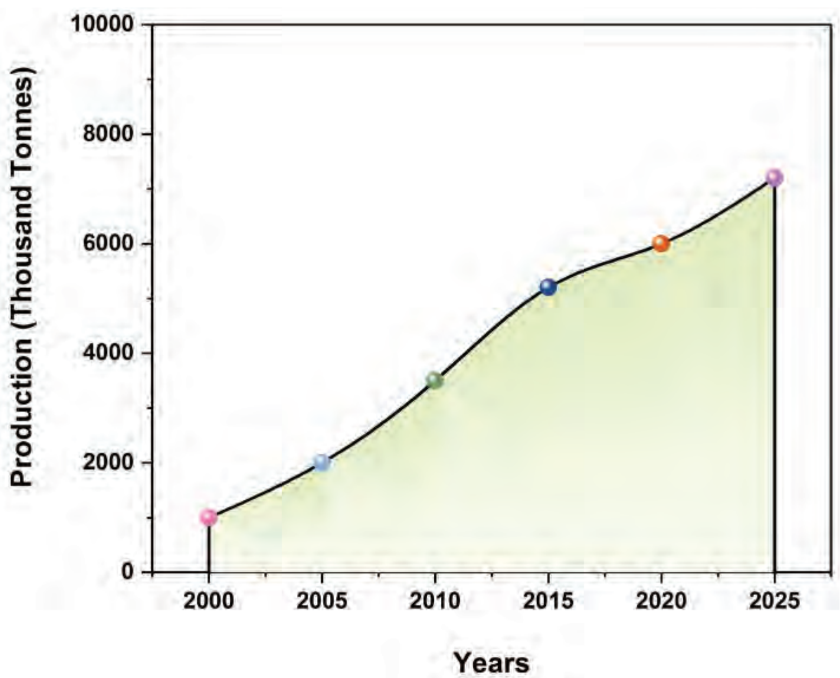

Fig. 4: Growth of Tilapia aquaculture production

to analyze how sustainable Tilapia aquaculture helps to enhance economic and social development efforts in Phayao, Thailand. It indicates an average upward trend in revenue from 2018 to 2022, and that the potential for growth from aquaculture could indeed translate to growth in revenue. Tilapia aquaculture is becoming a reliable income source for local communities, supporting the research of promoting inclusive growth (Fig. 4). The rapid revenue rise in 2020 and 2021 can indicate the success of targeted acquisitions in improving aquaculture practices.

The above figure suggests that sustainable aquaculture is a viable economic strategy and can be expanded to create resilient, self-sustaining urban and rural economies while enhancing social growth through environmentally sustainable practices.

The development period of Tilapia farming

The current advancement in three key categories of Tilapia fish production is shown in Fig. 5. Aquaculture production, farmed and wild Tilapia production, and aquaculture and fisheries production over 20 years from 2005 to 2025.

These data points indicate growth across all three areas, with growth in Tilapia production standing out. Aquaculture production appears to be steadily advancing from around 48% in 2005 to approximately 85% by 2025, indicating an apparent shift toward controlled and sustainable fishing and agriculture methods. Farmed and wild Tilapia production continues to exhibit an increased rate of change from a low of 18% in 2005 to nearly 90% in 2025, paying attention to expanding its role in food systems as well as economic development. The category of aquaculture and fisheries production also perceives a substantial increase from around 15% to 80% during that period, refocusing attention on the combination of traditional and modern practices.

Descriptive analysis

In the framework of this research, descriptive analysis is being utilized to characterize essential aspects of Tilapia farming in Phayao. Descriptive analysis provides an extensive overview of

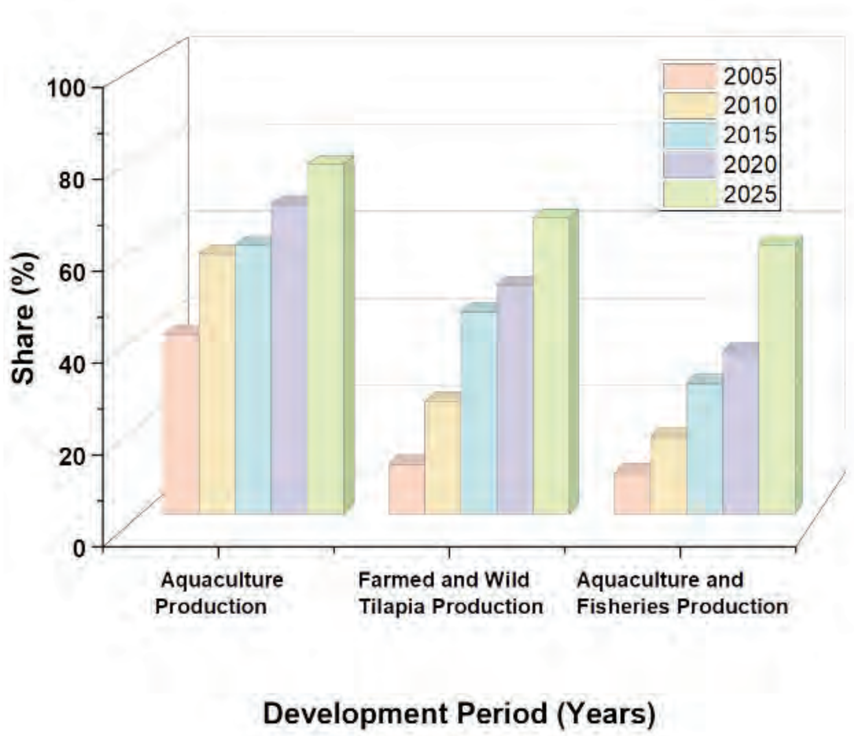

Fig. 5: Graphical representation of the development period for Tilapia farming

demographics and on-farm factors about farmer behavior and can be used to evaluate statistical testing. Table 2 provides descriptive statistics of the demographics of the respondents. The mean age category was between 19 and >61 years, with a mean = 2.52. Predominantly male respondent population (Mean = 1.33). Most respondents were predominantly primary or secondary-level educated (Mean = 2.61), lived with moderately sized families (Mean = 1.99), and were married (Mean 1.26). The mean occupation status indicates that the respondents were between part-time and full-time Tilapia farmers (Mean = 2.25). The mean and Standard Deviation (SD) values for a variety of demographic characteristics are shown in Fig. 6. Education level has the greatest mean, whilst gender and married status have the lowest. Standard deviations generally appear stable across variables, showing modest variability.

Table 2: Numerical outcome of descriptive analysis

Variable	Mean	SD	Minimum	Maximum
Age (Years)	2.52	0.89	1 (18–30)	4 (>61)
Gender	1.33	0.47	1 (Male)	2 (Female)
Education Level	2.61	0.89	1 (No formal)	4 (Higher)
Household Size	1.99	0.66	1 (1–3)	3 (>6)
Marital Status	1.26	0.44	1 (Single)	2 (Married)
Occupation	2.25	0.81	1 (Full-time)	3 (Others)

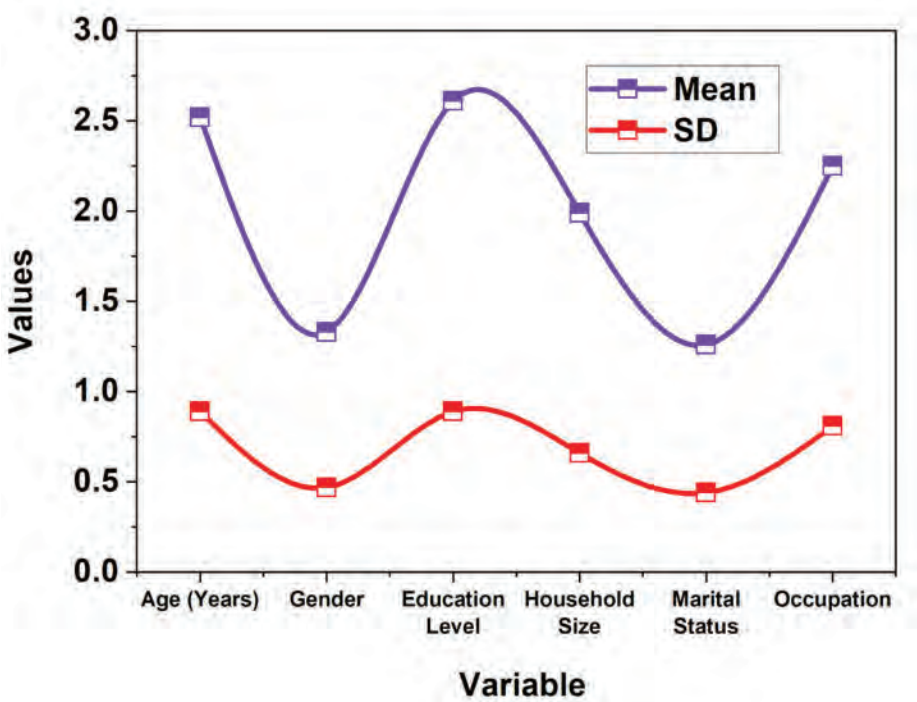

Fig. 6: Comparison between mean and SD

Findings of multiple regressions

This research used multiple regressions to explore factors influencing the profitability of Tilapia farming in Phayao, Thailand. The relationship between farm profitability (dependent variable) and a range of independent variables was examined. The regression model allowed for a classification of influence on profitability for each variable included in the model while controlling for the influences of other factors. It assesses the relative influences of relevant concepts to develop a more thorough understanding of the economic contributors to the sustainability of Tilapia aquaculture. The outcomes of the regression analysis, as shown in Table 3, indicate that several predictors are significantly associated with the profitability of Tilapia farming in Phayao, Thailand.

The predictor variables refer to certain factors that are believed to impact the profitability and sustainability of Tilapia farming. These variables shed light on the connection that exists between the different aspects of the farming system and the results that farmers experience in terms of their economic situation. These predictor variables are very important as they help determine the most significant factors that influence the economic viability and sustainability practices of Tilapia farming. Knowledge of these associations will allow researchers to make recommendations on how to improve farm management and the overall contribution of aquaculture to the local economy and people's well-being. Farm size has a strong and positive effect ($B = 3200$, $p < .001$), meaning that larger farms are associated with increased income. Access to quality feed ($B = 2050$, $p < .001$) and market access ($B = 1800$, $p < .001$) also demonstrated significant contributions to improved profitability. Pond management practices ($B = 1150$, $p = .022$) and having access to a reliable source of water ($B = 920$, $p = .041$) demonstrated moderate but meaningful contributions as well. Government support emerged as a strong predictor ($B = 3800$, $p < .001$), indicating the importance of institutional support for farm outcomes. Farm size, quality feed supply, and market access all had an apparent impact on income levels, whereas pond management and water source had a minor instead of a substantial effect. Overall, all predictors were statistically significant, and all predictors highlight the multiple drivers of economic success across sustainable aquaculture.

Role of RoI in economic assessment

ROI is applied to measure the financial feasibility of Tilapia culture in Phayao. It is useful to measure profitability, compare the performance of farm types, and identify variables that explain variation in returns, such as farm size, feed quality, and government assistance; these findings are represented in Table 4. Additionally, RoI can also be used in city development, support policy recommendations, and promote better aquaculture practices.

It emphasizes that the size of the farms is a major determinant of profitability; larger farms achieve an ROI of 28%, due to economies of scale, while small farms have a return of 12%, based on less capacity to produce, and medium farms have a return of 20%. Another major determining factor is the quality of feed; producers who purchased commercial feed found a higher ROI (26%) due to improved growth and yield than those who used locally available feed (14%). The location of farmers' market access also determined profitability; farmers connected to regional or export markets received better pricing and demand, yielding an RoI of 27%, compared to farmers with local market opportunities who yielded

Table 3: Predictors of multiple regression

Predictor Variable	Regression Coefficients (B)	Std. Error	t-value	p-value
Farm Size	3,200	550	5.82	<0.001
Access to Quality Feed	2,050	430	4.77	<0.001
Market Access Score	1,800	390	4.62	<0.001
Pond Management Practices	1,150	500	2.30	0.022
Government Support	3,800	720	5.28	<0.001
Water Source	920	450	2.04	0.041

Table 4: Evaluating RoI influencers in Tilapia aquaculture in Phayao

Factor	Category	Average ROI (%)	Observation
Farm Size	Small	12%	Reduced ROI related to constrained capacity for manufacturing.
	Medium	20%	Optimal price and efficiency
	Large	28%	Increased ROI through efficiencies of scalability.
Feed Quality	Local Feed	14%	Reduced productivity and efficiency in conversion
	Commercial Feed	26%	Higher production yield
Market Access	Local Market	18%	Insufficient pricing authority.
	Regional/Export Market	27%	Improved demand and supply
Government Support	With Support	25%	Supports and instructions for improved ROI
	No Support	13%	Increased operational threats and the expense of inputs
Pond Management	Traditional	15%	Fundamental procedures for handling freshwater and trash.
	Improved	24%	Increased fish survivability and reduced illness frequency

an ROI of 18%. The availability of government support, in terms of training and subsidy program participation, increased farm profitability with an ROI of 25%; meanwhile, farms that did not receive support realized lower profitability with an RoI of 13% due to high cost and risk. Furthermore, improving pond management practices results in the desired RoI improvement, achieving 24%, based on improved seasonal fish survival and management of disease, versus relying on traditional methods that yielded an ROI of 15%. Tilapia farming is a scalable model for sustainable urban development, food security, and income generation, with the potential to be modified for similar situations in Phayao. To characterize and benchmark aquaculture systems, stakeholders should strengthen the database for their particular features and performance, enhancing current statistical databases (Rossignoli *et al.*, 2025). Aquaculture policy and investment decisions should be based on comprehensive developments that generate data for significant species and ecosystems. Digital technologies can encourage the development of dynamic assessment tools for benchmarking the performance of systems and data accumulation. The research investigates how incentive function elements affect system efficiency, multi-target optimization methodologies, adaptive compensation functions, energy-aware control strategies, and renewable energy integration in RAS facilities (Elmessery *et al.*, 2025). It also investigates the application of modern control technologies for energy optimization and using sustainable energy sources to decrease environmental impacts. The findings of this research provide a complete understanding of significant economic and social factors that shape sustainable Tilapia aquaculture in Phayao, Thailand. From the descriptive analysis, most Tilapia farmers were middle-aged, mostly males, had a moderate level of education, and were either part-time or full-time engaged in fish farming. These demographic factors contribute to identifying how the farms would decide on a course of action, and the farms are forced to seek external innovation, ideas, or support programs. Several factors significantly impact the profitability of Tilapia farming, including farm size, access to quality feed, market connections, pond management practices, government support, and water sources. Government support, farm size, and access to commercial feed have the strongest positive effects on income levels, indicating the importance of both structural resources and institutional support for sustainability in aquaculture. Higher farm size allows for economies of scale, while feed enhances production and profitability. Farmers connected to a regional or export market can achieve better prices, thereby maximizing RoI. Government support programs and modern pond management practices significantly boost profitability, with supported farms achieving an average 25% ROI. It emphasized the importance of integrated urban aquaculture planning that exploits both internal capacities and external support in the detection of better economic outcomes. Sustainable aquaculture stands as a vital factor for regional economic growth and social development, focusing on Phayao, Thailand, because it merges environmental protection with financial progress and social harmony. The main aquaculture pursuit in the region, which is Tilapia production, supports economic targets through proper management solutions and innovative operational methods. Sustainable aquaculture practice has gained significant emphasis in recent years. Md Noor and Harun (2022) explain that proper management methods serve as critical elements to sustain aquaculture systems in the long run. Engle and van Senten (2022) confirm that community resilience, together with the regulatory environment, plays a vital role in developing sustainable aquaculture systems. According to their research, governance systems need to modify their structures to fit each place while guaranteeing local communities receive sustainable practice advantages. Laktuka *et al.,* (2023) present an investigation of sustainable aquaculture intensification through maximizing productivity without creating negative environmental effects. Phayao's Tilapia farming requires this approach since it enables local economic growth by maintaining natural resource health despite higher productivity levels. Technology integration in aquaculture serves as an approach to enhance sustainability, according to Kassem *et al.*, (2021). Modern technological systems enable better checks on water state and fish wellness and resources management, thus lowering disposal rates and enhancing operational efficiency. The authors da Silva Morales *et al.,* (2022) advocate using energy synthesis as an assessment methodology to understand aquaculture sustainability since it analyzes energy consumption and water management practices alongside waste management systems. Managing Tilapia farms in Phayao through this approach would provide vital benefits by maximizing the sustainable use of water resources. The health and welfare condition of farmed fish demonstrate vital significance in maintaining sustainability by complementing technological and management strategies. According to Rocha *et al.,* (2024), immune nutrition stands as an essential tool for improving fish health and catching performance, especially when applied to Tilapia farming. The support of fish immune systems at fish farms decreases the dependence on external ingredients such as antibiotics while making the operations more sustainable. Urban growth and sustainability are closely connected because the expansion of built-up areas impacts fish farming operations in Phayao. Alqahtani *et al.,* (2021) report that sustainable urban development faces multiple obstacles, requiring complete integration to achieve balanced growth and preservation of natural resources. Urban aquaculture integration offers pioneers a chance to simultaneously address food market security problems and city planning difficulties. Urban management is transforming digital tools and integrated modeling systems, as noted by Grotto *et al.*, (2024). Their research sheds light on how digital solutions can enhance sustainability in urban planning through digital twin technology for urban mobility management. Bennedetti *et al.,* (2023) explain that urban agriculture sustainability faces challenges, but properly integrated agricultural systems in cities can strengthen food systems. Tilapia farming in Phayao could benefit from adopting urban-based strategies to enhance food sources and sustainability levels. The sustainable development of aquaculture relies heavily on optimizing resource utilization, including energy consumption. Adibhesami *et al.,* (2023) explore how sustainable urban energy strategies can benefit urban health and well-being. Implementing sustainable energy solutions in aquaculture practices across Phayao could reduce operational costs and minimize environmental impact, thereby increasing the long-term success potential of Tilapia farming. The development of regions, including Phayao, Thailand, depends heavily on sustainable aquaculture because it provides essential support for local food stability and economic expansion through Tilapia farming activities. The latest studies on sustainable aquaculture practices provide methods to boost production levels, decrease environmental hazards, and increase social value for developing areas hosting aquaculture farms. The Phayao region can benefit from sustainable development methods within smart city platforms, as described by Yigitcanlar *et al.,* (2019), for future aquaculture development. Smart city technologies based on data management and digital infrastructure systems would enhance aquaculture operations and management practices, according to this research evidence. Such applied technologies would allow Phayao's Tilapia farms to monitor their resources, fish health, and water quality more effectively, thus enhancing operational sustainability and efficiency. Small-scale fish farming households operate as the fundamental basis to advance sustainable aquaculture practices. Research by Aung *et al.,* (2021) develops an understanding of how sustainable aquaculture practices benefit communities in Myanmar through positive changes. Small-scale fish farms can achieve higher production rates and lower operation costs after implementing advanced feed management practices, integrated pest management methods, and water quality improvement methods. The introduction of specific technologies for Tilapia farming in Phayao would strengthen local communities while creating more profitable farms that advance regional economic expansion. Majeed *et al.,* (2025) deliver an extensive study that examines freshwater macrophytes within aquaculture systems to explain their beneficial roles in water purification and nutrient management, alongside their contribution to ecological stability. The adoption of macrophytes in Phayao Tilapia farming operations provides a suitable solution to decrease aquaculture environmental effects through runoff management and water quality stabilization. This method enhances both ecological sustainability and leads to improved fish stock quality and better resource effectiveness. The approach to sustainable aquatic resource management requires interdisciplinary and transdisciplinary work according to Schiemer *et al.,* (2024). The authors demonstrate that managing inland fisheries and aquaculture systems effectively demands joint participation between numerous scientific fields, together with local community stakeholders and policy systems. A structured approach in Phayao will help stakeholders, such as farmers with environmental scientists, join forces alongside policymakers to build an enhanced, sustainable, resilient aquaculture sector. A joint working approach between stakeholders would create improved policies and resource optimization and enhance community participation in managing aquaculture operations. The investigation by Campanati *et al.,* (2021) about sustainable aquaculture intensification examines the implementation of nutrient recycling along with circular economic principles. The authors point out that sustainable aquaculture development involves waste reduction and resource reuse along with minimal environmental influence. Philippine aquaculture can achieve major environmental benefits through implementing nutrient recycling systems in Tilapia farms in Phayao, which will decrease waste output, improve water efficiency, and decrease aquaculture's ecological footprint. Local farmers experience increased long-term profitability together with sustainability through this system. The future development of aquaculture in Phayao depends strongly on uniting sustainable technologies, interdisciplinary approaches, and circular economy principles. The region will improve Tilapia farming through these strategies, which will boost productivity and economic value while preserving environmental sustainability to support local progress and regional environmental protection. The development of sustainable Tilapia farming in Phayao's region of Thailand requires multiple strategies involving practical management techniques, modern technologies, and united urban development methods. Studies suggest that Phayao should use these findings to create sustainable aquaculture models that drive economic development, protect the environment, and preserve the social well-being.

CONCLUSION

The integrated Tilapia aquaculture systems in the urban management approach of Phayao, Thailand, serve as a strategic framework to create sustainable economic and social progress. The increase in urban food localization continues to push urban management toward sustainable, intensive aquaculture of Tilapia as an adaptable food production approach that promotes sustainability, combined with food security and community empowerment. The investigation shows that all-purpose components, including farm dimensions and high-quality feed availability, together with ideal market locations and effective government assistance, determine Tilapia farming success rates. These factors influence individual farm results while maintaining community economic stability, indicating that aquaculture functions beyond agricultural operations by becoming an advanced urban development method. Data from the research shows that proper pond care combined with reliable water sources among farmers strongly influences their production levels. The study confirmed that these variables demonstrated a statistical relationship with success potentials, which demonstrates why technical education and resource planning should become essential aspects of aquaculture practice. When properly managed, Tilapia farming enables job establishment alongside reduced city food needs, which facilitates domestic security through regular, affordable protein provision for residents. The development of social betterment proves substantial through the practice of Tilapia aquaculture. The Phayao communities' benefit from aquaculture practice since it serves as a stable career path while expanding both nutritional offerings and family wealth. The model develops entry opportunities that support farmers, including marginalized groups, to start local agricultural businesses and small-scale entrepreneurship. The decentralized food production helps cities gain better control over their food systems in times of worldwide uncertainties, including supply chain disruptions and climate change. The investigation presents compelling evidence that supports the intentional suspension of Tilapia farming within urban organizational plans. Urban policymakers, together with local governments, NGOs, and community organizations, should build infrastructure that allows for the sustainable growth of aquaculture operations. For maximum success in this practice, supportive policies, infrastructure investment, training accessibility, and streamlined supply chains must all be established. The field requires future research with specified priorities to enhance the theoretical foundation and practical usability. To determine the sustained economic effects of aquaculture, research needs to follow changes over time at both the household level and the municipal level. The study of climate change interactions in aquaculture systems gains increasing significance because it affects areas that face temperature changes, along with water scarcity. Investigating the capability of urban infrastructure systems, especially water distribution and waste management systems, to handle aquaculture operations will determine their widespread potential for adoption. The understanding of market connections, along with consumer preference studies, will help companies develop products while creating their brand identity. Comparative research across various urban areas will identify flexible models of sustainable aquaculture as well as best practices that become part of a global resource base. Tilapia farming represents an essential strategic tool for urban development because it delivers food production synergistically with development advantages that enhance community resilience and sustainable urban growth in Phayao and surrounding areas.

AUTHOR CONTRIBUTIONS

W. Madhyamapurush: Conceptualization, project administration, writing—original draft preparation, supervision. N. Somyarone: Methodology development, data analysis, investigation, validation. K. Mairin: Literature review, visualization, writing, review, and editing. S. Makkhun: Data collection, fieldwork coordination, resources. K. Ratanasanguanvongs: Technical support, software development, environmental assessment. K. Seetapan: Funding acquisition, stakeholder engagement, final manuscript approval.

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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)

ANOVA	Analysis of Variance
DDPG	Deep Deterministic Policy Gradient
IMTA	Integrated Multi-Trophic Aquaculture
PEM	Proton Exchange Membrane
RAS	Recirculating Aquaculture Systems
RoI	Return on Investment
SD	Standard Deviation

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ORIGINAL RESEARCH PAPER

The role of financial technology and financial literacy in driving financial inclusion among the women workforce in the informal sector

M. Maria Vijay[1], K.T. Vijaykarthigeyan[1], M. Maria Evelyn Jucunda[2,*], D. Sivakumar[3], A. Rekhapriyadharshini[2]

[1]*Faculty of Management, SRM Institute of Science and Technology, Kattankulathur 603203, Tamil Nadu, India*

[2]*VIT Business School, Vellore Institute of Technology, Chennai 600 127, Tamil Nadu, India*

[3]*School of Agriculture and Horticulture, Kalasalingam Academy of Research and Education, Krishnankoil 626126, Tamil Nadu, India*

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ABSTRACT

BACKGROUND AND OBJECTIVES: Financial Inclusion is directly related to economic growth and is an integral factor in achieving sustainable development goals. As India plans to achieve Viksit Bharat by 2047, which calls for inclusive growth, the role of women and their participation in the economy becomes a significant factor in its achievement. Women have long been suppressed by patriarchal norms in a country like India, which prohibits them from availing formal financial services. However, with the development of financial technology, the gap between underserved populations and formal financial services can be reduced if used effectively. This study attempts to unravel the importance of urban financial advancements in driving financial inclusion of women's workforce in the informal sector.

METHODS: This study adopted a confirmatory quantitative survey method using Structural Equation Modeling to explore the mediating role of financial literacy between fintech and financial inclusion among women in Chennai's informal sector. Data were collected over eight weeks through snowball sampling, using both online and in-person surveys administered in Tamil. A structured questionnaire with a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) was used. Responses were coded by researchers, data consistency verified with an independent sample t-test, and analyses conducted using the Statistical Package for Social Sciences and Analysis of Moment Structures.

FINDINGS: The findings of the study indicate that financial technology and Financial Literacy have a significant positive impact on Financial Inclusion. The study also finds that Financial Literacy mediates the impact of financial technology on Financial Inclusion. Partial mediation exists in the relationship between financial technology, Financial Inclusion, and Financial Literacy, and the impact of financial technology on Financial Literacy is strengthened with a beta estimate of 0.481 after Financial Literacy is introduced as a mediating variable as compared to 0.347 before mediation. This suggests that financial technology can provide access to financial services, but utilization of these services effectively depends on Financial Literacy.

CONCLUSION: This study highlights the complementary roles of financial technology and literacy in advancing inclusion among women in India's informal sector. While fintech improves access to services, its impact is greater when users have financial knowledge and skills. The findings emphasize the need for integrated policies combining digital tools with financial education, supporting India's inclusive growth goals under Viksit Bharat 2047. These insights are valuable for policymakers, regulators, fintech providers, and agencies working to close gender and financial gaps.

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*Corresponding Author:
Email: *memari89@gmail.com*
Phone: +91-8838168332
ORCID: 0000-0003-2395-4969

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INTRODUCTION

Financial Inclusion (FI) is a significant tool for achieving 7 out of the 13 Sustainable Development Goals (SDGs) as per the World Bank. Success requires those who are unbanked and financially excluded to start using the formal banking system and its products and services (Barik and Sharma, 2019). Empowering women promotes gender equality, which is one of the major aims of the SDGs (Barik and Lenka, 2021). According to Sarma and Pais (2008), FI is the process of making sure that all underprivileged and marginalized people have a way to get access to inexpensive financing. The FI committee of the Reserve Bank of India (RBI) defines FI as *"access to the formal financial sector for marginalized and finance-deprived sections of society"*. Despite the efforts of the RBI, a large sector of people remains disconnected from the official financial system (Mahadeva, 2008). Unbanked individuals comprise a large segment of the global population, disproportionately impacting women and young people (UNDESA, 2021). In 2022, 1.4 billion people globally didn't have a basic bank account, which has been significantly reduced from 2.5 billion individuals in 2011. Though this might seem like a huge improvement, it has been found that most of the banked population is living in developed countries, while the majority of the unbanked population continues to live in developing countries. While 94% of the population in developed countries is banked, over 63% of the population in developing countries is unbanked. Financially excluded sections of society include farmers, unorganized workers, women, craftsmen, the self-employed, and convicts (Dev, 2006). The gender divide in FI is still a significant issue in developing countries, where more than 50% of women from poor households and the informal sector are still unbanked. In a country like India, which is rapidly approaching the status of one of the world's greatest economies, women FI play a significant role. The Indian government has established a blueprint to become a developed and empowered economy by 2047, known as 'Viksit Bharat 2047', coinciding with India's 100th anniversary of independence. One of the three pillars of 'Viksit Bharat' is women's empowerment, and a developed economy by 2047 requires inclusive development without gender parity. According to the NITI Aayog's (2022) report, the long-term development of the country depends on women's participation in the economy, their growth, and poverty reduction. In 2016, India planned to increase its Gross Domestic Product (GDP) by 0.7 trillion US dollars by bringing an additional 68 million people into the workforce. But despite this, Indian women's contribution to GDP accounts for only 17%, less than half the global average. The informal sector employs around 82% of all working women in India, accounting for 95% of women in South Asia. These women labour as street vendors, minor product and service sellers, subsistence farmers, seasonal workers, domestic helpers, and factory workers. Economic participation and contribution by women can only be achieved by the FI of these women. Most Indian women from a rural background don't hold a bank account, and even if they do, it's either dormant or operated by the men in the family. In a country like India, where men hold the upper hand in decision-making and finances of the family, it is a challenge to bring women into availing and using financial services effectively. The introduction of digital financial services through financial technology (Fintech) has enabled people, including women, to avail of financial services more effectively and easily. Among the developing countries, India is one of the countries to leverage Fintech for FI. Because of Fintech, over 80% of the people in India are banked now, and it is in the process of moving from 'having a bank account' to 'using the bank account effectively'. Fintech has been proven to increase financial awareness among women and also empower them in financial decision-making skills (Sidana *et al.,* 2023). This study examines the influence of Fintech in promoting women's FI in India's informal sector. Fintech, short for Fintech, refers to a wide spectrum of technological innovations in financial businesses like cryptocurrencies, blockchain, electronic payments, electronic transfers, virtual trading, etc., that improve or change the delivery of financial services (Philippon, 2019). Mobile connectivity has been rather more accessible and reasonably priced during the last two decades. In this context, fintech, technological advancements in the financial sector, has opened up numerous opportunities. Fintech startups typically target sectors where traditional financial institutions do not have a presence or perform poorly. In the current digitally advanced environment, fintech has the capability and capacity to democratize financial systems, remove information gaps, and digitize financial services, all the while boosting speed, efficiency, and cost-effectiveness. Thereby, digital financial services could be a great way to encourage economic growth by increasing market participation and FI. Providing access to basic financial tools it could drastically help poor people, particularly women, boost their income, improve their living conditions, and build resilience. The novelty of this research lies in its comprehensive exploration of the role of fintech and Financial Literacy (FL) in driving FI among women in the informal sector. Unlike traditional approaches that emphasize supply-side parameters (Sarma, 2008), this study shifts the focus to demand-side factors, analyzing how women actively use financial services for saving and transactions. It highlights the critical influence of FL as a driver of FI, examining its interplay with fintech to create meaningful access and utilization of financial resources. Many studies in the literature have focused on the supply-side parameters of FI (Yadav and Reddy, 2023; Singh *et al.,* 2022), but there is a lack of research that analyzes the demand-side parameters (Nandru and Rentala, 2020). Furthermore, primary data is scarcely used to analyze FI (Bhatia and Singh, 2019). FI is no longer just about owning a bank account, but about actively using it for saving and transacting (Barik and Sharma, 2019). Therefore, it is essential to measure FI using demand-side parameters and to explore the factors driving it. This study represents one of the foremost efforts to analyze the role of fintech in driving FI through primary data, capturing demand-side factors. FL is another major factor that has been highlighted in the literature. Numerous studies analyze the importance of FL (Togun *et al.,* 2022; Cole *et al.,* 2011; Huston, 2010), yet combined research on both FL and FI constitutes only about 11% of the total literature (Khan *et al.,* 2023). This research is among the first to analyze the connection between FL, fintech, and FI specifically among women in the informal sector in India. Additionally, there is a lack of in-depth and exhaustive measures in the literature to understand the factors that effectively impact and determine the FI of women in India's unorganized sector (Singh *et al.,* 2022. This study aims to set the first precedent to measure the determinants of FI for women in Southern India and to capture the role of fintech and FL in contributing to it. This research also pioneers an in-depth analysis of the determinants of FI specifically for women in the unorganized sector, setting a precedent for understanding and enhancing their economic participation in Southern India. This study attempts to unravel the significance of financial advancements and FL in driving the FI of women in India. The two main purposes of this study are

(i) To assess the impact of fintech and FL on the FI of women in the informal sector; and

(ii) To determine the role played by fintech and FL combined in driving the FI of women.

Furthermore, the significance of this research stems from three perspectives:

(i) The role of fintech in increasing FI among women while lessening gender inequality can be established.

(ii) The determinants or factors that contribute to measuring the FI of women from a demand-side perspective are identified; and

(iii) The combined effect of fintech and FL, and how these two factors complement or supplement each other in promoting FI, is measured.

Thus, to investigate the role of fintech and FL in driving FI among the women workforce in the informal sector, data were collected from Chennai City in 2024.

MATERIALS AND METHODS

This study investigates the determinants of FI, focusing specifically on FL and Fintech as key influencing variables. FL is measured through the dimensions of financial knowledge, financial skills, and financial attitudes, based on validated constructs from existing literature. Fintech is assessed using structured indicators such as accessibility, cost reduction, and ease of transactions, derived from established conceptual frameworks. A mediation model is applied to test the hypothesis that FL mediates the relationship between Fintech and FI. The model further integrates demand-side factors, including availability, affordability, ease of access, and usage of financial services, to enhance construct validity. Primary data are collected through structured surveys targeting women in the informal sector, using questionnaires translated into Tamil to ensure linguistic and cultural appropriateness. Responses are analyzed using regression techniques and mediation analysis within a Structural Equation Modeling (SEM) framework (Jucunda and Vijay, 2022). All methodological choices, including instrument design, sampling approach, and analytical procedures, are explicitly defined to enhance transparency and replicability within the Indian context.

FI of women in India

There is a notable gender gap in banking activities in almost every society. Women typically have limited ways to utilize the formal financial system's products and services. Due to factors like low assertiveness accumulation, informal and irregular income sources, difficulties with their legal identity, and low financial education, many women avoid using the formal banking system (Kunt and Klapper, 2012; Demirguc-Kunt *et al.,* 2015; Fanta *et al.*, 2016). Since men often hold the majority of the family's economic power, there is a greater likelihood of a bank account in a man's name in every family. Women also participate very little in income-generating activities in developing and less-developed nations. Women participating in fewer economic activities cannot create bank accounts in their names. States with higher proportions of female populations have been found to have lower levels of FI. The patriarchal ideals and customs of Indian society grant men greater privileges than women, and there is a dearth of research examining the hurdles to women's FI in the unorganized sector or the determinants of women's FI. Financial exclusion is Bluemore common in those who experience social exclusion (Ozili, 2020). The Global Findex Database 2014 reveals that socially avoided and stereotyped gender groups, including women, who make up 50% of the world's unbanked population, remain largely excluded from the formal banking system (Demirguc-Kunt *et al*., 2015). The issue of women and transgender people's exclusion from the formal financial system was not focused on by the researchers (Barik and Sharma, 2021). More research on the FI of women is required, as it directly impacts economic growth and development, and this study aims to address the factors that influence and determine FI, which must be understood to promote its development.

Determinants of FI

The majority of the literature has focused on measuring FI using secondary data and developing the FI index (Sarma, 2008; Sarma, 2012; Singh *et al.,* 2022). Nandru and Rentala (2020) were one of the first few studies to measure FI using demand-side parameters of the tribal groups in Andhra Pradesh. The study concluded that affordability, ease of access to banks, ease of usage of financial services, and availability of financial services are measures of FI. Nandru *et al.,* (2021) analyzed the demand side measures of FI and their impact of FI on the financial well-being of street vendors. The study considered FL, availability of financial services, affordability, accessibility, and ease of usage of financial services as determinants of FI. The results indicated that FI, which paves the way for financial well-being, can never be achieved without FL and that availability, affordability, usage, and ease of access are effective determinants of FI. Grohmann and Menkhoff (2020) argued that financial development influences FI. As per their study, the criteria for FI in developing economies may be holding a mere bank account, but for developed countries, it is the rational utilization of financial resources. Allen *et al.,* (2016) developed three regression models for three measures of FI, such as account ownership, frequency of use, and FI. Among the three regressions, the study found that greater income, good education, a small household, and a proper job were highly related to FI. Based on the extant research, this study takes four determinants of FI from the demand side, derived from the existing literature, including availability, affordability, ease of access, and usage to measure FI.

Measuring FL

Defining and accurately measuring FL is essential to studying its impact on FI. Huston (2010) summarized a broad range of accepted measures of FL. Having summarized 71 studies that discussed FL, this study found that 72% of the studies did not define FL. He identified that FL significantly impacts the financial behavior and well-being of individuals and that financial knowledge is a strong measure of FL. A study done by Togun *et al.,* (2022) found that FL is the capability to have financial product knowledge, knowledge about credit, and the financial math skills to make financial decisions. Cole *et al.,* (2011) stated that customers with basic financial knowledge will be able to make informed decisions, which is a significant part of having a good financial structure in a country. Hasan and Hoque (2021) analyzed the influence of financial knowledge on the use of financial services in Bangladesh. The study identified three ways of accessing financial services: banks, microfinance, and fintech. Using three models of financial access through probit, logit, and log-log regression models, the study found that a lack of financial knowledge acts as an obstacle to attaining financial development. The study identified that FL did have an influence, a positive one at that, on FI and insisted on the significance of financial knowledge as an influencer on FI. This study measures FL through financial knowledge, financial skills, and financial attitude as determinants.

FL and FI

Though FL and FI are independently studied in most of the literature, the joint impact of both these parameters together hasn't been given as much importance as it should have been (Khan *et al.,* 2023). The capacity to make wise financial decisions by assessing the conditions surrounding it is referred to as FL (Martinez *et al.,* 2013). Understanding financial terms is known as FL or financial education, according to Kostov *et al.,* (2015), and it is reasonable to assume that this knowledge is a prerequisite for any kind of access to financial services. Lack of FL or the inability to understand it is the primary cause of the decline in demand for access to official loan sources (Beck and Le Da Torre, 2007). The lower degree of financial knowledge is typically caused by financial exclusion (Ghosh, 2012). FL has a major impact on FI and ownership behavior, according to a study by Noor *et al*., (2020). Martinez (2016) determined FI by measuring FL as one of the factors. One key component in fostering FI is thought to be financial education (Das and Chouby, 2015). Grohmann and Menkhof (2020) analyzed the relationship between FL and FI. They examined both micro-level and cross-country evidence on FI and FL. The study found that there are three levels of FI: ownership of account, usage of account, and rational use of financial services. The study tells that the first two levels of FI are satisfactory measures for developing economies, while the third level is a factor of measure for developed economies. Further, the study finds that at the macro-level, FL has a causal effect on FI globally, while the causal effect is not proven in micro-level studies. According to Morgan and Long (2020) and Grossmann *et al.,* (2019), there is a desirable correlation between FL and FI. Thus, from the above literature references, this study concludes that *FL has a significant positive impact on FI,* which is hypothesis 1 (H1) of the study.

Fintech and FI

Morgan (2021) analyzed the role of Fintech in increasing FI. The study analyzed how well Fintech and FI correlate with each other in Association of South Asian Nations (ASEAN) member countries and India. It concluded that Fintech increases FI by reducing transaction costs, lowering the cost of business-related payments, enabling transactions without a bank account, and helping small firms access formal financial opportunities easily. Several other research articles have also shown that Fintech has a significant positive impact on FI (Kirana and Havitz, 2020; Martin *et al.,* 2021; Mutamimah and Indriastuti, 2023), but research on Fintech and FIs' relationship is still in the nascent stage. Thus, it can be stated that *'Fintech has a significant positive impact on FI,'* which is hypothesis 2 (H2) of the study.

The nexus between Fintech, FL, and FI

Research examining the effect of both fintech and FL on FI has shown mixed and contradicting evidence on their interrelationships. The academic literature is still not in consensus on how these three factors are related to each other. Marini *et al.,* (2024) analyzed the impact of FL, fintech, and FI on Micro, Small, and Medium Enterprises (MSMEs) performance in Bengkulu City using regression analysis. The study identified that FL didn't have much of an impact on FI, while fintech did have an impact on FI. Togun *et al.,* (2022) analyzed FL as a mediator between the relationship of FI and the performance of Small and Medium Enterprises (SMEs). The study was conducted on Nigerian SMEs. The study argued that the majority of SMEs in Nigeria were unbanked despite developed financial services only because their FL levels were very low. Their findings showed FL partially mediates the relationship between FI and SMEs performance Klapper and Lusardi (2020) examined FI and FL and studied their relationship and came to the conclusion that people who do not have ownership of bank accounts had lower FL levels compared with people who own accounts. Mutamimah and Indriastuti (2023) examined FL being the role of the moderator in the effect of fintech on FI in Indonesian SMEs. The findings of their study suggested that fintech cannot increase financial performance and that FL does not moderate or strengthen the bond between fintech and FI. The study attributed the findings to the weak understanding and poor use of technology in financial products and services among Indonesian SMEs. Kirana and Havitz (2020) examined the validity of FL and fintech as determinants of FI in Indonesia.

The study identified Financial Attitude (FA), Financial Skill (FS), and Financial Knowledge (FK) as indicators of FL, and two variables of the Technology Acceptance Model (TAM) as indicators of fintech. Using multiple regression on the data collected from 100 respondents, the study found that, except for financial attitudes, all the other independent variables were significant and that the increase in FL and the increase in using mobile phones for payment in turn increase FI. Martini *et al.,* (2021) analyzed the moderating impact of FL in the relationship between fintech and FI in Indonesia. The paper substitutes variables from the TAM model as indicators of fintech, and FL was tested as a moderator to determine if it strengthened the relationship between FI and fintech. Collecting primary data from 8 districts of Lubuklinggau, PLS analyses were employed to analyze the direct and indirect relationship between the variables. The results suggested that FL was able to impact the perception of ease of use and reduced risk in fintech (two indicators out of 4 tested for fintech). However, one of the unique findings of the study is that as FL grew among people, their interest in the usage of fintech reduced, and they started to use more selective plans. From the extensive literature, it can be seen that FL has been used as a moderator or a mediator in the relationship between fintech and FI. Most of the studies that have used FL as a moderator have concluded that it couldn't moderate the relationship, whereas studies that have used FL as a mediator have found it to be an effective mediator between fintech and FL. However, it could be said that the relationship between fintech and FI may be stronger in the presence of FL. Thus, the authors state the third hypothesis (H3) as *'FL mediates the relationship between Fintech and FI.'* The conceptual framework between Fintech, FL, and FI is presented in Fig. 1. From Fig. 1, it can be seen that there are interrelationships between FL and FI, with various factors influencing both. Hypotheses H1 and H3 serve as connecting elements between FL and FI, suggesting that improving FL can enhance FI. Hypothesis H2 bridges the gap between Fintech and FI, highlighting the role of technological advancements in promoting inclusion. Additionally, FA, FS, and FK are key factors related to FL, emphasizing the importance of accessibility, services, and knowledge in improving FL. Meanwhile, availability, ease of access, and usage affordability are crucial components of FI, ensuring that financial services are accessible, affordable, and usable by underserved populations. Together, these factors demonstrate how FL and inclusion are

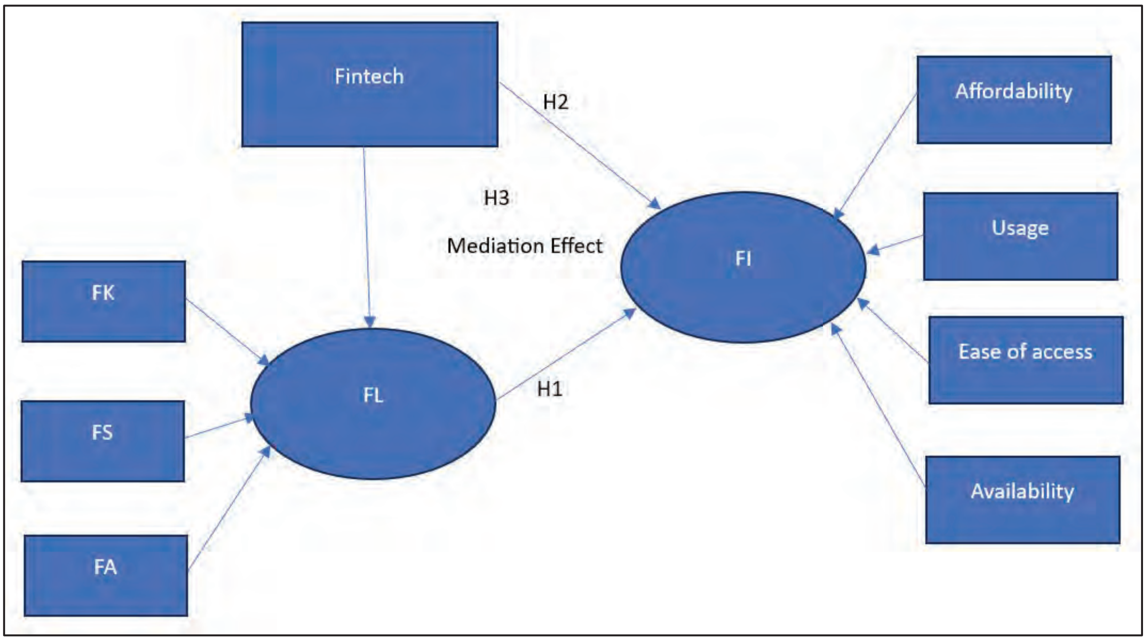

Fig. 1: Conceptual framework

interconnected and influenced by both traditional and technological elements. Fig. 1 concludes that improving FL can enhance FI, with technological advancements in Fintech playing a key role in bridging the gap between them. Factors such as accessibility, services, and knowledge are critical for FL, while availability, ease of access, and affordability are essential for ensuring FI. This visual framework underscores how both traditional and technological elements are interdependent in promoting FL and inclusion.

Conceptual foundation

Building on this conceptual framework**,** the research questions in this study are anchored in a structure that interrelates FI, FL, and fintech. Prior studies emphasize that FI is a critical component of sustainable economic development and directly contributes to SDGs, particularly SDG 5 (Gender Equality) and SDG 10 (Reduced Inequalities). Although fintech has emerged as a tool for improving access to financial services, especially among underserved populations, its true impact is contingent upon users' financial capabilities. This study builds on the premise that FL is not merely a complementary skill but a mediating factor that determines whether fintech adoption leads to meaningful financial inclusion. Therefore, the research questions are framed to explore the strength and nature of these interdependencies, particularly how FL mediates the relationship between fintech and FI.

Empirical evidence

Empirically, the study identifies a noticeable gap in the existing literature concerning demand-side determinants of FI, especially within marginalized communities such as women in India's informal workforce. While fintech's potential to expand financial access has been extensively acknowledged, the role of FL in enabling users to effectively navigate and utilize these digital financial tools has not received equivalent scholarly attention. Most previous research either overlooks the interaction between fintech and FL or focuses primarily on supply-side factors like infrastructure and policy. The current study addresses this gap by empirically testing whether FL enhances the effectiveness of fintech in promoting FI, with a specific focus on women in Chennai's informal sector.

Contextual relevance

The formulation of the research questions is also deeply informed by the socio-economic and geographic context of the study. In India, a significant portion of the female labour force remains engaged in the informal sector, where access within formal financial systems continues facing structural and cultural barriers. Urban centers such as Chennai, with high levels of informal employment among women, present a critical opportunity in examining how digital financial tools economically empower women. The success of fintech in this environment depends not only on its availability but also on the end-users' financial understanding and engagement with available tools. Investigating how FL enables women in this sector to fully benefit from fintech solutions allows the study to contribute actionable insights that support inclusive economic development and align with India's broader vision under initiatives such as Viksit Bharat 2047.

Survey design and data collection

The study employed a confirmatory quantitative research method using SEM. A structured questionnaire was used in this study to collect data, with both computer-based and in-person surveys conducted in Chennai to test and verify the hypothesis. In India, 94% of the women are employed in the informal sector, and that is why the authors chose women in the unorganized sector for the study. More than 57% of the workers in the Mahatma Gandhi National Rural Employment Guarantee Scheme are women, and about 70% of India's domestic workers are women (National Commission for Women, 2024). Also, Chennai is a place where women from all over Tamil Nadu come to work as domestic workers in households and organizations. That is the reason to choose Chennai, as it'll be a representation of both urban India and also a representation of women all over the state. The questionnaires were framed using A Likert scale with responses from 1 to 5, where 1 is 'strongly disagree' and 5 is 'strongly agree'. The respondents were given each question in their native language, Tamil, and answers were coded by the researcher. The research was conducted in the Chennai area, and the snowball sampling method was used by the researchers to reach a wide range of women employed in different informal sectors. The authors, along with students and scholars, circulated the questionnaire to friends and family, requesting them to gather data from women workers in their households, nearby shops, roadside vendors, community workers, etc., for over 8 weeks. Since both paper-pencil and online methods of data collection were employed, an independent sample t-test was run to verify the procedures. The effect sizes are regarded as inconsequential when they are smaller than 0.3 (Cohen, 1992). As a result, the techniques used to obtain the data were the same.

Measurement

The study's measurement variables were drawn from earlier research publications. The "FL" measurement scale items are taken from Rastogi and Ragabiruntha (2018) and Noor *et al.,* (2020), which were further divided into three sub-dimensions: financial skill, financial knowledge, and financial attitude. The metrics for "usage" (Salathia, 2015), "accessibility" (Bongomin *et al.,* 2020), "affordability", "availability", and "FI" (Salathia and Androtra, 2015) are drawn from research studies. The metrics for measuring fintech were developed and referenced from the Asian Economic Policy Review (Morgan, 2021).

RESULTS AND DISCUSSIONS

The data screening process identified and removed 25 outliers, yielding 302 valid responses. EFA confirmed unidimensionality with acceptable factor loadings and reliability (Cronbach's alpha > 0.7). Sampling adequacy was supported (KMO = 0.813), and no multicollinearity issues were found (VIF < 10). CFA validated the measurement model, ensuring construct reliability. SEM then assessed direct and indirect relationships, supporting the proposed hypotheses.

Data screening

Examining the role of financial technology and financial literacy in driving financial inclusion among women in the workforce within the informal sector, the authors began by identifying anomalies within the collected data through a rigorous screening process. This initial step ensured data integrity and reliability, which is crucial when analyzing financial behavior among underserved populations. Exploratory Factor Analysis (EFA) verified that the selected components, such as financial technology adoption, financial literacy levels, and financial inclusion indicators, were unidimensional and statistically sound. Analysis of Moment Structures (AMOS), version 22.0, tested the proposed model through a two-stage SEM approach (Anderson and Gerbing, 1988), ensuring that the relationships among key variables were accurately assessed. At this stage, the validity and reliability of the measurement scales were evaluated through Confirmatory Factor Analysis (CFA), ensuring that the constructs accurately captured financial literacy, technology usage, and inclusion levels among women within the informal workforce. A structural model analyzed both direct and indirect relationships, shedding light on how financial technology and literacy interact, influencing financial inclusion outcomes among women within the informal economy.

Data analysis

Identifying univariate outliers involved the use of standardized values (z-scores) and box plots, ensuring that extreme data points did not distort the analysis of financial technology adoption, financial literacy levels, and financial inclusion among women in the informal sector. Mahanobis' distance was applied to detect multivariate outliers, addressing anomalies that could affect the relationships among key variables (Hair *et al.,* 2010). Through this process, 25 outliers were identified and removed, refining the dataset for more accurate and reliable results. As a result, 302 valid responses were retained, providing a robust foundation for examining how financial literacy and technology contribute to financial inclusion for women in the informal workforce.

EFA

The factors of the questionnaire were measured using the Likert scale. The fifty-five items in the questionnaire have been tested for standardization and factor loadings using principal component analysis and varimax rotation with EFA. All the factor loadings were between 0.592 and 0.883. Cronbach's alpha test was used to test for reliability, and in all the constructs, the values were in the range of 0.7 to 0.913 and were above the accepted threshold level of 0.7 (Hair *et al.,* 2010). The results of the EFA are presented in Table 1. Bartlett's test of sphericity requires a sampling adequacy of 0.6 (Haridasan *et al.,* 2021), and the EFA analysis provided a KMO

Table 1: Factors influencing FI among women in the informal sector: availability, accessibility, affordability, usage, FL, and fintech adoption

Factor	Items/Statement	Loadings	Eigen Value	% of Variance Explained	Cronbach Alpha	Mean	SD
Availability (Nandru and Rentala, 2020)	My bank branch is very close to my home	0.761	11.265	21.255	0.700	3.377	0.669
	ATM is very close to my home	0.780					
	The post office is very close to my home	0.760					
	SHG’s loans are available	0.739					
	My bank employees are very helpful in explaining the products and services	0.632					
	My bank has locker facilities	0.65					
	Availability of No frills	0.709					
	Bank branch providing credit facility counseling	0.714					
Ease of Access (Nandru and Rentala, 2020)	I can easily avail myself of bank loans through SBLP	0.785	5.14	9.698	0.818	3.158	0.856
	I can easily open a bank account through the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS)	0.684					
	I can very easily open a bank account through SBLP	0.794					
	I can avail of a house loan easily if I want	0.747					
	Not many documents are required for opening bank accounts	0.763					
	I can easily avail of a gold loan	0.775					
Affordability (Nandru and Rentala, 2020)	I can afford the interest rate on SHG loans	0.742	4.075	7.69	0.875	3.505	0.848
	I can afford the interest rate on a vehicle loan	0.742					
	I can afford the interest rate on a gold loan	0.792					
	I don’t have to spend much to open a bank account, and it is affordable for me	0.712					
	The charges for availing bank facilities are not too much	0.753					
	I can have a bank account with a zero balance	0.786					
	The fee charged for the usage of a debit or credit card is minimal	0.723					
Usage (Nandru and Rentala, 2020)	I save money in the bank constantly	0.576	3.904	7.366	0.799	3.249	0.771
	I often visit bank branches to withdraw money	0.698					
	My bank has locker facilities, and I use them	0.583					
	I often withdraw money from ATMs using a debit card	0.719					
	I got a crop loan through my bank account	0.673					
	I often visit my bank to transfer money	0.777					
	I use a bank account to receive wages under the scheme of MGNREGS	0.773					
	I visit my bank branch regularly for repayment of the loan amount	0.665					
	I use bank accounts to avail of the SHG loan	0.712					

Continued Table 1: Factors influencing FI among women in the informal sector: availability, accessibility, affordability, usage, FL, and fintech adoption

Factor	Items/Statement	Loadings	Eigen Value	% of Variance Explained	Cronbach Alpha	Mean	SD
Financial Knowledge (Noor *et al.*, 2020; Rastogi and Ragabiruntha, 2018)	I'm aware of the various schemes like PMDJY, Atal Pension Schemes, Mudra Scheme, etc.	0.673	2.959	5.583	0.813	3.475	0.886
	I can understand the scheme and its structure	0.769					
	I'm aware of the basic interest rate calculations of those schemes	0.792					
	I'm able to understand the concept of inflation and how it affects the interest rates	0.748					
	I know the importance of saving in my daily life	0.782					
	I know how to manage my income and allot money for savings	0.780					
Financial Skills (Noor *et al.*, 2020; Rastogi and Ragabiruntha, 2018)	I can make interest rate calculations on my own	0.592	2.158	4.072	0.814	4.050	0.680
	I can add, subtract, divide, and multiply numbers	0.689					
	I can fill out my application form when opening an account	0.797					
	I can identify numbers and understand how much they are	0.71					
	I know the difference between compound interest and simple interest	0.736					
Financial Attitude (Noor *et al.*, 2020; Rastogi and Ragabiruntha, 2018)	I need savings to be an integral part of my life.	0.735	2.054	3.876	0.79	4.190	0.691
	Minimizing expenditure and maximizing savings is good for my family and me.	0.833					
	Save today for a better tomorrow.	0.73					
	I want to learn more about personal finance	0.729					
Fintech (Morgan, 2021)	I use Fintech every day for my financial transactions.	0.671	1.568	2.959	0.913	3.607	0.824
	My transaction cost of business-related payments is reduced because of fintech use compared to other types of payments, such as credit cards.	0.738					
	I can use Fintech without having a bank account.	0.629					
	I need not visit banks or ATMs for any transactions, which makes using fintech more advantageous.	0.68					
	Being in the informal sector, fintech enables me to engage in e-commerce easily.	0.688					
	Fintech makes credit facilities more obtainable and the process transparent.	0.722					
	I learned about various financial products and schemes through fintech.	0.658					
	I'm aware of financial products (eg, Cryptocurrency, ETF, SGB, etc.)	0.689					
	Fintech helps me use banking products and services more effectively	0.755					

(Kaiser-Meyer-Olkin) value of 0.813, which is above the needed sampling adequacy. The total variance extracted for the seven constructs was 62.44%, and the eigenvalues met the threshold criteria. No deviation was observed from the structure of the adapted constructs, as all the items load 0.6 or higher on the hypothesized factor (Hair *et al.,* 2016). A test of multicollinearity was done using VIF (Variation Inflation Factor), and the values ranged from 1.303 to 1.826, which were below the recommended critical value of 10 (Hair *et al.,* 1992).

Table 1 explores the influence of fintech and FL on FI among women in the informal sector across multiple dimensions, including availability, accessibility, affordability, usage, financial knowledge, financial skills, financial attitude, and fintech adoption. The findings align with and expand upon prior research, particularly studies by Nandru and Rentala (2020), Noor *et al.*, (2020), Rastogi and Ragabiruntha (2018), and Morgan (2021). The comparative analysis provides insights into how these results corroborate or diverge from previous findings.

i. Availability of financial services and fintech integration: Nandru and Rentala (2020) emphasized that the physical presence of financial institutions plays a crucial role in FI. Access to bank branches, ATMs, and Self-Help Group (SHG) loans significantly influences financial participation. The findings confirm this, with factor loadings highlighting bank accessibility (0.761), ATM availability (0.780), and SHG loans (0.739) as key contributors. While earlier studies focused on traditional banking infrastructure, this research underscores the growing role of fintech in bridging accessibility gaps, especially in remote areas with limited banking facilities.

ii. Ease of access and simplification of financial processes: The ease of accessing financial services is a significant driver of FI, with simplified banking processes such as SHG-Bank Linkage Programs (SBLP) and MGNREGS reducing procedural barriers (Nandru and Rentala 2020). The study confirms that ease in opening bank accounts (0.684) and obtaining loans (0.785) positively influences financial participation. Minimal documentation requirements (0.763) further encourage financial engagement. While previous studies focused on traditional banking, this research highlights fintech's role in streamlining financial transactions, reducing dependency on physical banking infrastructure, and enhancing accessibility.

iii. Affordability and cost-effectiveness of financial services: Affordability remains a crucial determinant of FI, with access to low-cost financial services increasing participation (Nandru and Rentala 2020). The findings confirm this, with significant factor loadings for affordable SHG loans (0.742), vehicle loans (0.742), and gold loans (0.792). Maintaining a low-cost bank account (0.712) encourages financial engagement. While earlier research focused on affordability within traditional banking, these results highlight fintech's role in reducing transaction costs (0.738), enhancing financial accessibility, and expanding credit options for women in the informal sector.

iv. Usage patterns and digital financial transactions: Active engagement in financial services is key to FI, as frequent savings, withdrawals, and loan repayments indicate deeper financial involvement (Nandru and Rentala 2020). The findings confirm that women actively save in banks (0.576), withdraw from ATMs (0.719), and utilize accounts for government scheme payments such as MGNREGS (0.773). Unlike previous studies that focused on traditional banking transactions, this research highlights fintech's growing role in facilitating digital financial transactions (0.680), reducing dependency on brick-and-mortar banking, and enhancing financial participation.

v. Financial knowledge and awareness of digital financial tools: FL is critical to FI, as knowledge of government schemes, interest rate calculations, and inflation concepts helps individuals make informed financial decisions (Noor *et al.,* 2020, and Rastogi and Ragabiruntha, 2018). The findings validate this, showing that awareness of government schemes (0.673), financial concepts (0.769), and savings management (0.780) significantly influence FI. While previous research emphasized traditional FL, this study extends its scope by demonstrating fintech's role in financial education. Exposure to digital financial products such as cryptocurrency and ETFs (0.689) suggests that fintech platforms act as both financial service providers and educational tools.

vi. Financial skills and technology-enabled financial management: Financial skills, such as performing interest calculations and completing application forms, are essential for financial independence (Noor *et al.,* 2020, and Rastogi and Ragabiruntha, 2018). The study confirms the importance of arithmetic skills (0.689) and proficiency in completing financial applications (0.797) in improving financial participation. Unlike earlier studies, these findings highlight fintech's role in simplifying financial management for individuals with lower financial skills. Digital platforms enable users to access financial services without requiring advanced numerical proficiency, promoting greater financial engagement among women in the informal workforce.

vii. Financial attitude and proactive financial behavior: A proactive approach to saving and financial planning significantly influences FI (Noor *et al.,* 2020, and Rastogi and Ragabiruntha, 2018). The findings confirm that a strong inclination toward saving (0.735) and minimizing expenditure (0.833) contribute to financial participation. Fintech platforms further encourage financial awareness, as the desire to learn about personal finance (0.729) is positively influenced by digital financial resources. Unlike previous research that primarily focused on behavioral aspects of saving, this study suggests that fintech not only facilitates transactions but also fosters positive financial habits.

viii. Fintech as a catalyst for FI: Fintech is recognized as a critical enabler of FI due to its ability to reduce transaction costs, improve credit accessibility, and enhance FL (Morgan 2021). The findings strongly support this, showing the positive impact of fintech on daily transactions (0.671), cost reduction (0.738), and credit accessibility (0.722). Previous studies established that fintech benefits individuals without traditional bank accounts (Morgan 2021). This research confirms that women in the informal sector can access fintech services without conventional banking infrastructure (0.629). Additionally, fintech platforms serve as financial education tools, improving knowledge about financial products such as cryptocurrency and ETFs (0.689) and enhancing financial decision-making capabilities.

The findings confirm and expand upon prior research, demonstrating that fintech and FL play pivotal roles in FI among women in the informal sector. While conventional factors such as availability, affordability, and financial knowledge remain influential, fintech introduces new opportunities for digital inclusion, cost reduction, and financial education. Enhancing fintech accessibility and promoting FL will be crucial in fostering greater financial participation among women in the informal workforce.

Hypothesis testing

The authors used CFA to evaluate the degree to which the measurement is consistent with the real and actual. CFA allows the examination of the fit indices and parameter estimates. SEM in CFA illustrating relationships among latent and observed variables in the context of fintech is presented in Fig. 2. The model includes FL as a latent variable, comprising financial knowledge, skills, and attitude, and FI, which includes usage, affordability, ease of access, and availability. Arrows indicate relationships between variables, with path coefficients such as financial knowledge to financial literacy (3.18) and financial literacy to fintech adoption (3.62). Error terms associated with observed variables (e1 to e7) indicate unexplained variances, such as e1 (0, 0.60), while covariances between latent variables, such as financial literacy and financial inclusion (0.12), are represented by curved arrows. The model visually captures the interactions between financial literacy, financial inclusion, and fintech usage, offering insights into the strength and direction of these relationships. The CFA results support the model's fit. The chi-square value (χ^2) was 69.659 with 15 degrees of freedom (df), and a significance level of $p = 0.000$. Fit indices included a Comparative Fit Index (CFI) of 0.914, a chi-square to degrees of freedom ratio (χ^2/df) of 4.644, a Tucker-Lewis Index (TLI) of 0.840, a Normed Fit Index (NFI) of 0.90, and a Root Mean Square Error of Approximation (RMSEA) of 0.111. The chi-square value indicates that the model effectively represents the data, with widely accepted fit indices confirming overall model adequacy.

After confirming the fit of the measurement model using CFA, a structural model was tested using SEM. The SEM, which reveals the complex relationships between financial literacy, financial inclusion, and Fintech adoption, is presented in Fig. 3. Financial Knowledge, Skills, and Attitude significantly enhance Financial Literacy (path coefficients: 3.18, 3.63, and 4.27, respectively), which in turn strongly influences Fintech adoption (3.62). Financial Inclusion also impacts Fintech adoption (1.45), though to a lesser extent. The error terms for observed variables (e1 to e7) indicate the unexplained variances, such as e1 (0, 0.60). Positive covariances between latent

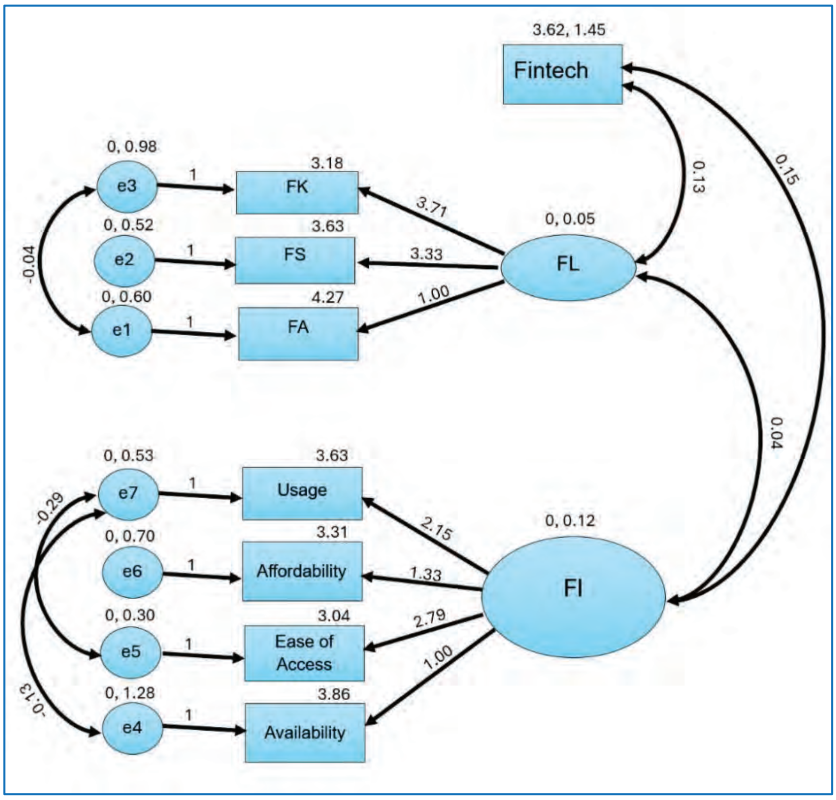

Fig. 2: CFA

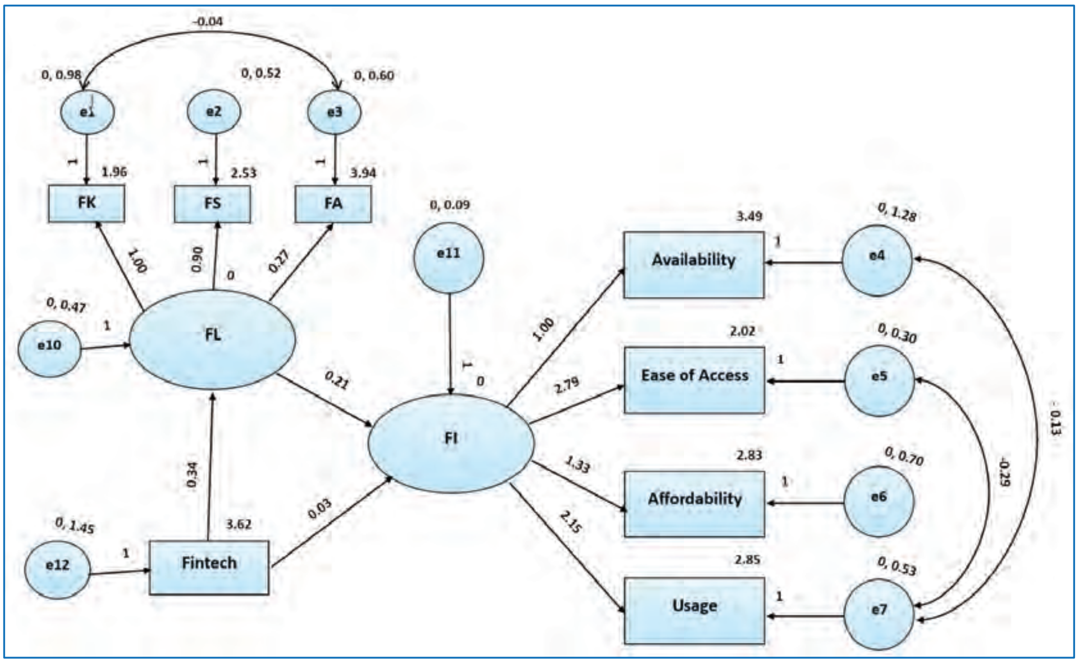

Fig. 3: SEM

Table 2: Impact of Fintech and FL on FI hypothesis testing

Hypothesis	Independent Variable	Dependent Variable	Estimate	p-value
H1	Fintech	FI	0.347	0.001
H2	FL	FI	0.457	0.001
H3	Fintech (after introducing the mediating variable)	FI	0.481	0.001

variables, such as FL and FI (0.12), highlight their interrelationships. The results suggest that improving financial knowledge, skills, and attitudes is crucial for promoting Fintech adoption, with financial literacy playing a more pivotal role than financial inclusion. Policymakers and educators should focus on financial education programs to enhance financial literacy, thereby fostering greater Fintech usage. This model offers valuable insights for understanding the dynamics of financial behaviors and outcomes.

The measurement model's fit indices results are as follows: χ^2 value = 69.659 with 15 degrees of freedom ($\chi^2/df = 4.644$, $p = 0.000$), Comparative Fit Index (CFI) = 0.914, Non-Normed Fit Index (NFI) = 0.90, Tucker-Lewis Index (TLI) = 0.840, and Root Mean Square Error of Approximation (RMSEA) = 0.111. The chi-square value indicates that the model is adequately fit, showing no significant difference between the observed and measured model covariance matrices. The widely accepted fit indices confirm the model's overall fit, supporting its reliability in assessing financial inclusion. Fig. 2 demonstrates strong factor loadings, with financial knowledge at 1.51, financial skills at 0.97, financial attitude at 1.00, ease of access at 1.31, usage at 0.99, affordability at 0.90, and availability at 1.00, indicating strong relationships between these constructs and financial inclusion. According to Hu and Bentler (1999) and Haridasan *et al.,* (2021), Modification Indices (MI) and parameter changes (Par change) were examined to assess whether the equality constraints were violated, and results confirmed that all factor loadings remained stable. This suggests that the hypothesized relationships between constructs were well-defined, without the need for additional modifications to the model. To estimate parameters, the Maximum Likelihood (ML) method was applied due to its efficiency and robustness under the assumption of multivariate normality. This approach ensures that unique values are generated for free parameters, improving model precision and reliability. The SEM results confirm that financial literacy and fintech adoption significantly contribute to financial inclusion among women in the informal sector, with strong factor loadings indicating the critical role of financial knowledge, skills, attitudes, and access to digital financial services.

Table 2 presents the results of hypothesis testing, demonstrating the relationships between fintech, financial literacy, and financial inclusion among women in the informal sector. The findings indicate that fintech significantly influences financial inclusion ($\beta = 0.347$, $p = 0.001$), supporting the premise that digital financial services improve access to financial resources. Financial literacy also has a strong positive impact on financial inclusion ($\beta = 0.457$, $p = 0.001$), highlighting the critical role of financial knowledge, skills, and attitudes in enabling women to engage with financial services effectively. The introduction of financial literacy as a mediating variable further strengthens the impact of fintech on financial inclusion, with the beta coefficient increasing from 0.347 to 0.481. This suggests partial mediation, meaning that fintech enhances financial inclusion both directly and indirectly through its influence on financial literacy. These results emphasize that while fintech provides digital access to financial services, its effectiveness in promoting financial inclusion is maximized when individuals possess adequate financial literacy. Women in the informal sector often face barriers such as a lack of formal banking access, low digital literacy, and limited awareness of financial products.

The study underscores that simply introducing digital financial services is insufficient; financial literacy initiatives must accompany fintech expansion to ensure meaningful financial inclusion. Policymakers and financial institutions should focus on developing programs that enhance financial literacy while promoting fintech solutions. This can include digital training programs, simplified user interfaces, financial applications, and targeted awareness campaigns. Strengthening financial literacy enables women in the informal sector to better navigate digital financial services, leading to greater financial independence, improved savings behavior, and enhanced economic security. The results affirm that fintech, when combined with financial literacy, serves as a powerful driver of financial inclusion, enabling women to participate more actively in the financial ecosystem. The study analyzed the significance and relationships among fintech, FL, and FI among women in the informal sector in Southern India. Measurement scales were developed from existing literature, and EFA was used to standardize constructs. Cronbach's alpha test confirmed reliability, and SEM was applied to test hypotheses. Findings highlight the critical role of fintech and FL in promoting FI. Consistent with previous studies (Martinez *et al.,* 2013; Kostov *et al.,* 2015), FL emerged as a significant determinant of FI among women in the unorganized sector in India. Higher financial knowledge enables informed financial decision-making (Lusardi and Mitchell, 2014). This is particularly important among women, where limited access to traditional banking services directly affects financial participation (Lyons and Kass-Hanna, 2021). The positive influence of fintech on FI aligns with existing literature (Morgan and Long, 2020; Mutamimah and Indriastuti, 2023; Martini *et al.,* 2021; Kirana and Havitz, 2020), reinforcing the role of technology-driven financial services in bridging access gaps. Digital financial platforms reduce barriers to entry, lower transactional and operational costs, and provide accessible services, even without conventional bank accounts (Arner *et al.,* 2016). However, findings indicate that FL mediates the relationship between FI and fintech. This underscores FL as a prerequisite for effectively leveraging fintech to achieve FI (Kirana and Havitz, 2020; Marini *et al.,* 2024; Martini *et al.,* 2021). Without adequate financial knowledge, fintech alone cannot ensure inclusion, as access to financial services must be complemented by the ability to navigate and utilize them effectively. Policy implications emphasize the need for prioritizing FL initiatives within FI strategies. Policymakers should design targeted financial education programs for women in the informal sector, addressing specific financial challenges to enhance confidence and capability in accessing financial services (OECD, 2017). Government initiatives on FL remain largely channeled through non-governmental organizations (NGOs) to reach rural populations, highlighting the necessity of focusing on educational measures rather than merely introducing new FI schemes. FL plays a crucial role in achieving SDGs, particularly SDG 4 (quality education), SDG 5 (gender equality), and SDG 8 (decent work and economic growth). Raising awareness among women in the informal sector about FL can improve financial management and decision-making. Developing fintech solutions tailored to the needs of women requires regulatory bodies to foster an enabling environment. Many women entrepreneurs in the informal sector face difficulties accessing formal credit due to digital platforms not being available in regional languages. Addressing such barriers can enhance inclusion within the financial system. Beyond language accessibility, tackling gender disparities remains essential to ensuring equitable access to financial services. Fintech companies can integrate FL into their platforms through interactive tutorials and advisory features, enabling women to make informed financial decisions (Desello and Agner, 2023; Zins and Weill, 2016). Designing inclusive financial products aligns with the broader goal of enhancing accessibility and usability. Collaboration among fintech firms, educational institutions, and non-profit organizations can create synergistic effects, leveraging collective expertise and resources to expand FL and inclusion. Policymakers can further support FI through community-based initiatives that bring together women in the informal sector, investing in research that identifies their specific financial needs and tailoring policies accordingly. Expanding FL and ensuring inclusive digital financial services can contribute to reducing economic disparities, empowering women, and fostering sustainable financial participation.

Recommendations

This study highlights the crucial role of FL and fintech in enhancing FI among women in the informal sector. To bridge existing gaps and ensure effective financial participation, the following recommendations are proposed:

i. *Enhance FL programs:* Policymakers should implement targeted financial education initiatives focusing on digital transactions, savings, and financial decision-making.
ii. *Integrate FL in fintech solutions:* Fintech companies should embed educational tools, tutorials, and personalized financial advice into their platforms to improve user understanding and engagement.

iii. *Develop inclusive fintech solutions:* Regulatory bodies should mandate the development of fintech products in regional languages with simplified interfaces to improve accessibility for women with low digital literacy.
iv. *Address barriers to FI:* Governments and financial institutions should conduct awareness campaigns and introduce simplified digital onboarding processes to eliminate socio-cultural and technological barriers.
v. *Strengthen public-private partnerships:* Collaboration between fintech firms, government agencies, and NGOs can create comprehensive FI strategies tailored to the needs of women in the informal workforce.
vi. *Monitor and evaluate FI initiatives:* Regular assessment of FL and fintech adoption programs will help refine policies and ensure long-term financial empowerment.

Future scope of the study

The role of fintech and FL in driving FI among women in the informal sector remains a crucial area of study, particularly in urban regions like Chennai, where a significant portion of the female workforce is engaged in informal employment as domestic workers, street vendors, and cleaners. While FI has been widely studied in India, limited research has focused on demand-side factors and the specific challenges faced by vulnerable groups such as women, senior citizens, transgender individuals, and persons with disabilities. This study highlights the importance of fintech and FL as key drivers of FI and establishes FL as a mediating factor in the relationship between fintech and FI. The findings emphasize that while fintech enhances access to financial services, its effectiveness depends on FL, which enables individuals to utilize digital financial tools efficiently. Despite the introduction of several government schemes promoting FI, their impact remains limited without adequate financial education. Therefore, future research should explore additional dimensions influencing FI, addressing behavioral aspects, barriers, and the long-term effects of fintech adoption. Future research directions include:

i. *Financial attitude and decision-making:* Investigating how financial attitudes among women in the informal sector influence their financial decisions. Understanding behavioral factors, cultural perceptions, and economic constraints can provide insights into designing more effective FL programs.
ii. *Barriers to FI:* Identifying and analyzing obstacles such as digital illiteracy, lack of access to financial services, socio-cultural constraints, and regulatory limitations. Exploring how fintech solutions can overcome these barriers will help in tailoring financial products to meet the needs of women in the informal workforce.
iii. *Impact of FL initiatives:* Evaluating the effectiveness of FL programs, particularly those focused on digital finance, mobile banking, and digital payment systems. Research should assess how these initiatives enhance women's ability to access and use financial services effectively.
iv. *Sustainability and long-term effects:* Conducting longitudinal studies to examine the sustained impact of fintech adoption and FL programs on FI. Comparative studies across different demographic groups and geographic regions can provide a broader perspective on financial behavior and inclusion strategies.
v. *Integration of FL in fintech platforms:* Exploring ways fintech companies can embed FL tools into their platforms. Features such as interactive tutorials, financial decision-making guidance, and AI-driven financial assistance could empower women to navigate financial services more effectively.

Addressing these research gaps, future studies can contribute to a more inclusive financial ecosystem, ensuring sustainable economic empowerment for women in the informal sector.

CONCLUSIONS

Finance constitutes a foundational element of any national economy, with increasing relevance as global systems transition toward sustainability. FI serves as a cornerstone of sustainable financial development, directly supporting SDGs such as SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth). The financial inclusion of women further aligns with SDG 5 (Gender Equality) and SDG 10 (Reduced Inequalities). The advent of fintech has introduced transformative mechanisms for enhancing access to FS, contributing to SDG 9 (Industry, Innovation, and Infrastructure). This study evaluates the integrated impact of fintech and FL on advancing FI among the female workforce engaged in Chennai's urban informal sector. Urban FM among women remains a critical area of inquiry due to their substantial contributions to national economic development. Chennai comprises a significant concentration of informal women workers, including domestic workers, street vendors, and cleaners, who frequently remain excluded from formal financial systems. Although previous studies have examined FI within India, limited research addresses demand-side determinants or focuses on marginalized groups such as women, senior citizens, transgender individuals, and persons with disabilities. The present study emphasizes the synergistic role of fintech and FL in improving FI among women in the unorganized sectors. Data were collected from women employed in the informal sector using snowball sampling, and a structured questionnaire was administered. SEM was employed to test the proposed hypotheses. Findings reveal that both fintech and FL exert statistically significant positive effects on FI. A key result demonstrates that FL functions as a mediating variable in the relationship between fintech and FI. Thus, even comprehensive financial schemes introduced through government initiatives may yield limited impact in the absence of adequate FL. Policy efforts should extend beyond the creation of schemes toward establishing comprehensive FL interventions. This study contributes to existing literature by identifying FL as a frequently overlooked determinant of effective FI. Despite increasing fintech adoption, FL remains a prerequisite for realizing inclusive outcomes. The findings underscore the necessity for policymakers, regulatory authorities, and fintech providers to prioritize financial literacy centers and structured empowerment programs targeting women. Enhanced financial awareness enables women to more effectively utilize and benefit from digital financial instruments. The study introduces a novel direction in academic discourse by addressing the limited understanding of the interdependencies among fintech, FL, and FI. A theoretical contribution is offered through a custom-designed questionnaire based on India-specific fintech constructs, advancing beyond the commonly used TAM. The study holds significant implications for policymakers, regulatory bodies, financial institutions, and fintech enterprises. Future research may further investigate the influence of financial attitude among women and associated socioeconomic and behavioral determinants. Findings reaffirm that fintech may support FI only in the presence of adequate FL. While this study focused on establishing relationships among key constructs, future research should explore barriers to financial inclusion and examine how fintech innovations may address these challenges across women in the informal sector.

AUTHOR CONTRIBUTIONS

Mr. Maria Vijay contributed to the introduction and analysis section of the paper. Dr. Maria Evelyn Jucunda contributed to the theory, hypothesis development, and data collection. Dr. Rekhapriyadharshini contributed to the hypothesis testing and methodology section. Dr. Sivakumar provided overall supervision of the research. Dr. Vijay Karthigeyan contributed to the final proofreading and corrections.

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CONFLICT OF INTEREST

The authors declare that there are no conflict 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.

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)

AMOS	Analysis of Moment Structures
ASEAN	Association of South Asian Nations
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
EFA	Exploratory Factor Analysis
FA	Financial Attitude
FI	Financial Inclusion
FIN	Fintech
FK	Financial Knowledge
FL	Financial Literacy
FS	Financial Skill
GDP	Gross Domestic Product
ILO	International Labor Organization
KMO	Kaiser Mayer Olkin
MGNREG	Mahatma Gandhi National Rural Employment Guarantee
MI	Modification Indices
ML	Maximum Likelihood
ML	Maximum Likelihood
MSME	Micro, Small, and Medium Enterprises
NFI	Non-normed Fit Index
NGO	Non-Governmental Organizations
PLS	Partial Least Square
RBI	Reserve Bank of India
RBI	Reserve Bank of India
RMSEA	Root Mean Square Error of Approximation
SDG	Sustainable Development Goals
SEM	Structural Equation Model
SHG	Self-Help Group
SME	Small and Medium Enterprises
TAM	Technology Acceptance Model
TLI	Rucker-Lewis Index
US	United States
VIF	Variation Inflation Factor

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ORIGINAL RESEARCH PAPER

Aerotropolis, economic development, and agriculture synergy: International airports' influence on regional growth and SDG achievement

T. Y. Iswati[1,*], E. Gravitiani[2], P. Setyono[1], O. Purwani[3], A. Ratnadewati[2]

[1]*Environmental Science Doctoral Degree, Post Graduate School, Universitas Sebelas Maret, Surakarta, Indonesia*

[2]*Magister of Economic and Study Development, Faculty of Economic and Business, Universitas Sebelas Maret, Surakarta, Indonesia*

[3]*Department of Architecture, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, Indonesia*

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ABSTRACT

BACKGROUND AND OBJECTIVES: The aerotropolis concept has been increasingly recognized as a driver of regional economic development. However, its impact on social, agricultural, and environmental factors remained underexplored, particularly in regions surrounding newly developed international airports. This study analyzed the influence of the aerotropolis concept, which was reviewed from a regional, social, agricultural, and environmental perspective, on the economy of the Yogyakarta International Airport area.

METHODS: This study examined 10 districts and cities around Yogyakarta International Airport from 2017–2023. The data were analyzed using panel data regression and further analyzed using spatial analysis with Geo-Map Orange Data Mining. The aerotropolis concept was adopted to understand the interaction between these factors in the region's economic development around Yogyakarta International Airport.

FINDINGS: The results revealed that all variables significantly influenced GRDP ($p < 0.01$). A 1% increase in average schooling raised GRDP by 3.23%, population by 1.63%, and agricultural land by 0.70%. Meanwhile, a 1% increase in distance from YIA reduced GRDP by 0.69%, confirming spatial proximity's economic advantage.

CONCLUSION: Implementing the aerotropolis concept in the area around Yogyakarta International Airport created a synergy between education, demographics, and the agricultural sector, which supported dynamic and sustainable economic growth overall.

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*Corresponding Author:
Email: *yuniiswati@staff.uns.ac.if*
Phone: +6281227095830
ORCID: 0000-0002-0126-8805

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INTRODUCTION

Yogyakarta International Airport (YIA) is an international airport in the Special Region of Yogyakarta Province (DIY) and also the Province of Central Java (Fatimah & Rahayu, 2023). The construction of the airport, which began in the last year of 2018, cost approximately Rp 12 trillion on a land of 600 hectares (Suyoto *et al.*, 2022). The construction of YIA aims to increase the capacity of both domestic and foreign flights, which at the previous airport, Adisucipto International Airport, could not accommodate a larger number of passengers (Basuki *et al.*, 2023). YIA International Airport is located in Temon District, Kulon Progo Regency, Special Region of Yogyakarta, which is precisely located in 10 affected districts/cities, namely: Kulon Progo Regency, Bantul Regency, Sleman Regency, Gunungkidul Regency, Yogyakarta City, Klaten Regency, Kebumen Regency, Magelang Regency, Magelang City, and Purworejo Regency. The existence of YIA International Airport plays a role as the main driver in accelerating economic growth in Kulon Progo Regency and its surroundings (Rahmawati, 2022). The presence of the airport increases accessibility to this area, which in turn facilitates the movement of goods and people. The impact directly encourages an increase in trade, investment, and business activities in the region. This influence can be seen from the increase in regional revenue through the calculation of Gross Regional Domestic Product (GRDP). Several areas that are close to YIA International Airport have an indirect influence or effect on the economy, especially within a radius of 18 – 87 kilometers from the city center to Yogyakarta International Airport. These areas include Sleman Regency, Kulon Progo Regency, Yogyakarta City, Gunungkidul Regency, Bantul Regency, Magelang City, Magelang Regency, Purworejo Regency, Kebumen Regency, and Klaten Regency. The ten regions are located in Central Java Province and Yogyakarta Regional Province, as shown on the map in Fig. 1. In addition to location, according to research by Yenny & Anwar (2020), Desmawan *et al.,* (2023), and Hasibuan & Rukiah (2023), the economic level of an area is influenced by the number of residents of that area. The more people in an area, especially the productive age population, the more the economic level of the area will increase. A large population provides a large workforce that can be used in various sectors of the economy, such as industry, agriculture, and services. This increases productivity and economic output. The population of an area is a potential resource that can contribute to productivity to produce output (Sakkaraeva *et al.*, 2024). Improving the quality of human resources can be done, one of which is

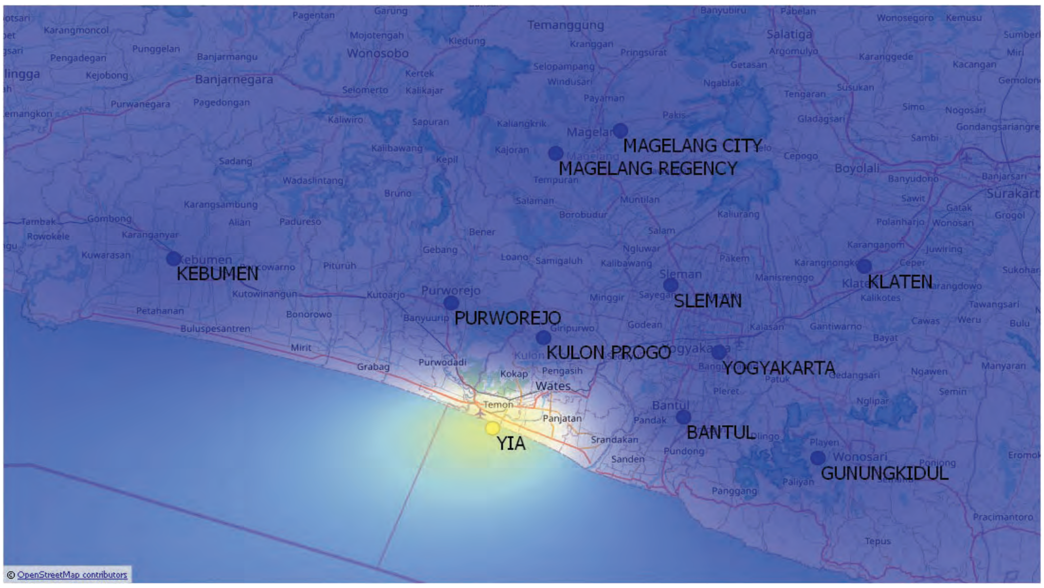

Fig. 1: Map of regency and city locations around YIA airport (Source: Central Statistics Agency of Indonesia processed using Orange Data Mining GeoMap (2025)).

through the implementation of basic education. According to data from the Central Statistics Agency in 2023, as many as 40% of the population aged 15 years and above in Indonesia have the highest high school education or higher. However, as many as 3.4% of the population in Indonesia still have never received formal education at all. Research conducted by Fatimah & Rahayu (2023), Kevin *et al.,* (2022), and Sitorus *et al.* (2024) raises the fact that areas that have good population quality characterized by a high average level of school length tend to have a relatively better economic level compared to areas with a low average length of schooling. Adequate formal education can support the thinking power and personality influence patterns of a person to have a better economic status. Central Java Province and the Special Region of Yogyakarta are areas that still depend on the agricultural sector, some of which are even included in the agricultural green belt zone. The Agricultural Green Belt Zone is an area planted with various types of crops, functioning as a green open space that separates urban areas from rural areas. The main goal is to control the expansion of land use and reduce activities that can damage the surrounding environment. The contribution of the agricultural sector to the Gross Regional Domestic Bruto (GRDB) in the two provinces is quite high, as much as 14.28% for Central Java and 9-10% for the Special Region of Yogyakarta. Previous research conducted by Rahmawati & Mulyaningsih (2019) stated that agricultural land, especially large irrigated rice fields, can increase agricultural production, so that the level of GRDB in the agricultural sector also increases. However, there are obstacles faced today, one of which is large-scale development that can narrow rice fields. This is also experienced in ten areas located around YIA International Airport. The construction of the airport also increases the attractiveness of the property business, including hotel and housing development. Thus, several agricultural lands have also changed their function into business and property buildings. The existence of YIA not only provides economic benefits but also presents several challenges. The airport construction process often requires the conversion of agricultural land into commercial areas, which can have an impact on decreasing local food production (Shcherbak *et al.*, 2024). In addition, the existence of airports can cause environmental problems, such as noise and air pollution, as well as the risk of flooding. From a social perspective, these changes can trigger population migration and change social dynamics in local communities. Overall, Yogyakarta International Airport makes a significant contribution to the economy of the surrounding area. However, it is very important to manage the negative impacts that may arise so that this economic development can take place sustainably and inclusively. This discussion will be further studied to determine the influence of demographic factors calculated through the population, social factors through the average length of schooling, the area of agricultural land, and the distance between the city center and YIA International Airport on GRDP. The data used is secondary data covering ten districts/cities, namely Sleman Regency, Kulon Progo Regency, Yogyakarta City, Gunungkidul Regency, Bantul Regency, Magelang City, Magelang Regency, Purworejo Regency, Kebumen Regency, and Klaten Regency, within a period of 6 years, namely 2017 – 2023. The data was processed using panel regression and then further analyzed using GeoMap Orange Data Mining spatial analysis. Although the aerotropolis model has been studied in various contexts, empirical research on its comprehensive impacts, particularly integrating demographic, educational, agricultural, and locational factors, remains scarce in the Indonesian setting. Specifically, the economic implications of the newly developed YIA have not been thoroughly examined. Therefore, this study aims to analyze the impact of YIA on regional economic growth by examining the influence of population size, education levels, agricultural land, and proximity to the airport. The aerotropolis concept has been widely recognized as a catalyst for regional economic development by integrating transportation hubs with urban and economic activities. However, empirical studies that comprehensively examine its impact on demographic, educational, agricultural, and locational factors remain limited, particularly in the context of newly developed airports such as YIA. Most existing research focuses only on general economic outcomes, leaving a gap in understanding the multidimensional influences of aerotropolis development. This study addresses this gap by providing empirical evidence on the economic dynamics in the regions surrounding YIA. To achieve these objectives, this research examined 10 districts and cities around YIA, Indonesia, from 2017 to 2023.

MATERIALS AND METHODS

The data used in this study is secondary data sourced from the Central Statistics Agency (BPS) of Indonesia in the range of 2017 – 2023. The determination of the period was taken into consideration because the concept of aerotropolis at YIA Airport had begun to be launched and compiled since the initial construction of the airport in 2017. The range was also chosen because of the latest data available until 2023. There are two types of variables used, namely the dependent variable in the form of GRDB and the independent variable, namely demographic and distance factors, namely the population, the average length of schooling, the area of agricultural land, and the distance between YIA Airport and the city and district centers. The following (Table 1) are operational definitions of variables and data sources.

The data was then processed using two methods, namely panel data regression and Orange Data Mining Geo Map analysis. Panel data regression analysis is a statistical approach used to evaluate data that has two dimensions, namely the time dimension (time-series) and the individual dimension (cross-sectional). The data panel consists of repeated observations coming from the same individual or unit over time. According to Kurniawati & Sugiyanto (2021), there are three main approaches in panel data regression analysis, namely the Pooled Least Square (PLS), Fixed Effect Model (FEM), and Random Effect Model (REM). PLS integrates all panel data into one large dataset and estimates the regression model using the usual least squares method. On the other hand, FEM assumes that each unit has unique characteristics that remain constant over time, using dummy variables for each unit in estimating those characteristics. Meanwhile, REM assumes that the differences between individual units are random and do not correlate with independent variables, making it more efficient in terms of the number of parameters estimated because it does not require a dummy variable for each unit. The choice between FEM and REM should be based on assumptions regarding the correlation between independent variables and individual differences; if this assumption is met, REM is more appropriately used, while if not, FEM is more appropriate. This approach assists researchers in dealing with individual heterogeneity and time dynamics, which ultimately improves the efficiency and validity of estimates in panel data analysis. The following is the equation of the regression analysis of panel data in this study:

$$LnPDRB_{it} = \alpha_{it} + LnLHP_{it} + LnJP_{it} + LnRRLS_{it} + LnYIA_{it} + e_{it} \quad (1)$$

Where the $LnPDRB_{it}$ is GRDP, *LnLHP* is the area of agricultural land, $LnRRLS_{it}$ the average length of schooling, and $LnYIA_{it}$ the distance between YIA airport and the city/district center, where all variables are in natural logarithmic units. The next analysis is the mapping of factors that affect GRDB using the Orange Data Mining Geo Map. This method is used to see the distribution of data based on the average economic, social, agricultural, and environmental factors that affect GRDB in 10 districts and cities around YIA. $LnPDRB_{it}$ $LnLHP_{it}$ $LnRRLS_{it}$ $LnYIA_{it}$ (Ratnadewati *et al.*, 2024). The distribution can be seen from the dots and also the colour, which illustrates how much influence it has on the amount of GRDB. The analysis is illustrated in Fig. 2.

Table 1: Variable operational definition (Source: Processed from Indonesian Central Statistics Agency, 2025)

No	Types of Variables	Variable	Information
1.	Dependent	Gross Regional Domestic Bruto	GRDB based on the price valid for the year 2017 – 2023 in Billion Rupiah
2.	Independent	a. Number of Population	The population from 2017 – 2023 is in millions of people.
		b. The average length of school.	The average length of schooling for residents in 2017 – 2023 in units of years.
		c. The area of agricultural land.	Total area of agricultural land in 2017 – 2023 in units (Ha)
		d. Distance between YIA airport and the city/district center.	Distance between YIA airport and the city/district center in km

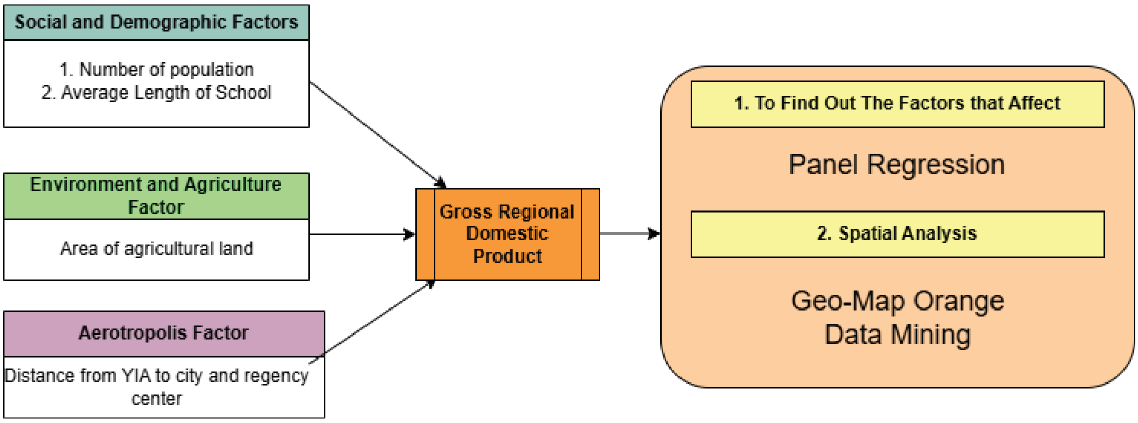

Fig. 2: Steps of research

RESULTS AND DISCUSSION

Factors affecting GRDP

- *Chow test*

It is a tool used to determine the most accurate model between fixed effect and common effect (Anugerah & Nuraini, 2021). The hypothesis used in the Chow test is H0 if the chi-square > 0.05, then the selected model is a common effect, and H1 if the chi-square is < 0.05, then the selected model is a fixed effect. The results show that the chi-square value < 0.05 means that the selected model is a fixed-effect model.

- *Hausman test*

It is a test used to determine the right model between fixed effect and random effect. The hypothesis used is that if H0 is if the chi-square probability value is more than > 0.05, then the model chosen is fixed effect, and H1 is if the chi-square probability value is < 0.05, then the model chosen is random effect. The results show that the probability value is > 0.05, so the appropriate model is a fixed effect model.

Classical assumption testing

To ensure the validity and reliability of the panel data regression analysis, classical assumption tests were conducted. The results are as follows:

- Normality Test: The Jarque-Bera test indicated that the residuals were normally distributed, with a p-value of 0.128 (> 0.05), suggesting no violation of the normality assumption.
- Heteroskedasticity Test: The Breusch-Pagan test yielded a p-value of 0.217 (> 0.05), indicating the absence of heteroskedasticity across the dataset.
- Multicollinearity Test: The Variance Inflation Factor (VIF) values for all independent variables were below 3, confirming that multicollinearity was not present.

Based on these tests, the model fulfills the classical assumptions, ensuring that the estimated coefficients are unbiased, consistent, and efficient.

Results of panel data regression analysis

The regression analysis of panel data was used to determine social, demographic, environmental, agricultural, and aerotropolis factors that affect the GDRP. The results are seen from the probability value of each variable with an error tolerance rate of 5%. The test results from ten districts and cities around YIA from 2017 – 2023 are shown in Table 2.

Table 2 is the result of the regression analysis of panel data shown through the following equation:

$$LnPDRB_{it} = -8,44_{it} + 0,70LnLHP_{it} + 1,63LnJP_{it} + 3,22LnRRLS_{it} - 0,69_{it} + e_{it} \quad (2)$$

Table 2: Results of panel data regression analysis (Source: Processed from Indonesian Central Statistics Agency, 2025)

Variable	Coefficient	Probability
C	-8.44	0.0002
LNLHP	0.70	0.0000
LNJP	1.63	0.0000
LNRRLS	3.23	0.0000
LNYIA	-0.69	0.0000

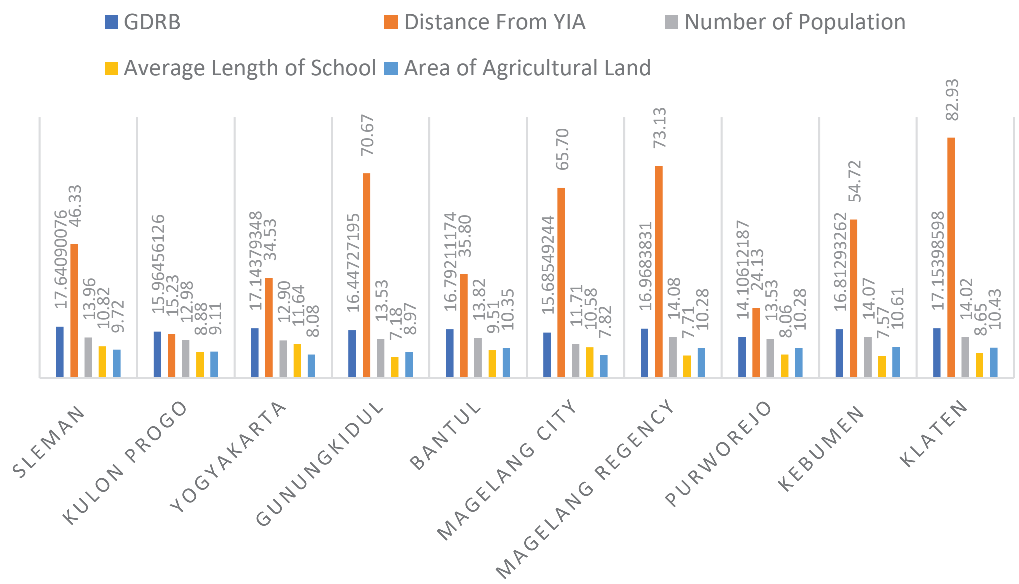

Fig. 3: Average dependent and independent variables in 10 cities and regencies around YIA in 2017 – 2023 (Source: Processed from Indonesian Central Statistics Agency, 2025.)

Fig. 4: Average GRDP in 10 cities and regencies around YIA In 2017 – 2023 (Source: Central Statistics Agency of Indonesia, Processed Using Orange Data Mining Geomap, 2025.)

The equation shows that the economic condition in Sleman Regency, Kulon Progo Regency, Yogyakarta City, Gunungkidul Regency, Bantul Regency, Magelang City, Magelang Regency, Purworejo Regency, Kebumen Regency, and Klaten Regency will decrease by -8.44% if other variables are worth 0. Table 2 shows that the probability value of all independent variables < 0.05, so it shows that the area of agricultural land influences the GRDB value of these areas, the population, the average length of schooling, and the distance between YIA Airport and the city center or district.

In the period from 2017 to 2023, the ten regions show an increasing trend in the average GRDP, as in Fig. 3. The city of Yogyakarta recorded an increase in GRDP from IDR 150 billion in 2017 to IDR 200 billion in 2023. Meanwhile, the Bantul Regency experienced growth from Rp 80 billion to Rp 100 billion, and the Sleman Regency increased from Rp 90 billion to Rp 120 billion. Gunungkidul, Kulon Progo, Purworejo, and Kebumen Regencies also showed a significant increase in GRDB. In addition, Magelang City, Magelang Regency, and Klaten Regency also experienced GRDB growth in the same period as in Fig. 4. This increase reflects a faster pace of economic development in urban areas compared to rural areas, as well as the contribution of sectors such as education, tourism, and agriculture to regional economic growth. Furthermore, this increase in GRDB contributes to the achievement of the Sustainable Development Goals (SDGs) by creating jobs, improving people's welfare, and supporting sustainable economic growth (Alfaris & Rustam, 2023; Nandita *et al.*, 2019; Hidayah & Tallo, 2020; Putra & Suharto, 2024). The economic condition in these areas is still supported by the agricultural sector, especially rice paddy areas that produce rice as a staple food. This is the result of the regression analysis of panel data, which shows that if there is an increase in agricultural land area by 1%, the GDRP will increase by 0.70%. The area of agricultural land has a significant impact on the GRDP in the area around YIA (Pradana *et al.*, 2020). The agricultural sector makes a substantial contribution to GRDB, especially through the production of food crops and horticulture. With the increase in agricultural land area, food production can be increased, which in turn supports food security and the local economy (Susanto, 2021). In addition, this sector also functions in creating jobs and improving people's welfare. However, it is important to note that the conversion of land from paddy fields to non-paddy fields also affects GRDP. Changes in economic structure, population growth, and industrial development also contribute to changes in the area of agricultural land and GRDB. The distribution of agricultural land can also be seen from the mapping results in spatial analysis using Geo-Map Orange Data Mining in Fig. 5.

Fig. 5 shows that Kebumen Regency, Klaten Regency, and Bantul Regency are the areas with the largest agricultural land area of these areas. The agricultural sector plays a role as one of the important economic pillars, especially in rural areas. With an increase in land area, agricultural production can increase, which has the potential to increase regional GRDB (Nilawati, 2019). However, although the area of agricultural land has a significant role, collaboration with other factors is urgently needed to encourage an overall increase in GRDB (Ahmad *et al.*, 2023; Anggreani *et al.*, 2023; Raihan *et al.*, 2023).

The second factor that affects the population is that every 1% increase in the number of people will increase the value of GRDB by 1.63%. Population growth often contributes to an increase in the value of the GRDB. As the population increases, the consumption of goods and services in a region generally increases, which in turn drives economic activity (Astuty *et al.*, 2025). In addition, a larger

Fig. 5: Average agricultural land in 10 cities and regencies around YIA in 2017–2023 (Source: Central Statistics Agency of Indonesia, processed using Orange Data Mining GeoMap, 2025.)

population provides a larger workforce that can be utilized in various industrial and service sectors, potentially increasing productivity and economic output. However, this effect is greatly influenced by a variety of other factors, such as education levels, workforce skills, investment in infrastructure, and economic policies implemented (Pooja & Bhavani, 2025). Therefore, effective human resource management and appropriate investment are essential to ensure that population growth has a positive impact on economic growth and GRDB improvement. Thus, a larger population can be one of the main drivers of economic growth if managed properly. One of them is shown in Fig. 6, where Kebumen Regency, Sleman Regency, Klaten Regency, and Bantul Regency are the areas with the largest populations.

The third variable that affects GRDB is the Average Length of School symbolized by RRLS where every 1% increase in RRLS will increase GRDB by 3.23%. The average length of education has a significant impact on the GRDB in the area around YIA. Research indicates that an increase in the average length of education can improve the quality of the workforce, which in turn contributes to economic growth and an increase in GRDB. Better education strengthens the capabilities of human resources, increases productivity, and encourages innovation, all of which have a positive effect on GRDB (Hepi & Zakiah, 2018). Yogyakarta City, Magelang City, and Sleman Regency are the areas with the highest RRLS, which is 11 years old or at the Senior High School level. This result is also evidenced by the high level of GRDB of the three regions, which can be seen in Fig.7.

The last variable, namely the distance between YIA Airport and the city center or district that is affected, namely the district or city with a closer distance from the airport, will increase the GRDB value by 0.69%. YIA, located in Kulon Progo, can be linked to the concept of aerotropolis, which is closely related to the GRDP. This concept describes the airport as the economic center and infrastructure of the city that can attract various businesses and economic activities around it. The closer an area is to the YIA, the greater the potential for integration with the aerotropolis ecosystem, which includes commercial, industrial, and logistics areas (Alif & Nugroho, 2021). This contributes to increased connectivity and accessibility, which is crucial for trade and investment. The proximity to the airport makes it easier to transport goods and passengers, speeds up business processes, and encourages the

Fig. 6: Average number of populations in 10 cities and regencies around YIA in 2017 – 2023 (Source: Central Statistics Agency of Indonesia, Processed Using Orange Data Mining GeoMap, 2025.)

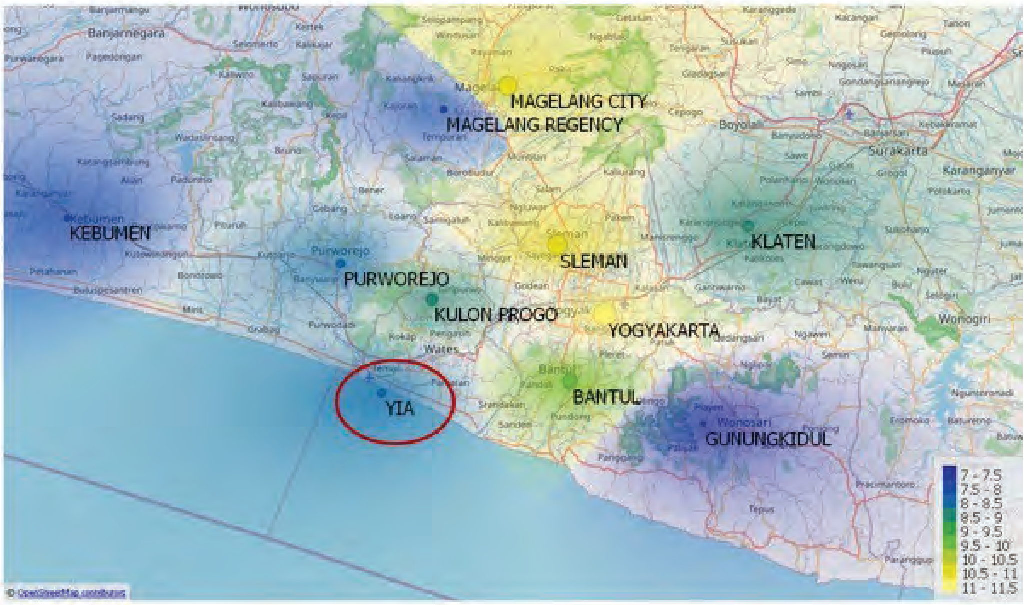

Fig. 7: Average school length in 10 cities and regencies around YIA in 2017– 2023 (Source: Central Statistics Agency of Indonesia, processed using Orange Data Mining GeoMap, 2025.)

growth of sectors such as tourism, real estate, and services (Yu & Santos, 2025). Therefore, areas located closer to YIA have a greater opportunity to attract investment and economic development, which will ultimately increase the value of GRDB. Integrated infrastructure around airports also supports increased productivity and efficiency, as well as encourages innovation and competitiveness at the regional level. The concept of an aerotropolis shows how modern airport infrastructure can serve as a key catalyst for economic growth and regional development, with YIA as a real example of improving the regional economy by increasing the value of GRDB. Integration with the concept of an aerotropolis can maximize this potential, making the area around YIA a center of dynamic and sustainable economic growth.

CONCLUSION

The findings of this study confirm that the aerotropolis development surrounding YIA has generated a dynamic synergy among education quality, population growth, agricultural sustainability, and regional economic performance. Higher levels of education, larger populations, expansive agricultural land, and proximity to the airport were identified as significant drivers of GRDB growth, emphasizing the multifactorial nature of regional development in the context of new infrastructure investments. The study further demonstrates that in regions where agriculture remains a critical sector, the aerotropolis model can be adapted to integrate both traditional agricultural strengths and emerging commercial opportunities. This reveals the necessity for development strategies that do not solely focus on industrialization, but also protect and enhance agricultural productivity as a foundation for sustainable growth. To ensure balanced development, policymakers should adopt integrated planning approaches that safeguard agricultural zones, invest in educational advancement, and strategically manage urban expansion surrounding airports. Special attention should be directed toward mitigating potential negative effects such as land conversion, environmental degradation, and social displacement through the establishment of regulatory frameworks and participatory planning processes. Moving forward, longitudinal studies are needed to evaluate the long-term impacts of aerotropolis-driven growth, particularly regarding social equity, environmental sustainability, and regional resilience. Future policies should not only aim to maximize economic output but also to promote inclusive, sustainable development that benefits diverse community groups across urban and rural settings. Thus, the aerotropolis approach can optimize the economic potential of the average length of schooling, the number of residents, the area of agricultural land, and the proximity to the YIA airport to encourage sustainable economic growth in the region.

AUTHOR CONTRIBUTIONS

All authors contributed significantly to the completion of this study. Tri Yuni Iswati was responsible for the conceptualization, methodology design, and overall supervision of the research. Evi Gravitiani contributed to data analysis, validation, and funding acquisition. Prabang Setyono provided methodological guidance and participated in the review and editing process. Ofita Purwani handled the spatial analysis and data visualization. Ainina Ratnadewati conducted the investigation, managed data curation, and prepared the original manuscript draft. All authors reviewed and approved the final version of 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

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ABBREVIATIONS (NOMENCLATURE)

α_{it}	Constant
e_{it}	Error term
$LnJP_{it}$	Logarithm of Population
$LnLHP_{it}$	Logarithm of Production Forest Area
$LnPDRB_{it}$	Logarithm of Gross Regional Domestic Product (GRDP)
$LnRRLS_{it}$	Logarithm of Average Years of Schooling
$LnYIA_{it}$	Logarithm of Employment in Agro-Industry
%	Percentage
Ha	Hectares
Km	Kilometre
YIA	Yogyakarta International Airport
GRDB	Gross Regional Domestic Bruto
PLS	Pooled Least Squares
FEM	Fixed Effect Model
REM	Random Effect Model
VIF	Variance Inflation Factor
SDGs	Sustainable Development Goals

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ORIGINAL RESEARCH PAPER

Shaping national identity: Unveiling the power of international idea promotion in enhancing the national image

Z. Hui, A. H. B. A. Ghazali*, S. N. Sha'ri

Faculty of Modern Language and Communication, Universiti Putra Malaysia, Serdang 43400, Malaysia

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ABSTRACT

BACKGROUND AND OBJECTIVES: In an increasingly interconnected world, nations compete through economic and military power and strategic promotion of their ideas, values, and cultural narratives. As global influence becomes more reliant on soft power, countries face the challenge of shaping international perceptions to foster cooperation, attract alliances, and strengthen their national identity. However, in an era of information saturation and geopolitical tensions, effectively communicating a nation's core principles is more complex than ever. This paper examines the critical role of international idea promotion in shaping a country's reputation and global standing. It argues that deliberately disseminating national values, political philosophies, and cultural identity can counter misinformation, bridge ideological divides, and enhance diplomatic relations. By understanding the mechanisms behind this process, nations can craft their global image more effectively, reinforcing trust and cooperation in an increasingly competitive international landscape..

METHODS: This study adopts a qualitative case study approach to examine the strategic promotion of international ideas and their impact on national reputation and identity. Data is collected through an in-depth analysis of selected cases where nations have actively engaged in diplomatic initiatives, international collaborations, cultural exchange programs, and strategic media campaigns to shape global perceptions. This research aims to explore patterns, strategies, and outcomes associated with international idea promotion by focusing on specific examples. The study employs purposive sampling, selecting cases that provide rich insights into successful and unsuccessful efforts in projecting national values and narratives. The population of this study includes governmental agencies, cultural institutions, and media organizations involved in soft power diplomacy. Through qualitative content analysis, the research identifies key themes and strategies that contribute to effective global influence. This methodological approach allows for a nuanced understanding of how nations navigate the complexities of international idea dissemination.

FINDINGS: International idea promotion is crucial in shaping core values, enhancing cultural communication, and strengthening national images. It fosters cross-cultural exchanges, promotes core values like democracy and freedom, and drives policy innovation and cooperation.

CONCLUSION: This study emphasizes the role of international idea promotion in strengthening core values, fostering cross-cultural understanding, and shaping national identities. Policymakers should focus on promoting values like human rights and sustainability through cultural exchanges, media outreach, and international partnerships to enhance global influence and address global challenges. These strategies can improve diplomatic ties, boost national reputation, and contribute to global development.

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*Corresponding Author:
Email: *zhouhui2022@gmail.com*
Phone: +60142316256
ORCID: 0000-0002-1960-8660

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INTRODUCTION

The power of promoting international ideas to enhance a country's image is an area of compelling research (Petroye *et al.*, 2020). This thesis aims to comprehensively explore how promoting international ideas shapes national identity and elucidates its crucial role in enhancing a country's image. A country's image is the external manifestation and perception of a nation on the global stage. It not only reflects a country's core values, cultural characteristics, and political viewpoints but also profoundly influences how other countries and the global public perceive the nation (Roth *et al.*, 2009). By widely disseminating a country's core values, culture, and political perspectives, international idea promotion contributes to establishing and shaping a country's image while boosting its reputation. Through the promotion of international ideas, a country can effectively convey its core values and cultural uniqueness to the world, thereby attracting attention and recognition from other countries and the global public (Jameson, 2007). Such promotion can be accomplished through various channels, including diplomatic efforts, international cooperation, cultural exchanges, and media platforms. Diplomatic endeavors involve engaging in formal and informal channels, such as high-level discussions (Lebovic *et al.*, 2016), international conferences (Kaufmann, 2016), and diplomatic missions (Malone, 2013). International cooperation entails collaborating with other nations to address global challenges and participating in international organizations and cooperative projects. Cultural exchanges foster mutual understanding and recognition through activities spanning art, sports, education, and tourism. Media channels, such as television (Atewolara-Odule *et al.*, 2016), radio (Saliu, 2017), and the internet (Schweiger, 2000), facilitate the rapid dissemination of a country's image and ideas. The impact of international idea promotion extends not only to other countries and global public perception but also plays a significant role domestically. By promoting international ideas, a country's domestic population can gain a deeper understanding and stronger identification with their country's core values and cultural characteristics, bolstering their sense of national identity and pride. Domestic promotion can be achieved through public education, cultural activities, and media campaigns. Nevertheless, international idea promotion faces certain challenges. Cross-cultural communication is a critical issue as disparities in language, values, and beliefs exist among different countries and cultures (Hurn *et al.*, 2013). Hence, it is imperative to consider these differences and employ appropriate communication strategies during the promotion process. Additionally, ideological conflicts between nations may impede promotion due to divergent political, religious, and social perspectives. To effectively promote international ideas, it is recommended to strengthen diplomatic efforts, harness the potential of emerging media platforms and social networks, and actively engage in international cultural exchange activities. Diplomatic efforts should focus on enhancing dialogue and exchanges with other countries, facilitating the dissemination and comprehension of ideas (Bicchi, 2014). Leveraging new media platforms and social networks, with their extensive influence, enables the rapid dissemination of information and facilitates interaction with the global audience (Razmerita *et al.*, 2014). Participating in international cultural exchange activities can heighten a country's exposure and foster mutual understanding and recognition among nations (Iriye, 2002). In essence, the aim and scope cover both theoretical and practical aspects of international idea promotion and its relationship with a country's image, culminating in actionable insights and conclusions. Building on this foundation, it is vital to acknowledge the dynamic nature of national image and identity in the contemporary global environment. The rise of non-state actors, the proliferation of digital platforms, and the increasing fluidity of cultural exchange have significantly altered the landscape of international relations. Consequently, strategies for international idea promotion must be adaptive and responsive, incorporating insights from fields such as strategic communication, cultural studies, and digital media analysis. Furthermore, evaluating the efficacy of these promotional efforts requires robust methodologies, including quantitative analysis of public opinion data and qualitative assessments of cultural impact. This research ultimately contributes to a deeper understanding of how nations can navigate the complexities of global perception and leverage their soft power to achieve strategic objectives. This research advances understanding of how nations navigate global perceptions and leverage soft power to achieve strategic objectives. However, gaps remain in assessing the long-term impact of international idea promotion on national identity and global influence. Future studies should explore how emerging digital platforms, evolving geopolitical dynamics, and non-state actors reshape national image strategies. Additionally, more empirical research is needed to measure the effectiveness of different promotional approaches across diverse cultural and political contexts.

Literature review

The concept of "national image" does not have a unified standard definition. The term was initially introduced by Boulding, an American political scientist, who is considered the pioneer in national image theory research. Boulding defined national image as "the result of a series of information inputs and outputs." He emphasized the importance of the "image of others" and "image of self" as significant variables in foreign policy-making (Boulding, 1959). Scholars hold different attitudes toward the concept. Realism scholars view the national image as the embodiment of national interests. Morgenthau, for instance, argues that national interests encompass territorial integrity, national sovereignty, and cultural integrity, and therefore, the national image reflects a country's comprehensive strength (Morgenthau, 1952). Kotler (2000) also acknowledges that "image" is an individual's subjective belief and perception of an object, which may not necessarily align with the object's true features. Thus, "national image" can also be understood as the characteristics of a country that people can perceive. Wendt (1999) suggests that a country's national image positioning is closely related to its recognition by the international community. Constructivism argues that national identity and national strength can exist independently, and people's identification with a country is shaped through social interaction, highlighting the importance of national image-building. Some scholars, such as Hall, believe that the national image perceived by people is the image that the media intends to portray. During image perception, individuals often draw on their country's history, culture, experience, and national interests while neglecting the cultural values of the target country. From a constructivist perspective, Liu Xiaoyan argues that the national image is the public's subjective perception of a country's objective state. It represents the audience's cognitive, opinionated, and evaluative stance towards the country and reflects their emotional inclination (Mossberg *et al.*, 2005). Chen (2012) suggests that a country's image encompasses its political, economic, social, and cultural aspects, which shape how both Chinese and international audiences understand and evaluate the country. Thus, the quality of a country's image is inseparable from its comprehensive strength (Meng, 2020). Some scholars have examined the media's role in shaping a country's image, focusing on different aspects. Initially, they explore the connection between a country's image and international politics. For instance, Boulding (1959) investigated the relationship between national image and the international system. Alternatively, some studies analyze the relationship between national image and the economy. For example, Bannister *et al.,* (1978) researched British consumers' stereotypes of imported goods. Another area of study focuses on major "national images" of China, such as the Beijing Olympic Games, the Shanghai World Expo, the Confucius Institute, and the Belt and Road Initiative. While international media research has generally paid less attention to the connection between shaping and presenting a national image, there are notable works on the media's role in image construction. These studies can be categorized into several areas. First, some explore the concept and historical evolution of "national image." Second, research examines the relationship between China's national image and its external communication. Within this framework, media image construction is a key component of external communication. Ding (2011) suggests that enhancing international communication in the digital age is crucial for shaping China's national image and overcoming foreign prejudices. Wu (2007) analyzed China-related reports in the print media of four countries to provide insights for China's foreign policy. Third, studies explore the strategies and methods employed by the media to shape China's image. Finally, research also looks into how foreign media portray China's image during specific events. For instance, Zeng *et al.,* (2011) analyzed TV media coverage in nine countries during the 2008 Beijing Olympic Games to understand how it influenced global perceptions of China.

MATERIALS AND METHODS

The case study method is a comprehensive approach used to delve deeply into a specific case, enabling exploration of phenomena, comprehension of complex scenarios, and evaluation of the impacts of particular interventions (Fidel, 1984). In this paper, a case analysis approach is employed to investigate the role of promoting international ideas in nation image building, aiming to uncover its influence and effectiveness. Case studies provide a broad understanding of how the promotion of international ideas affects the development of national image, revealing its underlying forces and mechanisms. By examining various strategies and approaches employed in promoting international ideas, such as brand promotion, cultural exchanges, and diplomatic activities, this study analyzes their contributions to the construction of a nation's image. Moreover, it delves into the disparities in the effects of international idea promotion across diverse countries and cultural backgrounds, highlighting its significance within the realms of international relations and foreign policy.

Definition and mechanism of international idea promotion

This section mainly introduces the definition and mechanism of international idea promotion. International idea promotion refers to the process of disseminating and promoting specific ideas, values, or cultural elements internationally through various means and strategies. It aims to enhance the image of a country or region and promote international cooperation, understanding, and communication. Mechanisms for International idea promotion also vary by country and cultural context. Different countries and regions may choose suitable promotion strategies and methods according to their own needs and characteristics.

The definition of international idea promotion

The promotion of international ideas aims to disseminate and advocate for a specific idea, value, or concept on the global stage, to influence and guide behavior, policies, and practices worldwide (Currie-Alder *et al.*, 2014). These ideas may encompass various fields, including politics, economics, society, culture, or the environment, all with the overarching goal of fostering cooperation, development, and progress within the international community. The promotion of international ideas typically involves utilizing diverse channels and methods, such as international organizations, governmental institutions, non-governmental organizations, media platforms, educational initiatives, and cultural exchanges, to effectively communicate and propagate these specific ideas to a global audience (Gao, 2021). This can encompass the advocacy of fundamental values like democracy, human rights, sustainable development, social justice, diversity, and inclusivity, as well as peace and security. The ultimate objective of international idea promotion is to spark transformative changes in the realms of intellectual exchange, policy formulation, and practical implementation by driving the dissemination of specific ideas on a global scale. It contributes to shaping the international order, strengthening international cooperation, addressing global challenges, and fostering mutual understanding and collaboration among diverse nations and communities. Nevertheless, the promotion of international ideas may encounter challenges and controversies, as different countries, cultures, and interest groups may hold varying perspectives and stances regarding specific ideas. Therefore, the successful promotion of international ideas necessitates consideration of diversity, respect for national sovereignty and cultural differences, and the establishment of consensus and shared benefits through dialogue, equitable cooperation, and mutually advantageous relationships.

The mechanisms for promoting international ideas

Mechanisms for the promotion of international ideas include advocacy, dissemination, and communication (Sanders *et al.*, 2015). First of all, publicity is one of the important mechanisms for the promotion of international ideas. Through promotional activities, countries can present their unique ideas, values, and cultures to the world. This may involve media communications in the form of advertisements, promos, posters, exhibitions, etc., to attract the attention of the target audience and convey a specific message. Campaigns can be run on international media, social media platforms, and various promotional channels to increase impact and reach a wider audience. Second, dissemination is one of the core mechanisms for the promotion of international ideas (Sanders *et al.*, 2015). Communication involves communicating ideas and values to target audiences to promote understanding and buy-in. This can be achieved in a variety of ways, such as speaking at international conferences and forums, writing professional articles or academic papers, organizing seminars and training, and cooperating with international organizations, academia, and civil society. Through active dissemination, international ideas can cross national borders, influence and inspire people's thinking, and arouse concern and resonance on a global scale. In addition, communication is also an important mechanism for the promotion of international ideas. By communicating with other countries and cultures, nations can foster mutual dialogue and understanding. This may include cultural exchange activities, academic exchange programs, mutual visits, and diplomatic dialogues. Through active exchanges, connections and bonds can be established between different countries and cultures, and friendly relations and cooperation can be promoted.

RESULTS AND FINDINGS

Promote core values and ideology

The promotion of international ideas plays an important role in the dissemination of core values (Thornton *et al.*, 2008). International philosophy refers to the universal principles, ideas, and values formed and widely accepted in international exchanges, which transcend national boundaries and cultural differences and are universally applicable. Core values are the basic beliefs and principles recognized by a country or society, which have an important impact on shaping social behavior and values. The promotion of international ideas can promote the dissemination of core values in the following ways:

(1) The promotion of international ideas promotes exchanges and dialogues between different cultures: Through interaction with other countries and cultures, people can understand and accept different ideas and values. This helps break down prejudices and misunderstandings and promotes mutual understanding and respect for different values.

(2) The promotion of international ideas can influence other countries and societies through demonstration and leadership: When a country demonstrates a positive core value in practice and succeeds, other countries are likely to follow suit and integrate these values into their social systems.

(3) The promotion of international ideas can spread core values through education and training: In international exchanges and cooperation, people can learn and understand the core values of other countries and apply them to their own lives and work. Educational institutions, international organizations, and multinational corporations can play an important role in providing training and educational programs to promote the concept of core values.

(4) The promotion of international ideas can convey core values through media and information dissemination channels: Platforms such as international media, social media, and the internet can spread ideas and values from different cultures and countries. This wide dissemination can increase people's awareness and understanding of different core values. The United States has always regarded freedom and democratic values as its core values and actively promotes these values. The following are some of the main methods and efforts of the United States in promoting the values of freedom and democracy:

(1) *Political diplomacy:* The United States promotes the spread and popularization of the values of freedom and democracy through political and diplomatic means, such as diplomatic negotiations, international cooperation, and multilateral institutions. The United States supports the principles of democracy, human rights, and the rule of law on the international stage and engages and cooperates with other countries through diplomatic channels to encourage them to adopt and strengthen these values.

(2) Human rights advocacy: The United States plays an important role in international human rights affairs, promoting human rights protection and democratic development through international organizations and human rights institutions. The United States promotes the popularization of human rights awareness and free values by sanctioning, condemning, and assisting system reforms against countries that violate human rights.

(3) Educational and cultural exchanges: The United States spreads the ideas and values of freedom and democracy to other countries through educational and cultural exchange programs. This includes offering scholarships and exchange programs to educate foreign students and professionals about American democracy and values and to spread these

ideas when they return home. In addition, the United States also demonstrates the lifestyle and values of freedom and democracy through cultural exchange activities, art performances, and movies.

(4) Media and social media: American media and social media have extensive influence around the world, and they spread ideas and values of freedom and democracy. American news media, social media platforms, and Internet companies provide a platform for people to freely express their opinions and promote public awareness and thinking about freedom and democracy.

The role of international idea promotion in cultural communication

The promotion of international ideas plays an important role in cultural dissemination. The following are the influences of the promotion of international ideas on several aspects of cultural communication:

(1) Cross-cultural communication and understanding: The promotion of international ideas promotes exchanges and dialogues between different cultures (Hurn *et al.*, 2013). Through cross-border exchanges, people can come into contact with ideas, values, and traditions from other cultures and enhance their understanding and respect for different cultures. This helps break down prejudices and stereotypes and promotes mutual exchange and integration of cultures.

(2) *Protection and dissemination of cultural diversity:* The promotion of international ideas encourages and supports the protection and dissemination of cultural diversity (Axelrod, 1997). Every country and region has a unique cultural heritage and traditions, and the promotion of international ideas advocates respecting and protecting the rights and interests of various cultural forms. This includes cultural expression in all areas of language, art, music, dance, literature, and more. Through international cooperation and exchanges, countries can share their cultural resources and enrich people's cultural experiences and cognition.

(3) *Development of cultural and creative industries:* The promotion of international ideas provides an opportunity for the development of cultural and creative industries. The cultural and creative industry includes film, music, art, design, fashion, and other fields, and is a cross-border industry (Peris-Ortiz *et al.*, 2019). The promotion of international ideas promotes exchanges and cooperation between different cultures and provides a broader market and cooperation opportunities for the development of cultural and creative industries.

(4) *Promotion of social change and development:* The promotion of international ideas can also promote social change and development in cultural communication (Castles, 2010). Some international ideas, such as human rights, gender equality, and environmental protection, can stimulate social attention and action on issues and promote social progress and reform. By widely disseminating and introducing these international ideas, people can think and reflect on social phenomena and actively participate in the process of social change and development. France has always been famous for its rich cultural and artistic traditions, so promoting the cultural and artistic image of France is one of the country's important tasks. The following are some main efforts and strategies of France in the promotion of cultural and artistic images:

(1) Protection and promotion of cultural heritage: France has invested a lot of resources and efforts in the protection and promotion of its cultural heritage. France has many world cultural heritages, such as Notre Dame Cathedral, Versailles Palace, Louvre Museum, etc. These landmark buildings and works of art have become important symbols of the French cultural and artistic image. France has attracted a large number of tourists and art lovers through the restoration, maintenance, and opening of these cultural heritages.

(2) Art exhibitions and museums: France has many world-class art museums and exhibitions, such as the Louvre, Musée d'Orsay, etc. These museums hold a large number of art exhibitions and cultural events, attracting audiences and scholars from all over the world. France actively promotes these exhibitions and museums, presenting its rich artistic resources and cultural charm to the world through various media channels and international cooperation.

(3) Film and music industry: France enjoys a high reputation in the field of film and music, and French film and music works have attracted worldwide attention and love. Events such as French film festivals and music festivals have become important platforms for attracting international audiences and artists. French films and musical productions promote France's cultural and artistic image through

international distribution and tours.

(4) Cultural exchanges and cooperation: France actively participates in international cultural exchanges and cooperation and conducts cultural projects, art exchanges, and cooperative exhibitions with other countries. The French government and cultural institutions support the exchange of artists and cultural messengers abroad and encourage international cultural exchanges and cooperation. This kind of cross-border cultural exchange helps to promote the image of French culture and art and enhances the understanding and dialogue between different cultures. France actively promotes its cultural and artistic image by protecting and promoting cultural heritage, holding art exhibitions and museums, developing film and music industries, and promoting cultural exchanges and cooperation. These efforts will help promote the cultural and artistic values of France, attract global audiences and tourists, and promote cultural and artistic exchanges and development.

The role of international idea promotion in the dissemination of policy ideas

The promotion of international ideas plays an important role in the dissemination of policy ideas (Nay, 2012). The following are some influences of international idea promotion on the dissemination of policy ideas:

(1) International idea promotion can provide inspiration and reference for policymakers: When new ideas, ideas, or policy practices emerge internationally, policymakers can learn from them and incorporate them to improve their policy framework and direction. The promotion of international ideas can provide a variety of policy options and experience sharing, prompting policymakers in various countries to think and compare on a global scale.

(2) The promotion of international ideas can stimulate policy innovation: When new policy ideas and practices emerge internationally, these ideas and practices may inspire other countries to think and try innovative policy solutions. The promotion of international ideas can break the traditional thinking mode and stimulate policymakers to think about new policy paradigms and methods.

(3) The promotion of international ideas can promote the improvement and development of policies through policy evaluation and feedback: When a country's policy ideas and practices are widely disseminated internationally, other countries can evaluate and give feedback on them. This kind of feedback can help policymakers understand the impact and effect of their policies internationally, and make policy revisions and improvements based on feedback information.

(4) The promotion of international ideas can promote policy cooperation and sharing: Countries can exchange and share their policy ideas and practices through international cooperation mechanisms, policy dialogues, and experience sharing. Such cooperation and sharing can help countries jointly face global challenges, jointly develop solutions, and promote policy development and innovation.

China's "Belt and Road" initiative is a global cooperation initiative covering the fields of economy, politics, culture, and infrastructure construction (Nordin *et al.*, 2018). By advancing the Belt and Road Initiative, China aims to promote cooperation and development among participating countries and achieve common prosperity (Dunford *et al.*, 2019). The following are case studies of China's "One Belt, One Road" initiative promotion:

(1) China promotes infrastructure construction in participating countries through the "One Belt, One Road" initiative to enhance connectivity in areas such as transportation, energy, and communications. For example, the China-Pakistan Economic Corridor is one of the important projects of the "Belt and Road" initiative. It promotes trade and personnel exchanges between China and Pakistan through the construction of infrastructure such as roads, railways, and ports, and strengthens economic cooperation between the two countries.

(2) China promotes and participates in the country's economic cooperation and investment through the "Belt and Road" initiative. China actively promotes trade facilitation and investment cooperation with participating countries to promote economic development. For example, China has cooperated with Cambodia to develop a high-speed rail project to improve Cambodia's transportation capacity and promote tourism and economic development.

(3) China promotes cultural exchanges and educational cooperation through the "Belt and Road" initiative. China encourages personnel exchanges, academic seminars, and cultural exchange activities to

enhance cultural understanding and friendship with participating countries. For example, China has set up a special fund for educational cooperation under the "Belt and Road Initiative" to support students from participating countries to study in China and promote the sharing of educational resources and cultural exchanges.

(4) China promotes the establishment of policy docking and cooperation mechanisms among participating countries through the "Belt and Road" initiative. China has signed intergovernmental cooperation agreements with participating countries to promote bilateral and multilateral cooperation and strengthen policy coordination and cooperation. For example, China has established economic cooperation zones and free trade zones with Kazakhstan, Russia, and other countries to promote regional integration and economic development.

The influence of the promotion of international ideas on the promotion of the national image

The promotion of international ideas has an important influence on the image of a country. International promotion of ideas can help shape a country's image and reputation (Roth KP, 2009). When a country's core values, cultural traditions, or policy ideas are widely recognized and accepted internationally, it helps build the country's image and presents its uniqueness and values to the world. International promotion of ideas can have a positive impact on a country's reputation. If a country can actively spread its core values, advocate positive policy ideas, and demonstrate integrity, responsibility, and cooperation in international affairs, it may win the respect and praise of the international community and improve the country's reputation. International promotion of ideas can increase a country's attractiveness, attracting foreign talent, tourists, and investment. When a country's core values are in line with global trends and people's common values, it can attract more people's attention and interest in the country, prompting them to choose the country as a tourist destination, a place to study, and work. The promotion of international ideas can enhance a country's cooperation and influence in international affairs. When a country's core values match those of other countries, it can better cooperate with other countries and exert a positive influence on international affairs. Increased international cooperation and influence have further enhanced the country's international image. The promotion of international ideas can become a bridge for cultural exchanges between countries. When a country's core values and cultural traditions are recognized and accepted by other countries, it helps to promote international cultural exchanges and dialogues and strengthen understanding and friendship between different cultures. Germany's "Made in Germany" image construction is a successful case; it has established the image of high quality and reliability of German products internationally (Williams, 1896). Germany's manufacturing industry has always been known for its high quality and technological leadership. German companies pay attention to product quality, craftsmanship, and innovation, and constantly pursue excellence. They are committed to developing and applying advanced technologies and processes to ensure that products are in a leading position in terms of quality and reliability. Germany has a strict quality control and certification system to ensure that products meet high standards of quality. German companies generally adopt the International Organization for Standardization (ISO) and other international certification standards and conduct strict quality inspection and control on every link of the product, from raw material procurement to production and delivery. Germany has a long tradition of craftsmanship, focusing on fine manufacturing techniques and craftsmanship. German enterprises inherit and carry forward the traditional manufacturing process, pay attention to details, and strive for perfection so that the products have unique value and texture. German companies pay attention to sustainable development and environmental protection in the process of product manufacturing. They are committed to reducing their environmental impact, using environmentally friendly materials and production methods, and are leaders in the circular economy and energy efficiency. Germany is active in marketing and brand building, promoting the image of "Made in Germany" to the world. German companies participate in international exhibitions, hold promotional activities, and strengthen their influence on international consumers through advertising, brand cooperation, and digital marketing.

The case study successful practice of international idea promotion

The promotion of Singapore's "beautiful city"

Singapore's "Garden City" image-building aims to integrate the city and nature as its core concept (Yuen, 1996). The goal is to improve the quality of life of residents and visitors by creating a green, beautiful, and sustainable urban environment, oriented towards sustainable development, promoting green buildings, energy conservation, and environmental protection; encouraging residents to adopt a healthy lifestyle and providing a suitable place for outdoor activities and sports. Singapore pays attention to urban planning and construction and integrates natural elements into urban design. Create a livable urban environment through a rational layout of parks, green belts, and natural landscapes. Singapore's urban planning emphasizes the preservation and creation of green spaces to ensure that green landscapes can be seen everywhere in the city. Singapore takes active steps to protect natural resources and ecosystems. Harmonious co-existence between cities and nature by protecting natural wetlands, conserving plant and animal species, and promoting sustainable water management and waste disposal. Singapore raises awareness and awareness of the "Garden City" concept among residents and visitors through educational and awareness campaigns. Promote the values of environmental protection and sustainable development, and encourage people to take action to protect and enjoy the natural environment. Singapore actively promotes the image of "Garden City" to the world. Through activities such as tourism promotion, international conferences, and exhibitions, Singapore's green city development experience and achievements are showcased to the world. Attract the attention of international tourists and investors, enhancing Singapore's image and reputation on the global stage. Singapore's "Garden City" image-building is a successful case, in which international idea promotion has played an important role and achieved remarkable results. The following is the application and effect of international idea promotion in shaping the image of Singapore's "Garden City":

(1) International idea promotion helps Singapore spread the concept and values of "Garden City" to the world: Through international publicity and promotion activities, Singapore has demonstrated its green city development model and successful experience. This image dissemination has sparked international interest in Singapore and attracted more international tourists, investors, and partners.

(2) The promotion of international ideas has promoted cooperation and exchanges between Singapore and other countries: Singapore actively participates in international green city initiatives and environmental protection cooperation, and shares experiences and best practices with other countries. Through international cooperation, Singapore has not only strengthened its relationship with other countries but also gained more support and recognition.

(3) The promotion of international ideas has enhanced Singapore's influence on the global stage: As a pioneer with sustainable development and a green city as its core concept, Singapore has won a good reputation internationally. Singapore has positively impacted global urban development by promoting its image as a "Garden City" and becoming a recognized leader in sustainability and environmental protection.

(4) The promotion of international ideas has enhanced Singapore's attractiveness as a tourist destination and business center. The image of "Garden City" has made Singapore a city full of greenery and natural beauty, attracting a large number of international tourists and business travelers. This has had a positive impact on Singapore's tourism and economic development.

South Africa's "rainbow country" image construction

South Africa successfully brought an end to the apartheid regime in 1994, marking a momentous democratic transition (Clarno, 2019). This historic transformation presents a significant opportunity for South Africa to cultivate an inclusive national image. With its diverse population comprising different races, such as black, white, Indian, and mixed race, South Africa's multiculturalism serves as a valuable asset for its image construction. To address the legacy of racial conflicts and violence, South Africa established a Truth and Reconciliation Commission, aiming to foster reconciliation and national unity. While progress has been made in racial integration, tensions and sensitivities in race relations persist. Healing the wounds of historical ethnic conflicts and trauma requires time, and efforts to build trust and solidarity must persist. The concept of internationalization has played a pivotal role in shaping the image of South Africa as the "Rainbow Country" (Habiyakare, 2009). Through various means such as diplomatic propaganda, international events, foreign aid, and investment, as well as cultural exchanges and educational collaborations, South Africa has successfully disseminated its message of diversity, tolerance, and harmony on a global scale. Consequently, the nation has established a commendable international reputation and attracted a substantial influx of foreign investments and tourists. These strategic endeavors have enabled South Africa to proudly showcase its rich cultural heritage and multifaceted societal fabric. South Africa takes great pride in its diverse ethnicities, races, and religions, actively fostering mutual understanding and embracing cultural differences. The promotion of internationalization has provided South Africa with an influential platform to project its inclusive and harmonious national identity to the world. This image resonates strongly with international investors and tourists, who are captivated by South Africa's enticing blend of opportunities and allure. Moreover, South Africa's collaborations and exchanges with other nations have further propelled economic growth and cultural prosperity. In summary, the promotion of internationalization has played a pivotal and positive role in South Africa's image-building and overall national development.

CONCLUSION

This research examines the role of international idea promotion in advancing core values, fostering cross-cultural communication, and shaping the global image of nations. The findings show that the promotion of international ideas is crucial for strengthening a country's core values, improving its diplomatic influence, and enhancing its cultural and policy dissemination efforts. This process occurs through a variety of methods, including political diplomacy, media engagement, educational and cultural exchanges, and participation in international initiatives. The research question explored the impact of international idea promotion on the dissemination of core values and the shaping of national identities. The findings reveal that through active engagement in global communication channels, countries can influence both their immediate neighbors and the broader international community. Moreover, the promotion of international ideas helps create platforms for global collaboration, fostering mutual understanding among cultures while preserving diversity. The research emphasizes that through strategic international engagement, countries not only enhance their reputation but also stimulate policy innovation and social change.

AUTHOR CONTRIBUTIONS

Z. Hui conceptualized the research, collected data, and wrote the manuscript. A. H. B. A. Ghazali advised on technical writing, improved the literature review, revised the manuscript, and managed publication. S. N. Sha'ri refined the methodology, provided feedback, and helped finalize 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.

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ORIGINAL RESEARCH PAPER

Cultural norms, placemaking, and social justice: Creating inclusive public spaces for women

A. Hadid[1,2,*], **B. Marir**[1,3], **A. Mebarki**[1,4]

[1]*Institute of Architecture and Urbanism, University of Batna 1, Batna, Algeria.*

[2]*Laboratory of Architecture, Urban Planning and Transport: Housing, Landscape and Urban Mobility (LAUTr), University of Batna 1, Batna, Algeria.*

[3]*Laboratory of Natural Risk Land Use Planning (LARNAT), University of Batna 1, Batna, Algeria.*

[4]*Laboratory of Bioclimatic Architecture and the Environment (ABE), Constantine 3 University, Constantine, Algeria.*

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ABSTRACT

BACKGROUND AND OBJECTIVES: In Algerian cities, access to and use of public spaces remain strongly conditioned by cultural norms, gender stereotypes, and spatial inequalities. Women are often perceived as less legitimate users of public space, resulting in unequal access, limited visibility, and a heightened sense of vulnerability. This research explores how collective representations, particularly gendered social expectations, cultural constraints, and socio-spatial dynamics, shape women's behaviors and restrict their appropriation of public space. Grounded in gender-sensitive placemaking, the study seeks to identify key obstacles and planning-related challenges while proposing inclusive urban strategies.

METHODS: The study adopts an anthropological and reflexive methodology, combining a literature review with mixed methods. It integrates qualitative interviews, field observations, and a structured survey of 100 women in the Ben-Boulaid alleys of Batna, Algeria. The empirical strategy was designed to investigate how cultural expectations, spatial arrangements (lighting, accessibility, urban design), and socio-economic characteristics (age, occupation, mobility) intersect to shape gendered uses of public space. This methodological framework allows for testing the assumption that these factors play a decisive role in producing spatial inequalities and limiting women's access and autonomy in urban environments.

FINDINGS: The results show strong associations between women's use of public space and multiple interrelated factors. A significant correlation was found between the frequency of visits and age/occupation. Cultural barriers were identified as the most influential factor limiting access, followed by inadequate infrastructure and perceived insecurity. Negative correlations were observed for perceptions of equal access ($r = -0.167$, $p = 0.098$) and women's access to the Ben-Boulaid alleys ($r = -0.189$, $p = 0.060$), indicating exclusion from certain spatial practices. Lighting was positively correlated with reduced fear of aggression ($r = 0.165$). Furthermore, 72% of respondents judged current gender equality measures as insufficient. These results confirm the hypothesis and emphasize the urgent need to integrate gender indicators into urban planning practices.

CONCLUSION: This research highlights the importance of rethinking urban policies through a gender lens, incorporating women's lived experiences and spatial needs into the design process. It calls for participatory placemaking strategies that promote safety, inclusivity, and cultural sensitivity, aiming to foster public spaces that are accessible, welcoming, and equitable for all.

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*Corresponding Author:
Email: *amani.hadid@univ-batna.dz*
Phone: +213553948187
ORCID: 0009-0004-8408-6151

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INTRODUCTION

The history of women, particularly within the Algerian context, is marked by their struggle to assert their identity and role within broader social movements for change (Beaud and Masclet, 2006). This dynamic includes a questioning of the traditional boundaries between public and private spheres, as well as of imposed social roles. During the colonial period, Algerian women played a central role in the struggle for freedom, shaping their narratives and resisting both colonial and patriarchal domination (Amrane-Minne, 2015). Anthropological studies conducted in the 1930s by researchers such as Jacqueline Rivière and Germaine Tillion explored Kabyle, Chaoui, and Mozabite societies, often through the lens of colonization (Boulhaïs, 1998). In her writings, Assia Djebar (Cheref, 2019) echoes this process of resistance, highlighting how these women were at the heart of histories marked by social violence and symbolic struggle. Despite significant progress, women continue to face numerous challenges in contemporary urban spaces. Safety concerns remain critical, with current security measures often proving insufficient and contributing to a persistent sense of vulnerability (Vera-Gray & Kelly, 2020; Bourel, 2012). The gendered impact of mobility and accessibility barriers stems from transportation infrastructures that inadequately reflect women's specific travel needs and patterns (Priya Uteng, 2021). The design of public spaces frequently overlooks the spatio-temporal dynamics particular to women, especially those balancing domestic and professional responsibilities (Libertun de Duren, 2022). Social norms and gender stereotypes shape expectations and behaviors in public space, limiting women's participation and freedom of use (Borgerson, 2005). This situation is further exacerbated by unequal access to resources and opportunities, which reinforces disparities between men's and women's spatial practices (Benny *et al*., 2024). Research on gendered public spaces has grown substantially in recent years (Beebeejaun, 2017; Kern, 2020). However, significant blind spots persist, particularly concerning the Maghreb and Algeria in particular. Urban studies remain predominantly focused on Western contexts (Gudekli *et al*., 2023; Spain, 2014), creating a geographical imbalance that limits our understanding of the specific dynamics at play in Arab-Muslim societies. This gap is all the more problematic as recent Algerian research demonstrates pronounced gendered differences in spatial practices (Rahmani & Messaoudene, 2021; Benneghrouzi & Zitouni, 2018), rooted in enduring cultural conventions. Academic research on Algerian cities has largely concentrated on the historical and political dimensions of women's participation (Tlemçani, 2009), often overlooking contemporary analyses of women's everyday use of public space. More recent studies, however, have highlighted the need to consider the diversity of women's spatial practices about cultural, religious, and territorial factors, particularly through the lens of "spatial dignity," shaped by prevailing social norms (Rahmani & Messaoudene, 2021). At the same time, the application of the placemaking concept in North African contexts remains extremely limited, despite its methodological potential for fostering inclusive and gender-sensitive public spaces (Friedmann, 2010; Mehta, 2014).This situation is further compounded by a lack of in-depth empirical data on the barriers women face in public spaces in North African societies, as well as on the strategies of avoidance, adaptation, or resistance they employ to cope with these constraints (Naamane Guessous, 2016). Recent methodological approaches emphasize the need for the active participation of women in urban planning processes, integrating their needs and experiences at every stage of project development (UNDP *et al*., 2022). As (Cooper Marcus and Francis, 1997) have shown, public spaces are too often designed without considering the specific needs of certain groups, particularly women, thereby exacerbating inequalities in access, comfort, and safety. Given these considerations, the need for gender-sensitive urbanism emerges as an urgent priority. Traditional urban design models have historically failed to integrate gender perspectives in sustainable urban planning (Gauvin *et al*., 2020), marginalizing those of women and gender minorities. This omission not only compromises equal access to public space but also undermines the sustainability and quality of life in urban environments (Parnigoni, 2020). An inclusive and equitable reconfiguration of these spaces, therefore, requires the explicit integration of women's perspectives into planning practices. The concept of placemaking aligns closely with this imperative. It is a collaborative approach aimed at strengthening the connection between people and the places they inhabit (Schneekloth &

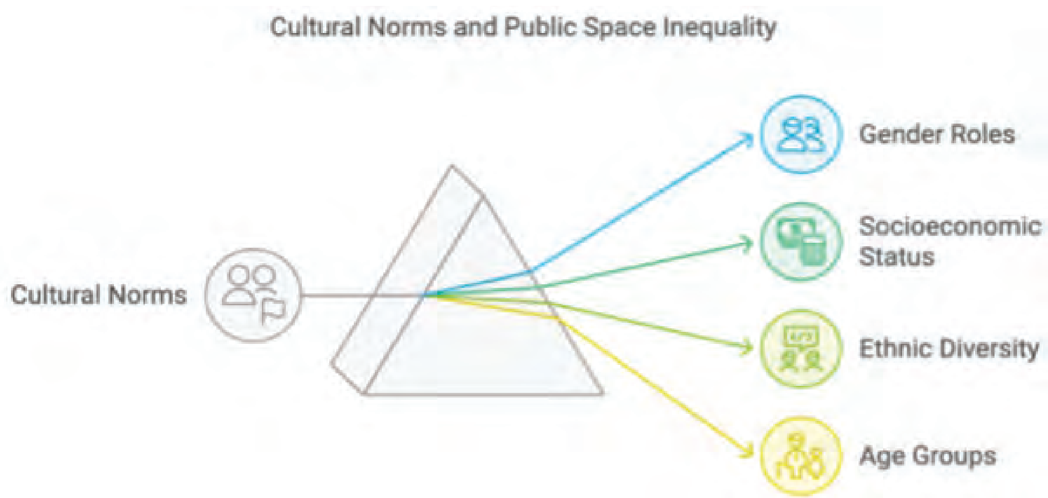

Fig. 1: Cultural norms and public space inequality

Shibley, 1993; Myers, 2002), while accounting for the cultural, social, and identity-specific needs of different groups, particularly women. Beyond its technical dimension, placemaking stands as a lever for social transformation that fosters more inclusive and equitable urban environments (Mehan, 2024). Several recent studies have highlighted the relevance of anchoring this approach in the fine-grained analysis of spatial behaviors to design interventions that are better adapted to local contexts (Sadeghi *et al*., 2022). This study focuses on gendered use of public space in Algerian cities. It aims to identify the main cultural, social, and urban planning factors that influence women's access, presence, and modes of appropriation of public spaces. Based on this analysis, recommendations will be developed to guide urban design practices in line with gender-sensitive placemaking principles. The central hypothesis of this study is that cultural norms and gendered spatial configurations significantly shape women's presence, practices, and the inequalities they face in public space, as illustrated in Fig. 1. To achieve these objectives, the research survey was conducted in the Ben-Boulaid alleys of Batna city, Algeria, in 2024. This research, therefore, aims not only to identify the cultural and spatial barriers that women face in Algerian public spaces but also to examine how urban planning practices can be rethought through the lens of gender-sensitive placemaking to respond to these challenges and create more inclusive environments.

Literature review

Research on cultural norms, placemaking, and social inequalities in public spaces highlights an urgent need to rethink the design of these spaces to make them more inclusive, equitable, and responsive to women's needs. A gender-sensitive approach to placemaking can not only improve the safety and accessibility of public spaces but also help to deconstruct traditional gender roles and promote social equality in cities. Over the centuries, cultures have placed varying degrees of importance on public space, with contemporary research emphasizing their role in community building and cultural engagement (Ramos-Vidal, 2024). The evolution of cultural norms regarding women's access to public spaces has been marked by profound transformations, influenced by feminist struggles, social changes, and political contexts (Laplanche, 2016). Historically confined to the private sphere, women have gradually claimed their place in public places, particularly in the 20th century, with the feminist movements that fought for equal rights and active participation in social and political life (Gubin, 2004). While in many societies today, women occupy these spaces more equally, challenges remain, such as street harassment, safety on public transport, and differences in access linked to social class. Thus, although progress has been made, the complete and secure appropriation of public spaces by women remains a major challenge in the fight for equality (Bandauko *et al.*, 2024).

The development of public spaces must be gender inclusive, especially for women, as actions taken in the public spaces could affect their presence or full participation in public life in public places. Placemaking is an approach to urban planning that developed in the 1960s as a reaction to a conception of the city centered on motor vehicles and commercial activities (Akbar *et al.*, and Edelenbos, 2021). Urban planners such as Jane Jacobs and William H. Whyte promoted a vision that focused on pedestrians and community life rather than on road infrastructure and buildings. According to architect Jan Gehl, this philosophy places “everyday life [first], followed by spaces, then buildings “, emphasizing that the reverse “never works” (Cappelli et chardonnet-darmaillaq, 2019). Placemaking, therefore, favors an approach centered on the uses and needs of residents to create public spaces conducive to social interaction and the development of the local community (Kutay Karacor, 2014). To assess the quality of perception of public spaces by their users, Jan Gehl has developed an analysis tool composed of twelve criteria. These criteria, divided into three distinct categories (protection, comfort, and pleasure), make it possible to assess whether a public space offers a safe, pleasant, and stimulating environment for its users (Cappelli et chardonnet-darmaillaq, 2019). However, despite these theoretical frameworks, a critical analysis of international urban planning studies reveals significant gaps in the practical application of gender-sensitive placemaking principles. While Gehl’s criteria provide a foundation for space evaluation, most urban planning projects lack specific methodologies for measuring gender-differentiated impacts of spatial interventions.

International studies of urban planning solutions for gender inclusion

Gender-sensitive urban planning has been most extensively developed in Vienna, which, since the early 2000s, has systematically applied a gender mainstreaming approach across all its urban policies (Jacquot, 2013). Studies conducted in public parks revealed a male-dominated spatial occupation, prompting targeted planning interventions. These included pilot projects involving teenage girls in the design process, reconfiguring park layouts to create multifunctional environments, and including gender criteria in urban planning regulations. This approach effectively operationalizes Gehl’s principle of prioritizing “everyday life” by tailoring it to gender-specific needs in public space design (Cappelli et Chardonnet-Darmaillacq, 2019). Empirical research further emphasizes the central role of safety in shaping women’s use of urban environments (Ntakana *et al.*, 2022). A quantitative study involving 256 women in developing countries identified key planning interventions for improving perceived safety, such as technically standardized public lighting, redesigned public transport access points, the replacement of male-dominated spaces with mixed-use commercial areas, and the integration of playgrounds within public areas (Sadeghi *et al.,* 2023; Mowri *et al.,* 2024). Complementing this, the World Bank’s *Handbook for Gender-Inclusive Urban Planning and Design* offers practical tools to incorporate gender perspectives into urban design through the placemaking framework (Terraza *et al.,* 2020). Recent research also highlights the need to critically question how public spaces are conceptualized and built, emphasizing that male-dominated design paradigms in fact shape many so-called “neutral” spaces; a gender-sensitive approach must therefore address these structural biases to truly foster inclusivity (Moonen, 2024).

The social construction of gender in public spaces

Judith Butler, an American philosopher and gender theorist, argues that male and female roles are not determined by biology but rather shaped by social constructions. According to her, gender is not a stable identity but rather a performance that is constructed through repeated acts in each social context. Butler thus challenges the idea of a natural and essential gender identity and highlights the fluid and performative nature of gender (Dichman, 2024). While Butler’s theoretical framework provides important insights into gender construction, urban planning research requires moving beyond performativity theory to examine concrete spatial interventions. The challenge for urban planners is translating these social understandings into measurable design solutions.

*Judith Butler’s Key ideas on gender (*Baril, 2008*):*

1. *Gender is not a stable identity, but rather a performance that is constructed through repeated acts in each social context.*
2. *Male and female roles are not determined by biology but are shaped by social constructs.*

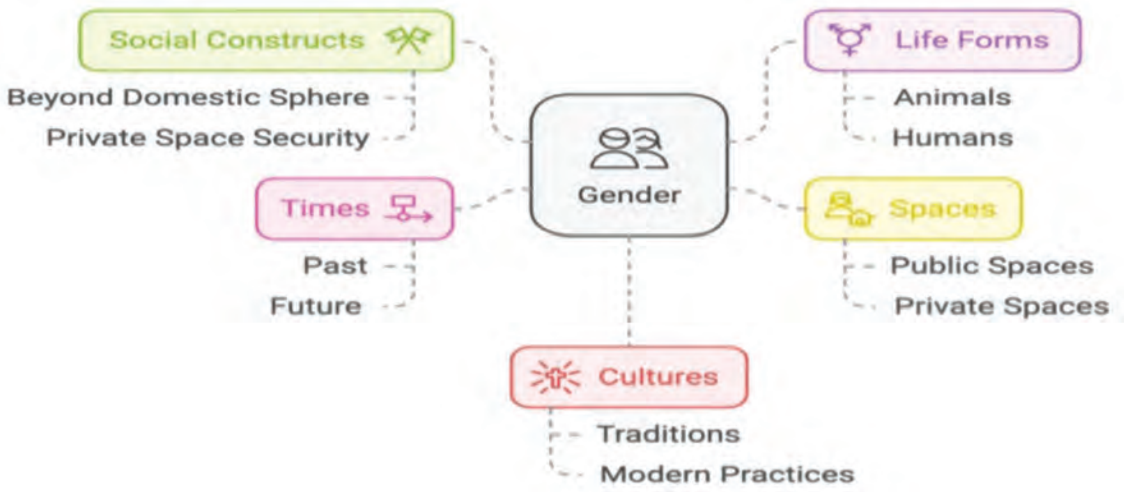

Fig. 2: The social construction of gender in public spaces

3. *Gender identity is not natural and essential, but rather fluid and performative.*
4. *Gender is the result of a stylized repetition of acts, gestures, and desires that create the illusion of a stable and coherent gender identity.*

Contributions of Judith Butler's gender theory

Judith Butler's work has had a significant impact on gender studies and feminist movements. Her ideas have notably helped to:

1. *To challenge gender essentialism and show its socially constructed nature.*
2. *Paving the way for a more fluid and inclusive understanding of gender identities.*
3. *Encourage critical reflection on gender norms and their effects on individuals.*
4. *Contribute to better recognition of the diversity of gender expressions.*

Public spaces mirror the gender dynamics of society (Bassand, 2001). Gender stereotypes and social norms strongly influence how individuals behave and navigate these spaces. Gender identity often dictates what is perceived as appropriate or acceptable behavior in public settings. These gender dynamics shape interactions and uses of public space, reflecting the inequalities and power relations present in society (Rusek et Banasiewicz, 2017). Cultural norms, both implicit and explicit, do indeed have a significant influence on how men and women occupy and behave in public space (Jalalkamali et Doratli, 2022). The critical gap in current research lies in the lack of empirical studies that measure how specific urban design interventions can modify these gender dynamics in practice. While social construction theory explains why gendered behaviors exist in space, urban planning requires evidence-based solutions for creating more inclusive environments. It is necessary to study traditional social and scientific order, since gender inequalities become visible only when individuals become aware of social, gender, and racial disparities and their persistence (Verry, 2022). This calls for an analysis of the gendered nature of specific spaces and the recognition of these spaces as expressions of cultural identity rather than mere geographical boundaries; see Fig. 2. Gender is not limited to the social roles attributed to men and women. It is part of broader realities, such as the organization of living spaces, the perception of time, or even cultural practices (Ucciani, 2012).

Relationship between woman/culture/space

The relationship between women and public spaces is complex, influenced by historical, social, and design factors that shape their experience and accessibility. As cities transform, understanding these dynamics becomes essential to promoting inclusion (Bassand and Joye, 2001). The main elements of this relationship are:

The historical context: Public space is not a neutral container but a historically and culturally produced setting, continuously reshaped by social practices and power dynamics (Low, 2022). Each period has brought its challenges and ideals, shaping how these places are perceived and used today. Understanding this history is essential to designing public spaces that meet contemporary needs while honoring their rich cultural heritage. The influence of design and accessibility on public spaces is crucial to creating inclusive urban environments where everyone can move freely and safely (Evans, 2009). With a collaborative approach that integrates diverse needs and perspectives, it is possible to improve not only physical accessibility but also the sense of belonging and community engagement within public spaces, as shown in Fig. 3. Space and culture are seen as a two-way exchange: space, as a social product, is imprinted by the culture that produced it; culture, on the other hand, also has certain spatial dimensions.(Houssay-Holzschuch, 2005) how women orient themselves, name and divide space (profane/sacred, private/public), or how their relationship to the environment is mediated by culture (technical mediation, food mediation, etc.). The relationships between space and culture are dialectical in the sense that the landscape is imbued with culture; it is also a matrix because it preserves the very culture that is found there, as explored in contemporary ethnographic approaches to space and place (Low, 2016). Space is the fruit of this culture. Thus, each geography must be considered as a cultural geography; it is no longer simply a question of understanding geographical limits but of grasping society as a whole, where culture occupies a central place (Bonnemaison, 2000). In this context, space is seen as a relevant and effective tool for understanding society, as illustrated in Fig. 4. Within and around geography, or the importance of gender analyses, because Gender geography is part of cultural geography to the extent that the place and role of women are cultural constructs. (Louargant, 2002). The analysis of the relationships between societies and space always begins with society, because space is reconfigured through communicative and practical processes reflecting evolving social (Christmann *et al.*, 2022) (Fig. 5).

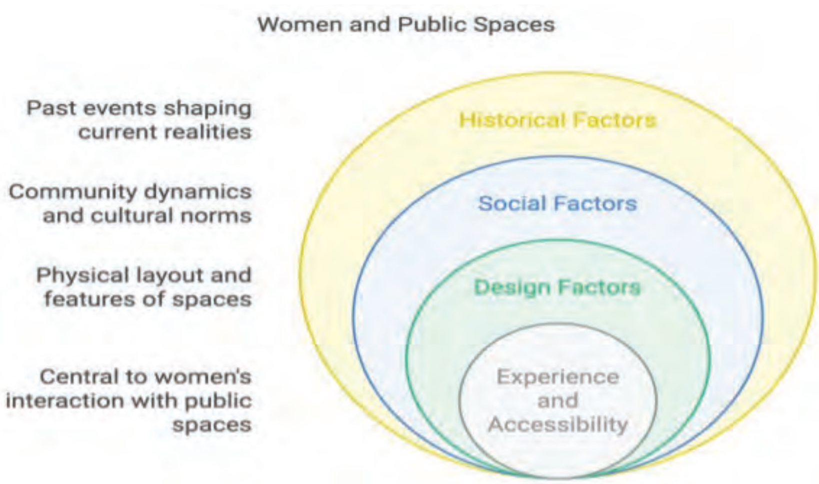

Fig. 3: Women and public space

Fig. 4: Relationship between space and geography

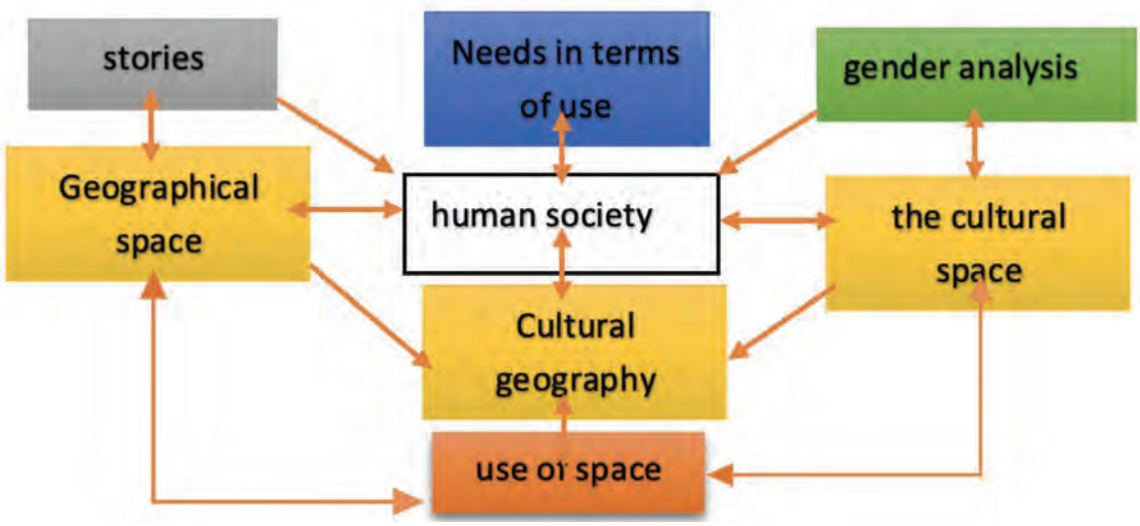

Fig. 5: Relationship between space and culture

The needs of women in public spaces

Research on women's needs in public spaces reveals a multidimensional complexity that transcends simple architectural considerations. Contemporary studies on urban safety and gender demonstrate that women's experiences of public spaces are fundamentally shaped by perceptions of security and accessibility (Dubey *et al*., 2025). while contemporary studies like those of Tovi Fenster (Fenster, 2005) and researchers like Sanchez de Madariaga deepen the understanding of gender dynamics in urban space (Dutton *et al.*, 2022). Analysis of factors influencing the feeling of security highlights the emergence of security as a central concern (Ntakana *et al*., 2022). Women's experience in public spaces reflects a multidimensional reading of the space. Their approach favors dynamic criteria—visibility, lighting, and mobility—which are closely intertwined with deep social, cultural, and psychological constructions, revealing a lived geography that is much more than a simple spatial journey (Malhotra et Aulakh, 2023). Reports from international organizations such as UN-Habitat and the World Bank confirm that women's needs include not only physical security but also accessibility, comfort, respect, and the opportunity for active participation in the design of urban spaces (Falú, A. 2014). However, public spaces remain largely unadopted to these needs. Urban design has traditionally been dominated by men, resulting in a spatial organization that does not meet the specific needs of women. This approach often privileges infrastructures and facilities focused on masculine activities, such as rectangular sports fields, neglecting the creation of more inclusive and multipurpose spaces (Kaakour and Cartier, 2023). The feeling of invisibility and exclusion that women often experience in public spaces is a complex issue (Bourdieu, 2002). Indeed, urban planning does not always consider the specific needs of women, which can accentuate this feeling. For example, women use public spaces more for utilitarian travel than for strolling, which may reflect disparities in access to and use of these spaces. This raises important questions about equity and inclusion in the design of public spaces to better meet the needs and expectations of the entire population (Bigot, 2021). Safety is indeed a major issue, especially for women who frequently experience harassing behavior in public spaces. This situation creates a feeling of insecurity that significantly influences their movements. Faced with these experiences, many women adopt avoidance strategies, such as choosing routes that they consider safer or avoiding certain places at certain times of the day (Blidon, 2010). Cultural norms often dictate the expected behavior of women in public spaces. These expectations can restrict their freedom of action and reinforce the idea that they should not occupy these spaces equally to men. Studies show that women are regularly subjected to "calls to order" in public spaces, constantly reminding them of their vulnerability. These norms limit women's access to public spaces and contribute to perpetuating gender inequality (What place for women in public space?, 2023). Urban planning policies have long neglected the specific needs of women in terms of mobility, their more complex journeys linked to domestic and care tasks. This invisibility of female mobility creates inequalities in access to services and public space.

Critical analysis of research gaps in urban planning literature

Despite the substantial theoretical foundation established by social and cultural analyses of gender dynamics in public spaces, the urban planning and territorial development literature reveals significant methodological limitations that impede the advancement of evidence-based practice. First, the majority of gender-sensitive urban planning initiatives suffer from inadequate quantitative impact assessment, whereby current studies predominantly adopt descriptive approaches that document implemented solutions without establishing rigorous empirical measurements of their effectiveness on women's spatial usage patterns (Fenster, 2005). Second, the field demonstrates a notable absence of standardized intervention methodologies, creating a substantial disconnect between theoretical recommendations and practical implementation, where planning solutions exhibit considerable variation across different contexts without a unified methodological framework that would enable systematic comparison and reproducibility of results (Greed, 2003; UN-Habitat, 2021). Third, the research corpus exhibits insufficient longitudinal analysis, as studies predominantly focus on immediate post-intervention effects while neglecting long-term monitoring of women's spatial appropriation processes, thereby preventing comprehensive evaluation of intervention sustainability and durability (Terraza *et al*., 2020).

MATERIALS AND METHODS

This article adopts a reflexive and anthropological approach, inspired by the work of (Bourdieu, 2002), to analyze the social and cultural systems that underpin masculine and feminine identities (Hammoudi, 2007). It explores global cultural invariants and local specificities by highlighting the role of multiculturalism in perpetuating gender inequalities (Jodelet, 2015). By examining these dynamics, the mechanisms that naturalize local history and culture, often perceived as self-evident, are sought to be deconstructed (Edensor *et al*., 2002). The main objective is to highlight the paradoxes and inequalities that shape the design of public spaces in Algeria, an aspect often neglected by planners who focus mainly on the technical aspects of planning (Djouad, 2019). To better understand the different barriers related to gender inequality in public spaces, the methodology shown in Fig. 6 combines an in-

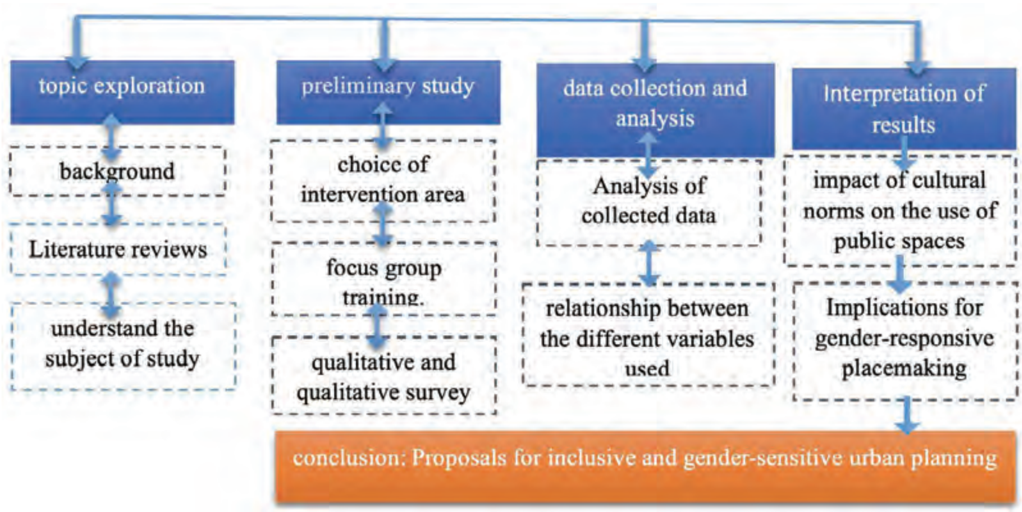

Fig. 6: Diagram of the methods used in this study

depth literature review, exploring how cultural norms shape women's use of public spaces, considering social, cultural, and environmental dimensions. Research then focused on a case study of the Ben-Boulaid alleys, a public urban space in the city of Batna. The alleys, frequented by a diversity of users, reflect like a mirror the complexity and richness of the local society, thus constituting a particularly fertile ground for observation. A purposive sampling strategy was employed to select 100 women aged 18-65 years, with specific selection criteria including regular use of the study area (at least twice weekly), residence within a 2 km radius of the site, and willingness to participate in follow-up interviews. This approach ensured representation of diverse socio-economic backgrounds while maintaining focus on research objectives. The study combined mixed methods: a structured questionnaire survey conducted with a sample of 100 women to collect data on barriers related to accessibility, gender, and multiculturalism, complemented by in-depth semi-structured interviews with a subset of participants and systematic observations using structured grids during different periods. To ensure reliability and validity, a pilot study was conducted to validate instruments and refine data collection procedures, with internal consistency of scales assessed using Cronbach's alpha ($\alpha > 0.70$ for all constructs). Validation strategies include triangulation of multiple data sources, member checking with participants, and systematic documentation of all methodological decisions. The study aims to establish correlations between the variables studied to rethink placemaking practices to make public spaces safer and more welcoming for women, as illustrated in Table 1.

Presentation of the case study

Batna is the "capital" of the Aurès (the Aurès mountain range, located south of Khenchela, Lambèse, and Timgad, stretches between the Chotts of Constantine and the Saharan depression of Ziban). These mountainous highlands, which reach their

Table 1. From theoretical constructs to measurable indicators: operationalization of concepts and variables

Concept	Variable	Indicator	Measurement Method	Justification
Gender and Perceptions of Cultural Norms	Gender roles, honor codes, and cultural beliefs	Agreement with statements on women's presence in public spaces	5-point Likert scale questionnaire + interviews	Captures internalized cultural beliefs affecting spatial behavior
Security Level and Feeling of Security	Fear of harassment, risk perception, and safety assessment	Safety ratings, reported incidents, avoidance behaviors	Likert scale + behavioral mapping	Subjective and objective security measures are crucial for spatial practices
Number and Time of Visit	Frequency patterns, temporal usage	Visiting frequency, duration of stay, preferred time slots	Self-reporting + observation logs	Reveals actual usage patterns and temporal preferences
Distribution of Activities	Activity types, spatial appropriation	Type of activities, location preferences, and space occupation	Behavioral mapping + structured observation	Shows how different activities are distributed across space
Frequency of Users	User density, demographic diversity	Number of users by time/location, user characteristics	Systematic counting + demographic surveys	Objective measurement of space utilization
Causes of Inequalities in Public Space	Structural barriers, design limitations	Physical obstacles, cultural restrictions, and policy gaps	Spatial analysis + policy review + interviews	Identifies root causes of gender-based spatial exclusion
Impact of Urban Policies on Gender Equality	Policy effectiveness, implementation gaps	Policy compliance, resource allocation, and enforcement	Document analysis + stakeholder interviews	Evaluates how policies translate into spatial practice
Influence of Placemaking Practices	Design interventions, spatial modifications	Before/after usage patterns, user satisfaction, and accessibility improvements	Comparative analysis + user feedback	Measures the effectiveness of spatial interventions
Equal Access	Accessibility barriers, inclusion levels	Physical accessibility, cultural acceptance, and usage equality	Accessibility audit + usage statistics by gender	Assesses actual vs. intended accessibility

highest point at 2,328 meters, constitute a veritable geographical barrier. The region is home to the Chaouia, a Berber-speaking ethnic group that has preserved its unique cultural identity through the intergenerational transmission of rich traditional knowledge, covering domains such as astronomy, meteorology, agriculture, and traditional medicine (Iles d'Imesli & Guedjiba Abdennacer, 2019). Located at approximately 1,048 meters above sea level and surrounded by the Aurès Mountains, Batna is the fifth-largest city in Algeria, with a population of around 290,645, according to the 2008 census. Despite its position in a basin, it is considered the tallest major urban center in the country (Zeraib *et al*.,2022). The city experiences a cold, semi-arid mountain climate, characterized by cold winters with occasional snowfall and hot, dry summers (Fig. 7). Batna's urban planning exhibits significant diversity. Established in 1844, the city consists of a dense historic center, a residential periphery, and newer, modern housing developments. Each area features distinct characteristics tailored to specific needs. The Ben-Boulaid alleys, Batna, Algeria. Located opposite the Ben Boulaid boulevards, there is a space measuring 4313.60 m². The space is delimited on all sides by lanes intended for mechanical traffic. It

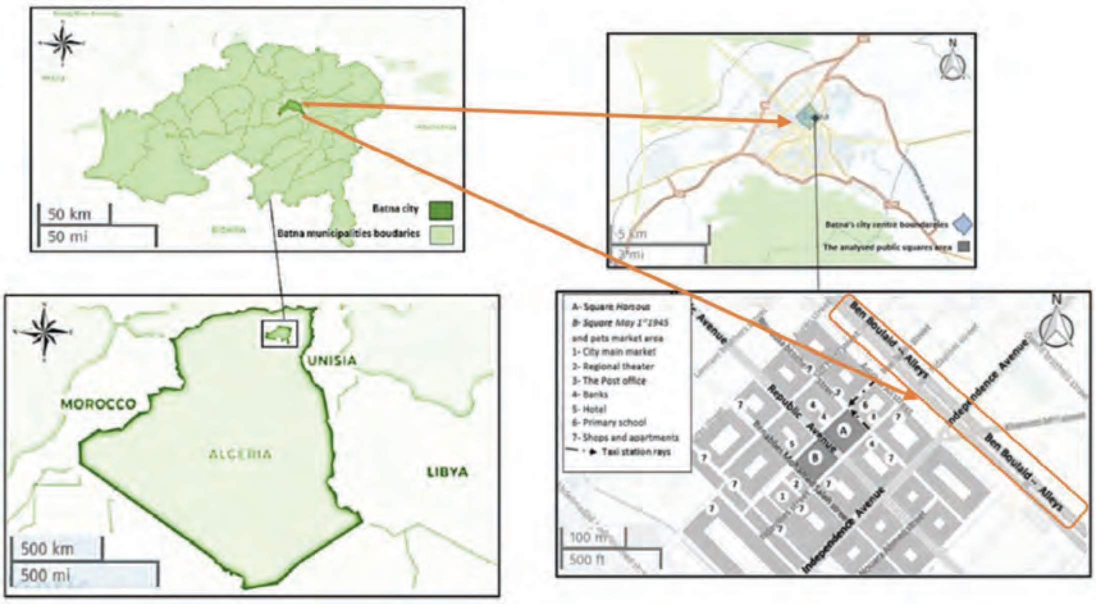

Fig. 7: Location of the study area (source: https://www.viamichelin.pl/web/Mapy-plany/Mapa_plan-Batna-_-Batna-Algieria)

Fig. 8: (a) and (b) photos taken on the Ben-Boulaid alleys

has a tiled floor and a barren land that serves as a courtyard (plot) for a garden. These boulevards, to be very busy and attractive, constitute a place of relaxation and socialization accessible to all social classes. It is appreciated by a very large number of families; it is also a space for summer festivals where outdoor concerts are frequently organized and various exhibitions take place. The Ben-Boulaid alleys, formerly known as the Bocca alleys, have undergone a profound metamorphosis since independence. This urban route, once a simple means of communication, has been transformed into a place full of history and symbols. Today, paved with marble and decorated with green spaces, it constitutes the beating heart of the city, where memories of the past and aspirations for the future mingle. The presence of the statue of Mustafa Ben-Boulaid, an emblematic figure of the Algerian revolution, further reinforces the memorial character of this space. Having become a privileged place for walking and relaxation, it regularly hosts cultural and sporting events, thus reinforcing its role as the living heart of the city (Naceur, 2017) (Fig. 8).

Investigation on women's urban practices

Combining mixed methods, focus group, and questionnaire survey, as shown in Fig. 9.

The formation of focus groups

Allowed for an in-depth exploration of the female category. The topics discussed revolved around women's urban practices, particularly about their family commitments, professional obligations, and consumer lifestyles. Emphasis was also placed on their conditions of access to public spaces and their perception of the level of security and the impact of gender among different users (Fig. 10).

Fig. 9: Methodological approach

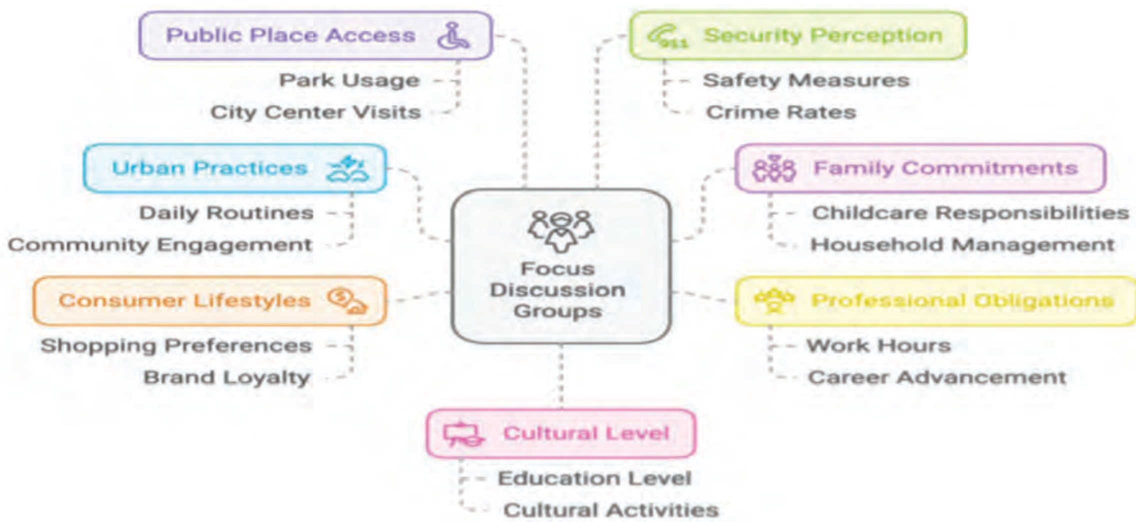

Fig. 10: The formation of focus discussion groups

Participants' profile

The ideal common profile for this study was that of women belonging to the economic middle class, whether they worked or not. These women had to be regular users of public spaces and frequent the city center. The main criterion for distinguishing these three groups was age, the hypothesis being that differences in urban emancipation were linked to generational effects. Thus, women were classified as follows: those aged over 45, retired, single or married (Group 1); single, or divorced mothers with dependent children (Group 2); and young working women (Group 3) (Fig. 11).

The objective is to collect varied perspectives on the cultural norms and social order that influence the female presence in this space.

RESULTS AND DISCUSSION

Group 1 people aged over 45, retired, single, or married, as represented in Fig. 12

With age, these women wish to move closer to the city center for practical reasons and due to fear of their usual fragilities. The Ben-Boulaid alleys constitute one of the most appreciated spaces by elderly women. Afternoons see retired women gathering at specific times for their social meetings. Mainly from the northern districts, these women leave their cramped and noisy homes to occupy this public space. Our analysis reveals a conscious avoidance strategy of certain urban sectors deemed hostile. They bypass the Bouakal neighborhood, stigmatized for its insecurity and strong masculine influence, as well as the 84-unit neighborhood. These results confirm the existence of a gendered urban geography that guides their daily movements. Despite inadequacies in street furniture and public lighting, they express satisfaction with the place.

Group 2 single or divorced mothers with dependent children, as represented in Fig. 13

Women have often faced gender discrimination, but despite this, they have managed to develop a strong identity linked to their place of residence. Although some may have initially hesitated to settle in a particular place, they have eventually managed to anchor themselves there and build part of their identity there. Batna City Center presents undeniable advantages: accessible public transportation and

Fig. 11: Classification by age

Fig. 12: Photos (i) and (j) women aged over 45 years

Fig. 13: photos (K) and (L) women 2nd group

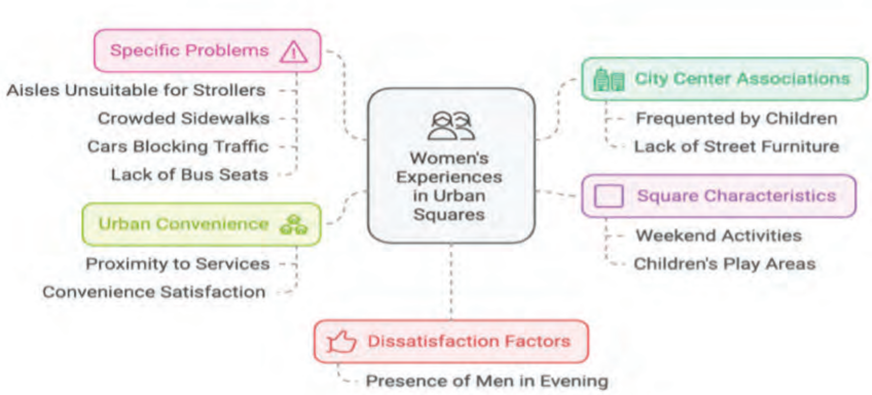

Fig. 14: Women`s experiences in urban space

proximity to shops and services. For these women, the proximity of Ben-Boulaid alleys to the city center serves mainly practical purposes. They go there for specific errands or official business, never strolling without a precise goal. This utilitarian use reveals how parental constraints restructure female spatial practices. Mothers highlight specific problems: inadequacy of strollers (described as “a nightmare scenario”), crowded sidewalks, traffic blocked by cars, and lack of stroller seats on buses. These obstacles reveal the inadequacy of urban space to parental mobility needs. They also express dissatisfaction with male presence in the evening, confirming a gendered temporality of public space use (see Fig. 14).

Group 3 young active women, as represented in Fig. 15.

Fig. 15: photos (M) and (N) women 3rd group

Young women emphasize the narrow-mindedness of Batna residents and obstacles to newcomer integration: "When you come from another city, integration becomes difficult. There are social circles, and you must be well-connected to belong ". A native participant confirms, "I'm bored. I feel like I'm always in the same routine, always meeting the same faces." This spatial monotony reveals a generational gap in public space appropriation (Fig. 15). These discussions have allowed us to reconsider preconceived ideas about the freedom of movement of women, particularly young women. Nighttime anxiety seems to limit urban entertainment activities by drawing boundaries around certain places and specific times. However, the qualitative data highlighted other barriers, such as the gender issue. This is why a second analysis was carried out to understand the multiple facets.

Questionnaire survey

A questionnaire was designed to collect data on the frequency of use of public spaces by women (N = 100), their feelings of safety, and their perceptions of cultural norms. This will allow us to obtain statistical data on the subject using an analysis of the different variables. This method is illustrated in Fig. 16.

Number and time of visits

Table 2 presents the descriptive statistics for visiting hours (M = 2.93, SD = 1.26, N = 100).

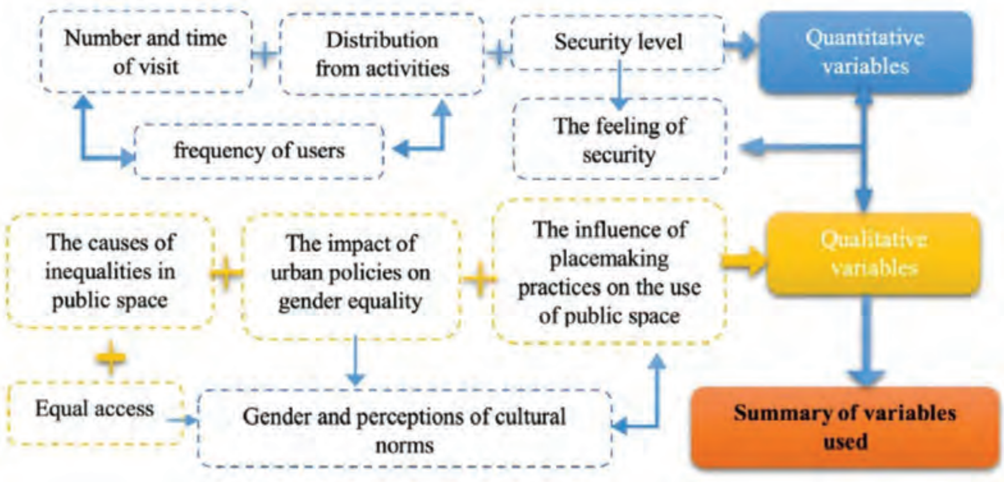

Fig. 16: The variables used in the survey

Table 2. Descriptive statistics

Descriptive statistics			
variables	average	standard	N
Visiting hours	2.9300	1.25734	100

Table 3. Correlation

Correlations		Visiting time in public spaces	Number of visits to public spaces
Visiting Hours of the Mustapha Ben-Boulaid alleys for Women	Pearson correlation	1	-.0576
	Sig. (bilateral)	-	. 576
	N	100	100
Number of visits	Pearson correlation	-.0576	1
	Sig. (bilateral)	.567	-

Pearson’s correlation is a statistical measure that assesses the degree of linear relationship between two quantitative variables. The significance (bilateral) is an important indicator for determining whether a statistical result is significant or not. Table 3 demonstrates this correlation analysis, revealing no significant relationship between visiting hours and number of visits to the Mustapha Ben-Boulaid alleys for women (r = -.0576, p = .576).

Figs. 17 and 18 show a perfect correlation between the number of visits and the time of visit of the space studied, which means that these two variables are closely related. In other words, the variations in the number of visits are directly and perfectly explained by the variations in the time of visit. This very strong relationship indicates that there is probably a cause-and-effect link between these two variables, where the number of visits depends on the time of visit or vice versa. Factors such as age and occupation influenced the number and timing of visits.

Distribution of activities between men and women is shown in Table 4

The correlation coefficient r = -0.167 indicates negative correlations between activity types and visit numbers, suggesting that men and women participate in different activities. This differential participation reflects gendered spatial practices where women’s access is systematically constrained. For women’s access (alone or accompanied), r = -0.189 with significance approaching threshold (p = 0.060) indicates women have reduced access or feel less comfortable frequenting the alleys

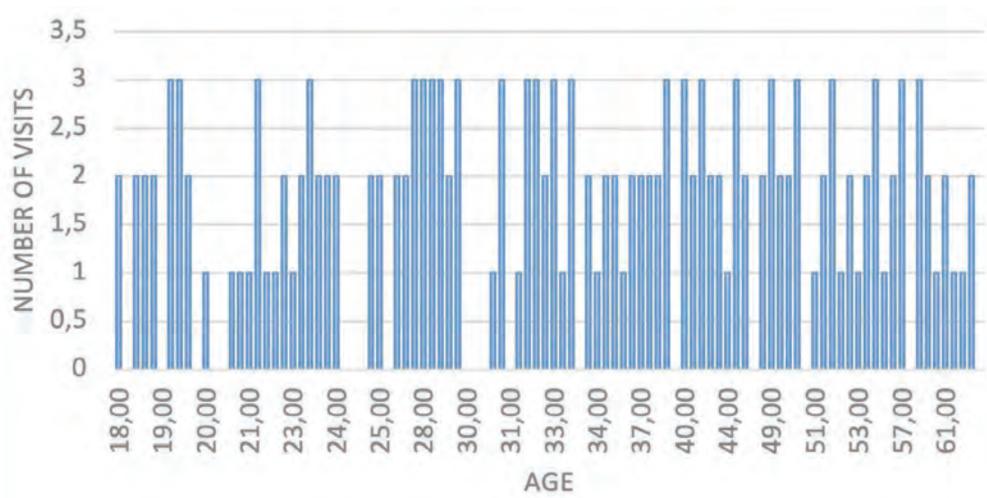

Fig. 17: Bar chart/number of visits by age

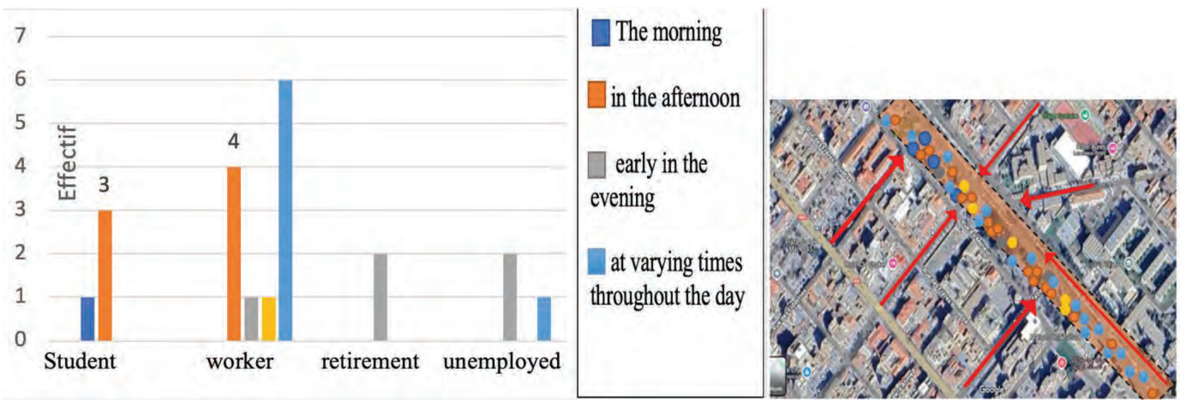

Fig. 18: bar chart + map showing time of visit by profession

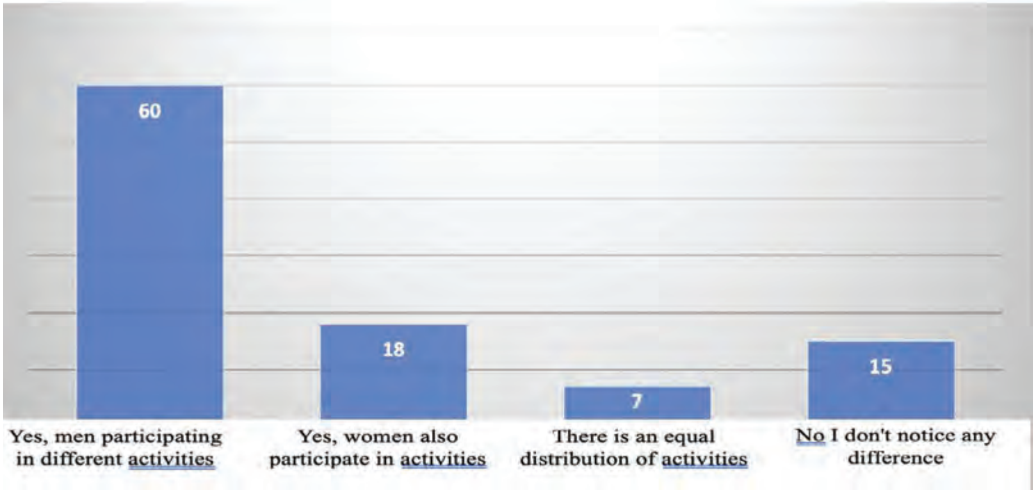

Fig. 19: Relating to the types of activities in which men and women participate

Table 4. Relating to the type of activities

Model		Differences in the types of activities in which men and women participate	Access between men and women	access for single or accompanied women
Differences in the types of activities in which men and women participate in the Ben-Boulaid alleys	Pearson correlation	1	-.167	-.189
	Sig. (bilateral)	-	.098	.060
Access between men and women	N	100	100	100
	Pearson correlation	-.167	1	.150
access for women in public spaces alone or accompanied	N	100	100	100
	Sig. (bilateral)	.060	.137	-

due to cultural and social factors. Results show marked perception differences in male-female participation. Most respondents recognize that men are more active in various activities, while female participation remains limited. These findings confirm the existence of structural barriers to female engagement in public space, which can be seen in Fig. 19.

According to the level of security in the space: Figs. 20, 21, and 22

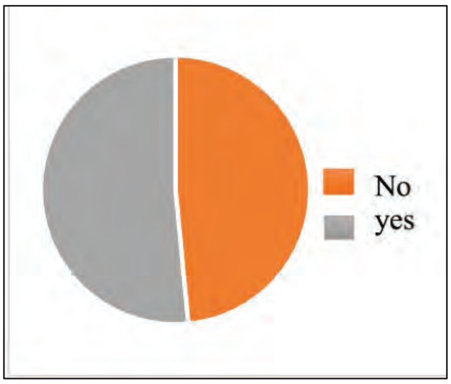

Fig. 20: Relative to the lighting level

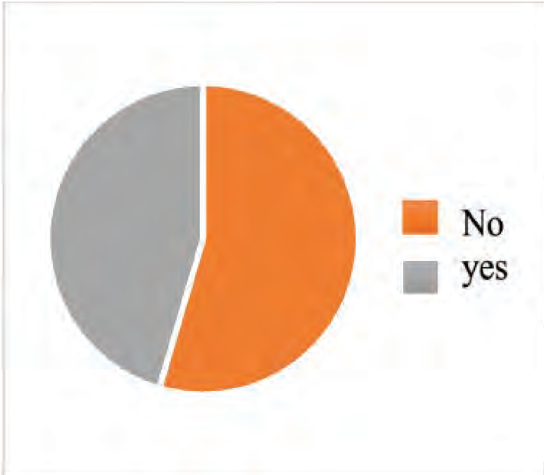

Fig. 21: Presence of aggression

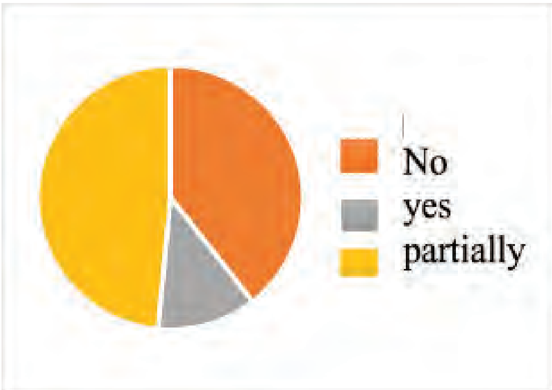

Fig. 22: Equipment on the plot

Lighting level and presence of aggressions

Table 5 shows that the lighting level is positively correlated with the presence of aggression (r = 0.165), suggesting that improved lighting may be associated with a reduction in aggressive incidents. The analysis indicates that variables related to physical infrastructure significantly influence perceptions of security, with lighting emerging as a key factor in shaping women's spatial comfort.

The causes of cultural inequalities in the use of the Ben-Boulaid alleys

Figs. 23 and 24 show that respondents identified cultural barriers as the primary source of inequality (40%), followed by socioeconomic disparities (25%), while cultural discrimination was less frequently cited (15%). This hierarchy underscores the role of cultural norms as dominant mechanisms of spatial exclusion, surpassing economic factors in shaping women's access to public space. These results are further detailed in Table 6.

The impact of urban policies, urban planning, and public services on gender equality

Results presented in Table 7 indicate limited policy effectiveness: 50% of respondents believe that urban policies have no significant impact on gender equality, while 43% acknowledge partial improvements, albeit with persistent gaps. These findings underscore the inadequacy of current urban planning approaches in addressing gendered spatial inequalities. However, Table 8 shows that 72% of respondents believe that

Table 5. Relating to the different variables on the perception of security level

Model		Equipment in the Ben-Boulaid alleys meet user needs or not	Lighting level in the Mustapha Ben Boulaid alleys sufficient or not	Presence of attacks or not in this public place
Does the equipment in the Mustapha Ben Boulaid alleys meet the needs of users or not	Pearson correlation	1	.016	.032
	Sig. (bilateral)	-	.871	.752
	N	100	100	100
Lighting level in the Mustapha Ben Boulaid alleys sufficient or not	Pearson correlation	.016	1	.165
	Sig. (bilateral)	.871	-	.102
	N	100	100	100
Presence of attacks or not in this public space	Pearson correlation	.032	.165	1
	Sig. (bilateral)	.752	.102	-
	N	100	100	100

Table 6. Relating to the causes of cultural inequalities in the public space studied

The answers		Frequency	Percentage	Valid percentage	Cumulative percentage
	Discrimination or cultural prejudice	15	14.7	15.0	15.0
	barriers of cultural origin	40	39.2	40.0	55.0
Valid	socio-economic differences	25	24.5	25.0	80.0
	others	20	19.6	20.0	100.0
	Total	100	98.0	100.0	100

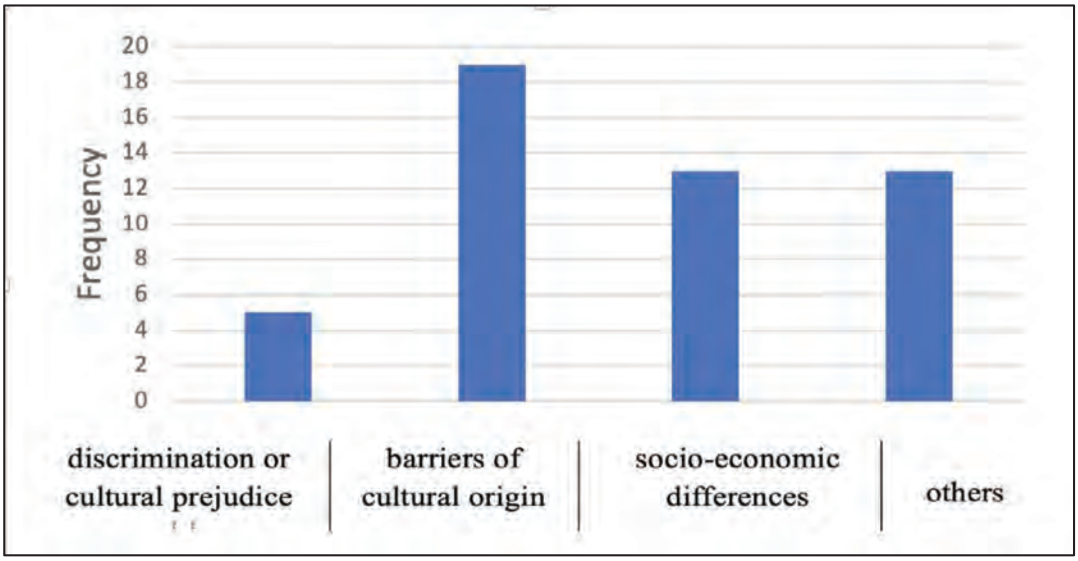

Fig. 23: Diagram on the causes of cultural inequalities

placemaking practices can be reimagined to promote more inclusive, responsive, and safe public spaces for women. This positive perception highlights the potential for transformative urban interventions when gender considerations are systematically integrated into planning processes.

The influence of placemaking practices on the use of the Ben-Boulaid alleys for public decision-makers

Summary of variables used in Figs. 25 and 26.

Table 9 indicates that the two-dimensional model, with satisfactory internal consistency, accounts for 63% of the observed variance. Figs. 25 and 26 illustrate the robustness of this model, particularly in highlighting the significant influence of cultural level on the appropriation and use of public spaces by women. This finding underscores the importance of integrating sociocultural variables into spatial

Table 7. The impact of urban policies and developments on gender equality

The answers	Frequency	Percentage	Valid percentage	Cumulative percentage
They promote gender equality by improving accessibility and safety for all	7	6.9	7.0	7.0
They do not appear to have a significant impact on gender equality	50	49.0	50.0	57.0
They can improve on the genre in some aspects, but there are still gaps to fill.	43	42.2	43.0	100.0
Total	100	100.0	100.0	-

Table 8. The influence of placemaking practices on the use of the Ben-Boulaid alleys

The answers		Frequency	Percentage	Valid percentage	Cumulative percentage
	Negatively	28	27.5	28	28
valid	Positively	72	70.6	72	100.0
	Total	100	100.0	100.0	

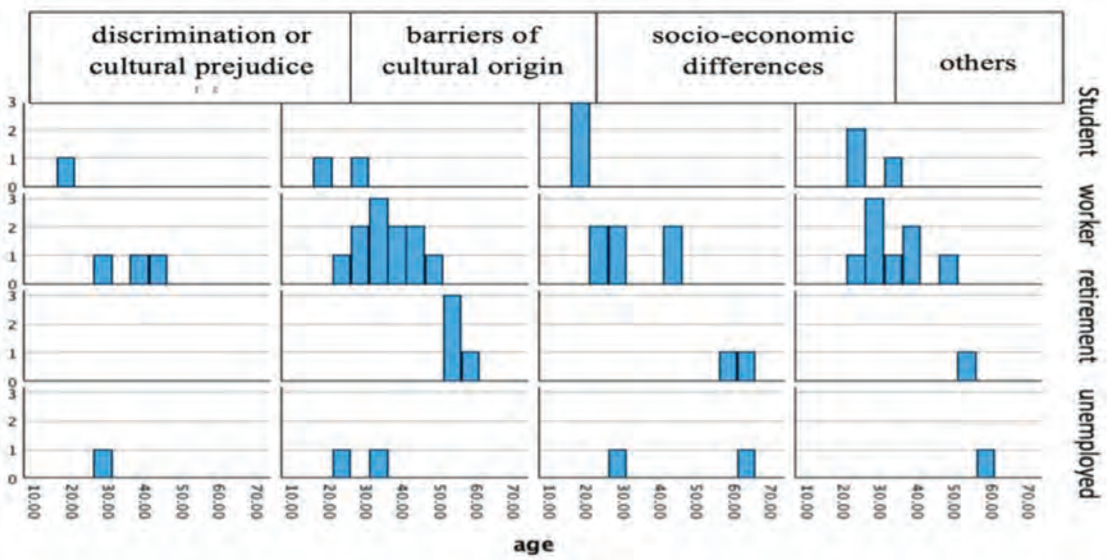

Fig. 24: Diagram on the causes of inequalities by profession

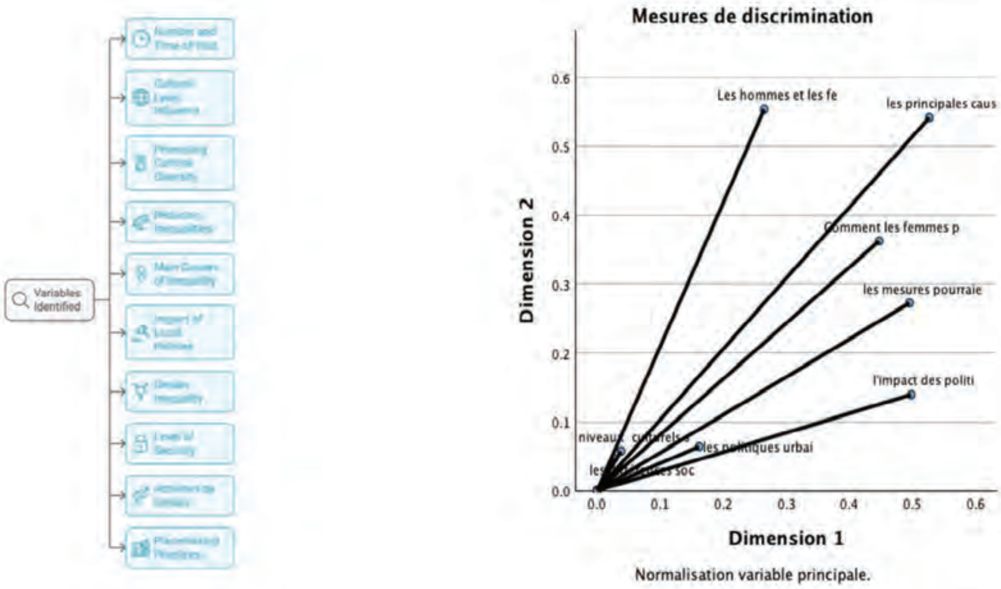

Fig. 25: Diagram on a set of variables studied

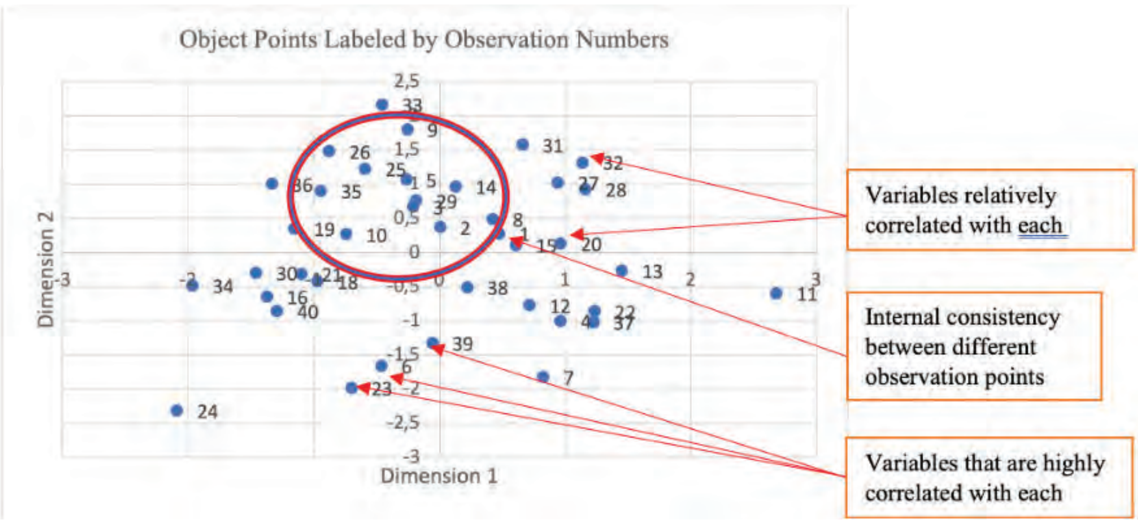

Fig. 26: Diagrams on the number of observations

Table 9. Summary of the models studied: Model summary

Dimension	a Cronbach's alpha	Total (Eigenvalue)	inertia
1	.687	2.432	.347
2	.581	1.991	.284
Total	1.268	4.423	.632
Average	.639a	2.212	.312

a. Cronbach's alpha is based on the mean eigenvalue.

analysis frameworks. It calls for a rethinking of public space design that is sensitive to differentiated patterns of use. More specifically, the data point to the necessity of creating inclusive environments where women can circulate freely, feel safe, and access spaces adapted to their daily practices. In this perspective, participatory design processes where women's voices and experiences are structurally embedded appear not only beneficial but essential to achieving genuinely inclusive urban planning.

CONCLUSION

This research on cultural norms, placemaking, and social justice in creating inclusive public spaces for women through the case study of Ben-Boulaid alleys in Batna reveals significant spatial inequalities rooted in socio-cultural barriers and infrastructural deficiencies, with mixed-method analysis of 100 women demonstrating that age and professional status determine temporal engagement patterns while negative correlations between gender equality perceptions and spatial access ($r = -0.167$, $p = 0.098$) confirm asymmetrical public space utilization. The positive association between adequate lighting and perceived safety ($r = 0.165$) underscores the infrastructure's critical role in women's spatial belonging and points to concrete intervention pathways. Applied recommendations include mandating women's participation in municipal planning processes and policy revision to address gender-specific spatial needs, implementing gender-sensitive infrastructure improvements such as enhanced lighting systems and child-friendly pathway design by urban planners, and developing targeted community awareness campaigns to challenge cultural stigmas and promote equitable public space usage. Although this research presents certain methodological limitations, including its focus on a specific urban context and cross-sectional design with 100 women participants, future comparative multi-site studies across diverse Algerian urban contexts and longitudinal analyses tracking policy intervention effectiveness would strengthen the understanding of gendered spatial dynamics and inform evidence-based urban transformation strategies. Ultimately, transforming Ben-Boulaid alleys into inclusive environments requires sustained commitment to intersectional equity, where urban policies actively foster collective ownership and universal right to the city rather than perpetuating exclusionary spatial practices, thereby contributing to broader theoretical understanding of gendered urbanism while providing actionable frameworks for municipal authorities, planners, and community stakeholders seeking to implement gender-responsive urban development in North African contexts.

AUTHOR CONTRIBUTIONS

A. Hadid contributed to the research design, theoretical framework, data collection, analysis, and writing. B. Marir contributed to the literature review, experimental design, data analysis, and interpretation. A. Mebarki contributed to the interpretation of the results and the preparation of the manuscript.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in the publication of this work. In addition, they affirm having respected ethical standards relating to plagiarism, informed consent, responsible conduct of research (including fabrication and falsification of data), double publication and/or submission, as well as dismissals.

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ABBREVIATIONS (NOMENCLATURE)

N	Observation number
M	Average
p	Sig. (bilateral)
r	Correlation coefficient
SD	Standard Deviation

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CASE STUDY

Urban growth prediction and development pattern using CA-MARKOV and SLEUTH models

Sh. R. Jabari, H. Motieyan*, A. Sam-Khaniani

Department of Geomatics, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

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ABSTRACT

BACKGROUND AND OBJECTIVES: Urbanization and rapid population growth are significant global challenges, especially in cities with outdated planning systems. Effective urban growth models, which utilize historical data, land use patterns, and population dynamics, are essential for predicting future expansion. In Kirkuk, Iraq, urban growth has occurred unregulated due to an outdated master plan, and a new plan has been introduced. However, no local studies have assessed the effectiveness of urban growth models against this plan. This study aims to fill this gap by evaluating urban development in Kirkuk from 1993 to 2023 and forecasting growth to 2037 using remote sensing and Geo-spatial Information System-based models.
METHODS: This research applied two urban growth models: Cellular Automata Markov chain modeling (CA-MARCOV) and SLEUTH, to analyze urban expansion in Kirkuk. Satellite imagery from 1993, 2003, 2013, and 2023 was used for land use classification. The Cellular Automata Markov chain model used transition probability matrices derived from land use data, while the SLEUTH model incorporated urban density, road networks, and slope data for simulations. Both models were tested for accuracy by comparing predicted urban growth for 2023 with actual land use data. The study also used these models to forecast urban expansion for 2037, comparing their predictions with the city's new master plan.
FINDINGS: The land use classification indicated significant urban growth in Kirkuk, from 41.57 km² in 1993 to 155.5 km² in 2023. The accuracy of the predictions for 202F3 showed that the SLEUTH model achieved 87% accuracy, outperforming the Cellular Automata Markov chain model, which had 76% accuracy. For 2037, the Cellular Automata Markov chain model projected urban growth to 201.43 km², while the SLEUTH model predicted a larger expansion of 219.78 km². The SLEUTH model also excluded water bodies and restricted zones (such as oil fields and airports), which were manually identified, while the Cellular Automata Markov chain model did not account for these exclusions.
CONCLUSION: The SLEUTH model provided more accurate predictions of urban growth and was selected for comparison with the new master plan. The results indicated discrepancies between the SLEUTH model's predictions and the master plan, particularly in areas experiencing rapid growth, suggesting the need for adjustments. The southeastern and southwestern regions showed alignment with the plan. These findings highlight the importance of using accurate urban growth models for sustainable planning in Kirkuk, offering valuable insights for urban development through 2037.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
35	20	9

*Corresponding Author:
Email: *h.motieyan@nit.ac.ir*
Phone: +989122405512
ORCID: 0000-0002-3733-7147

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INTRODUCTION

In recent decades, developing countries have been grappling with the phenomenon of urbanization and rapid population growth, leading to increased population density in urban areas (Angel *et al., 2021*; Asghar Pilehvar, 2021). Urbanization is a process that results in the expansion of cities and is primarily driven by population growth, rural-to-urban migration, and lifestyle changes (Badri Gari, 2020). An urban area is defined as a region that is more densely populated than its surrounding areas and experiences more intense human activities. In recent years, the importance of urban areas has increased, and urbanization has expanded at a faster pace than before (Barman *et al.,* 2024). Urban structures are dynamic, making cities complex systems. A city consists of several fixed elements and their interaction with social and human dynamics. According to a recent United Nations report, about 55% of the world's population lives in urban areas, and this figure is expected to reach 68% by 2050 (Badri Gari, 2020). This population growth, in addition to increasing urban density, has led to the uncontrolled expansion of urban land in the suburbs; a phenomenon often referred to as "urban sprawl" that typically occurs on the fringes of urban areas or along highways (Barman *et al.,* 2024). This sprawl has resulted in significant changes in land use, with agricultural land being the most affected by this rapid urban development (Dutta & Das, 2019; Ghasemi *et al.,* 2025). Land use changes and urban expansion have widespread negative impacts on natural resources and the environment (Njiru, 2016; Ghobadiha & Motieyan, 2023). Unplanned and uncontrolled urban development not only affects the environment and natural resources but can also directly impact access to urban infrastructure and services such as transportation networks and public services (Mihun *et al.,* 2022). This also has significant impacts on the quality of life and social welfare of individuals (Pavithra, 2020). Unplanned urban growth and its widespread dispersion can create serious challenges for urban planners, policymakers, and development agencies, which ultimately can lead to unsustainable development and significant economic and social damages (Mihun *et al.,* 2022). In the face of these challenges, researchers and urban planners have turned to the use of various Remote Sensing (RS) and Geo-spatial Information Systems (GIS) models and techniques to assess and analyze changes in land cover and land use (Barman *et al.,* 2024; Thamaga *et al.,* 2022). These tools have been widely used to analyze urban growth patterns, examine land cover changes, and provide the possibility of simulating the dynamics of urban growth (Ongsomwang & Saravisutra, 2011). Urban growth models are among the important tools in understanding and analyzing the driving forces of urban development, which can predict potential future scenarios in the field of urbanization (Lec & Mahmut, 2018). Given the importance of accurate prediction and planning for urban development, CA-MARKOV and SLEUTH models have been recognized as effective tools for simulating land use changes and predicting urban growth. The CA-MARKOV model is based on cellular automata and is often used to simulate land use changes and predict urban development (Al-Aali and AL-Khakani, 2022). On the other hand, the SLEUTH model, which includes various factors such as slope, transportation networks, and shadow maps, is more effective in analyzing land changes in a more detailed and comprehensive manner (Ongsomwang & Saravisutra, 2011). These models enable urban planners and policymakers to analyze various urban dynamics and development patterns. However, there are limited studies in Kirkuk that have compared the performance of these models and the accuracy of their predictions. Urban growth prediction and Land Use/Cover Change (LUCC) analysis have become essential components of urban planning and sustainable development. Numerous studies have employed various models and techniques, including Cellular Automata (CA), Markov chains, logistic regression, and remote sensing data, to forecast urban expansion and evaluate its impacts. Aziz *et al.,* (2022) analyzed LUCC dynamics and urban growth in the Tabriz Metropolitan Area, Iran, using four modeling methods: CA, Markov chains, logistic regression, and weighted linear combination analysis. Their results identified key factors such as proximity to large cities and access to roads as major drivers of urban expansion. They also simulated three development scenarios to predict LUCC until 2050, offering critical insights for policymakers on sustainable urban development strategies. Similarly, Shikari and Rudra (2022) applied the CA-Markov model to predict urban growth in Purulia Municipality, India, highlighting the rapid spread of built-up areas and the encroachment of agricultural land, underscoring the need for strategic land use planning. Remote sensing and GIS-based studies, such as Mohammad *et al.,* (2021), utilized satellite imagery to classify land use in Potiskum, Nigeria, and assess urban expansion from 1999 to 2018. By analyzing the accuracy of classified maps, this study provided vital data for urban management and infrastructure planning in rapidly urbanizing regions. Mataraj *et al.,* (2021) employed the CA-Markov model in Sri Lanka, demonstrating its effectiveness in predicting land use and urban expansion between 2000 and 2020, with significant projections for 2030. In addition to traditional models, the SLEUTH model has gained traction for urban growth prediction due to its ability to incorporate various spatial factors such as road networks, elevation, and land density. Gomez *et al.,* (2021) further explored the uncertainties in urban growth predictions, noting that the SLEUTH model can enhance accuracy by reducing spatial uncertainties in land use change predictions. Studies also highlight the need to account for environmental and social factors in urban growth modeling. Kharram *et al.,* (2021) applied the CA-Markov model in Duhok, Iraq, demonstrating significant shifts in land use and the importance of monitoring LUCC for sustainable urban planning. In Najaf, Iraq, Al-Basri *et al.,* (2022) used the Markov chain method to predict urban expansion patterns between 2005 and 2015, emphasizing random growth in residential areas and the model's utility in guiding urban management. Jayasinghe *et al.,* (2021) conducted a comparative evaluation of three open-source urban growth models: SLEUTH, FUTURES, and MOLUSCE, to determine the most suitable model for simulating urban growth in Colombo, Sri Lanka. Using Landsat satellite images from different time periods (1997, 2005, 2008, 2014, and 2019) for model calibration and validation, the study applied minimal datasets to ensure fair comparison. The results revealed that SLEUTH provided the most accurate spatial predictions, with a Figure of Merit (FoM) score of 0.26, outperforming FUTURES and MOLUSCE, which both scored 0.20. While FUTURES gave better overall estimates of urban area, SLEUTH excelled in spatial accuracy and flexibility in representing multiple urban growth scenarios, such as sprawl and infill growth, which were not available in MOLUSCE. The study recommended incorporating exclusion layers in SLEUTH to improve model accuracy and mitigate overestimations in urban growth predictions. SLEUTH was concluded to be a highly effective tool for simulating urban growth, particularly in cities undergoing significant transformations, offering valuable insights for sustainable urban planning. Kumar and Agrawal (2023) applied the SLEUTH model to simulate and predict future land use and urban growth in the rapidly developing smart city of Prayagraj, India. Using historical LULC data from 1990 to 2020, road networks, and elevation data, the study forecasted significant urban expansion, projecting an increase in built-up area from 85.89 km² in 2020 to approximately 118.66 km² by 2040. The model calibration process emphasized the critical influence of slope and road gravity coefficients, identifying them as primary drivers of land use change. Despite the model's rigorous calibration complexity, it yielded satisfactory results that align with observed LULC trends and were validated using satellite imagery and topographic maps. The study highlighted both the capabilities and limitations of SLEUTH, particularly the exclusion of socioeconomic factors, and stressed its potential as a tool for urban planners and policymakers to anticipate and manage urban sprawl more sustainably. Dhanaraj and Angadi (2022) applied the calibrated SLEUTH model to study urban growth in Mangaluru, India, from 2000 to 2020, with future projections until 2031. The study identified significant urban growth, from 3,798 ha in 2000 to 11,984 ha in 2020, with a predicted increase to 18,880 ha by 2031. Key drivers of growth were identified as slope resistance, spread, and road gravity. The study also emphasized the importance of combining spatial metrics with urban modeling to support sustainable urban planning in rapidly urbanizing small and medium-sized cities in developing countries. These studies collectively underscore the importance of predictive modeling in urban planning, with various approaches offering valuable tools to anticipate and manage urban growth in different geographical and socio-economic contexts. Furthermore, many previous studies have not compared the results of simulation models with actual urban master plans. Kirkuk, as one of the developing cities in Iraq, has faced random urban growth and the pressure of unplanned development; especially since the previous master plan also failed to address these needs. With the adoption of the "Kirkuk Basic Plan

2037”, the goal is to manage the rapid growth of this city and address the problems caused by uncontrolled development and encroachment on government lands. This research, focusing on the city of Kirkuk, evaluates the results of the CA-MARKOV and SLEUTH models and compares these results with the city’s master plan until 2037, which has been developed by the government. In this way, the advantages and disadvantages of each model and urban master plan can be examined in terms of sustainable development and controlling urban growth.

MATERIALS AND METHODS

Survey design and data collection

Kirkuk, a city in northern Iraq and the capital of Kirkuk Governorate, located at 35.4571° North and 44.3832° East, is one of the most important and strategic regions of the country (Fig. 1). Due to its connection between the Kurdistan Region and the capital and southern cities of Iraq, it holds significant importance. Kirkuk covers an area of approximately 9,679 square kilometers and, due to its geographical location, borders areas such as Erbil in the north, Sulaymaniyah in the east, Salah al-Din in the west, and Diyala in the south. The city is located 233 kilometers north of Baghdad, the country’s capital. The Zab River passes through part of the governorate, and the Khasa River runs through the city center, dividing it into two parts. Fig. 1 shows the geographical location of Kirkuk in Iraq.

In the data preprocessing phase for Land Use/ Land Cover (LULC) analysis using ENVI and GIS software, several steps are involved to enhance the accuracy and quality of the results. Initially, primary data, including satellite imagery and other relevant layers, is collected from reliable sources such as the USGS (United States Geological Survey) website and OpenStreetMap. Subsequently, the preprocessing of satellite imagery commences, which involves radiometric correction to eliminate errors caused by atmospheric conditions and sensor issues. Furthermore, various image bands are combined to generate multi-band images that contain more information about the study area. Additionally, other spatial layers are prepared for analysis. These layers include urban and transportation layers to depict human infrastructure, elevation layers to identify topographic changes, exclusion layers to define unclassified areas, and shaded relief layers for visual analysis. After the completion of the preprocessing steps, the data is input into ENVI and GIS software to prepare for advanced analyses such as supervised classification, change analysis, and accuracy assessment. Table 1 presents the details of the input datasets required for each of the SLEUTH and CA-Markov models.

In remote sensing, image classification plays a pivotal role in identifying and mapping various land cover types, such as urban areas, vegetation, and water bodies. This process involves categorizing

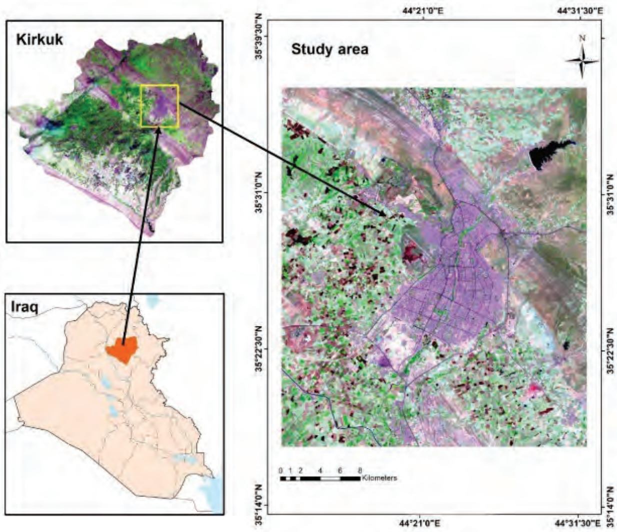


Fig. 1: Location of Kirkuk City

individual pixels within satellite images into distinct classes based on their spectral characteristics. ENVI software, a widely used tool for image processing, employs a variety of methods, including supervised and unsupervised classification, to accomplish this task. In this study, Landsat satellite imagery with a spatial resolution of 30 meters was acquired from the USGS website for the years 1993, 2003, 2013, 2017, and 2023. Subsequently, these images were processed and classified using ENVI 5.3 software to analyze land cover changes over this period. By examining the spectral signatures of different land cover types, we can identify trends in urban expansion, deforestation, and other land use changes. Table 2 shows the characteristics of the images used in this study.

In the process of preparing satellite images, existing errors, including radiometric errors and data gaps, are initially removed to improve image quality. This step involves correcting any noise or errors present in the image, such as those caused by the satellite sensor or atmospheric conditions, to produce a clearer and more analyzable image. Subsequently, the different bands of the images are merged using a layer stack operation to create a multi-band image for each year, providing a more comprehensive analysis of land cover. In satellite imagery, each band represents information about a specific wavelength of light. By combining these bands, more information can be extracted from each pixel, leading to a more detailed analysis of land cover. To focus on the study area, extraneous portions of the images are cropped using the Subset via the ROI tool. This means that only the desired portion of the image is selected for analysis, increasing processing speed and allowing for a more focused analysis of the area of interest. Finally, sampling of various land cover types, such as urban areas, vegetation, and water bodies, is conducted to train classification models accurately and assign pixels to the correct classes. This step is crucial as it teaches the model the spectral characteristics of each land cover type. Using these samples, the model can correctly classify

Table 1: Data collection

Input Layer	Data Source	Format	Data Years	Input Format and Data for CA-MARKOV Model	Input Format and Data for SLEUTH Model	Software Used
Slope	DEM	Raster		Raster	Raster (GIF)	ArcMap 10.8
In percent %						
Land Use Land Cover	USGS (Landsat images)	Vector	1993, 2003, 2013, 2017, 2023	Raster	Raster (GIF) 1993-2017	ENVI 5.3
Urban	Shapefile from land use	Vector	1993, 2003, 2013, 2017		Raster (GIF) 1993, 2003, 2013, 2017	ArcMap 10.8
Transportation	OpenStreetMap	Vector	2023		Raster (GIF) 1993, 2003, 2013, 2017	ArcMap 10.8
Exclusion	On-screen (master plan)	Vector			Raster (GIF)	ArcMap 10.8
Hill Shade	DEM	Raster			Raster (GIF)	ArcMap 10.8

Table 2: Satellite data for classification

Satellite Images	Dates	Sensor	Path/Row	Cloud cover	Scale (Resolution)	Data source
Landsat 5	20/6/1993	Thematic mapper (TM)	169/35	0 %	30 m	Earth Explorer, USGS
Landsat 7	11/5/2003	Enhanced Thematic mapper Plus (ETM+)	169/35	0 %	30 m	Earth Explorer, USGS
Landsat 7	6/5/2013	Enhanced Thematic mapper Plus (ETM+)	169/35	0 %	30 m	Earth Explorer, USGS
Landsat 8	10/6/2017	Operational Landsat Imager (OLI)	169/35	0.01 %	30 m	Earth Explorer, USGS
Landsat 8	16/4/2023	Operational Landsat Imager (OLI)	169/35	0.05 %	30 m	Earth Explorer, USGS

unknown pixels in the image into different classes (e.g., urban, forest, water). These samples represent pixels that belong unequivocally to one of the defined classes. This means that the samples must be carefully selected to be representative of each class Therefore, the classification models are trained more accurately and can assign image pixels to the correct classes. Once the model is trained, it can be used to classify the entire image and create a land cover map. As shown in Table 3, different areas are represented by different colors, allowing for easy identification of different land cover types on the map.

In the final stage, image classification was performed using a supervised classification method and the Maximum Likelihood algorithm. Based on the selected samples, this method assigns the image pixels to one of the defined classes. This process was repeated for each image corresponding to different years to obtain classification results. This method enables a detailed analysis of land cover and land use changes over different years and contributes to a better understanding of urban dynamics and environmental changes in the region. The SLEUTH model requires six grayscale GIF images for its operation. These images should depict urban areas, transportation networks, areas excluded from urbanization, slope, and shaded relief. A sixth layer for land use is optional. The selection of these six input layers was based on the established structure of the SLEUTH model, which is specifically designed to simulate urban growth using these spatial parameters. These layers represent key physical and infrastructural factors that directly influence the spatial dynamics of urban expansion (Jantz *et al.,* 2004, Rafiee *et al.,* 2009). Their selection was driven by both their methodological relevance and the availability of consistent, high-quality data over the study period (1993–2023). Data preparation increasingly relies on GIS and remote sensing techniques, such as data conversion and reclassification (Tobgye, 2019).

Slope layer

Slope is a key element in urban development, as the cost of converting non-urban land to urban use is significantly influenced by the land slope. The steeper the land, the higher the construction costs. In this study, the slope layer was derived from a Digital Elevation Model (DEM) as a percentage (Fig. 2), and points with a slope greater than 25% were identified as CRITICAL-SLOPE, a suitable criterion for mountainous or hilly areas. Pixels were classified into integer values from 0 to 100, and the output file was produced as an 8-bit GIF image.

Urban layer

For effective construction and calibration of the SLEUTH model, at least four urban layers from the study area are required as input data. In this study, urban areas corresponding to the years 1993, 2003, 2013, and 2023 were selected. These layers were prepared by extracting urban pixels from land cover classification in images of each period. Here, urban areas in Kirkuk were defined with a value of 0 for non-urban areas and 1 for urban areas. Each output file was extracted as an 8-bit GIF image (Fig. 3).

Transportation Layer

The transportation network plays a crucial role in urban expansion, as cities typically develop along these networks. Therefore, the SLEUTH model requires two or more datasets of road and transportation networks from different years to simulate urban dynamics more effectively. In this study, four datasets of Kirkuk's transportation networks for the years 1993, 2003, 2013, and 2017 were collected using the OSM website and satellite imagery. These data were processed using ARMCAP software and converted into GIF format (Fig. 4). Values were set between 0

Table 3: Satellite data for classification

Class Number	Class	Color	Description
1	Urban/Built-up Areas	Red	Buildings, infrastructure, and roads (residential, industrial, commercial areas, street networks)
2	Vegetation Area	Green	Agricultural lands, natural and artificial forests, grasslands, pastures, and natural trees
3	Barren Land/Others	Yellow	All vacant spaces, sandy areas, and rocky regions
4	Water Bodies	Blue	Includes bodies of water like lakes and rivers

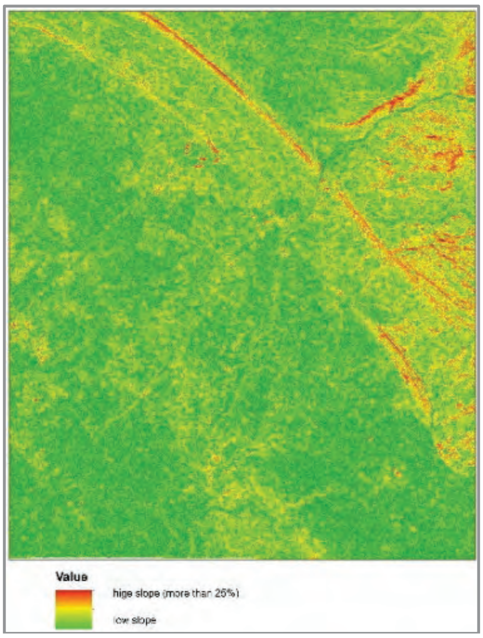


Fig. 2: Slope map of Kirkuk City

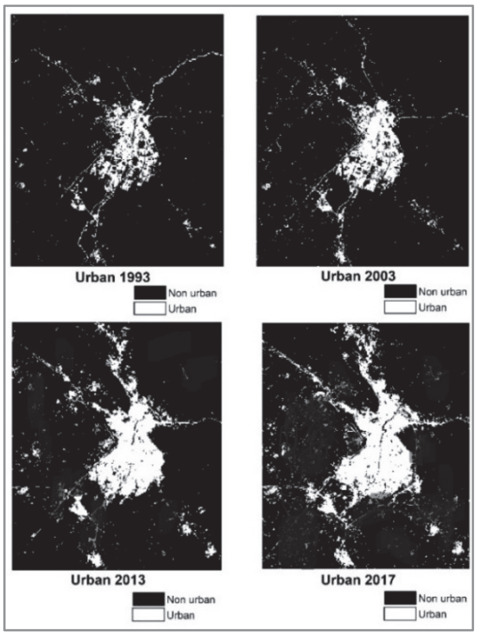


Fig. 3: Map of urban layers of Kirkuk

and 255, where 0 indicates the absence of a route and other values represent the relative accessibility to transportation networks. Additionally, this layer can also be defined as binary (0 or 1).

Exclusion layer

Exclusion layers consist of cells representing areas that are protected from future urbanization. In this study, the excluded classes include water bodies such as rivers and dams, as well as areas prohibited from urban development, including oil production areas owned by the National Oil Company. All data related to these layers were prepared as vector data, then merged and converted to raster format (Fig. 5). These layers have pixel values ranging from 0 to 100, where a value of 0 indicates the highest probability for urban development and no restrictions on urbanization, while values equal to or greater than 100 means that the area should be excluded from urban expansion.

Hill shade layer

The hill shade layer is used as a background image for the SLEUTH model's spatial data and does not directly affect the model simulation, but it helps to improve the visualization of the model results. This layer can be useful in visually analyzing the model output, and to enhance visual effects, a pixel value of 0 is used to represent water bodies such as rivers and lakes. This layer was created using DEM data and the "hill-shade" function in ArcGIS software and stored as an 8-bit grayscale GIF file. Fig. 6 shows an image of this layer.

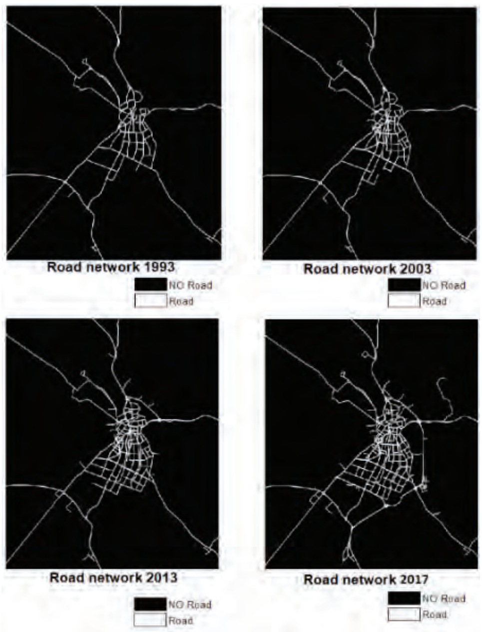


Fig. 4: Kirkuk city transportation layer map

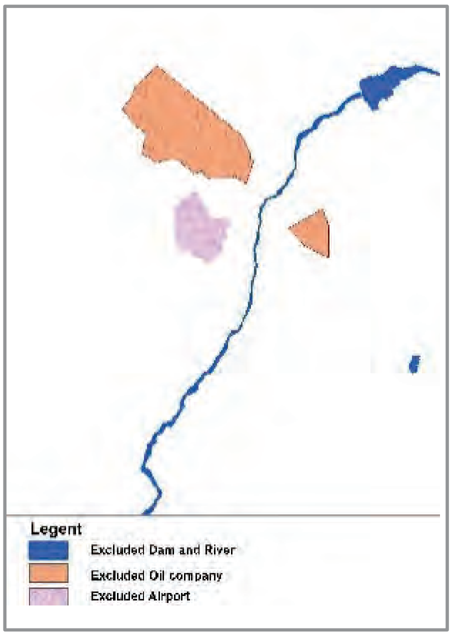


Fig. 5: Exclusion map of Kirkuk city

Fig. 6: hill shade map of Kirkuk City

Land use Layer

Land use data provides information about the land use of an area. Although this information is not essential for simulating urban growth, at least two classified land use categories at two different times are required to assess changes in land use (Mahamud *et al.,* 2019). Pixel values for input vary from 0 to 255

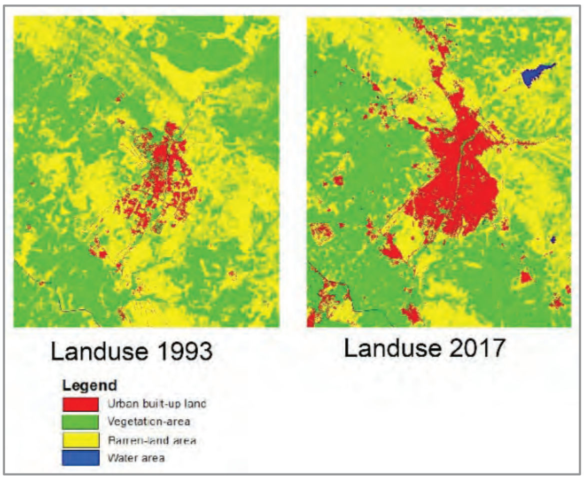


Fig. 7: The change of use layer of the city of Kirkuk

and images are stored as 8-bit grayscale GIF files. Fig. 7 shows the land use map of Kirkuk city.

Analytical framework

After collecting data from the study area and preparing and extracting classified images and the necessary factors for the model, the next step involves executing the workflow according to the flowchart shown in Fig. 8.

Dynamic models, such as SLEUTH and CA-MARKOV, are designed to simulate urban expansion and analyze land use changes (Das & Jain 2022; Zhang *et al.,* 2023). By considering time, these models help analyze the evolution of cities over time and space, and they utilize techniques like cellular automata to reduce uncertainty in understanding urban systems (Badri Gari, 2022). These models are widely used in urban research and planning and can provide accurate predictions for policymakers and planners (Yadav & Ghosh, 2019). The CA-Markov model is a powerful tool for analyzing land use changes and predicting urban growth, combining Markov Chain and Cellular Automata models. The Markov Chain component calculates the probability of land use change from one class to another based on historical data, while the Cellular Automata component examines spatial relationships and the influence of neighboring cells on one another (Li *et al.,* 2025; Tahir *et al.,* 2025). To run the 'TerrSet' program, satellite images from 1993 and 2017 are first classified using 'ENVI 5.3 software to generate land use maps. The

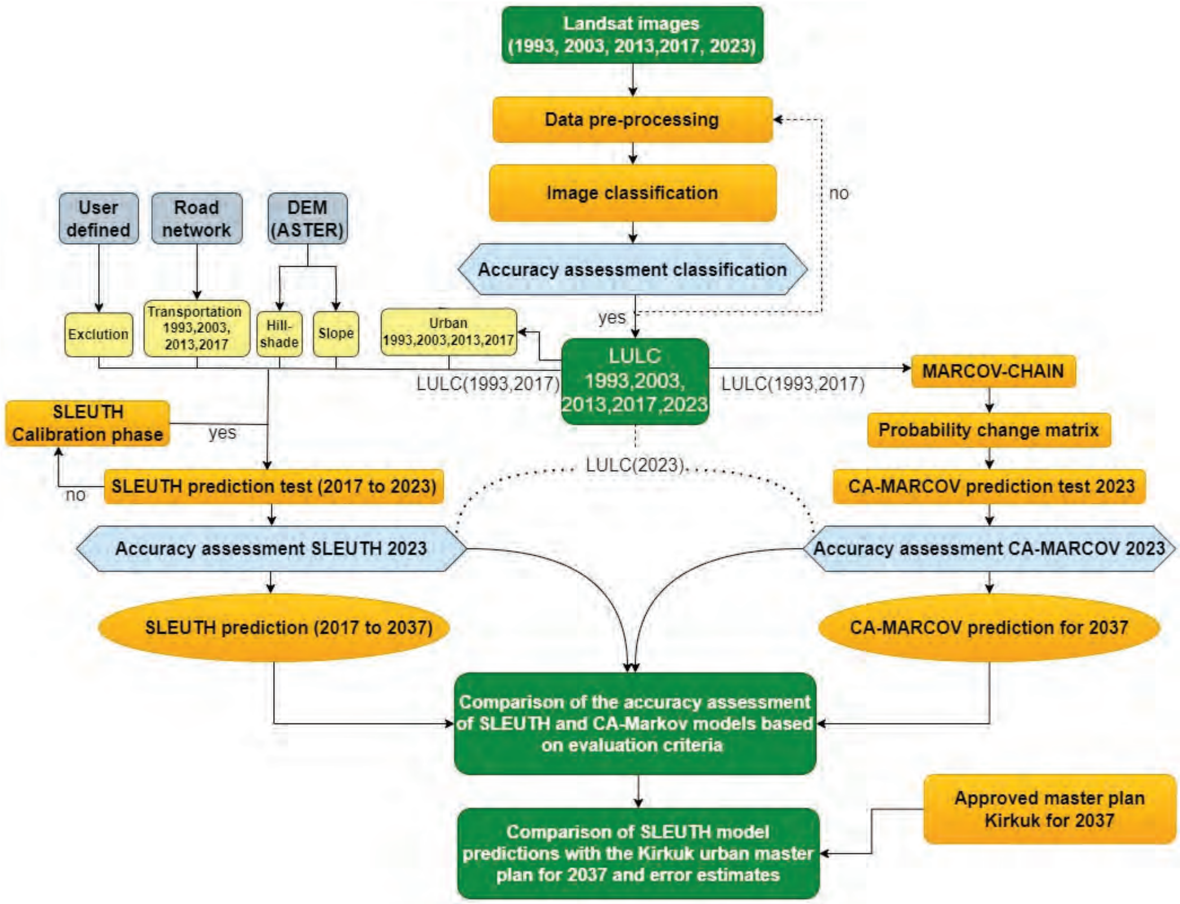


Fig. 8: Flowchart of the procedure steps

images are then imported individually, and the Markov Chain is used to select and compare the two images. This process generates a land use transition probability matrix. Using the CA-Markov model, the second image used in the Markov Chain analysis and the land use transition probability matrix are then applied to simulate and predict future land use maps. The SLEUTH model, based on cellular automata and written in C, simulates urban changes using various layers of information such as slope, land use, and transportation. This model involves experimental testing and calibration phases to achieve higher accuracy by adjusting its parameters (Lec & Mahmut, 2018; Parvar *et al.*, 2025). The SLEUTH model requires a set of key input data for simulating and predicting land use changes and urban growth, which must be prepared with high accuracy and quality. These data include slope maps that show the slope at different points in the study area, historical land use maps that display the land use status in the past and are used for comparison and prediction of changes, and urban density maps that show the extent of urban expansion at different times and help simulate urban growth. In addition, road network maps, including roads, highways, railways, and other transportation routes, play an important role in modeling accessibility and its effects on urban expansion. Furthermore, restriction maps identify areas that are excluded from development and land use change for various reasons. This comprehensive and accurate data forms the basis of the SLEUTH model to provide reliable results in predicting land use changes and urban growth. As shown in Fig. 9 for the input data of the SLEUTH model. In this study, classified images for the years 1993, 2003, 2013, 2017, and 2023 are compared to analyze land use changes over the study

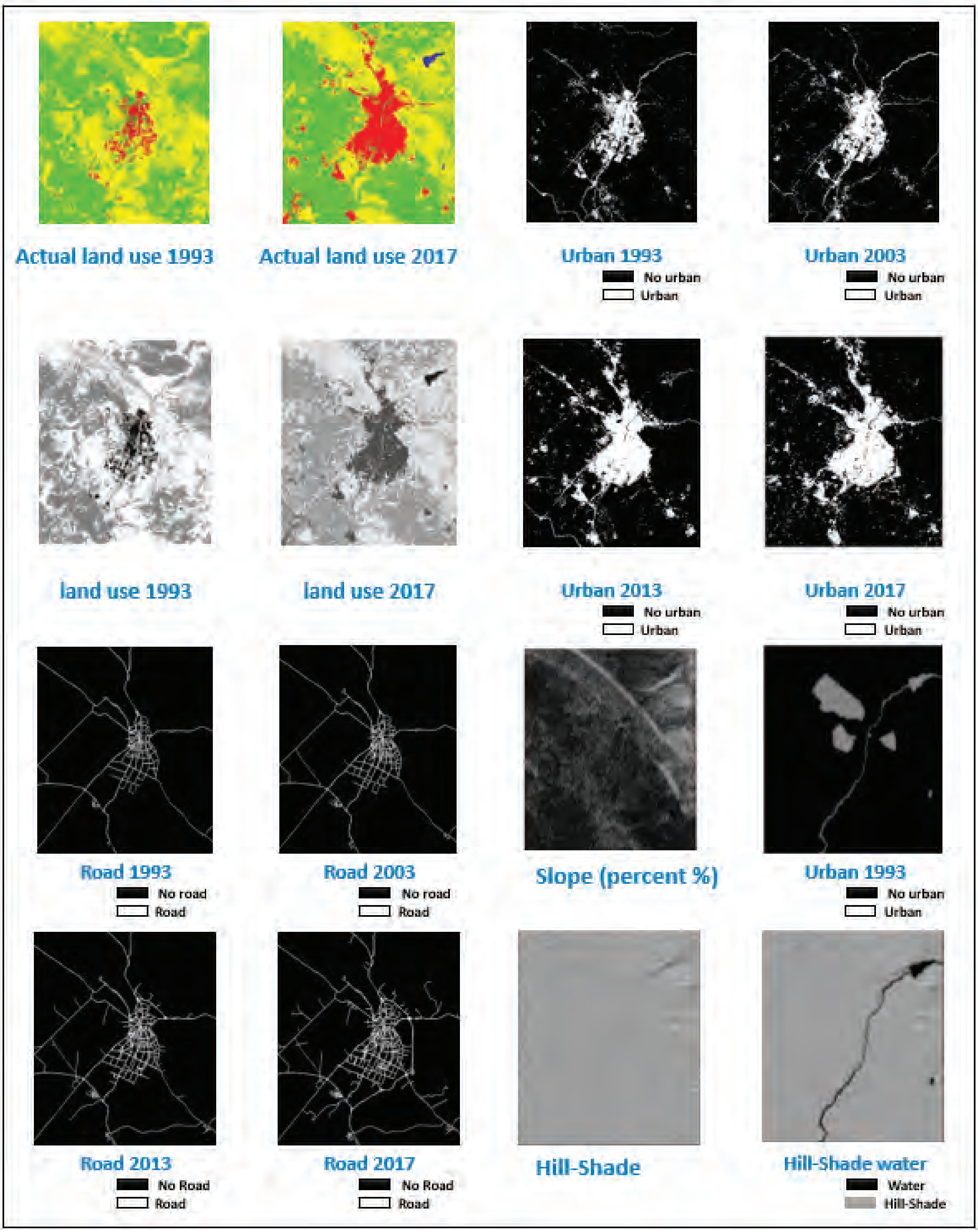


Fig. 9: SLEUTH model input data

period. The accuracy of the classified images for the years 1993, 2003, 2013, 2017, and 2023 is assessed using the Kappa coefficient and overall accuracy. After data preparation, the CA-MARKOV model is used to predict land use changes for 2023 using data from 1993 and 2017. The SLEUTH model, as one of the leading models in simulating and predicting urban growth, requires careful calibration to ensure that its results align with historical realities.

SLEUTH model calibration

The SLEUTH model, as one of the prominent tools for simulating and predicting urban growth, requires precise calibration to align its results with historical realities (Satari *et al.,* 2024; Saulawa, 2024). During the calibration process, various components of the model are tested by altering growth rates to determine a set of suitable values that can interpret historical land-use changes in the study area, covering the period from 1993 to 2017. The SLEUTH model incorporates five growth rates (Dispersion, Breed, Spread, Slope Resistance, and Road Gravity), The model applies several growth rules, including new spreading center growth, edge growth, spontaneous growth, and road-influenced growth. A unique feature of the SLEUTH model is its ability to assign relative importance to each parameter during the calibration process, measured on a scale of 0 (least important) to 100 (most important). This reflects the relative influence of each rate during the calibration phase. The calibration process aims to identify the optimal range for each parameter based on historical data. Afterward, the coefficients are adjusted to suit the specific characteristics of the study area. The Optimal SLEUTH Metric is used to evaluate the calibration and ensure the model's effectiveness. Through this meticulous process, the calibrated model provides reliable insights for simulating and predicting urban growth patterns.

As can be seen in Table 4, this table outlines the calibration results for the SLEUTH model, presenting the Optimal Growth Coefficients for five key urban growth parameters: Diffusion, Seed, Spread, Slope, and Road Gravity. The calibration process is conducted in three progressive stages (Coarse, Fine, and Final) to refine parameter values and achieve the highest accuracy based on the Optimal SLEUTH Metric (OSM). Key Insights:

- The Final Calibration provides the most precise parameter values, reflecting the dynamics of urban growth in the study area.

- Parameters such as Road Gravity (90), Seed (74), and Spread (67) emphasize the significant role of transportation networks and urban expansion from the city center.

- Minimal influence is observed from Diffusion (1) and Slope (9), indicating limited spontaneous growth and low topographical resistance.

- The progressive refinement of ranges and step sizes across calibration stages results in improved OSM values, ensuring a highly accurate model to simulate urban growth patterns effectively.

RESULTS AND DISCUSSION

CA-Markov model prediction

Classified images from 1993 and 2017 were used to predict the 2023 urbanization map. It is then compared with the actual image of the same year, and the accuracy of the predicted image is obtained. The classified images are then reused to obtain the

Table 4: SLEUTH model calibration results

Coefficient	Calibration Coefficient						Optimal growth coefficient
	Coarse		Fine		Final		
	OSM = 0.52		OSM = 0.55		OSM =0.57		
	Range	Step	Range	Step	Range	Step	
Diffusion	0-100	25	0-25	5	0-20	4	1
Seed	0-100	25	50-75	5	70-75	1	74
Spread	0-100	25	0-100	25	25-100	10	67
Slope	0-100	25	0-20	5	5-1	1	9
Road Gravity	0-100	25	25-100	15	20-30	2	90

2037 m. Fig. 10 shows a comparison between the CA-Markov model prediction results and the actual land use map in 2023; in this comparison, the left image shows the urban growth prediction by 2023 using the CA-Markov model, which includes urban areas (in red), vegetation (in green), Barren land (in yellow), and water areas (in blue), while the right image shows the actual land use situation in 2023.

Table 5 presents the results of urban growth forecasting using the CA-Markov model for the year 2023 compared to the actual values. The table shows that the CA-Markov model predicted 5.49 km² less than the actual value for urban areas, which necessitates the need to improve the accuracy and model adjustments for future predictions. Urban growth prediction using the CA-Markov model for the year 2037, showing changes in land use and the expansion of urban areas, is presented in Fig. 11. According to this map, urban areas (marked in red) have expanded in the center and other scattered points, indicating significant urban development and an increase in population density by 2037. Additionally, green areas representing vegetation can be widely observed around urban areas, while yellow areas indicating barren land are scattered throughout the map. Table 6 shows the land use changes from 2023 to 2037 using the CA-Markov model. The area of urban land has increased from 155.5 square kilometers to 201.43 square kilometers, indicating a significant growth of 46.36 square kilometers. These changes depict a significant expansion of urban and agricultural areas and a decrease in barren land, emphasizing the need for improved land management and sustainable development.

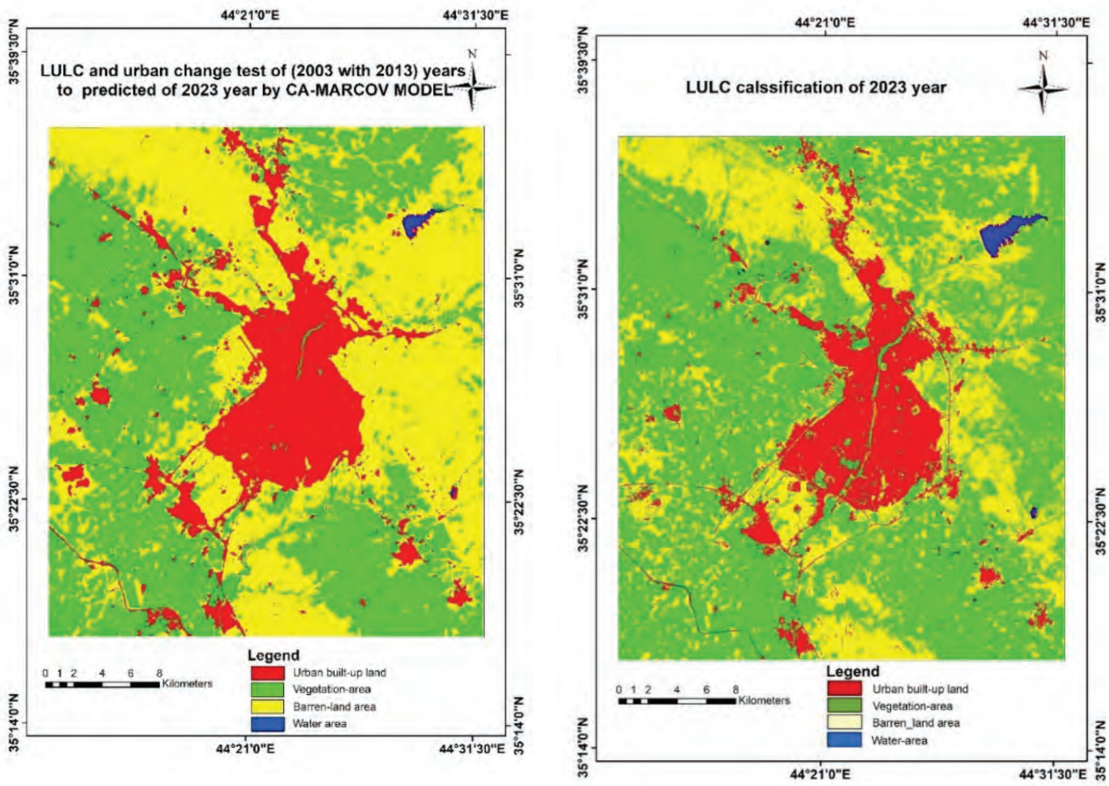


Fig. 10: Comparison of urban growth prediction using the CA-Markov model in 2023 with actual land use

Table 5: Urban growth prediction using the CA-Markov model in 2023

LULC Classes	Actual Value (Area, km²) 2023	Predicted Value (Area, km²) 2023	Difference (Area, km²)
Urban	155.5	150.01	-5.49

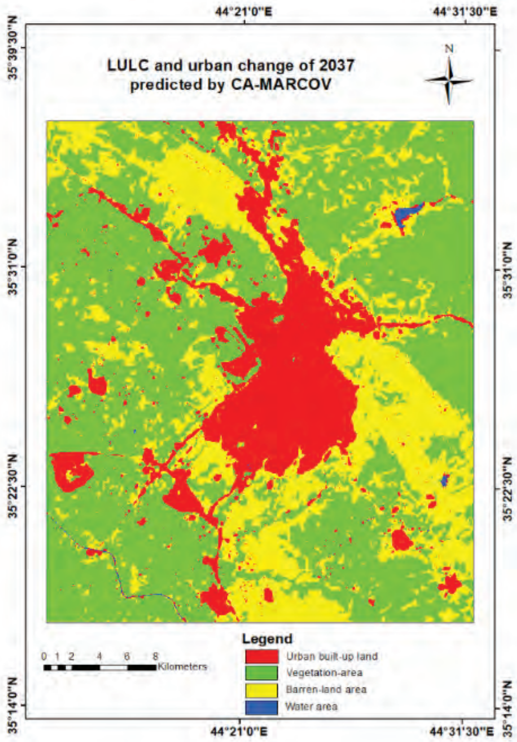


Fig. 11: Prediction with the CA-Markov model in 2037

Table 6: Comparison of Urban Growth Using the CA-Markov Model from 2023 to 2037

LULC Classes	Land Use (Area, km²) 2023	Projected Land Use (Area, km²) 2037	Growth (Area, km²)
Urban	155.5	201.43	46.36

SLEUTH model prediction

Various maps from 1993 to 2017, along with other input data, were used to forecast the state of land use in 2023, obtaining a similar urban growth forecast to the previous model in the same year, and then comparing them. The same map and data are then used to predict the 2037 map. Fig. 12 contains two maps that analyze and compare the accuracy of urban growth predictions using the SLEUTH model in 2023. The map on the left shows the urban growth predicted for 2023 using the SLEUTH model, with urban areas shown (in yellow/orange) and water areas in blue. The map on the right shows the actual land use classification in 2023, with urban areas (in red), vegetation (in green), Barren land (in yellow), and water areas (in blue). A comparison of these two maps shows the relative accuracy of the SLEUTH model in predicting urban growth; while the model can predict the main areas of urban development well, there are differences in detail and smaller areas. Table 7 compares urban growth forecasting using the SLEUTH model in 2023. The results show that the model has a difference of +3.89 km2 for urban areas with an actual value of 155.5 km2 and a predicted value of 159.39 km2. This analysis shows that the SLEUTH model has generally provided accurate forecasts, although there is room for improvement in some cases. The urban growth prediction for 2037 based on the SLEUTH model is shown in Fig. 13. In this image, existing urban areas and areas with high potential for urban growth (between 70% and 100%) are marked in yellow/orange. Areas with a medium probability of expansion (between 40% and 70%) are shown in red, and areas with a low probability (between 0% and 40%) are shown in

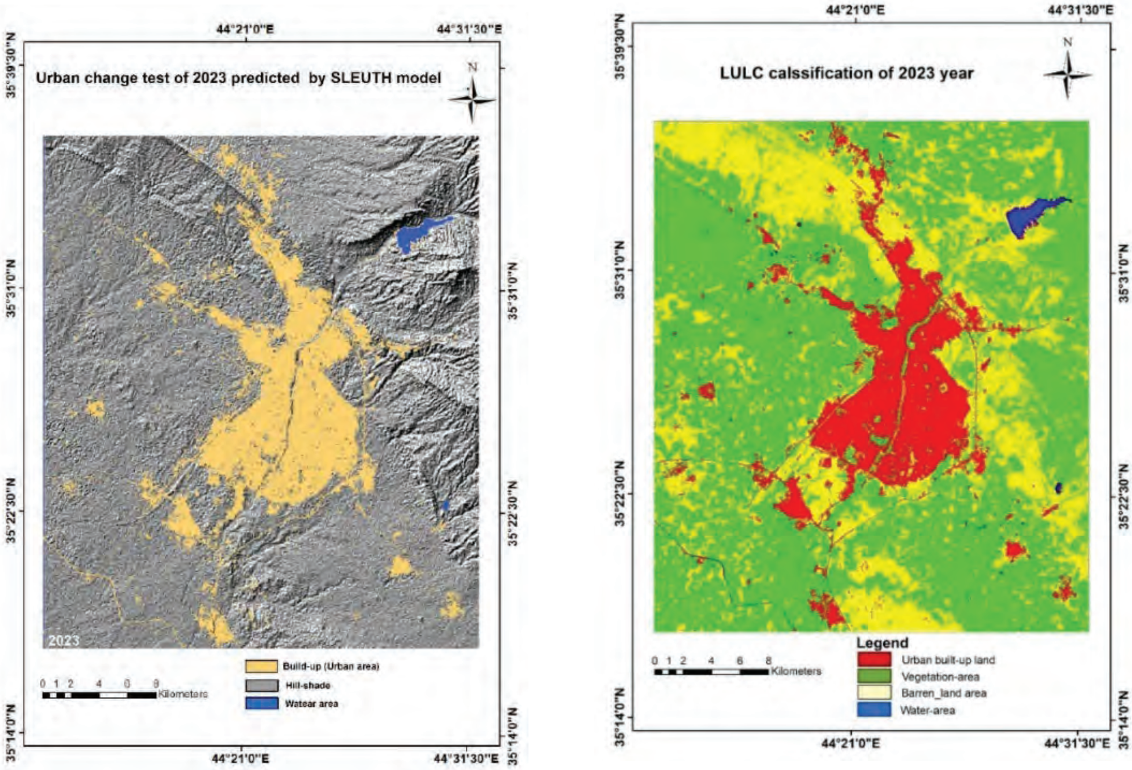


Fig. 12: Comparison of urban growth prediction using the SLEUTH model in 2023 with actual land use

Table 7: Urban growth prediction using the SLEUTH model in 2023

LULC Classes	Actual Value (Area, km²) 2023	Predicted Value (Area, km²) 2023	Difference (Area, km²)
Urban	155.5	159.39	+3.89

green. Additionally, water bodies are marked in blue. This image indicates a significant expansion of urban areas and an increase in their population density by 2037. This prediction indicates rapid and widespread growth of urban areas and an increase in population in these areas by 2037.

Table 8 indicates that, according to the SLEUTH model, the area of urban land has increased from 155.5 square kilometers in 2023 to 219.78 square kilometers in 2037, representing an increase of 64.28 square kilometers. These changes demonstrate the trend of urban development and shifts in land use patterns during this time period.

Accuracy assessment Comparison between CA-Markov Model and SLEUTH Model

Accuracy assessment is a process used to verify the accuracy of image classification by comparing the classified image with reference data. The accuracy of classified images is calculated using ground truth points randomly selected and distributed in the study area (Njiru, 2016). This study employs a pixel-based accuracy assessment method to evaluate classification accuracy in remotely sensed data using an error matrix. The assessment results include overall accuracy, with the Kappa coefficient being a widely recognized measure. The Kappa coefficient evaluates the agreement between actual and chance classifications. A Kappa value above 0.80 indicates good classification, values between 0.40 and 0.80 represent moderate classification, and values below 0.40 indicate poor classification. Fig. 14 shows a detailed comparison of urban growth forecasts in 2023 using both CA-Markov and SLEUTH models for urban

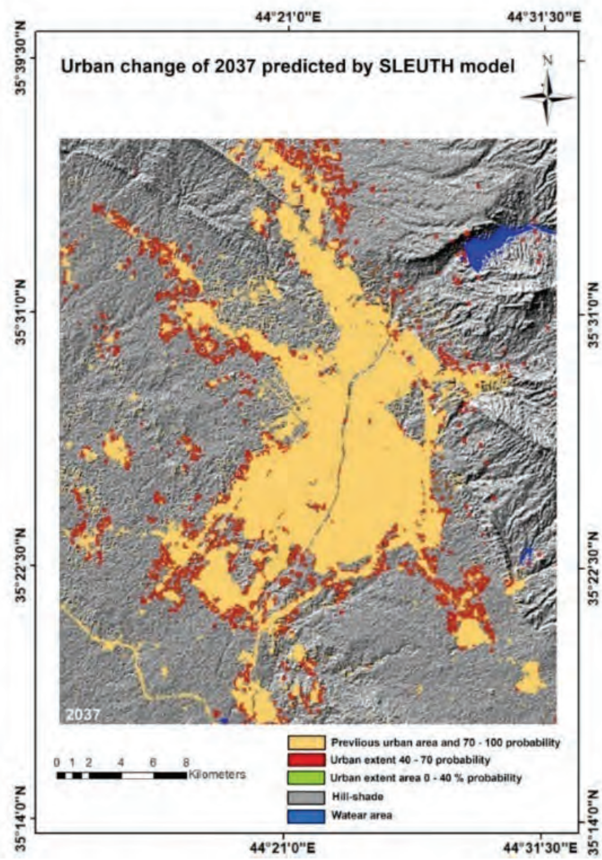


Fig. 13: Prediction with the SLEUTH model in 2037

Table 8: Comparison of Urban Growth Using the SLEUTH Model from 2023 to 2037

LULC Classes	Land Use (Area, km²) 2023	Projected Land Use (Area, km²) 2037	Growth (Area, km²)
Urban	155.5	219.78	+64.28

areas obtained in Figs. 7 & 8. The obtained results show that the CA-Markov model performed less than the true value in predicting the area of urban areas. In contrast, the SLEUTH model is closer to the true value in predicting the area of urban areas. According to Table 9, the kappa coefficient was 87.42 for the SLEUTH model, while this value was only 77.44 for the CA-Markov model. The overall accuracy rate for the SLEUTH model was also 80.26%, while this rate was only 69% for the CA-Markov model. These results show that the SLEUTH model had better performance than the CA-Markov model in predicting urban areas and overall accuracy.

The comparison of urban growth from 1993 to

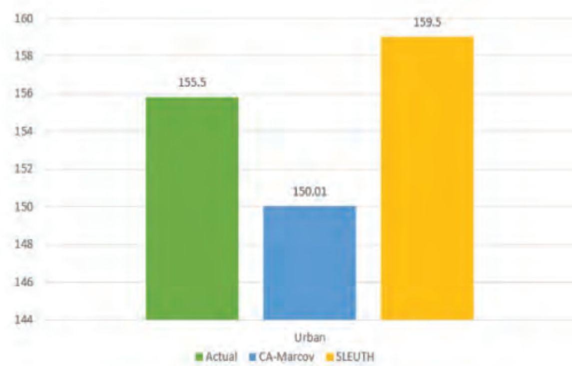


Fig. 14: Comparison of urban growth forecasting of CA-Markov model with SLEUTH in 2023

Table 9: Comparison of the accuracy of urban growth of the CA-Markov model with SLEUTH model in 2023

Accuracy Assessment	Land Use (Area, km²) 2023	Projected Land Use (Area, km²) 2037
Overall accuracy	87%,42	77٪,44
Kappa coefficient	80,26	0,69

2037 using two CA-Markov and SLEUTH models is shown in Figure 15. The chart allows you to see the actual changes in the area of urban areas between 1993 and 2023, followed by the forecast of both models for 2037 in square kilometers. The comparison of urban growth prediction for the year 2037 between the SLEUTH and CA-Markov models is analyzed and compared in Figure 16. The left-hand map shows the predicted urban growth for 2037 using the SLEUTH model, where urban areas are depicted in yellow/orange and water bodies are shown in blue. In contrast, the right-hand map illustrates the predicted urban growth until 2037 based on the CA-Markov model; in this map, urban areas are represented in red, vegetation in green, barren land in yellow, and water bodies in blue.

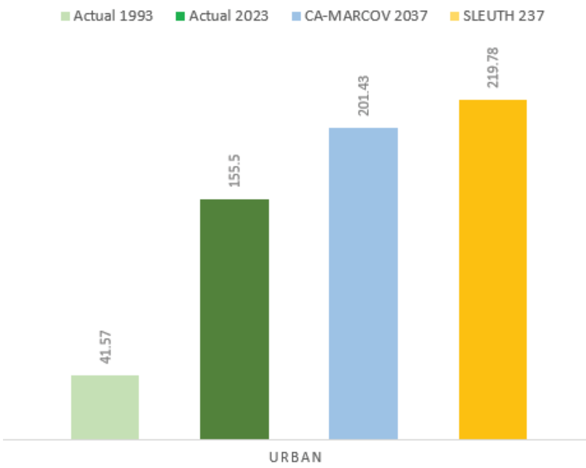


Fig. 15. The comparison of urban growth from 1993 to 2037

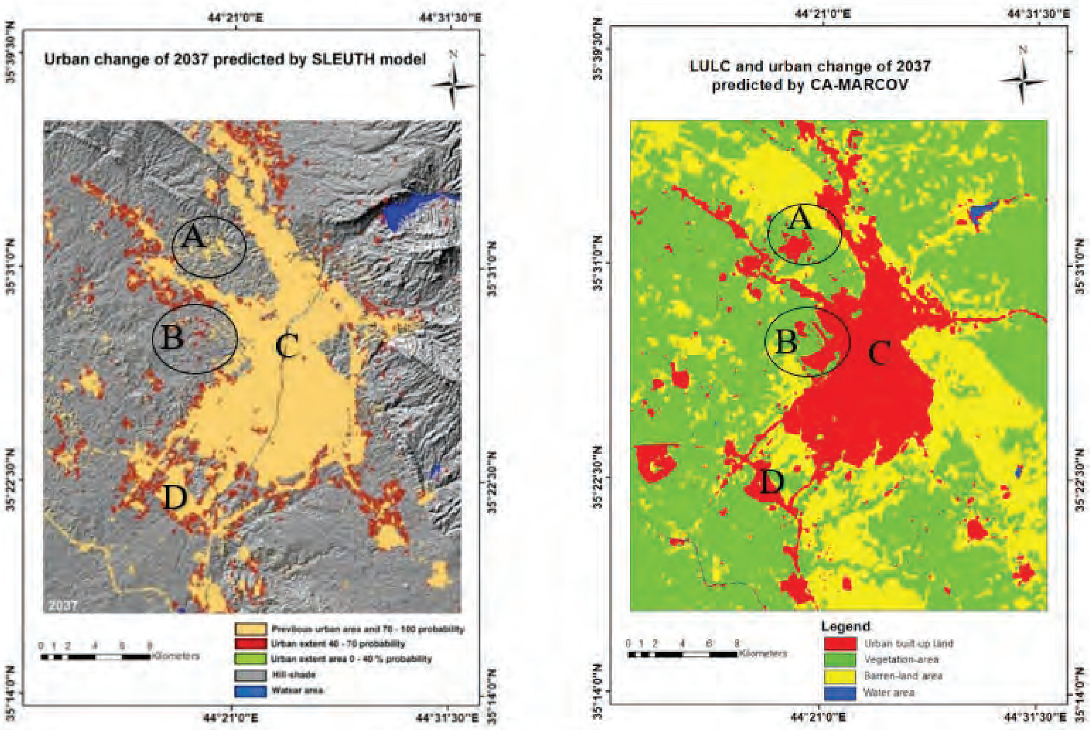


Fig. 16: Comparison of urban growth forecasting of the CA-Markov model with SLEUTH in 2037

When comparing the images, several observations can be made, including the areas marked with (A, B, C) that were removed from the SLEUTH model and excluded from urbanization, which are the areas of: (National Oil Company, airport, and rivers). However, with the CA-MARCOV model, these areas had become largely urbanized, indicating the superiority of the SLEUTH model compared to the CA-MARCOV model. On the other hand, as is known, roads are the main pillar of urban development, as more development of urban areas can be observed in the images marked with (D) along the roads in the SLEUTH model compared to the CA-MARCOV model. Due to the higher accuracy of the SLEUTH model urban forecasts compared to the actual city image in 2023, and the high level of determination of urban expansion patterns and the removal of restricted urban areas seen in the 2037 model forecast, SLEUTH for further analysis is selected.

Reclassification of the Kirkuk City Master Plan and Comparison of SLEUTH Model Results with Kirkuk's Comprehensive Plan

This research reclassified the Kirkuk Comprehensive Plan map (Fig. 17) to facilitate comparison with the SLEUTH model results. In this map, urban areas are colored red, vegetation green, and water bodies blue, while oil company boundaries and airports are gray, and the 2037 comprehensive plan boundaries are black. According to the 2037 Comprehensive Plan, the area of urban and residential areas, including the no-go zone for oil and airports, will reach 315 square kilometers. However, excluding oil fields and airports, which cover 75 square kilometers, the net urban area reduces to 240 square kilometers. Additionally, some villages and residential areas outside the comprehensive plan are added to this area, bringing the total urban area to 275 square kilometers.

Fig. 18 presents two maps with different colors,

Fig. 17: Reclassification of the Urban Comprehensive Plan

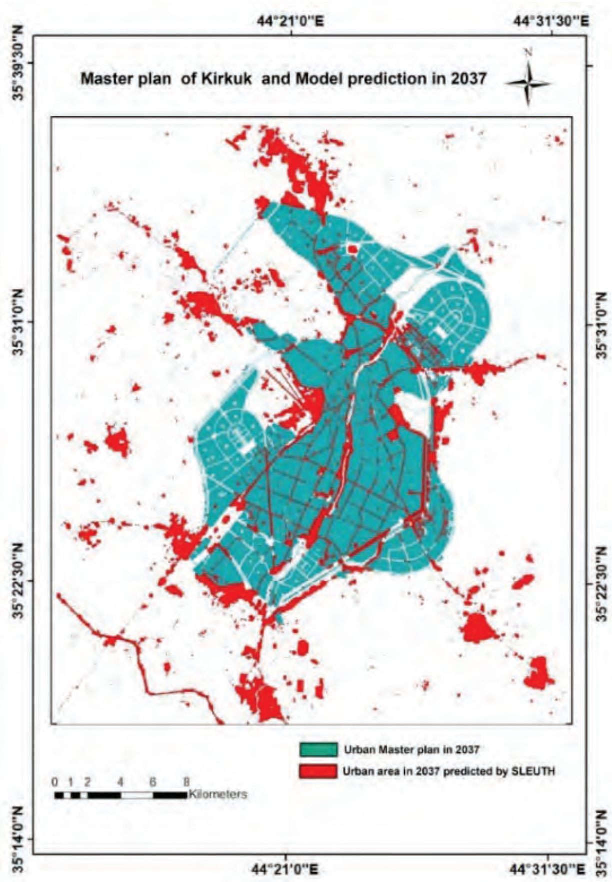
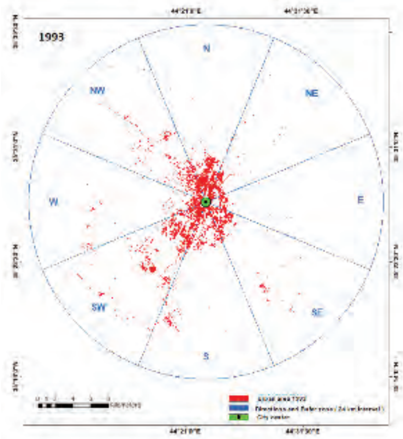


Fig. 18: Comparison of SLEUTH Model Classification Results with the Kirkuk Comprehensive Plan

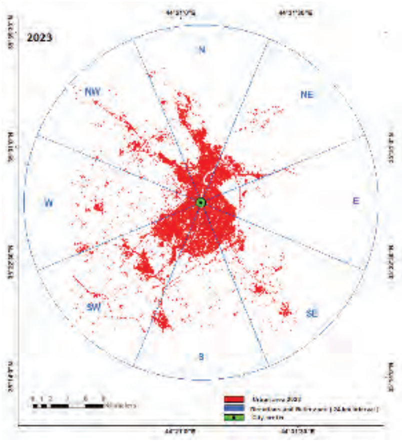
illustrating the predicted urban development for Kirkuk in 2037. The blue area represents the urban structures predicted by the Comprehensive Plan, while the red area indicates urban development predicted by the SLEUTH model. Comparing the Comprehensive Plan and the SLEUTH model's predictions for urban development in Kirkuk by 2037 reveals significant differences in the scope and approach to urban growth.

A comparison of the two models shows that the Comprehensive Plan, with an area of 275 square kilometers, is significantly more extensive than the SLEUTH model prediction of 219.78 square kilometers, indicating a more comprehensive and widespread development in the Comprehensive Plan compared to the SLEUTH model, which focuses more on specific and limited areas. The Comprehensive Plan addresses a wider range of land uses, including residential, commercial, and industrial, and assists decision-makers in more detailed planning. In contrast, the SLEUTH model emphasizes the overall trend of urban expansion and provides fewer details. Therefore, the Comprehensive Plan serves as an effective tool for detailed planning and urban development decision-making, while the SLEUTH model is more recognized as a tool for predicting overall urban growth trends and has limitations in the details and accuracy of specific predictions.

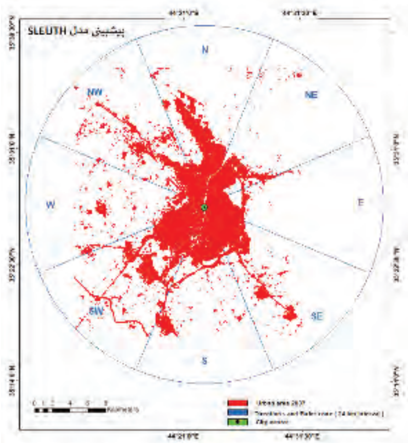
Based on Fig. 19 Analysis of urban growth in Kirkuk from 1993 to 2023 reveals a significant increase in various parts of the city. For instance, the eastern region experienced a 361% growth, expanding from 1.61 square kilometers to 7.29 square kilometers. The SLEUTH model predicts a further increase to 10.12 square kilometers by 2037, while the comprehensive plan projects a slightly smaller area of 8.21 square kilometers. Similarly, the northern region has grown from 6.55 square kilometers to 28.49



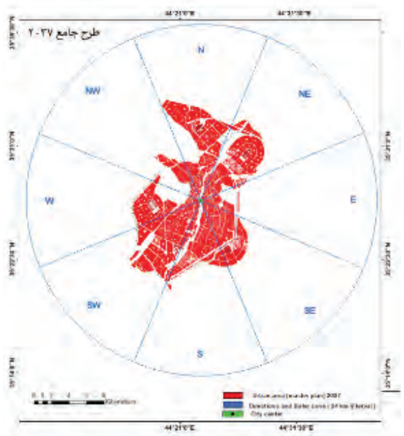
A- The direction of urban growth in 1993



B- The direction of urban growth in 2023



C- Direction of urban growth in 2037 (SLEUTH model)



D- The direction of urban growth in 2037 (master plan)

Fig. 19: Urban growth direction in 1993, 2023, and 2037

square kilometers and is projected to reach 43.24 square kilometers, although the comprehensive plan predicts an even larger growth of 54.11 square kilometers. However, significant discrepancies exist between the SLEUTH model and the comprehensive plan in other regions, such as the northeast, northwest, south, and southeast. For example, the comprehensive plan predicts a growth of 42.41 square kilometers in the northeast, which is double the SLEUTH model's prediction. Likewise, in the western region, the comprehensive plan shows double the growth compared to SLEUTH, possibly indicating an overestimation by the comprehensive plan. Therefore, it is recommended that the municipality carefully review the SLEUTH model's predictions and revise the comprehensive plan to align with actual and sustainable growth.

CONCLUSION

This study analyzed land use change and urban growth in the study area using satellite imagery from 1993, 2003, 2013, 2017, and 2023, remote sensing techniques, and ENVI 5.8 software. The results indicate that the area of urban land increased from 41.57 square kilometers in 1993 to 155.5 square kilometers in 2023, and the extent of green and water areas also experienced a significant increase. The overall accuracy of the maps was reported to be between 86% and 94%, and the predictions of both the SLEUTH and CA-Markov models for urban growth by 2037 indicate a substantial increase in urban areas. The SLEUTH model, with an accuracy of 87.42%, predicted that the urban area would reach 219.78 square kilometers, while the CA-Markov model predicted 201.43 square kilometers. A comparison of the SLEUTH model with the urban comprehensive plan revealed that the comprehensive plan forecasted a development of 275 square kilometers and served as a guideline for urban planning. This research emphasizes that the CA-Markov and SLEUTH models can be effective tools for predicting land use changes and sustainable resource management. Additionally, identifying environmentally sensitive areas and detailed planning for water resources and infrastructure are important applications of these results in urban planning. Ultimately, this study highlights the need to improve planning processes and integrate advanced techniques to manage the challenges of rapid urban growth and resource sustainability. In future research, it is recommended that input data for models be collected and pre-processed with greater accuracy, including the use of higher-resolution satellite imagery and regular data updates. Furthermore, developing hybrid models by integrating the results of CA-Markov and SLEUTH models with artificial intelligence and machine learning techniques can provide more accurate predictions. Community involvement in data collection and the use of ground-truth data to validate results are also highly important. Additionally, examining the impact of other environmental and socio-economic factors, such as soil type and land price, on urban development can contribute to a better understanding of development processes and lead to a more comprehensive approach, e.g., coupling SLEUTH with agent-based models, to analyze land use change.

AUTHOR CONTRIBUTIONS

Sh. R. Jabari conducted the literature review, data collection, and data analysis, outlined the research findings, and drafted the initial manuscript. H. Motieyan and A. Sam-Khaniani screened and analyzed the gathered data, synthesized the findings, discussed, and conclusion. All authors reviewed and approved the final version.

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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)

CA	Cellular Automat
CA-MARCOV	Cellular Automata Markov chain modeling
DEM	Digital Elevation Model
ETM+	Enhanced Thematic mapper Plus
GIS	Geo-Spatial Information System
LUCC	Land Use/Cover Change
LULC	Land Use/Land Cover
OLI	Operational Landsat Imager
RS	Remote Sensing
USGS	United States Geological Survey
TM	Thematic Mapper

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