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Assessing the potential for transformation into smart cities: Fallujah, Iraq as a case study

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Abstract:
With the trends of digital transformation and sustainability on a global level, the smart city model is a modern method to reduce environmental impacts and improve the efficiency of urban resource management. While the literature on smart cities is extensive, no research gap addresses the contemporary readiness of Iraqi cities, such as Fallujah, to evolve into fully integrated smart cities, parallel with the required infrastructure. Also, we find that there is a shortage of studies using SWOT analysis on this transformation. Based on this gap, this study assumes the existence of a correlational relationship between urban design and smart city indicators for Fallujah. The current study aims to answer the following research question: How is Fallujah prepared for smart cities? How does urban development relate to smart city indicators in Fallujah? Which has the primary impact on the transformation into a smart city? SWOT analysis: What are the opportunities, challenges, strengths and weaknesses? Thus, the current study aims to evaluate Fallujah's potential as a smart city by studying its urban structure, examining the key drivers of this transformation and developing plans for sustainable urban development following a descriptive-analytic approach by using field and electronic questionnaires, with nominal measurement ranges and 30 items to cover a set of indicators and variables for smart cities. The same questionnaire was filled out by a sample of 90 experts who live in Fallujah. It was also employed to make a SWOT analysis that indicated the strengths, weaknesses, threats, and opportunities of smart city transformation for Fallujah as well. The findings indicate a statistically significant relationship between urban development and indicators of smart city (Asympto, Sig < 0.05). Infrastructure was recognised as the most impactful aspect of this transformation. Meanwhile, analysis of SWOT results showed the SO strategy was considered the best solution for harnessing existing strengths. Nonetheless, this study stresses that to accomplish such a transformation, one must meet challenges brought on by the decay of critical infrastructure from the damage that the city has sustained and thus calls for integrated reconstruction policies fulfilling sustainable urban development for Fallujah.

Keywords:
smart city, SWOT analysis, urban planning, SO strategy, GIS, Fallujah city

1. Introduction

Due to the rapid transitions that entail urban sustainability, smart cities have emerged as a paradigm framework for managing congestion due to urban growth and increasing operational efficiency of services and resources [1]. Smart cities utilise modern technology such as the Internet of Things (IoT), artificial intelligence (AI) and geographic information systems (GIS) to help urban services achieve high efficiency [2]. While extensive literature exists on smart city applications in developed contexts, there is an evident research gap related to both the potential for and the prevailing environment required for cities in conflict-affected or reconstruction-prone environments like Iraqi cities to harness smart city transformation based on the integration of infrastructure and sustainable urban planning. Additionally, there is a dearth of field studies that use SWOT analysis to analyse this transformation in specific sites such as Fallujah.

Motivated by this gap, this study assumes the existence of a correlational relationship between urban design and smart city indicators for Fallujah, and aims to explore the following research questions: How is Fallujah prepared to become a smart city? To what extent is the connection between Fallujah urban planning character and the measures of studying smart cities? What are the most prominent factors influencing the transformation into a smart city? What opportunities, challenges, strengths, and weaknesses can be identified in a SWOT analysis? Accordingly, the current research aims to assess the readiness of Fallujah to become a smart city by analysing its urban structure, identifying the most influential factors in this transformation, and formulating strategic directions to achieve sustainable urban development. The research adopts a descriptive analytical approach based on field data collected through a questionnaire

directed to a group of experts, in addition to using statistical analysis tools and SWOT analysis, with the aim of providing a scientific applied framework that supports decision-makers in adopting sustainable urban planning policies.

1.1. The evolution of cities

Cities have always been important nodes for social, economic and technological development. Since antiquity and until the Industrial Revolution, cities were considered as drivers for production, knowledge exchange and cultural development [3]. Despite the "difficulty" with urban squalor, environmental degradation and social stratification, cities persisted in becoming larger while eliminating transaction frictions by packing economic agents together [4].

Cities developed because of agricultural surplus production, a tendency seen in Babylon and Memphis. Then cities evolved in response to a growing complexity of production, consumer requirements and social organisation, such as Manchester and Berlin [5]. The employment of technologies, such as steam power, electricity and eventually telecommunications, contributed to the most significant industrialisation and urban growth [6]. Today, many cities are transforming into innovation hubs and high-technology centres, best represented by regions such as Singapore or Tel Aviv [7,8].

Yet, mass urbanisation introduced externalities, pollution, poverty, and poor infrastructures that gave rise to public investments in services and institutions [9]. The main drivers for the conversion of a city into a smart centre for innovation and technology could be rationalised [10] as follows:

- Digital Transformation: Incorporating AI, big data, and cloud in urban areas.
- Human Capital Intensification: Cities centralise skills and post-compulsory education, attracting talent.
- Smart Transportation: “The mode of transportation a city uses speaks volumes about the standard of living available to its residents.
- Creative Cultures and Business Entrepreneurship Business centres and innovation accelerators promote start-ups and technical progress.

Study of the historic evolution of cities is not just descriptive; it also gives an interpretive framework for understanding urban systems' historical transformations from traditional to complex, technology- and knowledge-based models. It also points out the most critical ingredients which contributed to bringing these city transformations, such as infrastructure, integrated planning and innovation adoption. It is indicative of a cumulative history of the provision of urban services and resources. In order to ensure a systematic approach to sharing knowledge, the study site will be compared with regard to global smart cities (e. g. Singapore, see Table. 1.

Table 1. Comparative systematic analysis between the city of Fallujah and the smart city of Singapore

Indicators	Singapore city	Fallujah city
Smart Governance	Open data led to advanced digital governance and functional community participation	The digital governance is very limited because it is going through an institutional restructuring
Economy and Innovation	Innovation economy and startups	Doesn’t have this system and government support
Smart Mobility	Traffic Management and Smart Digital Transit Systems	Traditional transportation system
Environment and Sustainability	Green cities: efficient energy and water consumption	Resolution of some important environmental issues, including desertification
The above clearly indicates that the divergence between Fallujah and Singapore is as much a lag in development stage. Yet, the distinctive conditions of Fallujah, as a city in the process of reconstruction, provide it with a comparative edge in the potential implementation of smart city models.		

1.1.1. Challenges of cities' evolution

(1) Digital divide: A digital gulf is increasingly prevalent between having available technology and knowledge, both within city regions and between rural areas [11].

(2) High Cost of Living: Cities with a high concentration of knowledge workers bring in top-tier professionals, causing housing price inflation and shortage issues, as evidenced in San Francisco and London [11].

(3) Brain Drain: Large cities drain talent from smaller cities and developed countries, aggravating geographical and knowledge inequalities [11].

1.2. Theoretical foundations of smart cities

These theoretical foundations are emerging from the intersection between urban planning, digital technologies and theories of socio-economic development. A smart city is not just an advanced technological environment, however, but rather a holistic environment with intelligent utilities, governance and citizen engagement - designed to improve quality of life in cities.

Cassandra’s Definition This states that smart cities are cyber-physical systems – physical environments with sensors, actuators and data networks that enable monitoring of what is happening in real time as well as interaction between the related infrastructures for services to their inhabitants. These systems support feedback loops that take city data into account for traffic control, resource management, emergency response and more [12]. Badii (2017) emphasize the necessity of architectural systems that can integrate and interpret multi-faceted data collected from different city subsystems. They suggest the adoption of Smart City APIs as enabling how services can interact with and share information, an essential element for scalability and system integration [13].

But smart cities are not just a matter of technological infrastructure. Glasmeier and Christopherson (2015) call for a more comprehensive understanding that embraces social innovation, participatory governance and residents’ experiences. They then ask who exactly the beneficiary of smart cities is and argue that without equitable planning, digital innovation will only contribute to social inequality [14].

The knowledge economy-based economic theories also influence the construction of smart cities. In this world, the city becomes a place of innovation in which human resources, rather than nature or things, are the dominant factor driving progress.

Education and research institutions and digital literacy are vital ingredients for building a qualified and flexible workforce, fundamental inter alia to the success of smart city development.

Environmentally speaking, smart cities aspire to limit the ecological footprints induced through energy consumption, waste production and mobility. In this context, key technologies include smart grid [15], integration of renewable energy and intelligent water management systems, etc.

To conclude, the SC (smart city) model absorbs various theoretical domains:

- Technology-driven: Focuses on ICT, IoT, AI and big data.
- Social: Concerned with equity, inclusion and citizen engagement.
- Economic innovation, founded on: Economic innovation, education and entrepreneurship.
- Environmental: Emphasises sustainability and adaptability.

So, Smart cities are more than just a matter of deploying ICTs, but represent a complex system to advance sustainable growth, facilitate innovation and enhance quality of life for all citizens. Although it does not have a consensus definition, it has evolved from pure technological infrastructure to include good governance, environmental stewardship and social inclusion. At the heart of any smart city is an intelligent digital network, using real-time information to make better strategic decisions. In such a view, ICT infrastructures play an enabling role more than the final objectives of measures, providing avenues towards addressing urban problems and challenges like transport inefficiencies, energy management, waste collection and public safety issues. And a smart city is really one that values inclusiveness, invests in developing its human capital and disseminates knowledge with strong educational and scientific institutions. These are not separate but rather interconnected pillars. The success of a smart city is determined by the extent to which these dimensions are tightly integrated, and how they can be leveraged to build a responsive, intelligent and sustainable urban system. Based on these theoretical bases, this paper aims to examine how the Fallujah city province can create a local or contextual smart city model.

1.2.1. Major technologies of smart cities

- Smart Energy: intelligent energy systems and grids contribute to pollution reduction, and the use of energy optimally [16].
- Smart Transportation: Automated traffic signals and access to live public transit schedule data for better movement [16].
- Smart Data: Predictive management of the city is made possible through big data analytics and open portals [16].
- Smart Infrastructure: Proactive planning and public health enabled by real-time diagnostics [16].
- Smart Mobility: Autonomic and seamless interoperation of services and data through sensors and IoT [16].
- Sustainability: Smart cities encourage Resilient, fair and eco-conscious smart cities [2,17,18].

1.2.2. An example of smart cities (Shiraz City)

- Urban morphology and development: Shiraz has a two-layer urban structure, one central historical city core and another built up relatively more recently as a suburban area. In 1921, Shiraz was organised into 10 sprawling. The second phase of modernity (1941 to 1979) led to urban in-migration due to land redistribution and the development of rural–urban water infrastructure [19], as shown in Fig. 1.
- Transportation: To relieve the congestion of traffic and the growing demand for mobility, Shiraz began building its first metro system in 2002. The system is designed to relate to express bus lanes and secondary feeder roads and smart traffic control zones to provide friendly transportation solutions [20].
- Urban Green Space and Environmental Preservation: There are over 400 hectares of productive/functional gardens and using resilient local flora against drought, contributing to both public health and recreation space [21].
- Industrial and Waste Administration: to achieve sustainable waste management within Shiraz, organics separation from recyclables and non-recyclables could be proposed, also incorporated with agro-industrial processes for increased sustainability and financial efficacy [22].
- Growth in Population: over the period 1950 – 2020, based on United Nations population data, the population of Shiraz grew from 127,552 to around 1.65 million, demonstrating the imperative to plan sustainably for future demographic trends [23].
- Renewable Energy and Sustainable/Green Development: energy security still holds significant importance for Iran, considering the increasing environmental issues. Plans for the Shiraz Solar Power Plant, currently 250kW with plans to double capacity to 500 KWR [24]. So, Table 2 shows the SWOT analysis between Shiraz city and Fallujah city.

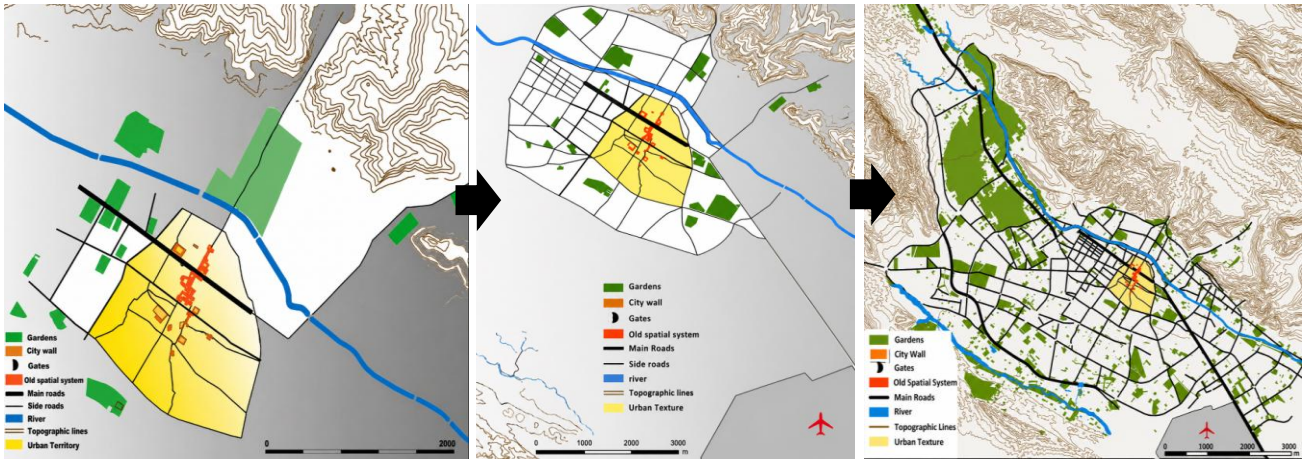

Fig. 1. Shiraz city before 1921 until after Islam. Source: Researcher based on several sources

Table 2. SWOT analysis is used to compare between Shiraz city and Fallujah city

Indicators	Shiraz city [25]	Fallujah city
Functionality	S: Local park, services, and market W: Lack of recreational facilities O: Gardens and malls T: Residents directed to other areas for entertainment.	S: Local markets, traditional business activity W: Weak recreational facilities and services O: The possibility of implementing recreational projects within the reconstruction efforts. T: Increase in immigration to access services
Access	S: Central location, public transport, wide streets and sidewalks W: Lack of parking spaces, traffic congestion O: Creating parking spaces T: Reducing comfort to increase the population	S: A strategic location connecting the cities of Anbar W: Weak public transportation, lack of parking spaces O: Developing an intelligent transportation network T: Increased congestion due to population growth
Physical	S: Open spaces W: Old urban fabric O: Development of old areas T: Demolishing courtyard houses and increasing the population	S: Developable land W: Informal settlements O: Reconstruction according to smart city principles T: Increasing informal settlements to accommodate the growing population
Environmental	S: Good ventilation due to the gardens W: Lack of green spaces O: Creating gardens T: Removing gardens to build housing.	S: The Euphrates River is an important environmental element. W: Weakness of environmental management O: Creating green spaces along the riverfront T: Urban expansion at the expense of the environment
Social	S: High cultural level W: Attractive commercial and cultural activities	S: Strong commercial ties W: The impact of conflicts on the community O: Enhancing community participation T: Weak trust and participation
Economical	S: Increase in income and real estate value W: Increase in commercial activities	S: Local business activity W: Limited investment O: The possibility of attracting investments T: Economic fluctuations

1.3. Literature review

Smart Cities are emerging as a topic of interest in academic and industrial communities around the globe. This paradigm has been evaluated from different perspectives, such as digital infrastructure, data management and socio- technological integration. A critical review of the present is an attempt to identify trends, challenges and solutions that have been developed over time around this issue.

Badii [13] presented a solid architectural framework for data aggregation, under the scope of the Sii-Mobility Smart City Project. The proposed solution meets interoperability issues by transforming heterogeneous data sources into cognitive light applications with smart APIs, for effective service orchestration and massive deployment of urban services.

Glasmeier [14] provides a critical reflection on Smart City imaginaries, stressing the interplay of technical infrastructure and the lived experiences of citizens. The authors appeal for the inclusive, context-aware planning that considers demographic changes and infrastructural inequality, urging participation in urban innovation.

Cassandras [12] considers smart cities, where such systems are enabling Cyber- Physical Systems (CPS) that integrate physical infrastructure with cloud-enabled devices, and mobile services. This system, regarding network dynamics and immediate regulation, is not to be trusted to technical availability alone but also needs consideration of knowledge integration and user orientation.

Coletta [26] introduces the "algorhythmic governance" that explores how urban rhythms are tracked and managed via sensor infrastructures and IoT-linked feedback structures. Concrete cases in traffic and noise control demonstrate how such algorithms coordinate infrastructural reactions to urban life by making them responsive to the vicissitudes of temporal order.

Wiselia [27] presents a simulation-based didactic model through simulating the real-life problems in environmental, economic and social aspects. It supports strategic thinking and stakeholder awareness of Smart City capabilities among decision-makers.

Santana [28] suggests a single software reference architecture for a smart city modular based on four pillars of strength addressed in the following units: IoT (Internet of Things), Big Data, CPS and Cloud Computing. This model deals with issues such as scalability, flexibility and standardisation, offering a framework for integrated software ecosystems in various urban environments.

Mahmoud [29] targets Smart Grid integration by the semantic middleware architecture SMArc. Developed to be scalable, interoperable energy data management, SMArc offers real-time monitoring and thus supports a sustainable use of energy in urban quarters.

Biswas [30] emphasises the security of Smart City networks by putting forth a Blockchain solution. Among its key findings: Blockchain's resiliency to cyberattacks, ability to maintain data integrity and scalability potential to support an increasingly interconnected world of devices are considered among its most significant benefits. The problem of urban surveillance data was solved.

However, some recent local literature suggests that a climate-adapted urban planning policy has started developing for cities in Iraq, considering climatic variables such as desertification and extremely high temperatures. It can be done

through green parks, shading, and better ventilation in urban design [31]. Another source highlighted the importance of planning that reduces the phenomenon of urban heat islands, including in the cities of Anbar, using smart infrastructure that reduces energy consumption [32]. The UN-Habitat [33] report explained that traditional urban planning is not adequately responsive to high temperatures and therefore recommends the use of heat-reflective building materials, the use of vegetation, and the narrowing of streets to increase shading. Jabbar [34] indicated that Iraqi cities suffer from outdated traditional planning and haphazard expansion, with a lack of integration between land use and infrastructure, amidst increasing population growth. The study confirms that current Iraqi urban planning does not respond to climatic conditions and therefore recommends the use of green spaces, which reduce the effects of heat and improve natural ventilation.

We next end that the body of literature we have reviewed represents a multitude of areas with respect to Smart City evolution, including data integration through educational facilities and governance models, up to security measures. Together, these studies underscore the importance of an approach informed by humanity yet powered by technology toward urban transformation that is both efficient and inclusive for innovation and resilience. Despite much literature on smart city applications in developed contexts, identifying the gap demands a potential preparedness assessment of conflict-affected and reconstruction-impacted cities, such as Iraq, to become smart cities operating infrastructure with sustainable urban planning. Additionally, this transition has been investigated using SWOT analysis only in limited field studies across specific regions like Fallujah. This study assumes a statistically substantial association between the level of urban development in Fallujah and smart city indicators. However, the ability of a city to become a smart city is constrained by poor infrastructure, a shortage of funds and low technical knowledge of local authorities. The objective of this study is to investigate the following questions: What can Fallujah do in order to become a smart city? How does the urban growth of Fallujah correspond to smart city indicators? What are the key drivers of smart city transition? What can be identified as strengths, weaknesses, opportunities and threats by SWOT analysis?

1.4. Research context and problem statement

Economic, political and security setbacks that trail urban development of the country in general were especially prominent after 2003. Although the resource-rich and high-potential province of Fallujah has many problems: haphazard placement, low-level planning, no environmental control, and the research-based urbanisation models have not been used. Critical issues identified:

- Planning: Overeager urban development and transformation into residential.
- Technological impediments: Lack of incorporation of smart technologies.
- Environmental issues: Dangers of pollution from archaic methods.
- Economic constraints: High infrastructure costs that cannot be borne individually.
- Social implications: High unemployment and a lack of social cohesion-development strategies.

1.5. Research objectives

Main objective: To propose a Smart Technology-based Urbanisation model for Iraq.

Specific Objectives:

- Synchronise urban expansion with ecological sustainability.
- Optimise land-use by 'intelligent' zoning.
- Propose a model comparing conventional versus smart planning.
- Use GIS to strategically identify the best locations.

2. Research methodology

The research is an observational-analytical design, including:

(1) Conceptual investigation: Definition. The processing for a smart city based on the literature review.
(2) Field Diagnosis: Analysis of the current condition of Fallujah's urban areas.
(3) Comparative analysis of benchmarking with global smart cities.
(4) Using a GIS program: Spatial analysis for the optimal site to be mediated.
(5) Stakeholder Involvement: Interviews with experts to confirm challenges and solutions.

This integrated method combines scientific accuracy with local relevance.

2.1. Measuring tools

2.1.1. Questionnaire

These research initiatives were generally based on a comprehensive review of literature and empirical assessment of field data in the study sites by a field and electronic survey was conducted with the participation of 90 experts from the residents of Fallujah Governorate, with the aim of shedding light on specific challenges, barriers and needs for planning and programming, especially in Fallujah city. For analytical richness, the study also adopted the SWOT matrix process and added expert perceptions collected through structured interviews in the case study. These expert opinions were recorded in a Likert-scale questionnaire, which was used as a major instrument for making knowledge-based decisions.

2.1.2. Data normalisation

To control overdispersion due to differences in the sizes of samples within each dataset, normalisation was conducted on the data to refine it and to remove extreme or non-pertinent entries that might influence results caused by random fluctuations or intentional misreporting. To identify and eliminate such inaccuracies, we used the Kolmogorov-Smirnov test as a filter in terms of statistical methods, validating the experimental data reliability.

2.1.3. Spearman's Rank Correlation

To assess associations between components of interest, especially the associations between questionnaire items and responses, we used Spearman's rank correlation. This non-parametric statistical technique detects the magnitude and direction of monotonic relationships between paired variables. Its meaning is like Pearson correlation, in that the closer its value is to ±1, the stronger the monotonic relationship. Spearman's correlation was used as an effect size measure to be able to make verbal classifications of strength based on Fig. 2.

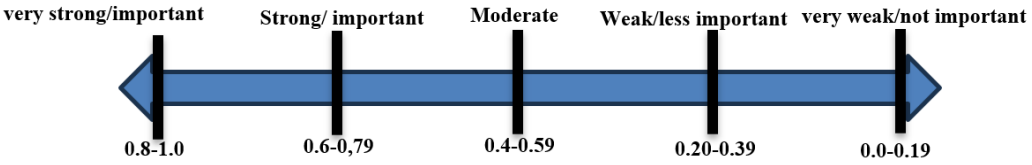

Fig. 2. Spearman's Rank Correlation

2.1.4. SWOT Matrix Analysis

The strengths–weaknesses-(internal), opportunities-threats (external) SWOT matrix is an essential strategic planning tool, aiming to evaluate the internal strengths & weaknesses and the external opportunities & threats of an entity. The method starts with articulating a desired outcome and then analysing the positive and negative factors which may be driving toward or against goal realisation. Originally conceptualised by Albert Humphrey during his work at Stanford University in the 60-70s, SWOT analysis is now used in strategic planning worldwide. For maximum relevance and usefulness, SWOT should be linked to the clearly defined ends. Correctly used complements further strategic planning tools like the objective-based SCAN analysis. These instruments, such as the SWOT and the SCAN models, have also been validated through empirical studies and real applications [35].

Strengths and weaknesses in the organisation's internal environment – including operational capabilities and financial and human resources – can either help or hinder achievements in pursuit of stated objectives. On the other hand, external factors could include changes in the macroeconomic environment, regulatory updates, technological progressions, sociocultural trends or competitive pressures. The findings of SWOT analysis may be analysed in matrix format to gain a clear strategic overview [36].

2.2. Research area and justification

While the area treated in this study represents a district (Fallujah/Iraq), there are strong reasons:

- Urban Planning Issues: Over many years, it has seen several urban sprawl and development reasons, including environmental and logistics.
- Strategic Position: Its access to cities of Baghdad, Babylon, Karbala and Salah Al-Din as well as its proximity to international boundaries increases the need for the area as an investment and progress centre.
- Natural and Human Assets: The area has an abundance of natural resources, as well as a capable workforce with extensive experience in the implementation of industrial operations, which constitutes one of the cornerstones for Iraq's economy.

2.3. Research sample (Fallujah/Iraq)

(1) Brief description: Fallujah is a major city in Al Anbar Governorate, situated approximately 100 km west of Baghdad, at the crossroad of the Euphrates River and the Al Warrar Channel. It is also close to Habbaniyah Lake and an important stopping point along the Baghdad–Rutba–Damascus highway, being well-situated for commerce and industry [37]. Its mosque, bazaar and water tower are important landmarks in Fallujah. The city's development and infrastructure integrate historical settlement patterns with modern industrial growth [38,39]. From a population of less than 10,000 in 1947, Fallujah has expanded to some 230,500 people today. Its urban subsistence has been based upon the interacting water bodies, topography and flood risk, which have constrained expansion in historical terms towards the highway rather than the Euphrates [38,39]. Fallujah was chosen for this study because it is the largest and most industrialised city in this province. The large industrial zone and the relatively well-developed infrastructure can provide an opportunity to study energy and environmental problems in urbanised regions.

(2) Culture: Fallujah population, characterised by an urban megalopolis with a tribal tradition of inbreeding family formations and excessive household size [40].

(3) Climate: The Western Plateau has a summer/winter, night/day temperature contrast with precipitation levels of 50-200 mm/year, which is conveyed in winter months. The dominant winds are northwesterlies all year. These regions are sparsely vegetated because of their arid climate and low precipitation. The major plants are saffron and thyme [41].

Contrastingly, the Iraqi drought and water scarcity have led to dramatic, far-reaching consequences, which are not, however, limited to agricultural lands [42]. These effects include:

- Economic Dislocation: The lack of water prevents the production of goods and services, especially in sectors that are highly dependent on water supply.
- Social and Public health concern: People and animals cannot live without water; water is also important for environmental integrity, even if there are personal hygiene living styles as well as public health standards.
- Decertification and Sandstorms: Drought has quickened the growth of decertified land and led to more sand dunes and sandstorms.
- Hydropower Restraints: Shortage of water has led to the failure of hydroelectric systems that support water purification, industrial production and provide power to oil refineries.
- Sanitation and water-borne diseases Tigris and Euphrates River flows are unlikely to recover, which would further deteriorate the already polluted state due to sewage discharges contaminating the depleted waters, spreading disease. Shallower water levels, in addition, reduce the effectiveness of water intake and promote the growth of aquatic weeds around intakes, which interfere with water treatment operations.
- Salinity Problems: A drying up of freshwater flow, diluted by seawater, has increased soil salinity on farming areas along rivers and their tributaries, reducing the fertility of the land.

2.4. Practical and applied side

The assessment identified certain components of a smart city in Fallujah (infrastructure, land use, transport approach, open spaces, population density and others. GIS and survey-based data gathering were used to visualise and analyse the urban dynamics for the assessment.

2.4.1. Land use / cover

The urban land classification approach in this study applies to a hierarchical structure like that adopted for the European Urban Atlas and divides land into five main categories: Artificial Area, Natural/Semi-natural Area, Agricultural Area, Wetland and Water Body. Each category has more specific subdivisions, therefore supporting multi-level spatial analysis, see Fig. 3.

Comparison of land use change from 2002 to 2025 in the Fallujah sector is shown in Fig. 4A, indicating a notable decrease in arable lands and an increase in the expansion of urban areas. This urban expansion, for the most part, has happened at the cost of agricultural lands, as shown in the growth map that indicates growing pressure on natural land resources. Appropriate mapping of settlement extent is essential, because it directly affects estimations for population distribution, resource use, infrastructure plan and socioeconomic development. Fig. 4B depicted growth of settlement and the ever-increasing impervious roads and buildings.

2.4.2. Transportation

Urban road classes deployed in the study area are Arterial Roads, Collector Roads and Local Roads. Each has a different function in traffic movement: arterials move a large volume of traffic, collectors connect arterials to local streets, and local streets receive access for properties. It can be seen from Fig. 5 that the central region has a higher transportation density, which agrees with accumulated economic and social activities. The knowledge of these trips is in fact crucial for the sustainable planning of urban mobility.

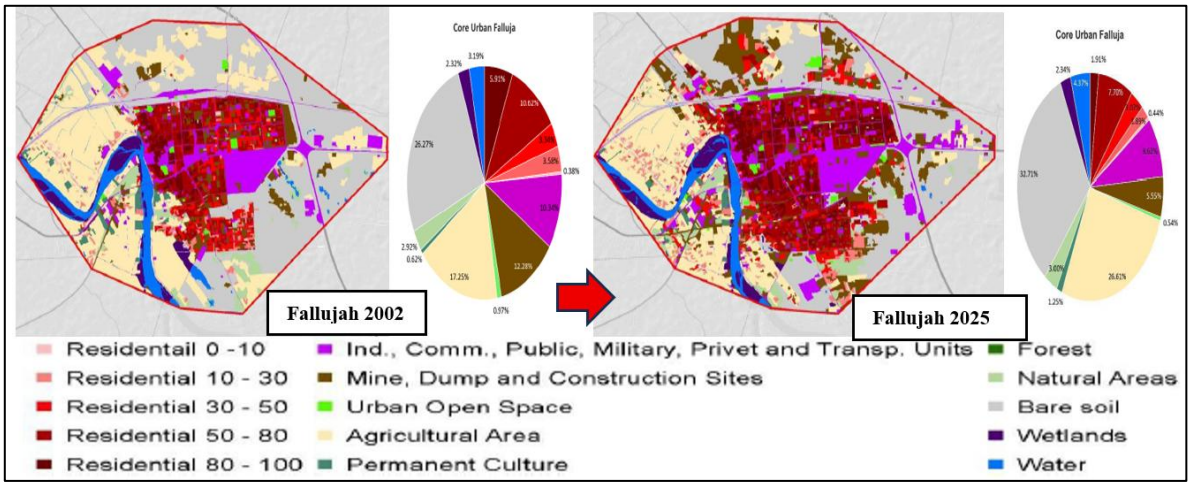

Fig. 3. Land Cover in Fallujah

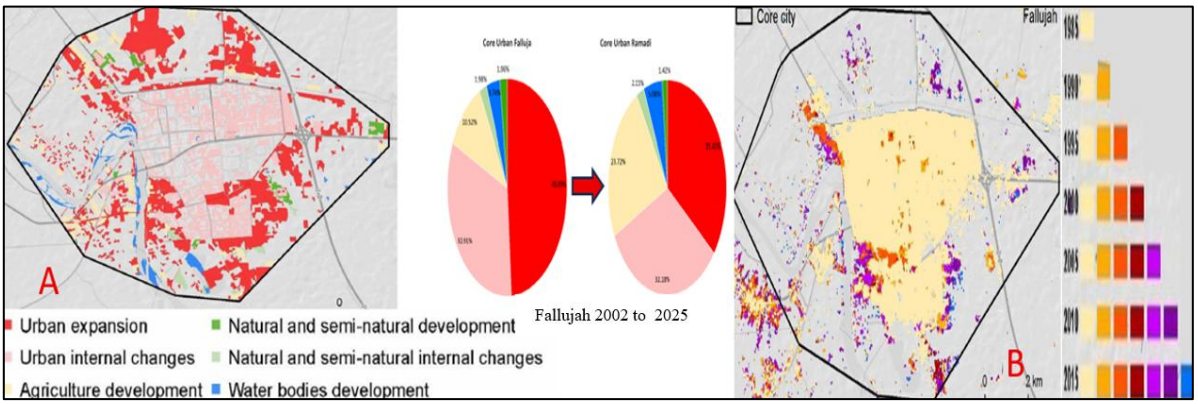

Fig. 4. (A) Fallujah city expansion, (B) Settlement area in Fallujah

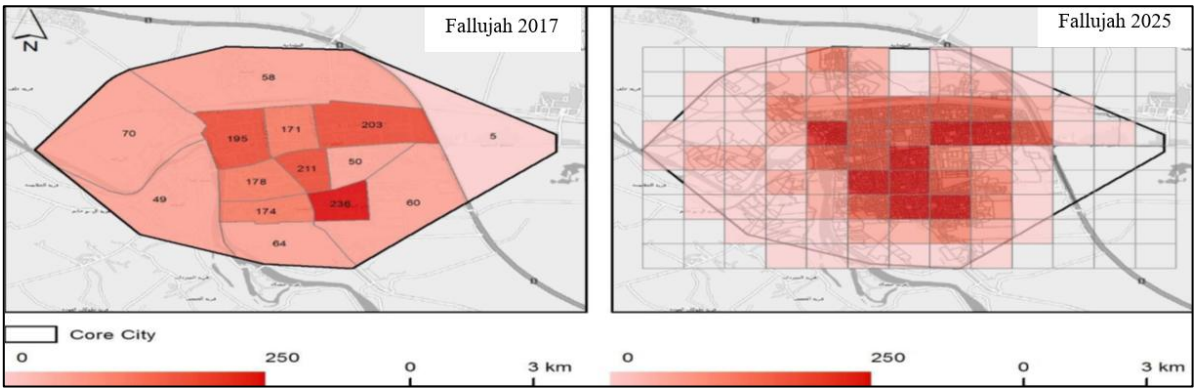

Fig. 5. Transportation in Fallujah

2.4.3. Importance of map data

Remote sensing maps have inherent uncertainties like those found in any cartographic product, caused by factors such as the quality of the satellite data, sensor crosscalibration, image processing techniques and the availability of reference information. Therefore, validation of the spatial products was thoroughly conducted to ensure they are reliable for secondary uses.

2.4.4. Green / open spaces

The green infrastructure of urban areas (parks and available open space) is recognised as an important contributor to the livability and ecosystem health of cities. As shown in the GIS configuration analysis in Fig. 6, the green open space area in the central part is relatively high, which provides an opportunity to incorporate green planning into a compact urban core.

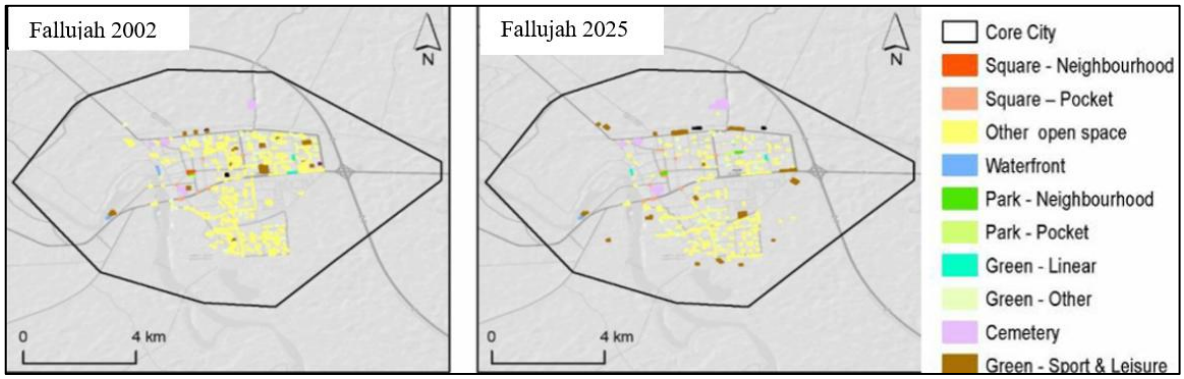

Fig. 6. Open area in Fallujah

2.4.5. Statistical survey

A structured questionnaire had been prepared based on four theoretical approaches to local views about smart city growth. The survey was conducted amongst 90 community members from the city of Fallujah and its vicinities, who volunteered to participate in this study via a convenience sampling, comprising a proportional distribution between gender and six different age levels.

3. Results and discussion

3.1. Descriptive analysis

Summary statistics, using 30 Likert scale questions for the four theoretical constructs, are measured based on participants' perceptions. The results were obtained by calculating the frequency of participants' responses and finding the percentages for each according to the equation attached in Table 3 and Fig. 7, which provide useful information about public knowledge and perceived importance of smart city components, as well as support for development policies.

3.2. Inferential analysis: SWOT approach

The SWOT analysis was used to determine internal strengths and weaknesses and external opportunities and threats for smart city development. The results were obtained by calculating the frequency of participants' responses and finding the percentages for each according to the equation attached in Table 4 and Fig. 8 A-B-C-D, put more character to the building [SO] i.e., Strengths–Opportunities strategic approach as a strategy that can be most suitable for smart urban transformation projects in Fallujah cities, as in Fig. 9.

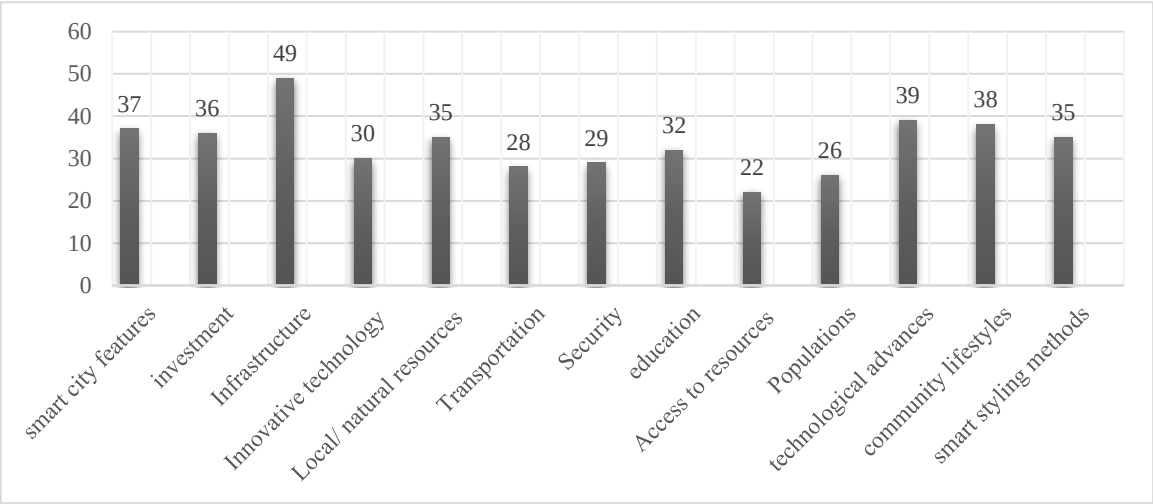

Fig. 7. Descriptive analysis for Fallujah city

Table 3. Descriptive analysis for Fallujah city

Hierarchical questionnaire, 90 participants, use $M = \frac{\sum(f_i \cdot w_i)}{\sum f_i}$ equation

Concept	Indicators	Possible values	very strong	strong	moderate	weak	very weak
How dedicated is your city to implementing smart city features?	Smart projects	High (100%)	7	7	37	31	8
		Medium (50%)					
		Low (25%)					
	Digital governance	High (100%)					
		Medium (50%)					
		Low (25%)					
	Digital strategies	High (100%)					
		Medium (50%)					
		Low (25%)					
Some investment in the city	Number of investment projects	Strong (100%)	12	10	22	36	10
		Medium (50%)					
		Weak (25%)					
	The volume of spending	Strong (100%)					
		Medium (50%)					
		Weak (25%)					
Infrastructure is ever advancing	Telecommunications network	Advanced (100%)	3	9	12	49	17
		Improved (50%)					
		Deteriorating (25%)					
	Road quality	Advanced (100%)					
		Improved (50%)					
		Deteriorating (25%)					
Innovative technology in city and building design	Using "lot"	Innovative (100%)	2	13	21	24	30
		Semi-modern (50%)					
		Traditional (25%)					
	BIM	Innovative (100%)					
		Semi-modern (50%)					
		Traditional (25%)					
	Smart energy	Innovative (100%)					
		Semi-modern (50%)					
		Traditional (25%)					
Local/ natural resources are one of the aims for self-sufficiency by the city	Water management	High (100%)	35	14	18	13	10
		Medium (50%)					
		Low (25%)					
	Using renewable energy	High (100%)					
		Medium (50%)					
		Low (25%)					
Transportation is efficient and dynamic	Smart transportation availability	Active (100%)	5	12	25	20	28
		Medium (50%)					
		Inactive (25%)					
	Traffic jam	Active (100%)					
		Medium (50%)					
		Inactive (25%)					
Security issues impede daily operations	Stability and security	High (100%)	15	8	21	29	17
		Medium (50%)					
		Low (25%)					
The young are well taught	Level of education	Excellent (100%)	3	10	24	32	21
		Good (50%)					
		Weak (25%)					
	Digital skills	Excellent (100%)					
		Good (50%)					
		Weak (25%)					
Access to resources required to grow the city	Providing services (electricity, water, internet)	Easy (100%)	17	19	10	22	22
		Medium (50%)					
		Difficult (25%)					
Populations impacted by environmental risks	Pollution, heat, and floods	High (100%)	23	15	26	12	14
		Medium (50%)					
		Low (25%)					
The city requires technological advances	Adoption of smart systems	High (100%)	28	39	8	10	5
		Medium (50%)					
		Low (25%)					
Smart city transformations impact community lifestyles	Changing lifestyles	High (100%)	38	27	15	7	3
		Medium (50%)					
		Low (25%)					
City styles are created with smart styling methods	Using smart design	Smart (100%)	1	5	21	28	35
		Modern (50%)					
		Traditional (25%)					
	Sustainability application	Smart (100%)					
		Modern (50%)					
		Traditional (25%)					

Table 4. SWOT factor analysis for Fallujah city

Strengths			Spearman's Rank	Average	Result
Concept	Indicators	Possible values			
Fallujah is a dynamic and growing metropolitan centre	Number of projects	High (100%)	0.1	2.8	0.28
		Medium (50%)			
		Low (25%)			
	Population growth	High (100%)			
		Medium (50%)			
		Low (25%)			
Urban Facilities are continuously being upgraded	Service maintenance	Continuous (100%)	0.07	4	0.28
		Periodically (50%)			
		Rare (25%)			
	Infrastructure renewal	Continuous (100%)			
		Periodically (50%)			
		Rare (25%)			
City is a high education, healthcare and accessible urban environment adapted to local conditions	Quality of services	Excellent (100%)	0.09	2.8	0.252
		Good (50%)			
		Weak (25%)			
	Ease of access	Excellent (100%)			
		Good (50%)			
		Weak (25%)			
	The number of hospitals and schools	Excellent (100%)			
		Good (50%)			
		Weak (25%)			
Active transportation system	Diversity of transportation methods (walking, cycling, public transport)	Active (100%)	0.05	3.2	0.16
		Medium (50%)			
		Low (25%)			
Strong potential for business	Job opportunities	Strong (100%)	0.12	2.6	0.312
		Medium (50%)			
		Weak (25%)			
	Investments	Strong (100%)			
		Medium (50%)			
		Weak (25%)			
Trained the manpower and youth with education	Type of skills	Advanced (100%)	0.06	3.8	0.228
		Medium (50%)			
		Weak (25%)			
	Training level	Advanced (100%)			
		Medium (50%)			
		Weak (25%)			
Local/natural resources	Water, land, and energy availability	Rich (100%)	0.08	3	0.24
		Medium (50%)			
		Limited (25%)			
Total average =sum result (1.752)*2 = 3.50					
Weaknesses					
The absence of local technology production has driven up costs	Local production rate	High (100%)	0.08	2	0.16
		Medium (50%)			
		Low (25%)			
	The cost of technology	High (100%)			
		Medium (50%)			
		Low (25%)			
Limited development of technical facilities	Number of technical projects	Good (100%)	0.05	3.1	0.16
		Medium (50%)			
		Low (25%)			
Challenges when collecting data	Data and system quality	Easy (100%)	0.06	2.7	0.162
		Medium (50%)			
		Difficult (25%)			
	Ease of access	Easy (100%)			
		Medium (50%)			
		Difficult (25%)			
Lack of financing	The size of government/private funding	High (100%)	0.07	3.3	0.231
		Medium (50%)			
		Low (25%)			

No safety	Stability level	High (100%)	0.07	3.8	0.226
		Medium (50%)			
		Low (25%)			
	Crime rates	High (100%)			
		Medium (50%)			
		Low (25%)			
Challenges facing city growth: poor construction and organisation	Slums	Good (100%)	0.08	3	0.24
		Medium (50%)			
		Low (25%)			
	Weak planning	Good (100%)			
		Medium (50%)			
		Low (25%)			
Lack of cognitive governance over technological infrastructure	Level of governance	Strong (100%)	0.04	3.2	0.128
		Medium (50%)			
		Weak (25%)			
Ineffective laws and legislation, and the failure to enforce them	Efficiency of legislation implementation	Active (100%)	0.05	3.1	0.155
		Medium (50%)			
		Weak (25%)			
Total average =sum result (1.462)*2 = 2.92					

Opportunities

Better access to resources	Justice in the distribution of services	Good (100%)	0.16	3.8	0.61
		Medium (50%)			
		Low (25%)			
Minimise expenses associated with frontline workers	Automation rate	High (100%)	0.14	2.6	0.36
		Medium (50%)			
		Low (25%)			
Cheap and natural resources	Energy cost	High (100%)	0.14	3.8	0.53
		Medium (50%)			
		Low (25%)			
	Raw materials	High (100%)			
		Medium (50%)			
		Low (25%)			
Total average =sum result (1.5)*2 = 3					

Threats

Shortage in investment	The volume of investments	High (100%)	0.12	3	0.36
		Medium (50%)			
		Low (25%)			
Economic contraction and uneven development	Economic growth/Gross Domestic Product	Positive (100%)	0.11	3	0.33
		Stable (50%)			
		Negative (25%)			
	Unemployment	Positive (100%)			
		Stable (50%)			
		Negative (25%)			
Competition for resources	Demand versus supply	High (100%)	0.06	3.5	0.21
		Medium (50%)			
		Low (25%)			
Transportation challenges	Efficiency of transportation networks	Good (100%)	0.07	2.1	0.147
		Medium (50%)			
		Low (25%)			
	Traffic jam	Good (100%)			
		Medium (50%)			
		Low (25%)			
Financial difficulties resulting from a lack of assistance	Financial stability	High (100%)	0.08	2.3	0.184
		Medium (50%)			
		Low (25%)			
Heightened security worries	Threats / Stability	High (100%)	0.07	3.6	0.252
		Medium (50%)			
		Low (25%)			
Total average =sum result (1.483)*2 = 2.96					

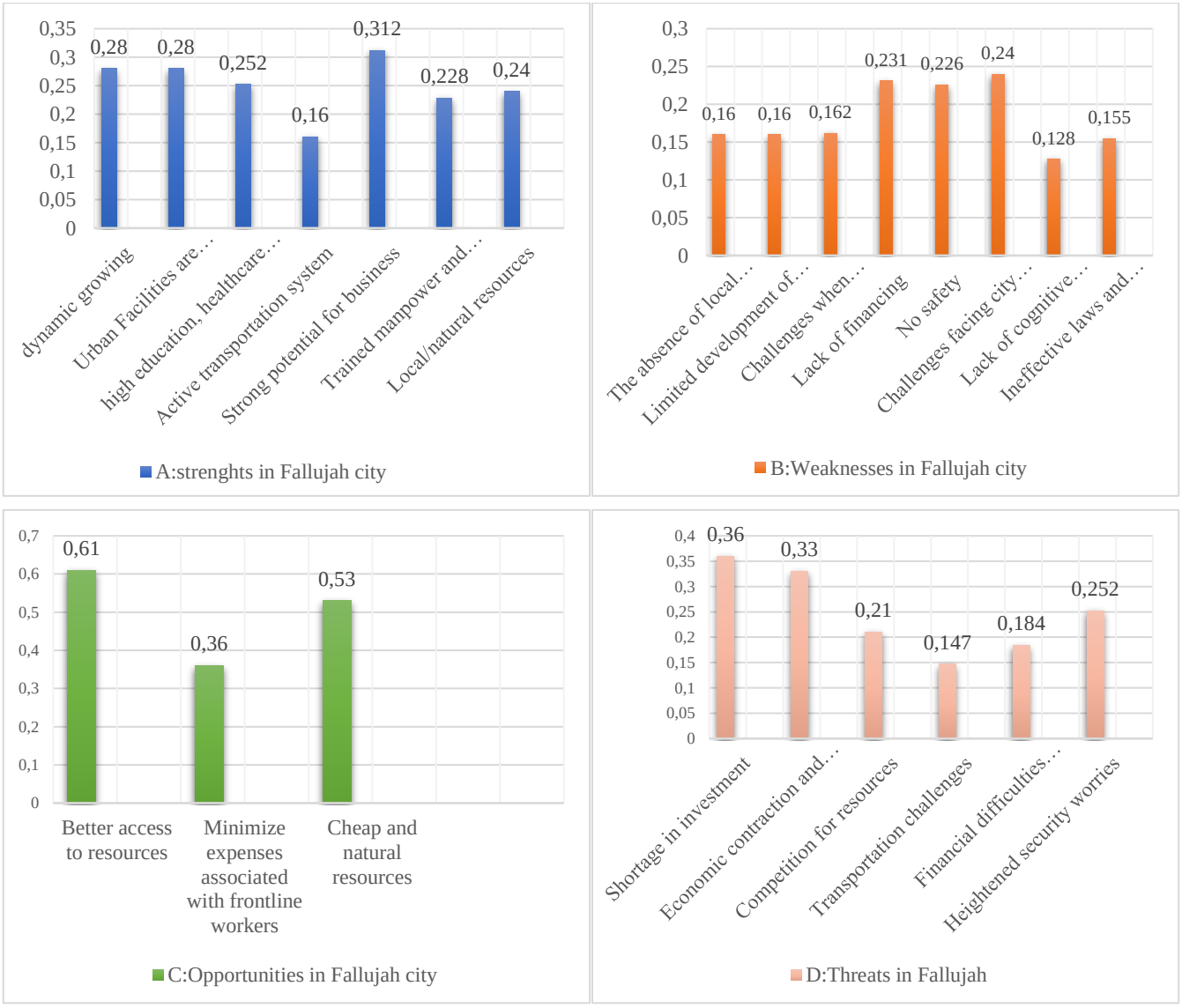

Fig. 8. Results of SWOT factor analysis for Fallujah city

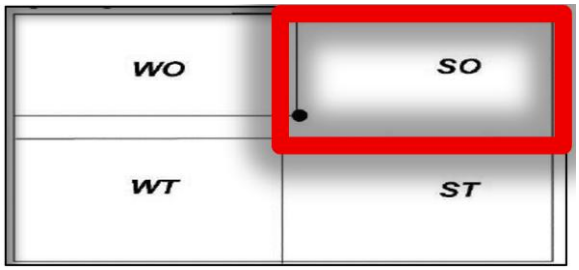

Fig. 9. SO as the optimal technique for the creation of the smart city in Fallujah

4. Conclusions

4.1. Conclusion of results

The assessments prove that Fallujah has dormant capabilities for building a Smart City with a focus on industry areas. Internal strengths are combined with external trends so that SO and WO strategies can be formulated in a double focus strategy.

4.2. Theory-driven analysis

Regarding the normality of data with the participation of 90 experts from the residents of Fallujah Governorate, Kolmogorov-Smirnov test could not be reached (Asymp. Sig < 0.01) so that data required for non-parametric testing has been (Asymp. Sig < 0.05) for Spearman's correlations that show a statistically significant association concerning smart city preparedness and four basic elements including resource availability and accessibility, urban infrastructure, social and political challenges as well as architectural modernisation. The infrastructure had the strongest association with smart city potential, highlighting the war's devastating legacy and the pressing necessity for deliberate investing in public utilities, see Table 5 and Fig. 10.

Table 5. Kolmogorov Smirnov analysis

Factors	average	std deviation	Z	Asymp. Sig.(2-tailed)	
Local/ Natural Resources	79	7.2	0.17	0	
Provision and Growth	32	2.4	0.11	0	
Community disturbance	40	3.1	0.14	0	
Contemporary architecture	30	3	0.10	0	
Intelligent urban area	61	3.5	0.1	0	
So, Smart city	Natural resources	Service and Growth	Community disturbance	Contemporary /recently architecture	
	0.05>0.001	0.05>0.001	0.05>0.001	0.05>0.001	Asymp. Sig. (2-tailed)
	0.35	0.70	0.56	0.45	Spearman's Rank Correlation

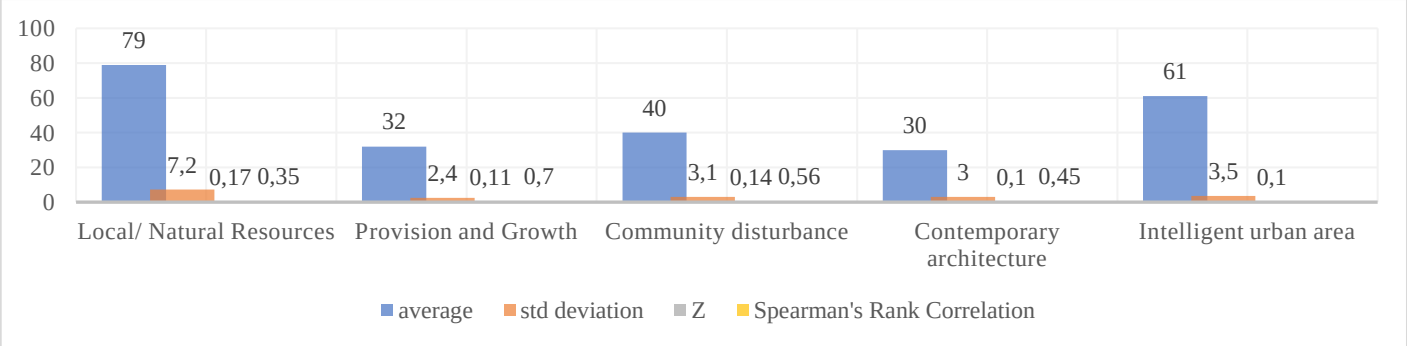

Fig. 10. Kolmogorov Smirnov analysis

4.3. SWOT matrix

It was applied to discover the internal and external factors of Fallujah smart city formation and assessment. The SWOT analysis was structured into four strategic quadrants: Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T). The results showed that, regarding the SO (Strength-Opportunity) strategy, the "offensive" strategy will present a preferable conceptual model for directing Fallujah's process of smart city transformation. The following strategic implications were obtained:

- SO Strategy - Strengths to Opportunities:

(1) Mobilise youth in the field of industrial and innovative urbanisation.
(2) Exploit local resources, especially for green energy projects.
(3) Enhance the current infrastructure to adapt to and expand.
(4) Develop methods using cheap natural materials.
(5) Introduce fiscal incentives to encourage local and foreign investment.

- WO Strategy- organisation Weaknesses by Opportunities

(1) Develop an industrial competence-related educational system.
(2) Employing smart solutions to step up quality of services in the field of education.
(3) Optimise scarce resources while doing efficient urban planning.
(4) Smart energy, transportation and water infrastructure.
(5) Promote public knowledge to reduce social barriers and enhance investors' confidence.

Reflection comparing with a smart city information in Shiraz, Kulonprogo, Indonesia, yields similar results. That case recommended four major steps, all corresponding closely to the strategic recommendations of this study:

(1) Promoting the Government-Community Synergy: Creating public awareness where local authorities collaborate with people, provide a legal foundation for the implementation of smart cities, and appreciate the ways in which technology can improve the quality of life. This is consistent with SO strategies 1, 3 and WO strategies 1,2,4.
(2) Foundational Infrastructure: Establishing infrastructure that is critical to long-term success as a smart city and supporting SO strategy 3 and WO strategies 3 and 4.
(3) Framing Technology Needs: Identifying and sourcing contextually suitable technologies to avoid inefficiencies. This approach combines both SO strategy 3 and SO strategy 4, and WO strategies 2, 3, 4.
(4) Facilitating investment: Strengthening readiness for investment by capitalising on natural assets and public engagement. This is equivalent to SO strategies 2 and 5, WO strategy 5.

The research confirms that Fallujah, like most other cities in Iraq, has high potential for becoming a smart city with the right approach, which is based on local situation and resources. However, several obstacles hinder this development, including:

- Funding mechanisms: such as reliance solely on government funding, weak local investment, and limited partnerships with the private sector.
- Governance structures: challenges in coordinating between local and international entities, coupled with the absence of regulatory frameworks to support smart city projects.
- Social factors: societal acceptance of digital development and technologies.

- Institutional capabilities: a lack of managerial and technical expertise to manage smart projects.

Therefore, (1) Local community involvement, (2) Investor transparency, and (3) Coordinated government are important. Richness in natural resources is for the good, but does not suffice; making a vision of a smart city work requires integrated, dimension-crossing management not only of technical forces but also social and institutional ones.

Author Contributions

Conceptualization, Sarah S. H., Israa M.; methodology, Sarah S. H. and, Israa M.; validation, Zahraa A., Sarah S. H; formal analysis, Sarah S. H., Fatin H; investigation, Sarah S. H., Zahraa A., Israa M.; resources, Sarah S. H; data curation, Fatin H; writing – original draft preparation, Sarah S. H., Zahraa A., Beshaer M.; writing – review and editing, Sarah S. H and Beshaer M.; visualization, Israa M.; supervision Sarah S. H, All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author

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Conflicts of Interest

The authors declare no conflict of interest

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