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DEVELOPMENT OF A PARKING INDEX FOR BAGHDAD CITY BASED ON GEOGRAPHIC INFORMATION SYSTEM APPLICATIONS

Summary. A systematic plan employing two analytical methodologies—an analytic hierarchy process (AHP) and a fuzzy analytic hierarchy process (FAHP)—was executed to pinpoint the various districts in Baghdad deemed most suitable for establishing new parking structures. These methods were applied to evaluate and weight multiple decision criteria, including district area, amenities, land price, car ownership, traffic volume, and road density. The weighted outcomes were subsequently represented using geographic information system (GIS) mapping tools, which served primarily for spatial visualization and presentation purposes rather than for computational spatial analysis. Within the 63 districts that constitute the urban landscape of Baghdad, the analytical outcomes derived from the AHP and FAHP methodologies revealed that car ownership (25%) and district area (23%) exert the strongest influences on parking site suitability, followed by land price (18%), amenities (15%), traffic volume (13%), and road density (6%). The spatial representation in the GIS showed that approximately 8.1% (AHP) and 12.3% (FAHP) of Baghdad's total area possesses very high suitability for parking development, whereas 34.9% (AHP) and 73.2% (FAHP) are categorized as low suitability zones. This study highlights the applicability of the AHP and FAHP in developing a parking index that can assist municipal authorities in prioritizing suitable districts for parking investments. The use of GIS in this work was limited to visualizing the analytical results to support better communication and understanding of spatial distribution patterns within the city.

1. INTRODUCTION

The global population has been steadily increasing over the years, and this trend is expected to continue in the foreseeable future, according to various demographic estimates. Alongside this growth, there has been a significant rise in the demand for resources and services, which is directly linked to the expanding global population. As the number of people increases, their collective needs and aspirations also grow.

The development and improvement of urban areas, including cities and towns, reflect this phenomenon. A larger population not only means more people but also necessitates upgrades to infrastructure and services to meet their needs. Both the escalating global population and the migration of individuals from less populated rural areas to densely populated metropolitan centers are key factors driving an unprecedented era of rapid transformation across various sectors of society and the economy. The global growth of urban populations has created substantial challenges for transport systems, land management, and infrastructure planning. As cities have expanded, the increasing number of private

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vehicles has intensified the pressure on available parking resources, leading to congestion, air pollution, and inefficiencies in urban mobility. The problem of inadequate parking has emerged as one of the most persistent and complex components of urban transport management worldwide. Addressing this challenge requires a structured, data-driven approach that combines spatial planning with multi-criteria decision-making methods to identify optimal parking locations and improve accessibility and efficiency. A wide range of international studies have explored the integration of an analytic hierarchy process (AHP), fuzzy AHP (FAHP), and other multi-criteria decision-making approaches for parking site selection and management.

Despite the extent of international research, there remains a notable gap in applying such systematic and multi-criteria frameworks to Iraqi cities, particularly Baghdad, where urbanization, land-use conflict, and rapid motorization have intensified parking shortages. Baghdad, the capital of Iraq, lies along the Tigris River and covers approximately 673 km², with a population exceeding 7.5 million inhabitants. The city's economic and administrative centrality attracts heavy daily commuting, resulting in high vehicular density and critical parking deficiencies, especially in central districts such as Karkh, Rusafa, and Al-Mansour. The transportation system is dominated by private vehicles, taxis, and small public buses, while formal off-street parking facilities remain limited. Consequently, illegal curbside parking and congestion at major intersections have become daily urban challenges, exacerbating travel delays and environmental impacts. Given these conditions, there is a growing need for a spatially explicit and systematic framework to evaluate and prioritize suitable areas for new parking development in Baghdad. This study responds to this need by integrating AHP and FAHP methods with GIS visualization tools to develop a parking index (PI) that quantifies and maps the relative suitability of districts for parking infrastructure. The GIS platform is used solely to visually represent analytical outcomes derived from the AHP and FAHP, thereby improving interpretability and urban planning communication. Additionally, the continuous development and improvement of technology, paired with an escalation in the sophistication of technological capabilities, are critical factors that have markedly contributed to the increased urbanization noted in recent decades. It is vital to understand that significant repercussions of this growing demographic in urban areas have led to various adverse outcomes, impacting several elements of urban living and the ecological context in intricate and multifarious ways. As a direct outcome of these advancements, there has been a notable rise in public consciousness pertaining to the diverse issues related to urban challenges and environmental deterioration, thereby creating a demand for more sustainable practices and policies. A plethora of challenges has arisen because of the swift population growth, combined with the increased development of urban centers, necessitating comprehensive strategies to address the implications of such rapid changes on both local and global scales.

These difficulties are often complex and usually culminate in significant shortages of necessary resources and crucial services that are essential for societal operations. As a direct result, there are observable and significant shortages that impact a diverse array of fields and systems, as documented in various studies [2]. Furthermore, as a direct consequence of this development, the transportation sector has experienced rapid growth, and, in conjunction with this expansion, the complexities associated with urban transportation have escalated significantly, necessitating urgent attention [3]. The continuous increase in the population has had a profound influence on the growing demand for greater reliance on automobiles [4], and, as a result, traffic has emerged as one of the most pressing challenges confronting urban transportation systems today [5]. A multitude of adverse consequences are being observed in urban areas as a direct consequence of the rising number of vehicles on the roads and the resulting deficiency of available parking spaces. Numerous cities are grappling with the reality that the availability of public parking has become one of the most critical issues pertaining to traffic management. Indeed, public parking stands out as one of the most formidable challenges that rapidly evolving urban centers need to confront [6].

Along with being one of the most crucial utilities in urban environments, public parking represents one of the most complex responsibilities that city administrations must manage. The pervasive issue of parking has emerged as a source of considerable frustration for motorists, manifesting itself as a widespread dilemma that cities across the globe are struggling to address [7]. The term "parking lot" is utilized to denote a designated surface area that has been systematically organized to accommodate vehicles, and such spaces are frequently sought after for this very reason. The challenge of locating suitable parking spaces has evolved into a significant societal dilemma that is both mentally taxing and time-consuming for individuals seeking to park their vehicles [8]. The effort to find adequate parking places constitutes a considerable problem that affects urban life. A plethora of issues, including but not limited to traffic congestion, environmental degradation, and an escalation of various related challenges, are exacerbated by the parking dilemma, which also has direct implications for the congestion experienced today. The availability and characteristics of parking spaces can vary significantly depending on the geographic location and specific attributes of the area in question. It is vital to make parking areas accessible to the entire public to adequately meet the substantial demand for parking.

The research conducted by Litman [10] and Demir et al. [9] highlights that the requirements for parking are influenced by an extensive array of circumstances that warrant careful consideration. The various factors that influence this situation include, but are not limited to, the geographic location of the real estate being assessed, the established land use regulations, the demographic characteristics of the local population, and the accessibility and availability of public transportation systems that enhance mobility in the area. It is vital to understand that parking areas are affected by a plethora of factors that jointly constitute the expansive transportation network, which incorporates multiple forms of transport and their interdependencies. The successful integration of urban land uses with transportation systems is becoming exceedingly reliant on parking facilities that are designed to be easily accessible to users, alongside the necessity to systematically map out the locations of these parking lots for effective planning and management purposes. For these objectives to be achieved, it is essential to employ complex methodologies that are recognized as extremely significant aspects of this discourse [6].

The provision of parking spaces fulfills a fundamental role within the contemporary framework of urban mobility, significantly influencing how residents and visitors navigate the urban landscape. Parking planning remains one of the most critical components of urban development initiatives. It also constitutes one of the principal objectives that urban planners prioritize as they engage in efforts aimed at enhancing the social amenities and overall quality of life within the urban environment [11]. It is anticipated that parking planning will continue to be one of the most pivotal aspects of urban development strategies. Within the sector of public urban spaces, one of the most impactful choices that must be thoughtfully deliberated is the selection of optimal sites for the establishment of parking facilities.

Due to the sophisticated nature of this decision-making process, an exhaustive examination of an extensive array of criteria, factors, and contextual circumstances is not only recommended but required to ensure informed and effective outcomes [12]. The parking system is poised to enhance its operational efficiency and overall effectiveness while addressing and alleviating a substantial portion of the traffic-related challenges that have been persistently observed in urban areas [13]. This enhancement can be achieved if additional public parking spaces are strategically selected and situated in a manner that is conducive to the needs of the urban populace. It is imperative that the designated location for parking facilities be readily accessible [14], regardless of whether the influx of vehicles is categorized as a parametric or a regular invasion of urban space. Local governmental entities must implement and monitor parking regulations, and these regulations must be designed without any discriminatory elements. Furthermore, it is vital that the design and layout of parking lots cater to the needs of individuals with disabilities by providing appropriate access lanes, safety features, and continuity throughout the parking experience [15]. However, it must be recognized that this provision alone is insufficient to comprehensively address the myriad issues associated with alternative solutions [16], particularly concerning the intricate processes involved in the selection and allocation of parking spaces designated for public use.

The effective management and placement of parking locations have been shown to contribute to a reduction in traffic congestion and the marginal parking demand that often plagues urban environments. Furthermore, the sorting and prioritizing of separate parking areas might be viewed as an obstacle that is included in the domain of multi-criteria decision analysis (MCDA), a methodical decision-making technique. Such a procedural framework commences with the identification and characterization of the most pertinent concerns, and it ends by presenting a variety of alternatives from which stakeholders can make informed choices [17]. Geographic information systems (GISs), which are complex tools that facilitate an extensive array of functionalities related to spatial analysis and the depiction of geographic data [18], do not adequately supply the thorough solutions necessary for addressing the intricate and multifarious challenges that occur in various areas. This limitation persists despite the extensive capabilities that GISs offer. Therefore, for the complex tasks that typify such challenging situations to be successfully and efficiently managed, it is vital to utilize a strategic framework that not only integrates the GIS with the analytic hierarchy process (AHP) [19] but also advances decision-making processes through this partnership.

Furthermore, in parallel with the unification of these information systems, it is critical to emphasize processes such as globalization, urbanization, and climate change, along with other technological and environmental transformations that are currently reshaping the world [20]. This necessity arises from the fact that these transformative processes are occurring concurrently with the integration and evolution of information systems, calling for a holistic approach to understanding their implications. The analytic hierarchy process (AHP), a framework for analysis first introduced by Saaty in 1980 [21], has proven effective and has been widely recognized as a method and measurement apparatus that is utilized across various site selection challenges to ascertain the relative weights of multiple criteria [22]. Manifestly, Saaty stands out as the contributor who first made the AHP technique known to the academic and professional world. Both the AHP methodology and the advanced GIS technologies have demonstrated their utility in effectively addressing challenges associated with site selection; they are also extensively applied in the process of identifying suitable parking spaces within urban environments [3]. This assertion has been substantiated through various studies and practical applications. This particular methodology was meticulously developed with the express intention of determining the most suitable locations for the establishment of parking facilities within the urban landscape of Konya, Turkey. Utilizing the seamless integration of the analytic hierarchy process (AHP) and the fuzzy analytic hierarchy process (FAHP), alongside geographic information systems (GISs), this evaluation engaged in a comprehensive examination of a wide array of factors, which includes, though is not limited to, the geographic regions of interest, the existence of multiple services, prevailing land prices, demographic traits related to vehicle ownership, traffic flow metrics, and the density of road networks.

2. METHOD

To enhance clarity, the methodological process of this study was systematically structured into sequential steps, as illustrated in Fig. 1. The flowchart demonstrates the full workflow used to develop a parking index (PI) for Baghdad City, from problem identification to the final spatial visualization. The applied steps are described as follows:

1. Problem definition and objective formulation: Identify the parking deficiency problem in Baghdad and define the research objective of determining suitable areas for new parking facilities using AHP, FAHP, and GIS visualization.
2. Selection of evaluation criteria: Determine the major influencing factors based on literature and expert consultation on the district area, amenities, land price, car ownership, traffic volume, and road density.
3. Data collection and preparation: Collect spatial and statistical data for each criterion from municipal, cadastral, and traffic authorities, and preprocess them into standardized vector and raster layers.
4. Expert consultation and pairwise comparison (AHP): Conduct an expert questionnaire among planners and engineers to assign relative importance to each criterion using the Saaty 1–9 scale. Compute the consistency ratio ($CR \leq 0.1$).
5. Fuzzy AHP weighting: Transform crisp AHP weights into fuzzy triangular numbers to capture uncertainty in expert judgments and calculate final FAHP weights.
6. GIS mapping and visualization: Use weighted overlay analysis in a GIS to map parking suitability for each criterion (note: GIS is used only for visual representation, not for analytical computation).
7. Result classification and index development: Combine all weighted layers to produce a parking index (PI) map categorizing suitability into five levels: very high, high, medium, low, and very low.

8. Validation and discussion: Compare AHP and FAHP outputs, analyze the spatial distribution of suitable areas, and discuss implications for future urban parking planning.
9. Conclusions and recommendations: Summarize findings, highlight policy implications, and propose actions for improved parking management in Baghdad.

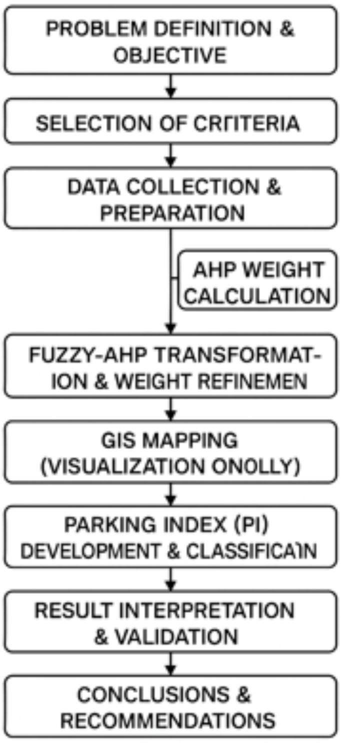

Fig. 1. Flow chart

2.1. Criteria

In the context of this research, a comprehensive analysis was conducted utilizing six distinct criteria that were applied with the objective of accurately identifying locations deemed suitable for the establishment of parking areas, thereby ensuring optimal functionality and accessibility for potential users. When thoroughly ascertaining the various elements that significantly influence the characteristics and viability of the parking areas under consideration, it is imperative to consider the ongoing research study that is being executed, which encompasses multiple variables that may affect the overall analysis. Specifically, the critical factors identified include the geographic area in question, the available facilities that support parking, the prevailing land prices, the total number of individuals who possess automobiles, the volume of vehicular traffic, and the density of roadway networks in proximity to the designated parking sites. These criteria were systematically categorized in accordance with both vector and raster datasets, while additional information was gathered through a diverse array of methodological approaches, thereby enriching the data collection process. This section of the research paper focuses on providing detailed descriptions of each criterion. It also explores the criteria that are fundamentally related to each primary criterion, thereby enhancing our understanding of their interdependence. In addition to this, cartographic representations were developed to illustrate the spatial distribution of appropriateness for each criterion, thereby visually conveying the findings of the analysis. A considerable allocation of effort was made in the production of these informative maps to affirm their fidelity and relevance to the research. To enhance the reader's experience, the results relevant to the criteria are delineated in Table 1, enabling seamless reference and understanding of the data compiled.

The data required for this study were obtained from a combination of official governmental, municipal, and statistical sources. Specifically, spatial and demographic datasets were collected from the Baghdad Municipality and the General Directorate of Roads and Bridges for the delineation of district boundaries, road density, and traffic volumes. Land price data were compiled from the Ministry of Housing and Construction, verified through market assessment reports. Population and car ownership statistics were gathered from the Central Statistical Organization (CSO) and supplemented through structured interviews with municipal transportation officials to validate recent figures. The number of service buildings (amenities) was derived from municipal land-use maps and verified through GIS digitization. All datasets were standardized to a unified coordinate system and converted into vector and raster formats for consistency. This approach ensured that the information used for the AHP and FAHP weighting processes was accurate and spatially comparable, thus forming a reliable foundation for the subsequent parking suitability evaluation.

2.2. Analytical hierarchy process (AHP)

In the realm of decision-making methodologies, the analytical hierarchy process, which is more commonly referred to by its acronym, AHP, employs a systematic approach to selections that is fundamentally grounded in the application of weights derived from a pair-wise comparison technique, which facilitates a thorough analysis of options. This methodological framework is commonly accepted among scholars as a semi-quantitative technique because of its capability to incorporate both qualitative and quantitative aspects into the evaluation methodology. By using this framework, one can efficiently rectify inconsistencies that may transpire during the decision-making process, thereby bolstering the overall reliability and soundness of the outcomes produced.

Table 1

Selected Criteria

Criteria	Code AHP	Code FAHP	Definition
District Area	C1	CF1	Total area in each district (km^2)
Amenities	C2	CF2	Number of service buildings in each district
Car Ownership	C3	CF3	Percentage of the population that has at least one vehicle in each district
Land Price	C4	CF4	Average price of one square meter in each district (in million)
Traffic Volume	C5	CF5	Average traffic volume in each district (veh/hr)
Road Density	C6	CF6	The area of the road network in each district (km^2)

The AHP comprises a detailed progression of five separate stages: (1) the breakdown of complex decision-making choices into their essential parts, (2) the structuring of these criteria within a clear hierarchical model that helps illustrate their connections, (3) the generation of numerical figures that represent the relative placement of each criterion variant in terms of their key importance, (4) the creation of a comparison matrix framework that facilitates the organized evaluation of alternatives, and (5) the adjustment of all criteria weights, ensuring they are sufficiently balanced and representative of their valueMany researchers have used the analytic hierarchy process (AHP) and its extension, fuzzy AHP, to assign weights to criteria related to both constructed and inconsistent causal factors. This approach enhances the analytical rigor of their studies. These elements are combined in the fuzzy-AHP structural process, which encompasses components such as establishing a comprehensive comparison matrix, aggregating multiple judgments, and assessing consistency levels among fuzzy weights, thereby contributing to a more nuanced understanding of decision-making frameworks.

Let the criteria set be $C = \{c1, c2, \ldots, cn\}$. The pairwise comparison matrix $A = [aij]$ is constructed as follows:

a_{ij} = importance of criterion i compared to criterion j, where $a_{ji} = 1/a_{ij}$ and $a_{ii} = 1$.

The normalized weight vector w is obtained from the principal eigenvector of A, satisfying $A \cdot w = \lambda max \cdot w$, and $\sum wi = 1$

2.3. Fuzzy analytical hierarchy process (FAHP)

The FAHP methodology was developed to address and correct the inherent deficiencies and limitations of the traditional analytic hierarchy process (AHP). It aims to provide innovative operational frameworks and solutions for complex problems that arise in unpredictable and dynamic environments. In a related context, the implementation of the AHP methodology can lead to the manifestation of undesirable attributes within the pairwise comparison matrix, particularly when one is confronted with a substantial and diverse array of criteria and alternatives, which significantly complicates the decision-making process. The FAHP approach has gained acceptance due to its utilization of linguistic variable stars within the pairwise comparison matrix, which enhances interpretability, and it has demonstrated a superior level of accuracy and reliability when compared with alternative methodologies employed in similar analyses. A significant modification was proposed within the FAHP framework to create a method that would incorporate fuzzy numbers possessing three dimensions into the pairwise comparison matrix, thereby enhancing the precision of assessments made during the evaluation process. This revision was structured to be enacted in a real-life context, assuring that the proposed approach could be deployed successfully for practical applications. The inquiry was influenced by the perspectives and cognitive deliberations of the individuals tasked with making critical decisions in the context of the study, thus facilitating the construction of a comprehensive pairwise comparison matrix [22].

The FAHP extends the AHP by incorporating fuzzy logic to handle uncertainty in expert judgments using triangular fuzzy numbers (TFNs). Each comparison is represented as (l, m, u), where $l \leq m \leq u$.

1. Represent each a_ij as a TFN (l_ij, m_ij, u_ij).
2. Aggregate multiple expert judgments using geometric mean for TFNs.
3. Compute fuzzy geometric mean for each criterion: gi = (Π a_ij)^(1/n).
4. Defuzzify using centroid method: (l + m + u)/3.
5. Normalize the defuzzified values to derive final weights.

2.4. Pairwise analysis

The primary objective of this analytical matrix is to conduct a comparative analysis and delineation of two criteria that are employed in the process of solitary dating, thereby providing a multifaceted understanding of their roles. This matrix highlights the importance of the column component, especially in relation to the approximate row element of the final output. It clearly distinguishes between the column component and the noise factor, while also emphasizing the column component's crucial role in the overall analysis. A quantitative measure of location strength was ascertained, with the resultant value falling within a range from approximately 1 to 9, thereby representing the specific amount that was achieved during the observational period. To better convey this notion, let's consider the possibility of two separate standards, which we shall call X and Y, and investigate their effects within solitary dating. Given that the significance of standard X is regarded as being of equal importance to that of standard Y, the location standards may be positioned quite closely to the value of 1, leading to the conclusion that the diagonal elements of the matrix would invariably reflect a value of 1. Moreover, the importance associated with standard X is unequivocally perceived to be considerably greater than that attributed to standard Y, indicating that the directory standards could reach an impressive high of up to 9, as referenced previously [21].

2.5. Criteria Weight

At this particular juncture in the analytical procedure, a significant amount of deliberation is devoted to the multitude of weighing criteria that are currently under consideration and evaluation within the framework of the study. In the initial phase of this methodological approach, an eigenvalue matrix, which has been standardized to ensure consistency and comparability, is generated as a foundational step in the overarching process. Subsequently, each matrix standard is systematically disaggregated by the total sum of its respective pillar so that the weight of each row mean within this newly formulated eigenvalue matrix is directly proportional to the weight assigned to that specific standard. Both processes are diligently reiterated cyclically until the eigenvalue matrix reaches a state of completion, thereby fulfilling all necessary criteria for analysis and interpretation.

Table 2

Pairwise Matrix

Criteria	C_1 (Area)	C_2 (Amenities)	C_3 (Land Price)	C_4 (Car Ownership)	C_5 (Traffic Volume)	C_6 (Road Density)
District Area	1.00	2.00	1.50	0.50	0.33	0.33
Amenities	0.50	1.00	0.67	0.33	0.25	0.25
Car Ownership	0.67	1.50	1.00	0.33	0.33	0.20
Land Price	2.00	3.00	3.00	1.00	1.50	1.00
Traffic Volume	3.00	4.00	3.00	0.67	1.00	0.50
Road Density	1.00	2.00	1.50	0.50	0.33	0.33

2.6. Consistency ratio (CR)

Employing the consistency ratio (CR), which acts in a somewhat easier manner due to a specific mathematical expression, allows for a forecast to be established regarding the analytical hierarchy process (AHP). Utilizing this information enables a more precise classification of the inconsistencies in the adapted balanced pairwise comparison matrix, which arises due to either expertise or the exercise of knowledge-based decision-making. In the context of a pairwise comparison matrix, any symbol that is associated with a CR value below 0.1 is deemed to have a dependable level of reliability in the framework. The random index (RI) values are established as fixed quantities that are susceptible to modification. This variability arises from the fact that these values are determined in accordance with criteria that can change depending on the context of the analysis.

3. RESULTS

In the process of determining the weights attributed to various criteria in this study, the analytical hierarchy process (AHP) in conjunction with the fuzzy analytic hierarchy process (FAHP) was applied to facilitate a comprehensive evaluation. To gather insightful feedback and informed opinions from individuals who possess a significant degree of expertise and authority in the relevant field, we developed a questionnaire and subsequently disseminated it to an array of professionals actively engaged in the industry. The professionals targeted for this research include urban planners, civil engineers, and specialized experts from both the private sector and governmental entities, including those employed by municipal governments. This research endeavors to employ a systematic pairwise comparison of the established criteria to ascertain the relative importance and value of each criterion through a defined scale that ranges from 1 to 9, thereby facilitating a nuanced understanding of their interrelationships. The methodological framework underpinning this research is rooted in the AHP methodology, which systematically constructs pairwise comparison matrices while considering the geometric mean of the collective opinions and assessments provided by seasoned professionals, such as engineers and urban planners, to accurately determine the respective weights assigned to the various criteria. The resulting criteria, along with their corresponding weights, are systematically presented and detailed in Table 3.

To ensure that the evaluation of parking suitability criteria was grounded in professional knowledge, we developed a structured expert questionnaire. The experts' contributions were not limited to providing general opinions but directly influenced the mathematical weighting process within both the AHP and FAHP frameworks. A total of 15 domain experts were selected based on their professional experience and institutional roles in the fields of transportation engineering, urban planning, and municipal infrastructure management. The panel included five urban planners, six transportation and traffic engineers, and four officials from the Baghdad Municipality and the General Directorate of Roads and Bridges. The experts' combined experience ensured that both technical and administrative perspectives were represented.

Table 3

Criteria Weight

Criteria	Code AHP	Code FAHP	Weight (%)
District Area	C1	CF1	23
Amenities	C2	CF2	15
Land Price	C3	CF3	18
Car Ownership	C4	CF4	25
Traffic Volume	C5	CF5	13
Road Density	C6	CF6	6

Car ownership, designated as C4 and assigned a substantial weight of 25%, emerged as the parameter with the highest relative significance, as shown in Table 2, which clearly delineates the comparative weights of various criteria. Therefore, this criterion is the most pivotal factor in the overall assessment framework. Conversely, the stipulation concerning road density, identified as C6, exhibited the smallest weight of 6%, making it the least influential requirement among all considered factors. To advance the search for optimal sites for parking provisions, we utilized a framework based on geographic information systems (GISs) that integrated the analytic hierarchy process (AHP) and fuzzy analytic hierarchy process (FAHP) in a coordinated strategy. An overview of all geographical analysis methodologies pertinent to the selected criteria (C1 through C6) is illustrated in Figures 1 and 2, which provide visual representations of the analytical procedures. These analytical techniques are relevant and applicable within the frameworks of both the AHP and FAHP methodologies, underscoring their versatility in the context of spatial analysis.

The graphical representations in Figures 1 and 2 depict all the intricate spatial analysis processes that were executed for the selected parameters, which were integral to the AHP and FAHP methodologies. For each criterion, the resultant spatial analysis maps that were derived based on the specific values associated with these criteria have been systematically classified into five distinct classifications, delineated as follows.

The color gray is indicative of areas that possess an exceedingly low level of suitability for the establishment and utilization of parking facilities, which suggests that these districts are not conducive to practically accommodating vehicles. Orange signifies districts that are characterized by a low level of suitability for the development and use of parking areas, implying that while some parking may be feasible, it is not optimal for efficient usage. Green represents districts that exhibit a medium level of suitability for parking area implementation, indicating that there are moderate conditions present that could support the establishment of parking spaces. Blue symbolizes districts that demonstrate a high level of suitability for the creation and usage of parking zones, which suggests that these areas are well-equipped to handle a significant volume of parked vehicles. Red denotes districts that reflect an exceptionally high level of suitability for the establishment of parking facilities, indicating that these areas are suited for accommodating many vehicles with great efficiency.

A raster calculator was employed to generate the meticulously crafted map that was produced as a direct consequence of the specific situational parameters under consideration. Sophisticated geographic information system (GIS) software was utilized to accurately determine the geographical locations corresponding to the selected criteria, while comprehensive density evaluations were conducted for each of the chosen criteria to ensure robust analysis and interpretation. The raster data obtained through this process were categorized into five groups, as indicated by the information presented in the preceding sections. Utilizing the analytical hierarchy process (AHP) alongside the fuzzy analytical hierarchy process (FAHP) frameworks, the diagrams presented in this document proficiently highlight the parking amenities identified as appropriate for each distinct area within the urban landscape of Baghdad, thus offering significant perspectives on the geographical arrangement of these crucial assets.

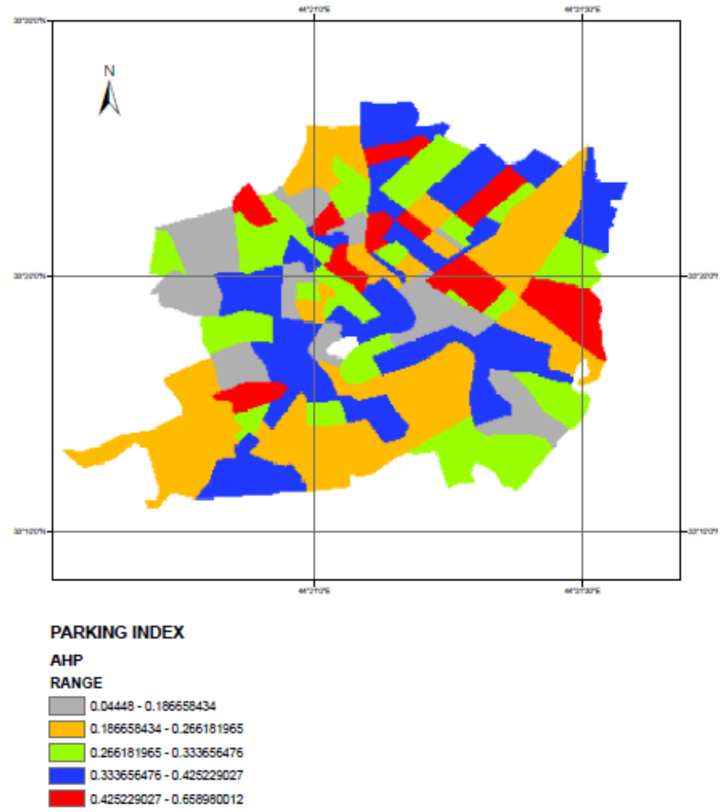

Fig. 2. Parking Index (PI – AHP)

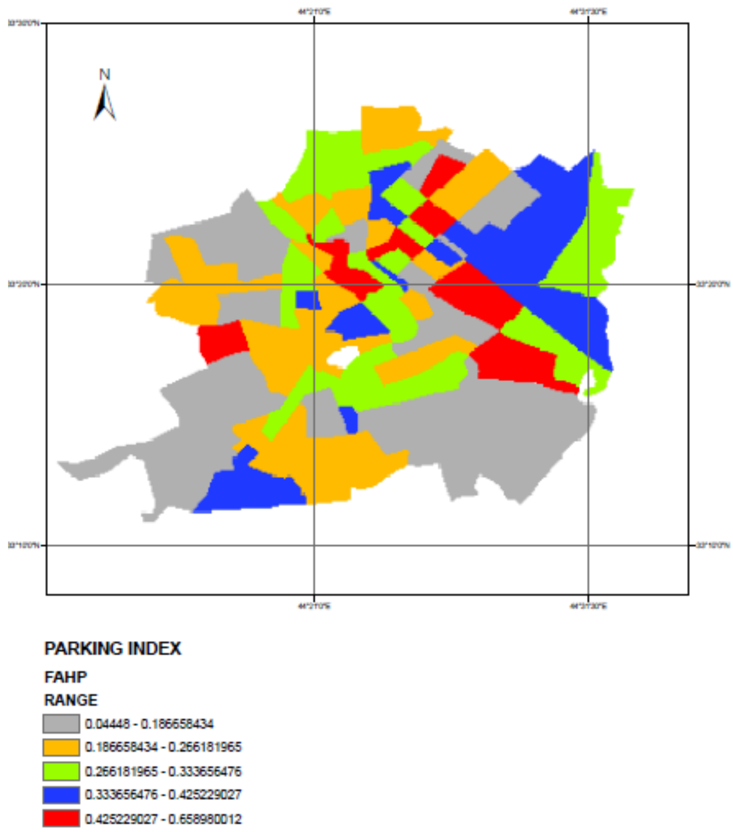

Fig. 3. Parking Index (PI – FAHP)

Table 4

Suitability Area for Parking

Suitability	AHP (km2)	AHP (%)	FAHP (km2)	FAHP (%)
Very High	4.822	8.11%	6.443	12.31%
High	8.011	12.71%	11.343	17.18%
Medium	17.088	31.99%	5.378	8.61%
Low	22.661	34.87%	40.173	73.24%
Very Low	5.908	11.97%	2.755	6.15%

4. CONCLUSIONS

The findings reveal that Baghdad City faces a critical imbalance between the growing number of vehicles and the limited availability of organized parking facilities. Through the integration of the analytic hierarchy process (AHP), fuzzy analytic hierarchy process (FAHP), and advanced geographic information system (GIS) spatial analyses, this study identified the suitability of parking zones across the city's 63 districts.

The analysis showed that only 8.1% (AHP) and 12.3% (FAHP) of Baghdad's total urban area is highly suitable for parking development, while a considerable proportion, 34.8% (AHP) and 73.2% (FAHP), falls under the low suitability category. These results indicate that most of Baghdad's districts suffer from a shortage of potential land for structured parking, largely due to high land prices, insufficient amenities, dense traffic volumes, and limited road capacity.

Among the evaluated criteria, car ownership (25%) and district area (23%) had the strongest influences on parking suitability, highlighting the city's need for land-use planning strategies that align with the spatial distribution of vehicles and population density. Conversely, road density (6%) was the least influential factor, reflecting the current inadequacy of the road network to support the city's increasing parking demand.

The results emphasize that Baghdad's existing parking facilities are insufficient, poorly distributed, and not integrated with the city's traffic management strategies. High-suitability areas are concentrated mainly in central and commercial zones, leading to congestion spillovers, illegal roadside parking, and environmental deterioration. Therefore, urban decision-makers should invest in multi-level parking structures, smart parking systems, and strategic zoning regulations in these high-demand regions.

The development of the parking index (PI) serves as a spatial decision-support tool for urban planners, transport authorities, and policymakers. It quantifies and visualizes the suitability of each district for parking investments, allowing for the data-driven prioritization of future parking projects. By providing an evidence-based framework, the parking index supports strategic urban planning, improved land-use efficiency, and reduced congestion, ultimately contributing to a more sustainable and livable Baghdad. The comparative analysis of the criteria showed that car ownership (25%), district area (23%), land price (18%), amenities (15%), traffic volume (13%), and road density (6%) were the final weights obtained through the AHP and FAHP methods.

The discrepancy noticed in earlier text (21%, 17%, 16%, 27%, 11%, and 8%) likely resulted from the use of a preliminary weighting stage before consistency adjustment; therefore, the correct and validated weights presented in Table 2 of this study (25%, 23%, 18%, 15%, 13%, and 6%) are adopted as the final results. Spatial suitability mapping using these weights revealed a substantial variation in parking potential across Baghdad's 63 districts. According to the GIS-based overlay analysis, very high suitability areas constitute 8.1% (AHP) and 12.3% (FAHP) of the total city area; high suitability areas cover 12.7% (AHP) and 17.2% (FAHP); medium suitability areas represent 32.0% (AHP) and 8.6% (FAHP); low suitability areas occupy 34.9% (AHP) and 73.2% (FAHP); and very low suitability areas account for 12.0% (AHP) and 6.1% (FAHP).

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