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Using GIS-supported MCDA method for appropriate site selection of parking lots: The case study of the city of Tetovo, North Macedonia

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Abstract

The provision of adequate parking spaces for vehicles has emerged as a prominent and challenging issue confronted by towns, cities, and municipal authorities in recent years. Addressing this problem necessitates a thorough examination of the prevailing physical conditions in existing parking areas, while simultaneously undertaking analyses to identify suitable locations for new parking areas or parking lots. This study focuses on the city of Tetovo, North Macedonia, investigating and assessing the available parking areas while analyzing potential sites in accordance with the city's needs and requirements. To facilitate decision-making, a Multi-Criteria Decision Analysis (MCDA) approach is employed to address the parking site selection analysis problem. The weightage of criteria utilized in the analysis is estimated, and potential parking solutions or site selections for new parking areas are identified through the combined application of Geographical Information System (GIS) and Analytic Hierarchy Process (AHP) techniques, identifying primary and sub-criteria, with a focus on Land Use and Transportation as the main criteria for selecting parking lots. The integration of GIS and AHP offers an effective and optimal methodology for site selection and identifying suitable parking locations. AHP method, applied to criteria, determined relative weights through expert opinions, while GIS facilitated spatial analysis for identifying suitable parking locations. The study identifies accessibility to main roads as the criterion carrying the greatest weight (0.517), while accessibility to cultural facilities holds the lowest weight (0.117). The study serves as a pivotal resource for sustainable urban management and decision-making, providing insights into future urban planning and the identification of suitable parking lot sites to foster sustainable development within the city.

1. Introduction

The world continues to show a gradual increase of population. The growing population has a parallel increase in demand. Such a growth and increase indicate growth of cities and towns. With the growth of the population and migration from rural areas to major urban centers [1], the modern world is changing rapidly [2]. Technological advancement and sophistication lead to increased urbanization too. The increased number of citizens into urban areas has principally impacted negatively in different characteristically form. Consequently, people are becoming aware of environmental issues and urban problems. The rapid growth of the population and development of cities and towns encounter different problems and inevitably results with more limited resources and services, which leads to significant shortages in different fields and different systems [3-5]. In this development, the transport sector is also a rapidly growing field and with this, problems in urban transportation have increased [6]. The growth of the population also affects the growth or the need for increased use of vehicles [7], and with this traffic is presented as one of the main challenges of urban transport [8]. Cities are suffering from the increasing number of vehicles and consequently from the absence of parking areas. Public parking is one of the main and serious traffic challenges and problems in different cities.

Public parking is one of the biggest challenges facing fast-growing cities, one of the most important urban facilities, and one of the most challenging tasks [9-11]. Parking is a headache for drivers and has become a common problem in all cities [12]. A parking lot is an organized surface or place that is desired for parking vehicles. Finding parking spaces is a major social problem, is stressful and time-consuming [13-15]. Parking areas vary according to location and characteristics. The problem with parking brings traffic congestion, environmental pollution, aggravates different concerns and affects road congestion [16-21]. Providing a parking area is to meet the demand for parking. According to Litman [22] and Demir et al. [9], parking requirements are affected by many circumstances such as location, land use, demographics, the disposability of public transport systems etc. Parking areas are affected by many elements within the transportation system. Easy access to parking facilities and mapping of parking lots comprises complicated techniques and is an excessively significant element in the achievement of urban land uses and transportation systems [6, 9]. Parking spaces enact a significant duty in modern urban transportation.

Planning parking remains one of the most significant components and one of the major intentions for urban planners to consider their work to increase social amenity in the urban ambience [23-25]. Site selection of parking lots is one of the fundamental verdicts in public urban spaces and it requires the attention of many criteria, parameters and factors and generally have a complex nature [3, 4, 26-28]. With the adequate selection of new places for public parking, the efficiency and effectiveness of the parking system is necessarily increased and at the same time it absorbs many traffic problems [7, 29]. The site must be accessible of any ordinary or perimetric invasion [30, 31]. Parking regulations shall be assigned by local governments, and they should not be discriminatory; parking planning shall ensure safety, continuity, and lanes for disabled people [9, 32]. However, this is not enough to solve the problems that offer special solutions [33], especially in the process of selection of public parking spaces. Efficient parking spaces decrease traffic load and reduce marginal parking.

The triage of a parking space is also intended as a Multi-Criteria Decision Analysis (MCDA) problem. Initially, such a process starts with defining and defining the concern and ends as a concluding verdict with many alternatives [23, 34-36]. Although Geographical Information System (GIS) provides wide range in spatial analysis and visualization [37], for solving complex problems such a range is not enough. So, it is hereby mandatory to use a combined GIS and Analytic Hierarchy Process (AHP) method to solve complex tasks of this type [5, 38]. Processes such as globalization, urbanization, climate change, as well as other environmental and technological advancements, necessitate significant attention and consideration, alongside the integration of information systems [39]. The AHP method, introduced by Saaty 1980 [40], is a successful and one of the most applied methods and measurements operated in diverse site selection concerns for determining the weights of criteria [35, 41-44]. The AHP method and GIS technologies are effective for solving site selection problems and are also operated for selecting suitable parking areas [1, 3]. In addition, GIS supported AHP method is used in site selection analyzes such as wind power plants [45], solar power plants [46], retail market locations [47], shelter areas [48], agricultural crop selection [49]. In decision-making problems, the abundance of evaluation criteria and available options poses a challenge in determining the most optimal choice and becomes crucial to quantify the evaluation criteria and employ mathematical techniques to arrive at the most suitable decision [50].

Numerous studies and research endeavors have investigated the selection of optimal parking lot locations utilizing the AHP in conjunction with GIS methodologies. In their 2021 study, Alkan and Durduran [1] employed the integrated AHP-GIS methodology to identify suitable locations for parking facilities within the city of Konya, Türkiye. In their 2020 study or diploma thesis, Iqbal [51] conducted a comprehensive analysis, focusing particularly on the case study of Pendik, Istanbul. The study utilized a combined approach, employing GIS-based multi-criteria decision analysis for the selection of parking sites. In their 2018 publication, Samani et al. [10] employed the AHP method of MCDA in conjunction with the GIS to identify new locations for public parking in Tehran, Iran. Some other authors used other combined methodologies related to site selection strategic decision. Ozturk and Kılıç-Gul [4], employed the GIS-Ordered Weighted Averaging (OWA) method in their study, which is based on parameters primarily characterized by fuzzy quantifiers. Farzanmanesh et al. [3] and Samani et al., [10] utilized the GIS fuzzy logic and the fuzzy majority method in their study for the selection of parking sites. Numerous works of a similar nature exist globally. While identifying such studies conducted in various countries and regions, it has been observed that there is a gap in similar research and studies within the territory of the Republic of North Macedonia. Some of the aforementioned works, alongside others, have served as foundational sources in shaping the conceptual framework of our study, playing a crucial role in its development.

The primary objective of this study is to perform an analysis to select optimal locations for establishing new parking lots in the central or urban area of the Municipality of Tetovo, with a particular focus on the city of Tetovo. This involves identifying and defining primary criteria and corresponding sub-criteria that significantly influence the decision-making process. For this study, two main criteria, namely Land Use and Transportation, were defined. Under the criterion of Land Use, five sub-criteria were identified, while the criterion of Transportation encompassed three sub-criteria. Each primary criterion was assigned a weight reflecting its relative importance. Density analysis was conducted, and the assigned weights were further distributed among the sub-criteria. Specific density maps were created for each sub-criterion. Utilizing various spatial data processing and analysis techniques, suitable parking locations were determined based on the assigned criteria weights. Ultimately, a map highlighting suitable areas for the establishment of new parking lots within the central or urban region of the Municipality of Tetovo was generated. To facilitate this process, the AHP method, supported by GIS technology, was employed.

2. Method

2.1. Research area boundaries and main features

Tetovo, situated in the northwestern region of North Macedonia, with a latitude of 42.006191 and a longitude of 20.959682, is a small city that holds significant geographical and strategic importance. Positioned near the Kosovo border, it is nestled amidst the picturesque foothills of Shar Mountain and divided by the flowing Pena (or Shkumbini) River. Tetovo is recognized as one of the prominent cities within the Republic of North Macedonia, forming a crucial part of the Polog Region. It shares its borders with the cities of Gostivar and the capital of North Macedonia, the city of Skopje, holding an area of 261.89 km^2 as a municipality, as illustrated also in Figure 1.

Being the sole urban hub in its region, Tetovo attracts a substantial presence of public sector entities, including service industries, diverse state institutions, private sector organizations, two universities, six central municipal high schools, numerous municipal primary schools, and childcare centers, both private and public. Additionally, the city is home to state and private hospitals, various medical clinics, and various professionals such as dentists and veterinarians. It also boasts a vibrant aesthetics and beauty sector, along with shopping centers, cafes, restaurants, and various recreational venues. Furthermore, Tetovo offers some tourist facilities, adding to its appeal for residents in the surrounding areas. Consequently, individuals residing in rural municipalities are compelled to gravitate towards the urban segment of the Tetovo municipality.

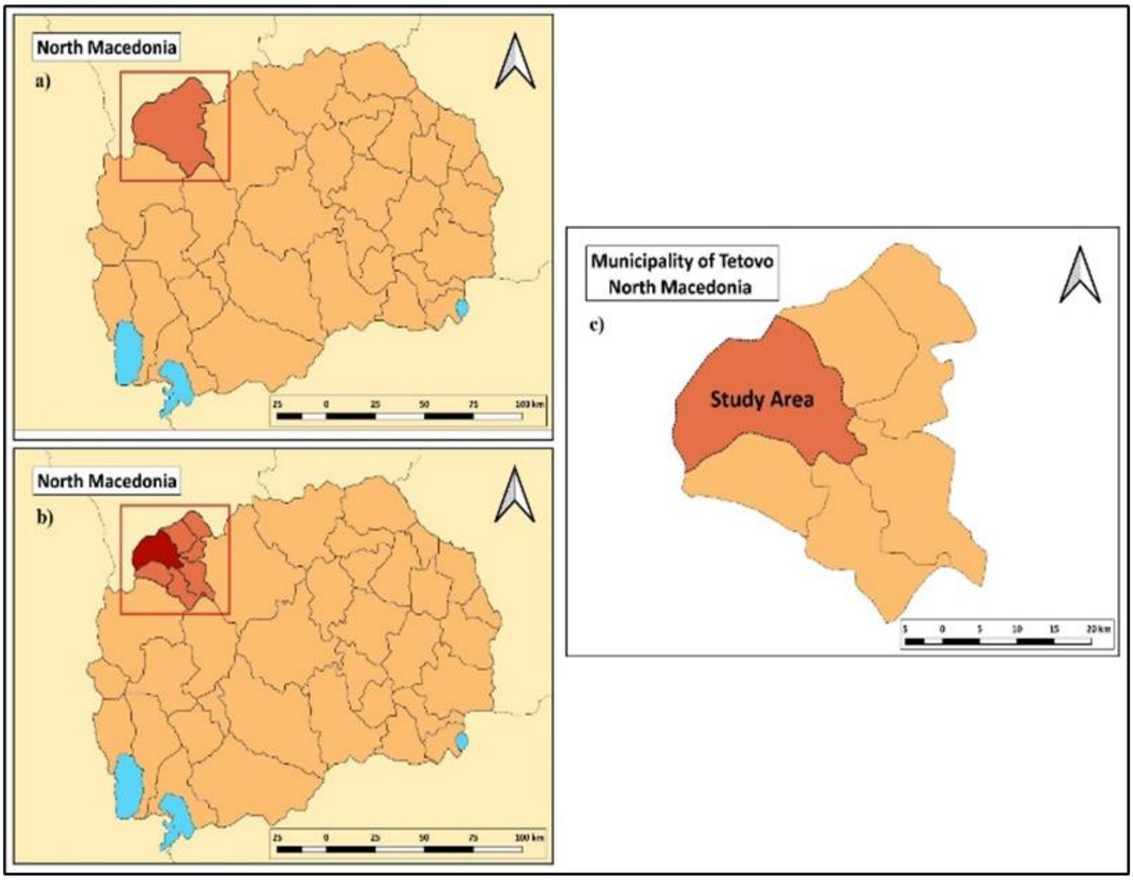

Figure 1. Study area – a) Location of the territory of the city of Tetovo; b) Location of the territory of municipalities located in the territory of the city of Tetovo (both urban municipality and five other rural municipalities); c) Location of the territory of Municipality of Tetovo (urban municipality), Polog Region, Northwest part of Republic of North Macedonia.

2.2. AHP methodology

The adoption of the AHP for decision-making processes is underpinned by its unparalleled capacity to systematically tackle complex, multi-criteria decision problems. AHP empowers decision-makers by providing a structured and prioritized framework through meticulous pairwise comparisons. This method not only establishes a robust and quantitative foundation but also adeptly integrates subjective judgments and objective data, thereby substantially reinforcing the transparency and rationality intrinsic to the decision-making process. The systematic rigor and comprehensive nature of AHP contribute to its efficacy in navigating intricate decision landscapes, making it an indispensable tool for informed and strategic decision-making.

This study utilized the AHP method to establish suitable parking locations. When employing the AHP method, it is essential to develop a hierarchical structure. Consequently, the identification of primary criteria becomes crucial, followed by the determination of sub-criteria due to their significant importance. In the context of selecting parking lots, two main criteria were defined: Land Use and Transportation. Under the Land Use criterion, the following sub-criteria were established: accessibility to public institutions, accessibility to educational institutions, accessibility to health institutions, accessibility to cultural facilities, and accessibility to shopping centers. Under the Transportation criterion, the following sub-criteria were defined: accessibility to bus stations, accessibility to main roads, and accessibility to existing parking areas.

The meticulous process of selecting criteria for studies involving parking site analysis or analogous urban planning research involves a rigorous integration of expert knowledge, existing literature, and the unique context of the study area. Urban planners, engineers, transportation experts, and local authorities assume a pivotal role in this endeavor, contributing valuable insights derived from practical experience and a nuanced understanding of the local context, crucial for the identification and prioritization of criteria. Drawing inspiration from various foundational studies conducted by different authors, served as a cornerstone for our investigation, the collaborative input of urban planners, engineers, transportation experts, and local authorities was also instrumental in shaping our methodology. Additionally, a comprehensive literature review constitutes another vital dimension of criteria selection, where researchers delve into existing studies and best practices in urban planning, parking analysis, and related fields to ensure a well-informed and robust foundation for the study's criteria framework.

2.2.1. Determining criteria – Developing the hierarchical structure

As a procedure, first the problem is defined and then the definition of basic criteria and sub-criteria follows. As a consequence of this, continues the definition and elaboration or progress of the hierarchical structure of criteria, which are presented in Table 1. Subsequently, a reference table of criteria and sub-criteria presented in Table 2 is also presented.

Table 1. A general framework of the criteria.

Main Criteria	Sub-Criteria
Land Use	1.1. Accessibility to public institutions 1.2. Accessibility to educational institutions 1.3. Accessibility to health institutions 1.4. Accessibility to cultural facilities 1.5. Accessibility to shopping centers
Transportation	2.1. Accessibility to bus stations 2.2. Accessibility to main roads 2.3. Accessibility to existing parking areas

Table 2. A general framework of the criteria definition for determination or selection of parking lot sites based on relevant references

Main Criteria	Sub-Criteria	[1]	[9]	[3]	[7]	[4]	[23]	[10]
C1	1.1	x	x	x	x	x	x	
	1.2	x	x	x			x	
	1.3	x	x	x	x	x		x
	1.4	x	x	x				
	1.5	x	x		x	x	x	x
C2	2.1							
	2.2	x	x		x	x	x	x
	2.3	x	x	x				x

2.2.2. Establishing of binary comparison matrices

For each criterion, are created pairwise comparison matrices and in the same matrices, are evaluated criteria using the comparison scale. In this process and in this course of development, the degree of prominence of the criteria is established, which is represented in Table 3.

Table 4 provides a comprehensive overview of the fundamental data sets, their corresponding sources, and the analytical methods employed in the study. The table is structured to offer a systematic presentation of criteria such as C.1.1 to C.2.3, encompassing diverse aspects ranging from Public Institutions, Schools, Universities, Hospitals, Cultural Facilities, Shopping Centers to Bus Stations, Roadway – Main Roads, and Public Parking. The data, meticulously sourced from the Municipality of Tetovo, is subjected to Kernel Density and Linear Density analyses, ensuring a robust foundation for the subsequent exploration and insights within the study.

Table 3. The 1-9 importance scale table of pairwise comparison presented by Saaty [52]

Prominence Level	Definition	Explanation
1	Equal	Two activities contribute equally to the objective.
3	Moderate	Experience and judgement slightly favor one activity over another.
5	Strong	Experience and judgement strongly favor one activity over another.
7	Very Strong	An activity is favored very strongly over another.
9	Extreme	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values	Values between two consecutive judgments to be used when compromise is needed.

Table 4. Basic data, sources and properties used.

Criteria	Data	Data Source	Analysis
C.1.1	Public Institutions	Municipality of Tetovo	Kernel Density
C.1.2	Schools, Universities	Municipality of Tetovo	Kernel Density
C.1.3	Hospitals	Municipality of Tetovo	Kernel Density
C.1.4	Cultural Facilities	Municipality of Tetovo	Kernel Density
C.1.5	Shopping Centers	Municipality of Tetovo	Kernel Density
C.2.1	Bus Stations	Municipality of Tetovo	Kernel Density
C.2.2	Roadway – Main Roads	Municipality of Tetovo	Linear Density
C.2.3	Public Parking	Municipality of Tetovo	Kernel Density

2.2.3. Assessing Criteria - Weighting process

The weighting criteria can be calculated and determined in different ways and methods which are presented in various forms. After the paired comparison matrices (Equation 1) are created the procedure of determining the values of importance weights continues.

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \quad (1)$$

After finding the total value of each column separately, each found value is proportionally separated by the total value of the column to which it belongs (Equation 2). Consequently, commanding the average of the values in each row of the received matrix, the column vector W is calculated (Equation 3).

$$c_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \quad (3)$$

2.2.4. Estimation of the consistency ratio

The base value (λ) is the first value that must be calculated to arrive at the calculation of the consistency ratio (CR). As a result, the pre-obtained weight vector (W) is multiplied by the pairwise comparison matrix (A). The result of this multiplication is reciprocally divided by the values in the weight vector W, and from this the arithmetic mean is taken (Equation 4). With these actions we calculated the value of λ.

$$\lambda = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\sum_{j=1}^{n} a_{ij}\, w_j}{w_i}\right) \quad (4)$$

The Consistency Index (CI) is calculated after calculating the base coefficient (Equation 5); while on the other hand the CR is calculated when the Randomness Index (RI) is divided by the CI value (Equation 6). The same is also represented in Table 5.

$$CI = \frac{\lambda - n}{n - 1} \quad (5)$$

$$CR = \frac{CI}{RI} \quad (6)$$

Table 5. Randomness index [40]

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3. Results

The determination of criteria weights in this study was conducted using the AHP method. To gather input from professionals in the field, a questionnaire was prepared and administered to engineers, urban planners, and experts from both the private and public sectors, including municipal employees. The AHP method employed in this research involves the pairwise comparison of criteria to assess their relative importance on a scale from 1 to 9. The questionnaire was distributed to a total of 27 participants, and the results were analyzed using the Expert Choice program. Out of the total sample size of 27 respondents, 13 individuals possessed a bachelor's degree, whereas 14 other respondents had completed a master's degree. Among the participants in the survey, 20 respondents were employed in the public or state sector, whereas the remaining 7 individuals were affiliated with the private sector. The program calculates the weights of the criteria based on the geometric mean of the opinions of experienced professionals, including engineers and urban planners, and generates pairwise comparison matrices. The obtained criteria weights are presented in Table 6, Table 7, and Table 8.

Table 6. Weights of main criteria for determination or selection of parking lot sites.

CR= 0.00	W
Land Use	0.601
Transportation	0.399

Table 7. Weights of land use sub-criteria for determination or selection of parking lot sites.

CR= 0.02	W
Accessibility to public institutions	0.177
Accessibility to educational institutions	0.117
Accessibility to health institutions	0.454
Accessibility to cultural facilities	0.082
Accessibility to shopping centers	0.170

Table 8. Weights of transportation use sub-criteria for determination or selection of parking lot sites.

CR= 0.03	W
Accessibility to bus stations	0.233
Accessibility to main roads	0.517
Accessibility to existing parking areas	0.250

The criterion carrying the greatest weight is the accessibility to main roads with a weight of 0.517. Conversely, the criterion of accessibility to cultural facilities holds the lowest weight of 0.117. The weights assigned to the remaining criteria are as follows: accessibility to health institutions with a weight of 0.454, accessibility to existing parking areas with a weight of 0.250, accessibility to bus stations with a weight of 0.233, accessibility to public institutions with a weight of 0.177, accessibility to shopping centers with a weight of 0.170, and accessibility to educational institutions with a weight of 0.117.

3.1. Land use criteria

Criteria locations were identified, and density analyses were conducted for each criterion using GIS. Kernel density maps were generated based on the point locations of public institutions, educational institutions, health institutions, cultural facilities, and shopping centers. These maps were then classified according to their density levels. Below, all the sub-criteria are explained and presented with the adequate maps, represented with figures.

3.1.1. Public institutions

A kernel density map was generated employing point location data of public institutions and subsequently categorized based on density levels (Figure 2).

3.1.2. Educational institutions

A kernel density map was generated employing point location data of educational institutions and subsequently categorized based on density levels (Figure 3).

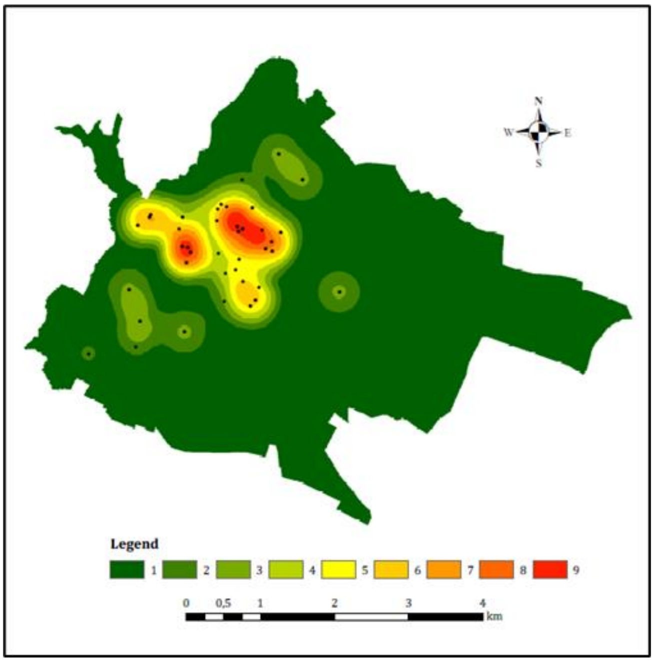

Figure 2. Public institutions density analysis map.

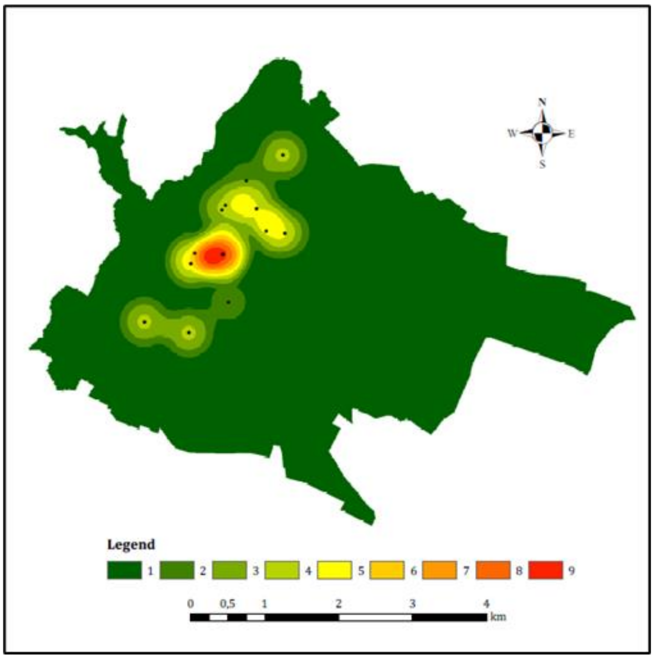

Figure 3. Educational institutions density analysis map.

3.1.3. Health institutions

A kernel density map was generated employing point location data of health institutions and subsequently categorized based on density levels (Figure 4).

3.1.4. Cultural facilities

A kernel density map was generated employing point location data of cultural facilities and subsequently categorized based on density levels (Figure 5).

3.1.5. Shopping centers

A kernel density map was generated employing point location data of shopping centers and subsequently categorized based on density levels (Figure 6).

3.2. Transportation criteria

Criteria locations were identified, and density analyses were conducted for each criterion using GIS. Kernel density maps were generated based on the point locations of bus stations and existing parking areas, meanwhile line density map was generated based on the line locations of main roads. These maps were then classified according to their density levels. Below, all the sub-criteria are explained and presented with the adequate maps, represented with figures.

3.2.1. Bus stations

A kernel density map was generated employing point location data of bus stations and subsequently categorized based on density levels (Figure 7).

3.2.2. Main roads

A linear density map was generated employing the linear location data of main roads and subsequently categorized based on density levels (Figure 8).

3.2.3. Existing parking areas

A kernel density map was generated employing point location data of existing parking areas and subsequently categorized based on density levels (Figure 9).

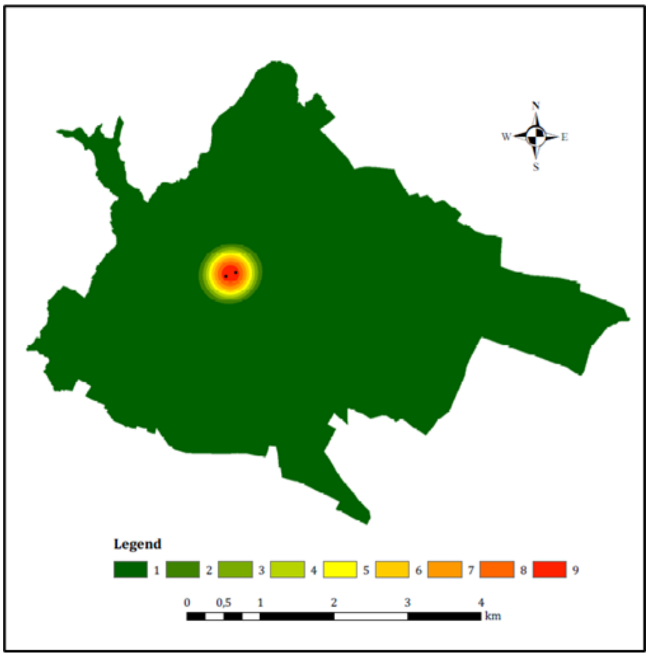

Figure 4. Health institutions density analysis map.

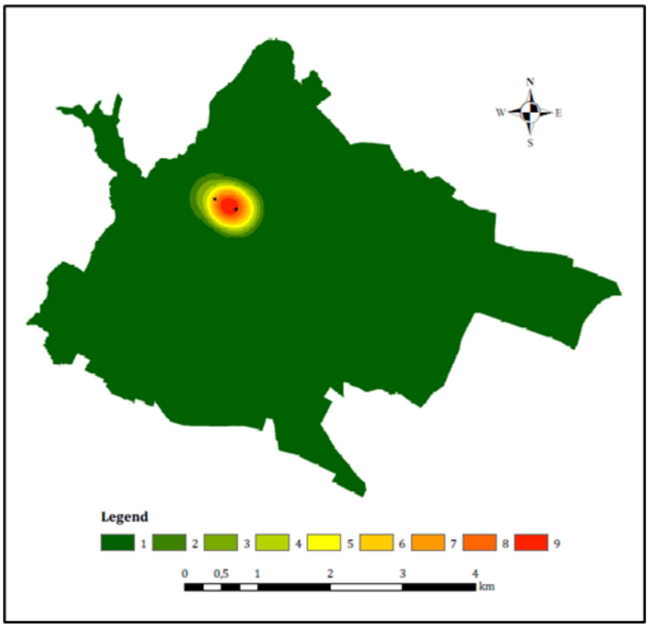

Figure 5. Cultural facilities density analysis map.

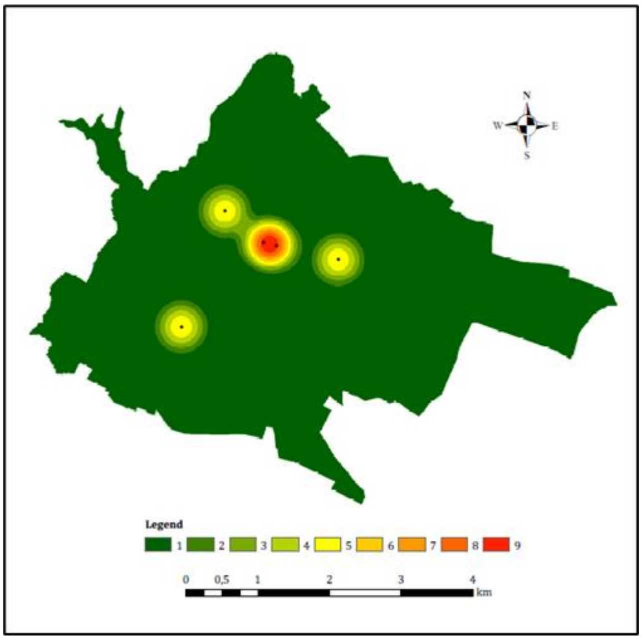

Figure 6. Shopping centers density analysis map.

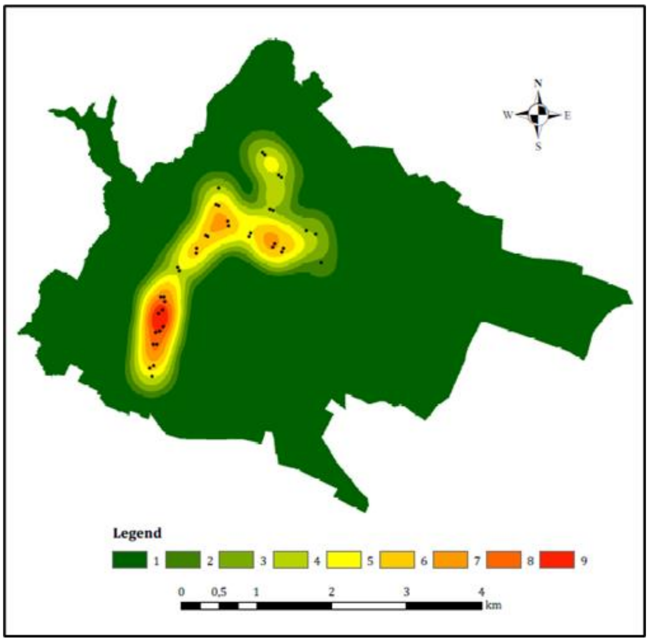

Figure 7. Bus stations density analysis map.

A conversion was made between the main criteria and sub-criteria, and the criteria weights used in the production of the suitable parking lot sites. From the converted weights, the criterion that carries the greatest weight is accessibility to health institutions with a weight of 0.273. In contrast, the criterion of accessibility in cultural facilities holds the lowest weight of 0.049. The weights assigned to the remaining criteria are as follows: accessibility to main roads with a weight of 0.206, accessibility to public institutions with a weight of 0.107, accessibility to shopping centers with a weight of 0.102, accessibility to existing parking areas with a weight of 0.100, accessibility to bus stations with a weight of 0.093 and access to educational institutions with a weight of 0.070 (Table 8).

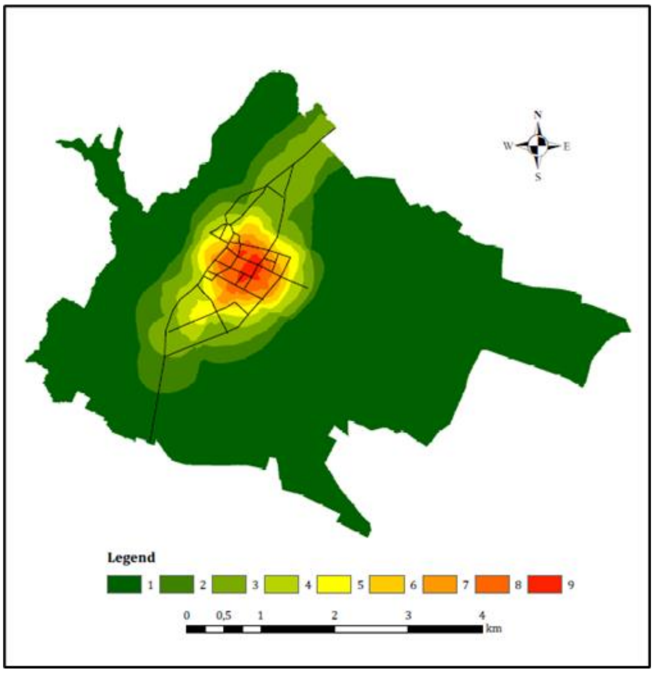

Figure 8. Main roads density analysis map.

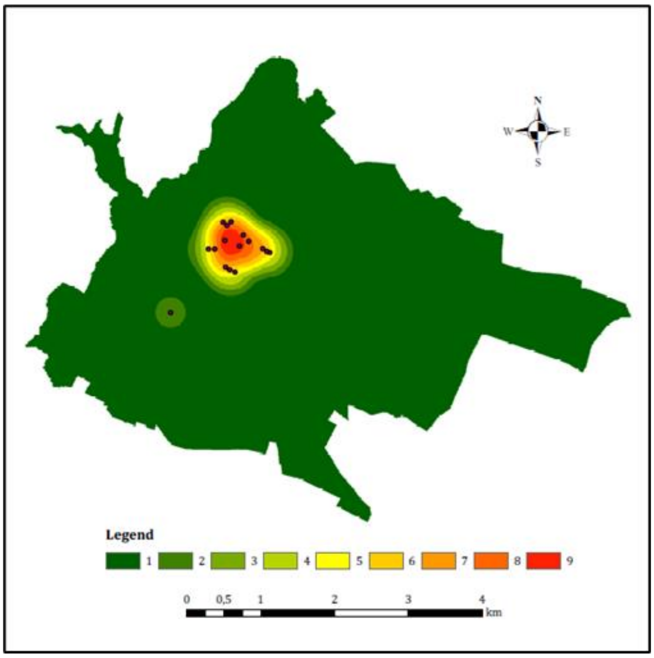

Figure 9. Existing parking areas density analysis map.

Table 9. Converted weights of criteria for determination or selection of parking lot sites.

Main Criteria	Sub-Criteria	Weights	Converted Weights
Land Use (0.601)	1.1	0.177	0.107
	1.2	0.117	0.070
	1.3	0.454	0.273
	1.4	0.082	0.049
	1.5	0.170	0.102
Transportation (0.399)	2.1	0.233	0.093
	2.2	0.517	0.206
	2.3	0.250	0.100

The resulting map was generated using a raster calculator, incorporating the criteria weights provided in Table 9. Criteria locations were identified, and density analyses were conducted for each criterion using GIS. The obtained raster data were classified. This map illustrates the suitable parking lot sites within the central urban area of the Municipality of Tetovo (Figure 10).

Based on the findings presented in Figure 10, the regions encompassing the city square, the vicinity of the two major boulevards within the city (crossed near the city square), the areas surrounding the municipality, the central courthouse, the city hospital, as well as certain primary, secondary, and high schools, are identified as the most favorable areas for establishing new parking lots. These areas exhibit higher suitability grades in terms of their potential for accommodating parking facilities. Results obtained are also presented in a tabular form, in the Table 10.

Table 10. The study findings obtained and presented in the tabular form.

Prominence Level	Area (km^2)	Distribution in percentage (%)
Extremely Suitable	0.590	2.55%
Suitable	0.577	2.49%
Moderately Suitable	1.218	5.26%
Less Suitable	3.457	14.94%
Not Suitable	17.301	74.76%

In the dynamic realm of urban planning and infrastructure development, a nuanced comprehension of suitable parking areas within residential zones assumes paramount significance. Our recent study undertakes a comprehensive exploration, not only to pinpoint areas conducive to parking but also to furnish a geodeterministic rationale for the observed concentration of these areas. The meticulous compilation and tabular presentation of our findings illuminate the diverse degrees of parking suitability across different residential zones. These figures not only quantify the extent of each category but also afford stakeholders a proportional representation, enhancing their understanding of the distribution dynamics. Augmenting our study, a numerical comparison with other crucial infrastructure elements in the residential zone serves as a valuable tool for urban planners and policymakers, facilitating a holistic grasp of spatial resource allocation. This article will delve into the underlying geographical factors influencing the concentration of parking areas. This research strives to be a guiding beacon in the intricacies of urban planning, offering a comprehensive overview of suitable parking areas, thereby fostering sustainable and efficient infrastructure development in residential zones.

4. Discussion

The municipality of Tetovo played a crucial role in providing the essential resources required for the successful execution of this study. The authorities of the municipality facilitated the provision of necessary materials for conducting the research. This included the procurement of relevant data and information essential for the compilation of density maps and the final map depicting suitable parking areas or locations. The municipal authorities were instrumental in supplying the required data and collaborating closely with the research team throughout the study.

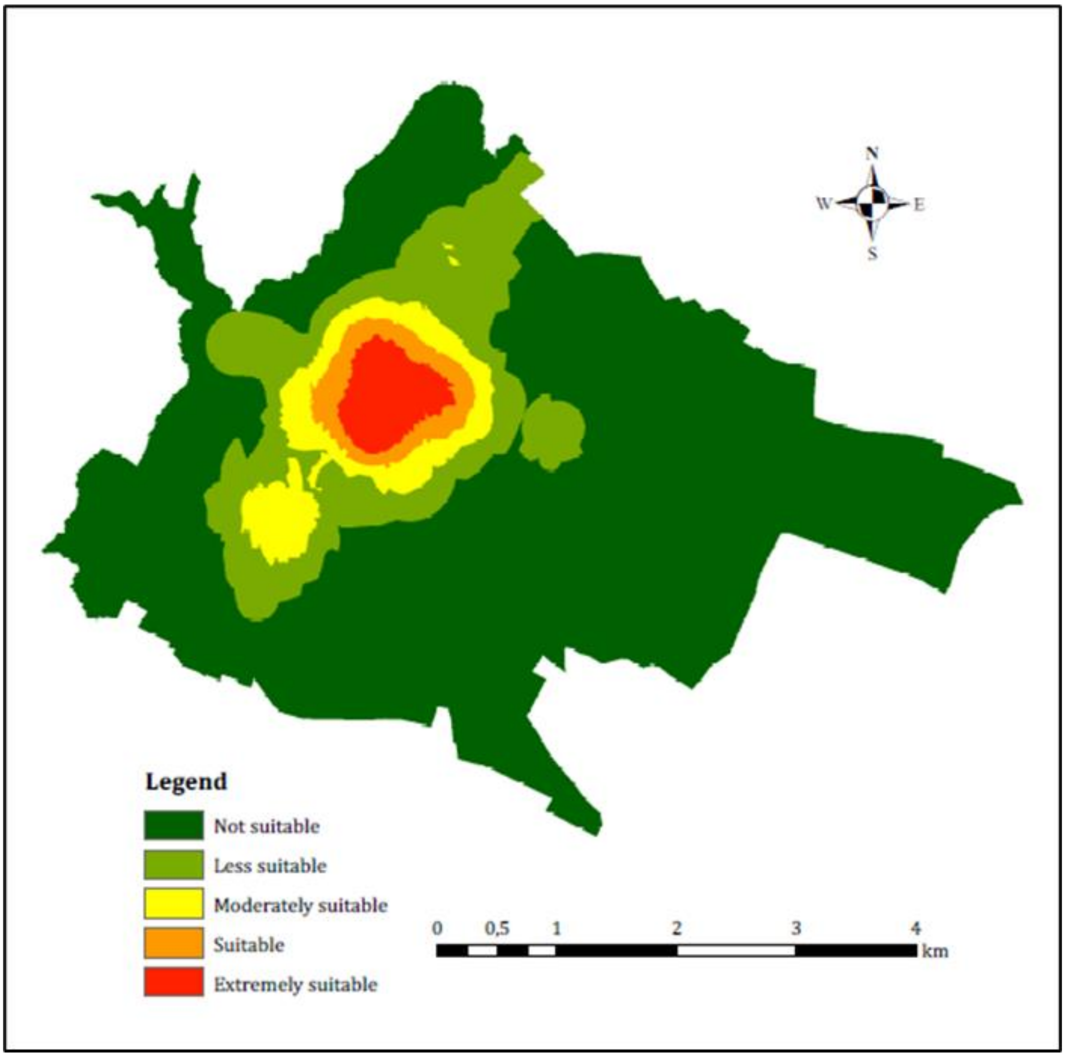

Figure 10. Suitable parking areas map in the central urban territory of Municipality of Tetovo, Polog Region, Northwest part of Republic of North Macedonia.

Employing GIS-based density analyses and kernel density maps significantly enhances the precision in identifying optimal parking lot sites, strategically revealing key areas within Tetovo's central urban zone. The results meticulously pinpoint regions encompassing the city square, major boulevards, municipal and healthcare facilities, and educational institutions, showcasing these locations as exceptionally advantageous for the establishment of new parking lots. This detailed analysis not only provides valuable insights but also furnishes municipal authorities and urban planners with essential data for informed decision-making and strategic urban development initiatives.

The density maps vividly illustrate a significant issue within the city of Tetovo, namely the concentration of public institutions, educational institutions, and health institutions in a confined and closely-knit area. This spatial clustering highlights an anomaly within the city and underscores the challenge of vehicular congestion, leading to an evident shortage of suitable and adequate parking facilities.

Nevertheless, with the implementation of a questionnaire administered to 27 experts, we successfully generated a comprehensive map delineating the appropriate parking zones within the city or municipality of Tetova. The empirical findings of this study can greatly assist municipal authorities and decision-makers in enhancing the quality of available parking facilities within the jurisdiction. Moreover, urban planners can utilize the study and accompanying materials as valuable resources to streamline the design process.

As part of the discussion in this study, a comparative analysis is conducted, juxtaposing the findings obtained herein with those of previous works by various authors in different countries. The following comparisons are represented as follows:

4.1. Main criteria comparison

Various criteria were considered in this study, as elucidated earlier. In the decision-makers' hierarchy established based on their judgments, the land use criteria held the highest weight (0.601) among the principal criteria, followed by transportation criteria (0.399). Given its direct correlation with the prevalent issue of heavy traffic in the city, decision-makers accorded priority to the land use criteria. This prioritization aligns with findings in other studies; for instance, Alkan and Durduran [1] similarly identified

Land use as the most weighted criterion (0.58), followed by Transportation (0.42). Conversely, in the study conducted by Demir et al. [9], transportation criteria appeared to carry the highest weight (0.55), succeeded by land use criteria (0.33). Iqbal [51] also observed a higher weight for transportation (0.60) compared to land use criteria (0.35) in their study.

4.2. Land use sub-criteria comparison

In the assessment of the land use sub-criterion, in our study the highest weights from pairwise comparison matrices were determined as follows: accessibility to health institutions (0.454), accessibility to public institutions (0.177), accessibility to shopping centres (0.170), accessibility to educational institutions (0.117), and accessibility to cultural facilities (0.082). Alkan and Durduran [1] reported similar weights derived from pairwise comparison matrices, listing accessibility to health institutions (0.357), accessibility to public institutions (0.165), accessibility to educational institutions (0.124), accessibility to shopping centres (0.119), and accessibility to cultural facilities (0.082). Moreover, Demir et al. [9] identified weights from pairwise comparison matrices as accessibility to shopping centres (0.354), accessibility to health institutions (0.261), accessibility to cultural facilities (0.151), accessibility to public institutions (0.107), and accessibility to educational institutions (0.047). In the study by Iqbal [51], weights from pairwise comparison matrices were listed as accessibility to shopping centres (0.197), accessibility to health institutions (0.172), accessibility to public institutions (0.084), accessibility to educational institutions (0.042), and accessibility to cultural facilities (0.024).

4.3. Transportation sub-criteria comparison

In the evaluation of the transportation sub-criterion, our study assigned the highest weights from pairwise comparison matrices as follows: accessibility to main roads (0.517), accessibility to existing parking areas (0.250), and accessibility to bus stations (0.233). Alkan and Durduran [1] reported similar weights derived from pairwise comparison matrices, listing accessibility to main roads (0.442), accessibility to existing parking areas (0.249), and accessibility to bus stations (0.308). Additionally, Demir et al. [9] identified weights from pairwise comparison matrices for accessibility to existing parking areas (0.252), accessibility to main roads (0.151), and accessibility to bus stations (or train, tramway, metro stations) (0.074). In Iqbal's study (2020), weights from pairwise comparison matrices were listed as accessibility to main roads (0.568), accessibility to bus stations (or train, tramway, metro stations) (0.397), and accessibility to existing parking areas (0.347).

5. Conclusion

Urbanization issues and challenges, particularly in the domain of traffic and parking, have emerged as a consequence of the rapid growth of urban populations and the haphazard development of cities. The model proposed in this paper addresses these concerns by offering a solution for predicting and determining available parking spaces. The approach presented here has distinct advantages as it aims to simplify the process of selecting suitable parking locations. This selection process, which employs the combined AHP method and GIS method, represents a complex decision-making problem for providing a more efficient and effective solution.

The AHP method was utilized to determine the relative weights of the predetermined criteria. Specifically, the selection of suitable parking locations in this study was based on criteria related to Land Use and Transportation. The AHP is a commonly employed method in site selection problems and involves determining the importance levels of criteria that influence site selection through expert opinions. By constructing pairwise comparison matrices, the weights of the predetermined criteria were computed. Subsequently, using the GIS method, the spatial locations of the criteria and sub-criteria were established, and a density analysis was conducted. This analysis resulted in the production of a map that highlights the suitable parking locations within the central territory of the urban area of Municipality of Tetovo, North Macedonia.

This study also serves as a valuable resource for decision makers, providing guidance on two key aspects for the future: sustainable urban management and the identification of suitable parking lot sites. The findings and recommendations of this study can aid decision makers in making informed choices regarding urban planning and the determination of suitable parking lot sites to promote sustainable development.

The research conducted, aimed at tackling urbanization challenges, with a primary focus on traffic and parking issues. The integration of the AHP and GIS not only proposed a model for predicting and determining parking availability but also presented a robust solution for urban planners and decision-makers. Acknowledging the pivotal role of municipality authorities in facilitating data procurement and collaboration, the study advocates for expanding research horizons by exploring additional decision-making methods. To further enhance decision-making processes beyond AHP, it is recommended to consider methodologies such as the Analytic Network Process (ANP), especially in scenarios with intricate interactions and dependencies among criteria and alternatives. ANP's nuanced approach is particularly beneficial for complex urban planning decisions. Additionally, exploring the application of Fuzzy Logic, specifically in handling qualitative and subjective information inherent in urban planning, could prove advantageous. Fuzzy Logic's capacity to represent uncertainty could significantly improve decision-making, especially in situations where data lacks precise values. Given the identified concentration of public institutions in Tetovo, the incorporation of Game Theory is suggested to model strategic interactions among stakeholders in urban planning. Game Theory can offer insights into the decision choices of various entities, optimizing outcomes and fostering effective collaboration in urban development. This comprehensive and integrative approach, encompassing diverse decision-making methods, is poised to provide a more holistic understanding of decision spaces, effectively addressing the multifaceted challenges associated with sustainable urban management and parking facility identification.

Author contributions

Edmond Jonuzi: Conceptualization, Methodology, Data collecting, Writing-Original draft preparation **Tansu Alkan:** Analysis, Visualization, Writing-Reviewing **Süleyman Savaş Durduran:** Investigation, Editing **Hüseyin Zahit Selvi:** Investigation and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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