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MITIGATING URBAN TRAFFIC: IDENTIFYING POTENTIAL PARKING LOTS USING GIS AND AHP METHODS IN YALOVA, TÜRKİYE

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ABSTRACT

Today, the increasing migration from rural to urban areas, the rising appeal of cities as hubs, and the contribution of unplanned urbanization have led to an increase in urban traffic density, which negatively affects daily urban life. The insufficient number of urban parking lots and the rapid increase in the number of vehicles are among the other significant factors negatively affecting urban traffic.

In today's cities with high traffic, increasing the number of parking lots and encouraging their use has a significant impact on alleviating urban traffic congestion. In this regard, using Geographic Information Systems (GIS) together with the Analytic Hierarchy Process (AHP), which is one of the Multi-Criteria Decision-Making methods, helps achieve highly efficient result. In this study, the issues related to parking lots, which is one of the causes of increased traffic congestion in Yalova, a city located between Türkiye's highly populated and developed metropolitan areas, were examined.

The aim of this study is to identify new optimal parking lots using the integration of Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP) methods to relieve urban traffic in the city. During the study, various sub-component maps were created within the Quantum Geographic Information Systems (QGIS) environment, and the weights of these maps were determined through survey studies using the AHP method. The weighted sub-component maps were integrated in the QGIS environment to create the final parking lot evaluation map for Yalova, which will contribute to relieving urban traffic, and results and recommendations regarding potential parking lot locations were provided.

Keywords: Geographic Information Systems (GIS), Analytic Hierarchy Process (AHP), Parking Lot Planning, Yalova, Traffic Congestion

1 INTRODUCTION

The information contained in the header will be completed by the journal, and therefore authors are not required to make any additional adjustments. Today, the rapid increase in population density in cities has led to a rise in vehicle density and traffic problems, which have become one of the most significant issues in urban life. Another issue contributing to traffic problems is the insufficient number of parking lots, which is directly related to the high number of vehicles in cities [1]. The increasing population density due to migration to urban areas, the concentration of work and living centres in specific parts of cities, and irregular urban development further escalate the demand for parking lots. Ensuring that drivers park their vehicles in appropriate locations within urban areas is a key factor in maintaining traffic order. Because vehicles generally spend considerably more time parked in parking lots than they do moving in traffic [2]. A parking lot indicates the areas where vehicles can be parked once they reach their destination [3]. Upon arriving at their destination, drivers aim to find suitable and secure parking lots to park their vehicles. In this context, the concept of parking refers to the act of leaving a vehicle in appropriate and authorized areas to complete the transportation process from one point to another. Once the parking process is completed, parking lots, which are essential components of the urban transportation system, fulfil their intended function. Considering these concepts, it becomes clear how significant the role of parking lots is in urban transportation [3]. When parking spaces are not sufficiently available within urban areas, it is expected that urban traffic will be negatively impacted [4,5]. Moreover, in areas where parking shortages occur, issues such as illegal parking, parking in inappropriate or prohibited areas, and the formation of double-parking frequently obstruct transportation routes, thus impeding the efficient flow of traffic. In resolving this issue, urban dynamics must be considered holistically, and well-planned and regulated inner-city parking strategies should be developed for urban areas. In this regard, Geographic Information Systems (GIS) emerge as one of the methodologies that provide significant contributions to the geographic-based planning of suitable parking lot areas, the execution of spatial analyses, and the resolution of parking problems in urban areas [6]. GIS are systems that conduct analyses by integrating non-graphical information with the graphical data of a specific region, and assist decision-makers in solving numerous engineering and planning problems through the spatial analyses they encompass [7,8]. When identifying suitable parking lot areas with GIS, it is necessary to determine the criteria that affect parking lot areas, create thematic maps for these criteria, and determine their weights. For this purpose, one of the Multi-Criteria Decision Making (MCDM) methods should be used, and the importance rankings of the criteria on which the determination of locations for suitable parking lot areas within the city, including expert opinions, is based must be determined. Additionally, a weight value should be obtained for these criteria. One of the MCDM methods, the Analytic Hierarchy Process (AHP), which is used in this study for weight determination, is a method that assists decision-makers and is frequently utilized in decision-making processes for location selection [9]. The weight values obtained through AHP are assigned to the thematic maps prepared in the GIS environment, and the final map is shaped accordingly. The combined use of AHP and GIS methods in parking lot location selection leads to more scientific results by incorporating expert opinions, field data, graphical data, and technical analyses of these data into the decision-making process [10]. In scientific studies involving the combination of GIS and AHP, Quantum Geographical Information Systems (QGIS) is a widely used software. It is an open-source software, which can be downloaded for free, and offers solutions for geographically-based projects [11]. QGIS is a project that was initiated in 2002 by a volunteer software development team and accepts contributions from users who wish to contribute to the software. In this study, spatial analyses were conducted using the combination of GIS and AHP to determine new parking lot areas in Yalova province, located in the northwest of Türkiye. The province of Yalova and its surrounding area, due to their proximity to the fault line, have historically been significantly affected by numerous devastating earthquakes originating from the North Anatolian Fault Zone (NAFZ) [12]. Especially in terms of earthquakes, immediately following such natural events, the newly designated parking lot areas could play a crucial role in reducing traffic congestion and even in the establishment of emergency assembly points after the earthquake. In the study area, to identify new parking lot areas, maps of main and secondary roads, slope maps, maps of existing parking lots, shopping centre areas, education, healthcare (hospitals), and tourism facilities, as well as protected areas, population data, land value maps, central business and commercial areas, traffic density, and sub-maps for population and vehicle density criteria have been prepared. These sub-maps, once generated, were weighted using the AHP method based on expert opinions gathered through surveys after obtaining the necessary ethical approvals, and were then integrated in the GIS environment using QGIS software to generate the final map according to these weights. By developing solution proposals and alternatives for potential parking lot areas on the final map, the aim was to support decision-makers in mitigating traffic problems in Yalova Province, both during normal times in the ordinary course of life and in the aftermath of an earthquake.

2 RESEARCH METHODOLOGY

2.1 Study Area

Within the scope of this study, the issue of insufficient parking lot areas, which is one of the factors contributing to traffic congestion in Yalova Province, was examined, and GIS- and AHP-based spatial analyses were applied in order to provide solution proposals for this problem. With the applied analyses, an attempt was made to identify parking lot locations within the city of Yalova and in suitable areas. Yalova Province is located in the northwest of Türkiye and in the southeast of the Marmara Region, based on its geographical position. Its geographical coordinates are 28° 45′ - 29° 35′ Eastern longitudes and 40° 28′ - 40° 45′ Northern latitudes. It serves as a natural bridge geographically, situated between three major cities: Istanbul to the north, Kocaeli to the east, and Bursa to the south. Yalova is an important city where investments have been made in sectors such as industry, tourism, logistics, and maritime. In the industrial sector, valuable investments have been made in the city, particularly with the organized industrial zone and large factories in the chemical sector. In the tourism sector, thermal tourism in the Termal district attracts significant attention from both domestic and foreign tourists, also bringing movement to the region in terms of traffic. In logistics, due to its proximity to major cities, its coastline along the Sea of Marmara, and having a Ro-Ro port, it is becoming a developing city in this field as well. In the maritime and shipbuilding industry, it is a city that hosts some of Türkiye's major shipyards and serves many regions both domestically and internationally. In addition to these investments, the city is also directly influenced by large-scale transportation investments due to its geographical location. As a result, with transportation investments such as the Osmangazi Bridge, the Northern Marmara Highway, and the Istanbul-Izmir Highway, the importance of Yalova Province is increasingly growing. Furthermore, Yalova Province is located on the North Anatolian Fault (NAF), making it a highly active region in terms of earthquake tectonics. It sustained substantial damage during the 1999 Great Marmara Earthquake [12]. Therefore, the parking lot locations identified in this study are also considered to potentially contribute to the number of gathering points for this city after an earthquake. The visual of the study area, obtained using Google Satellite Maps in QGIS, is provided in Figure 1 [11, 13].

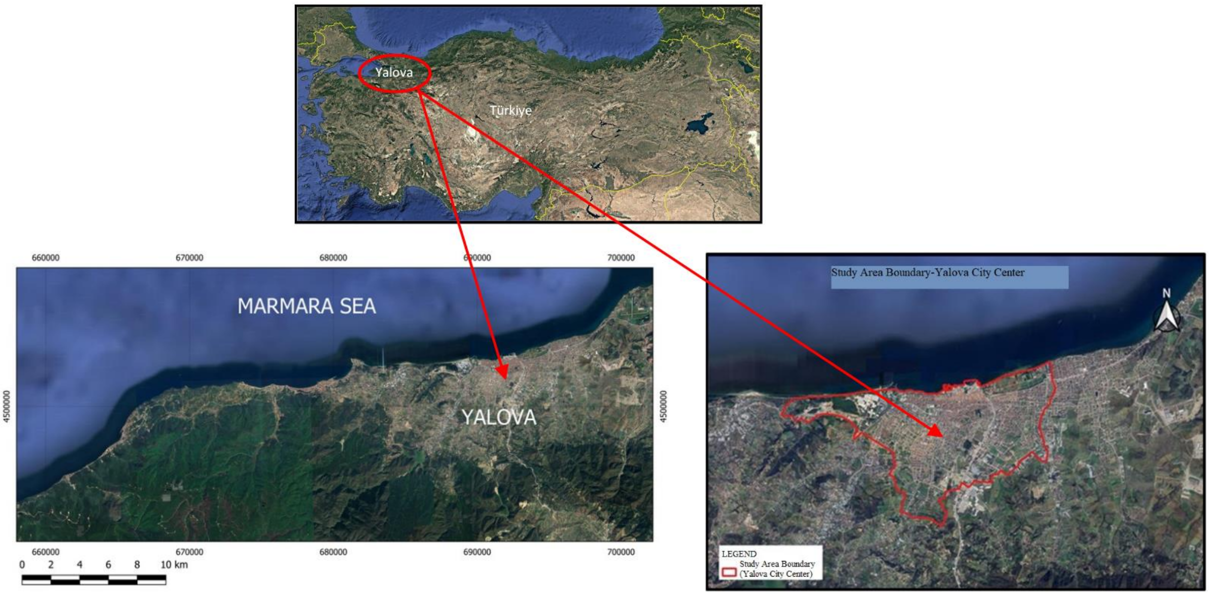


Figure 1. A Visual Representation of the Geographical Location of the City of Yalova Overlaid on A Google Maps Satellite Base Layer

2.2 Geographic Information Systems and QGIS

Site selection is the process of determining the optimal spatial locations for facilities, based on a set of specific criteria. The process generally includes the selection of location-related criteria using Multi-Criteria Decision-Making (MCDM) methods, the determination of the relative importance or weights of these criteria, and the identification of optimal areas for location selection by applying comprehensive spatial analysis methods based on these importance levels [14]. As can be understood from these steps, location selection is a spatial decision-making process that requires planning and strategy. It serves as a significant support tool for decision-makers, particularly in the planning of urban centres where a high concentration of institutions and facilities is present. In addition, spatial analyses conducted within Geographic Information Systems (GIS) significantly facilitate the work of urban decision-makers in determining appropriate locations and planning for parking lot areas within cities. Quantum GIS (QGIS) has recently become a widely used and significant GIS software in the field of geographic information systems (GIS) [11]. QGIS, which began development in 2002, has become a highly useful software for solving problems within the GIS environment. QGIS is an open-source and open access GIS software, available for free, that can be downloaded and used by anyone through its official website [15]. QGIS is a volunteer-based community project that includes platforms where users contribute to each other, and users who wish to do so can contribute to the development of the program [44]. Thus, every user who wishes to contribute to the development of QGIS becomes a part of this volunteer-based project.

Another important feature of QGIS is its plugins, which can be developed according to specific needs through the programming languages available in the software [42-43]. QGIS software provides a plugin library that enables users to create and share plugins developed using programming language support with other users. Geographical Information Systems (GIS) are integrated systems that contain both map-based spatial data and textual descriptive information. Suitable parking lot areas in a city are identified through GIS, which requires some specific thematic maps (sub-component maps). These types of thematic maps are produced as map layers for each of the criteria that need to be considered in identifying suitable and new parking lot areas in a region. They are also seen in the studies in the literature, where these sub-component map layers have been used [16-19]. Within the scope of this study, various criteria such as main roads, slope suitability, secondary roads, existing parking lots, shopping centres, educational areas, healthcare areas, tourism areas, protected areas, population density, land value, central business and commercial districts, traffic density, population-vehicle density values, were considered. Based on these criteria, base and sub-component maps were generated in a Geographic Information Systems (GIS) environment using QGIS software. In the subsequent stage, the base maps obtained were weighted using the Analytic Hierarchy Process (AHP), based on surveys conducted with experts in the field, following the acquisition of ethical approval.

2.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty, is a decision-support method used in multi-criteria analysis to prioritize factors affecting a decision and to identify the most suitable option among alternatives. [20-22]. Determining the significance levels of criteria obtained through AHP regarding a project or subject provides more realistic outcomes for solving the problem. During this process, data collected through surveys conducted with experts in the relevant field serve as the primary basis, while the decision-makers' own experience, knowledge, and expertise are systematically incorporated into the decision-making process. AHP determines the significance levels of criteria based on pairwise comparisons during its calculations [23, 24]. In this manner, the relative dominance of each criterion is determined, and the final weights of the criteria are subsequently computed. When determining the optimal alternative, the computed weight values are also taken into account. In solving a problem using AHP, the process begins with identifying the nature of the problem, followed by constructing a hierarchical model based on the criteria that define the problem's structure; then, pairwise comparison matrices are developed according to the established hierarchy, ultimately resulting in the derivation of weight, importance, or priority values for the criteria [21]. By carrying out all the procedural steps of AHP, a scale is employed to determine the relative importance levels of the criteria; in this scale, the values 1, 3, 5, 7, and 9 are used to represent increasing levels of importance from least to greatest, while the values 2, 4, 6, and 8 serve as intermediate levels within this scale of importance [21, 25]. During the application of the AHP method, the opinions of expert individuals and surveys may be consulted. In the calculations performed as a result of AHP, the Consistency Ratio (CR) is calculated using the Consistency Index (CI) and the Random Index (RI) values [26, 27]). Within the AHP approach, λmax is a key value used to measure the consistency of the eigenvector, and it is computed as presented in Equation (1) [27].

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{x_i}{c_i} \quad (1)$$

The CI value is calculated as follows according to the equation (2) given below:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

The value of λ_{max} in this context represents the largest eigenvalue, while n denotes the number of criteria [26, 27]. Another parameter, RI, is considered as the value corresponding to the n value in Table 1 shown below.

Table 1. Randomness Index [26]

Criterion Number (Matrix size) (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Randomness Index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

After determining these two parameters, the consistency ratio (CR) can be calculated according to Equation (3) [28].

$$CR = \frac{CI}{RI} \quad (3)$$

In order to confirm that the weight values obtained in the AHP analysis are consistent, the condition CR ≤ 0.10 must be satisfied, and in cases where CR > 0.10, the analysis result is considered inconsistent [25, 28]). Since consistency is an assessment that measures the relationship among the decision maker's preferences, in the case of inconsistency, the decision maker's preferences should be reconsidered. For the location suitability analysis conducted within a GIS environment, data relevant to the criteria influencing the decision-making process are gathered, and thematic sub-maps are developed for each criterion. In the AHP analysis, weight values are assigned to these sub-map criteria, and in the GIS environment, a merging process is carried out by considering the weights of these sub-map components, resulting in the final (integrated) map or the desired output. Thus, based on the weighted importance of the criteria, a result and an integrated map are obtained, showing the optimal regions for solving the location suitability problem. Considering the role of AHP in weighting location selection decisions and the spatial analysis capabilities of GIS, it can be stated that this integration provides a significant solution for spatial decision-making problems. A review of the literature reveals that studies combining GIS and AHP have yielded highly satisfactory results [29-34]. The integration of GIS and AHP, which is widely used in various fields, also plays a significant role in addressing traffic and transportation problems arising within and between cities, especially in the context of increasing population. Several studies have been conducted on this topic in the literature [10, 19, 35-37]. As evidenced by the studies reviewed and exemplary studies in the literature, the integration of the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) constitutes a widely adopted and comprehensive decision-support framework for location suitability assessment, applicable not only to traffic and transportation planning but also to a broad spectrum of spatial decision-making contexts. The integration of GIS and AHP employed in this study has been utilized for the purpose of determining suitable locations for new parking lots, contributing to the resolution of traffic problems specific to Yalova Province

2.4 Purpose and Flowchart

In the city of Yalova and its surroundings, as part of the study, with the investments made, the population is increasing, and as a result, there is a rise in urban mobility. These increases also bring along many urban issues. These urban issues can be categorized as environmental, social, economic, and infrastructure inadequacies. The current system is becoming incapable of meeting the increasing service demands along with the growing population. One of the most important of these is the increase in the number of vehicles, which is directly affected by the population. Despite the unchanged urban layout, the ratio of vehicle density increases as the number of vehicles rises. Along with the increasing number of vehicles, the demand for parking lots is also rising at the same rate. This results in the parking lot issue, which is one of the most critical transportation problems encountered by cities. In the city of Yalova, within the study area, the following key issues may lead to the formation of traffic problems and disorders resulting from the inadequacy of parking lots.

- Due to illegal parking on the city's heavily trafficked roads, one lane of the street is blocked by parked vehicles, which narrows the lanes on the streets and disrupts the flow of traffic. This situation causes traffic congestion on the roads. A road that is typically designed with two lanes for traffic is reduced to a single lane. As a result, it is observed that the road's capacity is reduced by half.
- There are a lot of minibus stop points on the main streets and roads of the city. In addition to illegal parking and the reduction of the road to a single lane due to such parking, public transportation vehicles stopping at the stop points to pick up and drop off passengers also contribute negatively to traffic congestion.
- Even on the streets and avenues where parking lots are available in the city, vehicles can still be seen parked along the roadsides. This indicates that the parking lots in the city are insufficient, as they are small in size and already full.

Lane obstructions, double parking, and illegal parking reduce road capacity, and together with the decline in traffic flow, lead to increased traffic congestion. Additionally, the narrowing of lane widths due to parking encroachments decreases both driving and pedestrian safety, thereby negatively affecting urban transportation. In this context, the identification of new parking lot locations in Yalova has been proposed due to the urban parking problems mentioned above, and for this purpose, GIS and the AHP method were used in combination. Within the scope of the study, while determining the locations of new parking lots on the map, the criteria to be considered for generating the final result or map were identified based on previous studies in the literature and expert opinions on the subject. In this context, to generate the final result map, 14 criteria were used along with their corresponding sub-component maps. These criteria include main roads, slope suitability, secondary roads, existing parking lots, shopping centres, educational areas, healthcare zones (hospitals), tourism areas, protected areas, population density, land value, central business districts, traffic density, and the population-to-vehicle ratio. Therefore, the data related to these criteria were obtained from open-access sources on the web, then prepared in raster format to produce thematic maps. Using all these sub-component criteria maps, the final and resulting suitability map for parking lot locations in

Yalova city was obtained through the combination of GIS and AHP. Figure 2 shows the flowchart illustrating the steps followed in the study.

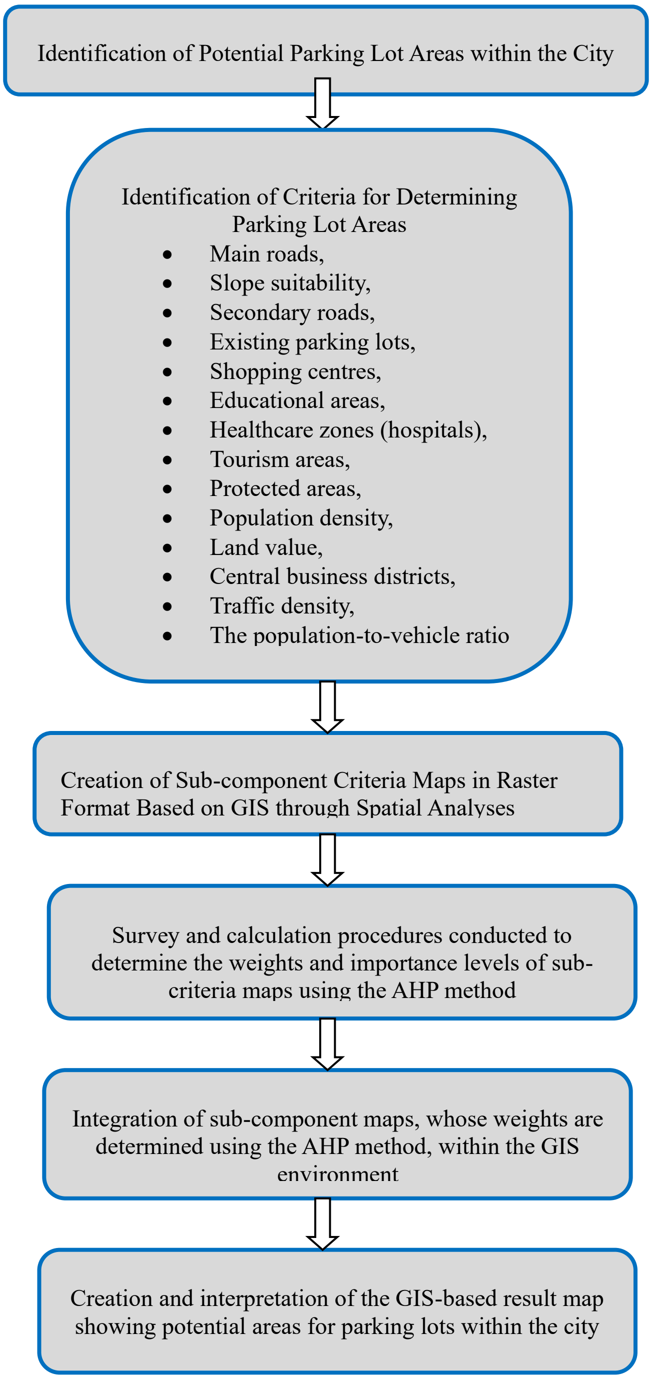


Figure 2. Flow Diagram Showing the Process Steps for the Study Conducted to Identify Potential Urban Parking Lot Areas in Yalova Province.

2.5 Production of Sub-component Maps and Results

In this study, all geospatial analyses were performed using the EPSG:5254 – TUREF / TM30 Coordinate Reference System (CRS), which is based on the Turkish National Reference

Frame (TUREF) and defined with reference to the International Terrestrial Reference Frame 1996 (ITRF96). This coordinate reference system employs a Transverse Mercator projection centered at 30 degrees East longitude, making it particularly suitable for geospatial studies conducted in the Marmara region of Turkey. All spatial data were processed in meters, thereby ensuring compatibility across datasets. The consistent use of this CRS enabled accurate overlay operations between layers and reliable distance-based analyses.

In addition, for each map produced in this study, the source data used have been explained in the relevant sections of the manuscript. Accordingly, the distance maps for main roads, secondary roads, healthcares (hospitals), shopping centers, educational areas, tourism areas, protected areas, central business and commercial areas, and existing parking areas were generated using data obtained in 2023. Additionally, the slope map was based on data from 2022, while the traffic density map used data collected in January 2023. The population-vehicle density map was produced using provincial vehicle statistics from January 2023, and the population data (also used for generating the population density map) were obtained from 2021 figures, as these were the most recent available during the analysis conducted in December 2022. The land value map was created using 2023 data.

2.5.1 Main Roads Suitability Map

Data related to road routes is a criterion considered when determining parking lot areas. In this way, vehicles must use these road networks to access parking lots. Therefore, the distance of parking lots from the roads is crucial in terms of accessibility. In this context, main road maps have been produced within the scope of the study. The OpenStreetMap application, which provides open access on the web, was used for these data related to the study area [38]. The main road data for Yalova province has been downloaded from this site and imported into the QGIS environment. The coordinate system has been adjusted to be compatible with the working area. A buffer zone analysis has been performed for the obtained main road data, and a five-tier buffer zone has been created for the vector road data, with buffer distances of 100, 200, 300, 400, 500 meters, and beyond. For parking lots within 100 meters, first-degree suitable areas have been identified; for parking lots within 200 meters, second-degree suitable areas have been identified; and for parking lots within 300 meters, third-degree suitable areas have been identified. Additionally, areas within the 400-meter buffer have been considered fourth-degree suitable areas for parking lots, while areas beyond 500 meters have been regarded as unsuitable for parking lots. The obtained vector map has been converted into raster format. In the process of converting to raster format, the AHP method was utilized, and the weight values of the areas ranging from first-degree to fifth-degree suitability were calculated based on the main road criterion. Accordingly, the weight was determined as 0.503 for first-degree suitability, 0.260 for second-degree suitability, 0.134 for third-degree suitability, 0.068 for fourth-degree suitability, and 0.035 for unsuitable areas. The AHP consistency ratio (CR) for this calculation was computed as 0.05, which is lower than the consistency threshold of 0.1. While calculating these values obtained for the main road suitability sub-criterion map, the relative importance of the suitability levels was taken into account, which allowed the distinction between the first-degree suitable areas and the completely unsuitable areas to be more clearly revealed. According to a 5-point rating system, there is a fivefold difference between these two criteria, whereas the new values obtained through the AHP method reveal a score difference of 14.3 times. This method enabled a more accurate scoring for the raster-format main road suitability sub-criterion map and contributed to making the map more distinct. This method has also been applied to the sub-component maps produced between Figures 3 and 4. Figure 3.a presents the primary road suitability sub-criteria map, produced in raster format, which is a component of the parking lot map for Yalova city. For the distance maps of main roads, secondary roads, healthcares (hospitals), shopping centers, educational areas, tourism areas, protected areas, central business and commercial areas, the classification values shown in the legend are in meters. In contrast, the map showing the proximity to existing parking areas is classified in reverse, with areas closer to parking lots considered more suitable. For example, dark green represents 100 meters (closer), and red represents 500 meters or more (farther).

- Dark green: 100 m
- Light green: 200 m
- Yellow: 300 m
- Orange: 400 m
- Red: 500 m and above

2.5.2 Slope Suitability Map

Slope is a critical engineering criterion for the production of the final parking lot map. It is a criterion that affects not only construction costs but also accessibility. When determining parking lot areas, locations with steep land slopes make access more difficult. At this point, the comfort of drivers who park their vehicles should also be taken into consideration, and this important criterion should be included in both site selection and spatial planning studies. In order to generate the slope map, a Digital Elevation Model (DEM) must first be generated. For this purpose, Digital Elevation Model (DEM) data for the study area, Yalova city centre, was obtained from NASA's Earthdata ASF Data Search Vertex site, which provides full and open access on the web [39]. The pixel size of the obtained data is 12.5 by 12.5 meters. Using this DEM data, a slope map was generated. The resulting map was produced in raster format. Figure 3.b presents the slope suitability sub-criteria map, produced in raster format, which is a component of the parking lot map for Yalova city. Regarding the slope map, the classification intervals indicated in the legend are given as percentage values:

- Dark green: 5% and below
- Light green: 5%–10%
- Yellow: 10%–20%
- Orange: 20%–30%
- Red: 30% and above

2.5.3 Secondary Roads Suitability Map

Within the scope of the study, secondary road data represent major urban streets and their connecting routes. The data related to secondary roads was also obtained from OpenStreetMap, which is openly accessible on the web [38]. In this map, as in the main road map, a buffer zone analysis was conducted in the QGIS environment. As a result of the analysis, five distinct layers were generated. The layers, created at 100-meter intervals, become increasingly unsuitable for parking lot allocation as the distance from secondary roads increases. Figure 3.c presents the secondary road suitability sub-criteria map, produced in raster format, which is a component of the parking lot map for Yalova city. The map legend includes five distinct colour layers. As the colour transitions from green to red, the distance increases by 100 meters, and the characteristic of suitability for parking lot planning diminishes.

2.5.4 Suitability Map According to Existing Parking Lot Areas

Existing parking lots constitute another criterion that should be taken into account when planning new ones. Implementing certain parking lot strategies, such as rehabilitating existing ones, making geometric adjustments, increasing their capacities, and modifying pricing strategies, might be perceived as more feasible than establishing new ones in close proximity to these. However, planning new parking lots at a minimum distance of 100 meters from the existing ones is more appropriate for reducing traffic congestion within the city. In order to produce the map of existing parking lots, spatial data representing parking lot areas within Yalova province was obtained from OpenStreetMap. A buffer analysis was applied to the finalized data in the QGIS environment, resulting in the generation of five distinct layers at 100-meter intervals. As with the other types of maps mentioned above, the vector-format map obtained was assigned scores derived from AHP to the attribute tables before being converted into raster format. Based on these scores, the conversion into raster format was carried out in the QGIS environment. Figure 3.d illustrates the suitability sub-criteria map for existing parking areas, generated in raster format, which constitutes a component of the parking lot map for Yalova province. As indicated in the map legend, areas that are highly suitable for parking lot placement are shown in dark green.

2.5.5 Shopping Centres Based Suitability Map

Shopping centres integrate businesses from diverse sectors, consolidating various commercial activities under one roof. This phenomenon results in shopping centres attracting a high volume of crowds. Shopping centres also enhance the commercial vitality of their surrounding areas, thereby increasing their ability to attract population. This situation also leads to an increase in the traffic congestion of the region. In this context, when planning parking lot areas, it is important to establish parking lots near shopping centres to facilitate access for people wishing to reach the centres and to reduce the traffic congestion caused by the increased mobility in the area. In this study, vector data of shopping centres located within the city of Yalova were downloaded from OpenStreetMap, which is freely accessible on the web. The downloaded data were analyzed in the QGIS environment. Figure 3.e presents the suitability sub-criteria map for shopping centre areas, produced in raster format, which forms an integral component of the parking lot map for Yalova city.

2.5.6 Suitability Map Based on Educational Areas

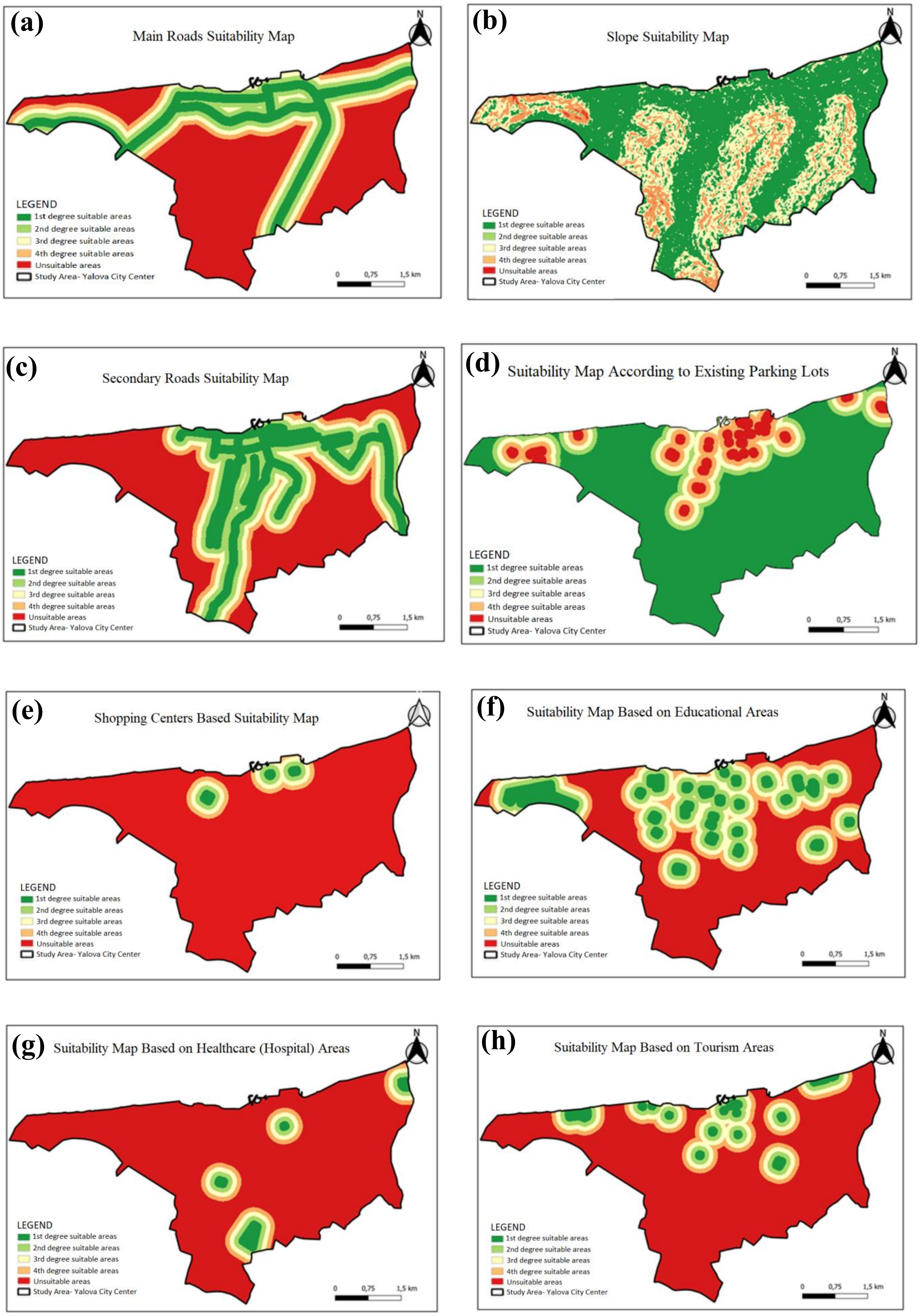
Educational areas attract a similar number of people each weekday, including students, teachers, staff and parents, to the region where they are located, and this increases the intensity of traffic activity in the area. As these areas are crucial focal points, they constitute one of the fundamental criteria to be considered when designating appropriate parking lot spaces. In order to generate a map of the educational areas, vector data related to the educational areas were first downloaded from OpenStreetMap, which provides open access on the web. In the QGIS environment, five-step areas were established at 100-meter intervals. Figure 3.f illustrates the suitability sub-criteria map for educational areas, produced in raster format, which constitutes a component of the parking lot map for Yalova province.

2.5.7 Suitability Map Based on Healthcares (Hospitals) Areas

Healthcare areas are spaces that generate a high population density due to patients, attendants, staff, and visitors, thereby increasing the traffic mobility in the region. The healthcare area criterion is also one of the factors that must be considered in the selection of parking lot locations for determining suitable parking areas within the city of Yalova. To prepare the map for the healthcare area criterion, data related to healthcare areas were downloaded from OpenStreetMap, which provides open access on the web. Locations near healthcare areas have been identified as suitable sites for parking lot planning. In this context, a five-level buffer zone analysis was conducted at 100-meter intervals. Figure 3.g presents the suitability sub-criteria map for healthcare areas, produced in raster format, which forms a component of the parking lot map for Yalova province.

2.5.8 Suitability Map Based on Tourism Areas

Tourism areas refer to places that provide tourism services, such as hotels and resorts, where visitors to the city stay. Due to their role as major attraction centres, the tourism criterion becomes an important factor to be considered in parking lot planning. The data to be used for generating the map for the tourism criterion were obtained from OpenStreetMap, which provides open access on the web. The downloaded data were transferred to the QGIS environment and classified into five categories at 100-meter intervals. Figure 3.h presents the suitability sub-criteria map for tourism areas, produced in raster format, which forms a component of the parking lot map for Yalova province.



Figures 3.(a–h) The Sub-Criteria Maps that Constitute the Final Map Produced for Parking Lot Planning in Yalova Province (Main roads, Slope, Secondary Roads, Existing Parking Lots, Shopping Centers, Educational, Healthcare (Hospital) and Tourism Areas).

2.5.9 Suitability Map Based on Protected Areas

Protected areas include locations such as historical and natural heritage sites, agricultural lands, parks, national gardens, nature reserves, and forest zones. As these areas also embody the natural beauty of cities, they serve as significant points of attraction. In this context, they represent one of the key criteria that must be taken into account during the site selection process for suitable parking lots. The data for the protected areas map were downloaded from OpenStreetMap, which provides open access on the web. As with the other maps, a five-level buffer zone analysis at 100-meter intervals was initially conducted on these data. However, an important point to consider here is that the interior boundaries of protected areas are entirely unsuitable for parking lot planning. Conversely, the zones immediately surrounding these boundaries have been defined as highly suitable areas. The resulting sub-component map for protected areas, converted into raster format, is presented in Figure 4a As shown in the figure, the boundaries of these areas are under protection, making it generally impossible to establish parking lots within them. Nevertheless, since these regions also function as centers of attraction, it becomes feasible to plan parking lots in the zones directly adjacent to them. In the map, areas shown in red indicate zones unsuitable for parking lots, while the dark green areas represent regions classified as “highly suitable” (1st degree suitability).

2.5.10Suitability Map Based on Population Density

Population density is a critical factor in determining suitable parking lot locations. In areas with high population density, the number of vehicles is also elevated, and each vehicle requires space in a parking lot. Furthermore, regions with higher population levels typically experience more intense commercial activities, expanded residential zones, and increased mobility. As a result, these areas exhibit the characteristics of significant attraction centres. The population density map was prepared at the neighbourhood level, using neighbourhood boundary data obtained from OpenStreetMap, which provides open access through an online platform. In addition, population data was gathered from the Turkish Statistical Institute (TUIK) website [40]. The resulting subcomponent map of preserved areas, converted into raster format, is presented in Figure 4b Accordingly areas with the highest population and first-degree suitability for parking lot selection are shown in dark green, as in other subcomponent maps. In contrast, areas deemed unsuitable for parking lot location, which represent zones with the lowest population density, are displayed in red. For the population density map, the legend values are based on population per square kilometer:

- Dark green: 15.1–34.5

- Light green: 10.4–15.1
- Yellow: 7.3–10.4
- Orange: 4.5–7.3
- Red: 1.5–4.5

2.5.11 Suitability Map Based on Land Value

The land value criterion is one of the important factors that can significantly inform the selection of suitable parking lot locations. Areas with high land values generally have high levels of commercial activities, settlement, attraction centres, and mobility. Due to these characteristics, areas with high land values that host important attraction centres tend to experience traffic congestion and parking problems. Although building a parking lot in these areas may be costly due to land prices, it will make a significant positive contribution to traffic, residents, and urban comfort. In such cases, it is important for local governments to subsidize public parking costs as part of urban planning. Therefore, although building a parking lot in areas with high land values may be initially costly, it is important for the overall benefit of the city. The land value map was prepared on a neighbourhood basis, and land value data were calculated from market value values obtained from the open-access website of Yalova Municipality [41]. The resulting map of the central land values for Yalova Province, converted into raster format, is presented in Figure 4c. As can be seen from the suitability map, the areas with the highest land value, located in the city center of Yalova and with the highest levels of commercial, educational, health, and population criteria, were found to be the most suitable locations for parking lots and are symbolized in dark green. In contrast, the areas with the lowest land value, which are less dense in terms of commercial, educational, health, and population criteria, were found to be the least suitable locations for parking lots and are symbolized in red. For the land value map, the legend values represent land price per square meter:

- Dark green: 7091–8104
- Light green: 1728–7091
- Yellow: 1473–1728
- Orange: 1264–1473
- Red: 595–1264

2.5.12 Suitability Map Based on Central Business and Commercial Areas

Central business and commercial areas are among the busiest parts of the city during the day. These areas attract not only many workers but also the people who come to use the services provided there. The fact that service providers from different sectors are located close to each other makes these areas even more crowded and active. Because of these features, the business areas in Yalova's city centre act as strong centres of attraction. As a result, the population in these areas increases during the day, which causes heavier traffic and increases the need for parking lots. For this reason, central business and commercial areas are an important factor when deciding where to place parking lots. Data on Yalova's central business and commercial areas were downloaded from OpenStreetMap, which provides open-access geographic information. The subcomponent map, prepared in the QGIS environment and converted into raster format, is shown in Figure 4.d

2.5.13 Suitability Map Based on Traffic Density

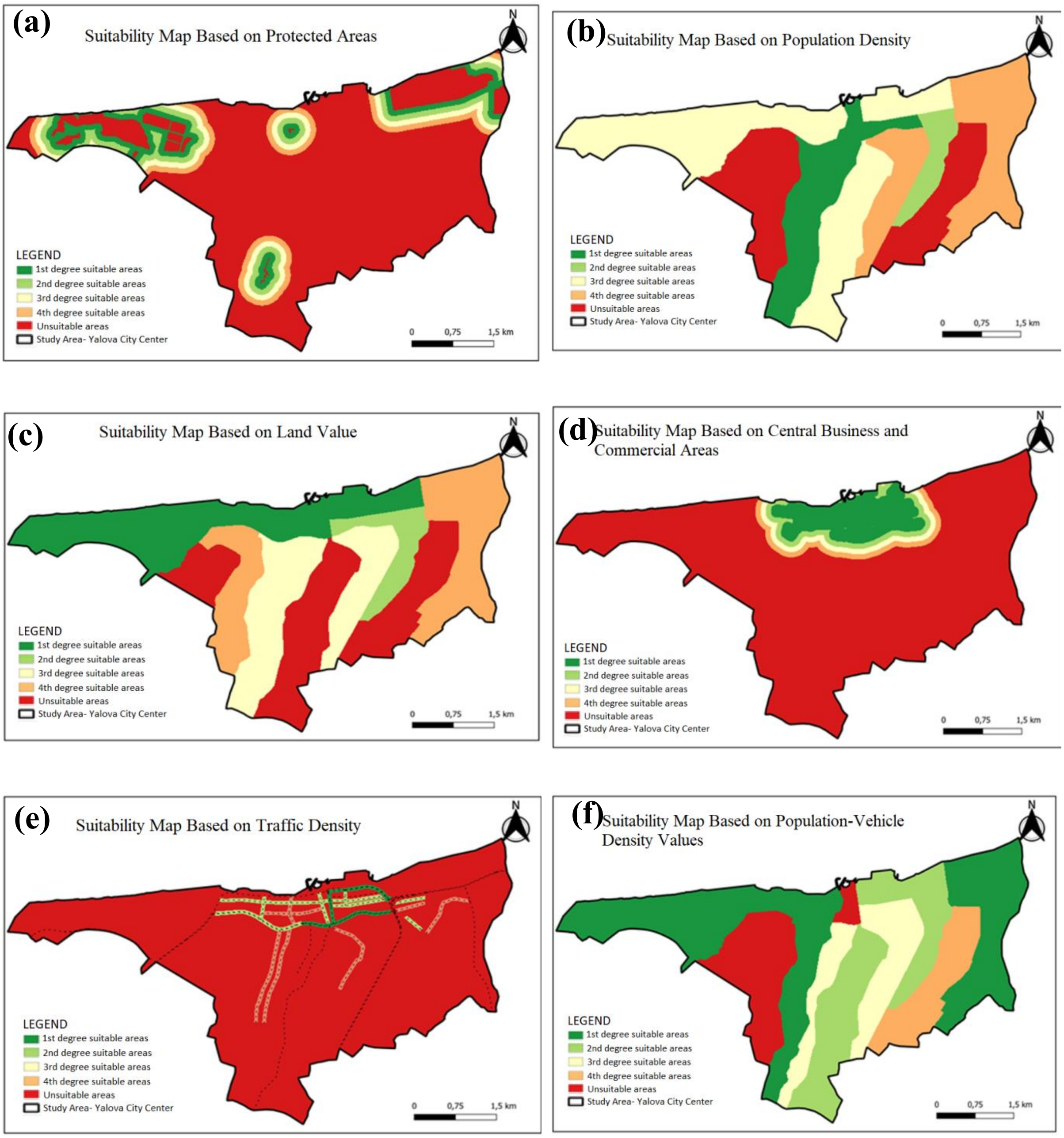
Traffic and parking areas are closely related and significantly interconnected. Parking problems, such as illegal parking, double parking, and parking in travel lanes, contribute to increased traffic congestion. Additionally, vehicles searching for parking lots for extended periods add extra strain to traffic. Therefore, encountering a parking lot problem in areas with heavy traffic is very common. In parking lot selection studies, traffic criteria are important for identifying suitable locations. In this study, a suitability map based on traffic density has been developed to obtain the final map of appropriate parking lots. For this purpose, traffic data for each road within the study area were examined with open-access information from Google Maps were utilized [13]. The traffic density subcomponent map for Yalova was developed in order to establish the final parking lot suitability map for Yalova. The raster maps obtained in the QGIS environment are presented in Figure 4.e. In this traffic density map, parking lots are considered most suitable in areas with the highest traffic density. As one moves from dark green to red areas, traffic density decreases. In this context, the green areas, representing the locations with the highest traffic density, are deemed the most suitable places for parking lots. Conversely, as the traffic density decreases toward the red areas, the suitability for parking lots also diminishes. For the traffic density map, the legend intervals are based on a traffic density index. Notably, areas shown in green represent regions of high traffic density, which are considered highly suitable for parking due to higher demand:

- Dark green: above 75
- Light green: 75
- Yellow: 60
- Orange: 45
- Red: 30

2.5.14 Suitability Map Based on Population-Vehicle Density Values

The population-vehicle density criterion is defined by the ratio of the population in a region to the vehicle density. Vehicle density gives an idea about the level of vehicle ownership in the area being analyzed. For the population-vehicle density suitability map, the analysis was conducted at the neighbourhood level, and in this context, the number of vehicles in each neighbourhood was determined. In order to find the number of vehicles per neighbourhood, it should first be calculated how many people there are per vehicle in Yalova city centre. In this context, the population and vehicle data at the provincial level, obtained from the open-access TUIK website, were proportioned [40]. As a result, the vehicle density value for Yalova city centre was found to be approximately 4. This value demonstrates that, on average, one out of every four residents in Yalova is a vehicle owner. In this context, the neighbourhood population data, also obtained from the open-access TUIK website, were proportioned to the previously calculated vehicle density value of approximately 4 in order to estimate the number of vehicles in each neighbourhood. For the population-vehicle density map, the legend intervals represent the number of vehicles per population unit:

- Dark green: 3905–4224
- Light green: 2785–3905
- Yellow: 2237–2785
- Orange: 1876–2237
- Red: 1008–1876



Figures 4.(a-f) The Sub-criteria Maps that Constitute the Final Map Produced for Parking Lot Planning in Yalova Province (Protected Area, Population Density, Land Value, Central Business and Commercial Areas, Traffic Density and Population-Vehicle Density Values)

Since areas with a high number of vehicles are likely to have a greater need for parking lots, this criterion plays a significant role in identifying suitable parking lot locations when evaluated alongside other criteria. "The obtained data were entered into the attribute table of the neighbourhood layer, and the population-vehicle density values were colour-coded into five categories to represent the suitability levels. The Population-Vehicle Density subcomponent map, created in the QGIS environment and converted into raster format, is shown in Figure 4.f. In the neighbourhood-based map, the areas with the highest population and vehicle density rates correspond to locations with the highest number of vehicles, and the places suitable for parking lot planning in the first degree are represented by dark green color. As we move towards the red areas, this value decreases, and the parking lot suitability degree also decreases accordingly.

2.6 Calculation of Criteria Weights Using AHP

In the scope of the study, thematic maps have been produced for the 14 sub-criteria mentioned above in order to generate the final or result map for determining the parking lot suitability areas in the central district of Yalova. In this context, a spatial integration analysis has been applied in the QGIS environment for each produced map. This analysis involves combining the maps by multiplying each map with a coefficient value that indicates its specific level of importance. This coefficient value also corresponds to the weight values for each criterion. To calculate the weight values, the Analytic Hierarchy Process (AHP) has been utilized. To calculate the weight values, the Analytic Hierarchy Process (AHP) has been utilized. The opinions of technical personnel specialized in the field, such as transportation engineers, civil engineers, and survey engineers, were utilized, and the necessary ethical approvals for the survey were obtained from the Yalova University. Additionally, the survey was conducted with a total of 7 participants over a period of 1 month. The pairwise comparison matrix (A matrix) used in the AHP process is presented in Table 2. The weight values obtained from this process are provided in Table 3 and Figure 5.

Table 2 - Pairwise Comparison Matrix, referred to as the A Matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14
K1	1	2	1	1	2	2	1	1	1	1/3	1	1/2	1	1/3
K2	1/2	1	1	1	1	1	1	1	1	1/3	1	1/2	1	1/3
K3	1	1	1	1/2	1	1	1	1/2	1/2	1/4	1	1/3	1	1/4
K4	1	1	2	1	1	1	1	1	1/3	1/2	1	1/2	1	1/2
K5	1/2	1	1	1	1	1	1/2	1/2	1/2	1/3	1/2	1/3	1/2	1/4
K6	1/2	1	1	1	1	1	1/2	1	1/2	1/3	1/2	1/2	1/2	1/3
K7	1	1	1	1	2	2	1	2	1	1/2	1	1	1/2	1/2
K8	1	1	2	1	2	1	1/2	1	1	1/4	1/2	1/3	1/2	1/5
K9	1	1	2	3	2	2	1	1	1	1/2	1	1	1	1/2
K10	3	3	4	2	3	3	2	4	2	1	4	2	1	1/2
K11	1	1	1	1	2	2	1	2	1	1/4	1	1/3	1/3	1/4
K12	2	2	3	2	3	2	1	3	1	1/2	3	1	2	1/2
K13	1	1	1	1	2	2	2	2	1	1	3	1/2	1	1
K14	3	3	4	2	4	3	2	5	2	2	4	2	1	1

As a result of this procedure, when the weight values for each criterion are examined, it has been observed that the cumulative weights of the criteria with the highest weights, namely C14, C10, C12, and C13, influence approximately 50% of the map.

Table 3. Criterion Weights Used in Determining Suitable Parking Lot Areas

Criteria	Code	Criteria Weights
Main Roads	C1	0.061
Secondary Roads	C2	0.049
Slope	C3	0.043
Existing Parking Lots	C4	0.054
Shopping Centers	C5	0.037
Educational Areas	C6	0.040
Healthcare (Hospital) Areas	C7	0.064
Tourism Areas	C8	0.047
Protected Areas	C9	0.074
Population Density	C10	0.136
Land Value	C11	0.053
Central Business and Commercial Areas	C12	0.102
Traffic Density	C13	0.084
Population-Vehicle Density Values	C14	0.156

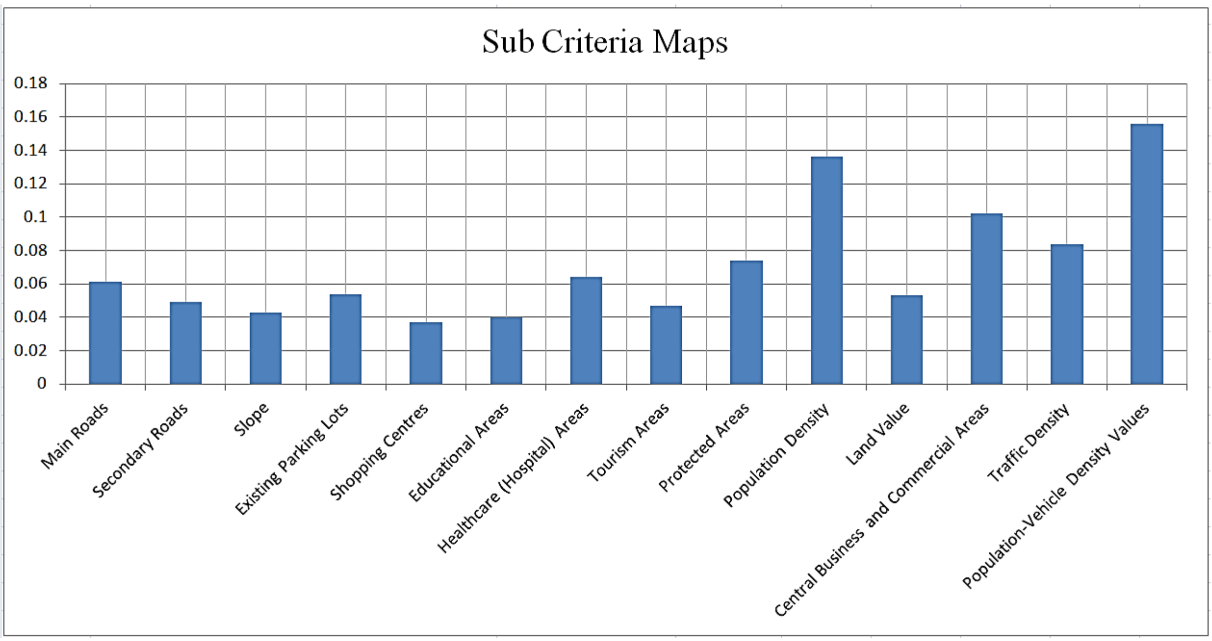


Figure 5. Graph showing the significance levels of the sub-criteria maps constituting the final parking lot map of Yalova Province

As a result of the procedures carried out, the CI (Consistency Index) value was found to be 0.05 in this study. When this value is divided by the RI (Random Index), the CR (Consistency Ratio) is obtained. In this context, based on the number of criteria in Table 1, the RI value was taken as 1.57 for 14 criteria. Accordingly, the CR consistency ratio was calculated as 0.03 by dividing CI by RI, yielding a value smaller than 0.10. This result indicates that the process is consistent. In the conducted study, the weighting of the 14 sub-component criterion maps prepared as raster data was carried out by multiplying each map by its own weight value within the QGIS environment, and in the subsequent stage, an overlay analysis was applied to these maps using the assigned weight values.

As a result of the overlay analysis conducted using the AHP method in the QGIS environment, the final map showing the suitable intra-urban parking lot locations in Yalova Province is presented in Figure 6, using the Google Maps Satellite base layer provided within the QGIS environment. In Figure 6, the dark green areas represent the locations most suitable for parking lot construction within the Yalova city centre. As the colour transitions toward the red areas, the suitability for parking decreases accordingly.

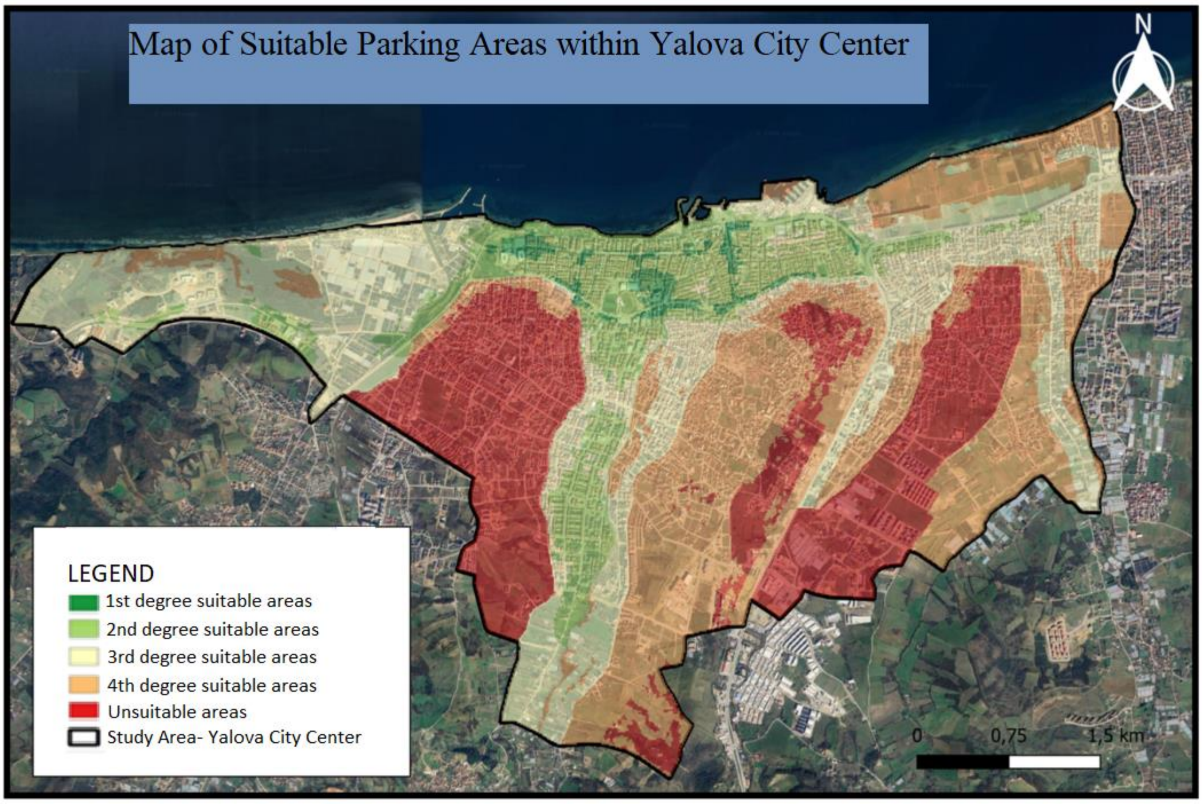


Figure 6. Map Showing the Potential Parking Lot Locations for Yalova City Centre, Produced Through The Integration of GIS and AHP, Presented Using The Google Maps Satellite Imagery Base Layer In QGIS

For the final parking suitability map**,** the legend values are based on the AHP-derived weighted scores**:**

- Dark green: above 0.2990
- Light green: 0.2389–0.2990
- Yellow: 0.1789–0.2389
- Orange: 0.1188–0.1789
- Red: 0.1188 and below

3 DISCUSSION AND RECOMMENDATIONS

The insufficiency of parking lot areas in the study area negatively affects traffic capacity, traffic flow, traffic density, traffic safety, and traffic comfort. In order to contribute to the solution of parking lot-related problems that also lead to traffic congestion in the city, it has been considered within the scope of the study that new parking lot locations should be determined in the city centre. In this regard, a solution has been explored by using the integration of GIS and AHP, taking into account literature studies, to determine suitable parking lot locations. Previous studies conducted in various urban contexts demonstrate that the integration of Geographic Information Systems (GIS) with multi-criteria decision-making (MCDM) methods such as the Analytic Hierarchy Process (AHP) provides an effective and systematic approach to urban parking planning. Particularly in cities with high traffic density, spatial analyses based on GIS and weighted criteria through AHP enable the production of visual maps that significantly support urban decision-making processes [10, 45, 46]. Similarly, in this study, GIS and AHP-based analyses have been utilized to identify suitable parking areas, generating data-driven and visually supported outputs that serve as a methodological framework to guide urban transportation planning. Therefore, the integration of GIS and MCDM methods proves to be a functional, applicable, and instructive tool in addressing urban traffic congestion, enhancing user comfort, and promoting safe mobility. In the parking lot site selection study, 14 criteria influencing the site selection were considered, and sub-component maps were produced for these 14 criteria. After the sub-component maps produced were assigned importance and weight values based on the opinions of experts in the field, a weighted overlay analysis was applied to these components in the GIS environment. In the study, the AHP method was applied to determine the weights of these sub-component map criteria, while the necessary ethical approvals were obtained, and a survey was conducted in which the opinions of experts were gathered. The following comments have been considered for specific areas shown in Figure 7, which were obtained using the AHP method in the QGIS environment. Accordingly, in the final or result map, the areas labelled A, B, and C, shown in dark green, are the locations most suitable for parking, and this map is presented using the Google Maps Satellite Imagery base layer. More detailed visuals are provided for regions A, B, and C, as shown in Figure 8, and these maps are also presented with the Google Maps Satellite Imagery base layer in QGIS

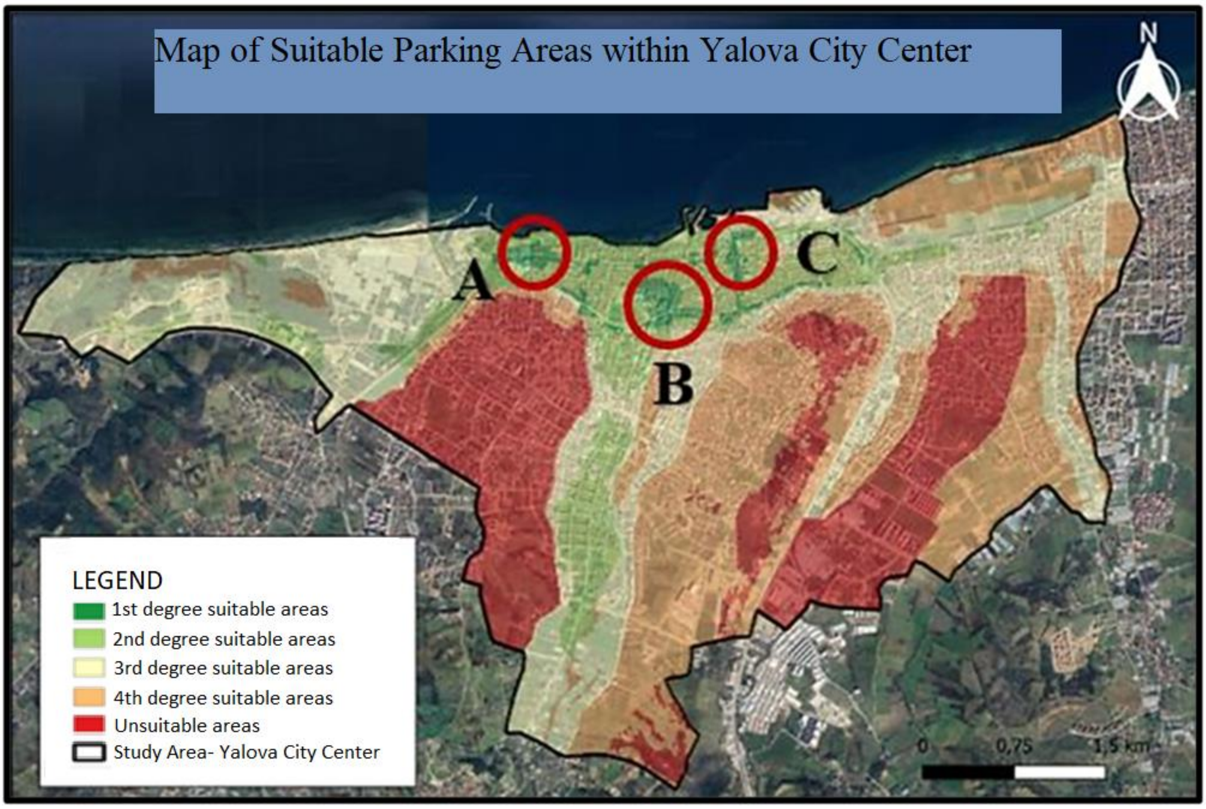


Figure 7. GIS-Based Map Produced for the City Center of Yalova, Indicating Suitable Parking Lot Areas (A, B, C), Presented Using the Google Maps Satellite Imagery Base Layer in QGIS

Region A is located on the bustling streets of the city. It is a region in proximity to major and secondary roads, making it highly suitable in terms of the specified criteria in this study. It is approximately 400 meters away from the existing parking lots. Furthermore, within the A district, there are four different educational areas. In terms of land value, the region is among the highest in the city, and based on land value, it is considered one of the most suitable areas of the first degree. The neighbourhood where the A district is situated also places among the most suitable areas based on population and vehicle density, and the number of vehicles in this area is higher than the city's average. A large parking lot is situated approximately 400 meters from the A district. When evaluated using GIS and AHP methods, it is recommended that one of the planned parking lots in Yalova province be located in the A district. It is expected that a parking lot planned within the A district will contribute to the improvement of traffic in Yalova city centre, reduce parking problems, and thus increase transportation comfort.

Figure 8. Detailed Visuals of The A, B, and C Areas, Identified as the Most Suitable Parking Lot Locations in the City Centre of Yalova, Presented with the Google Maps Satellite Imagery Base Layer in QGIS

Region B is located along a main road that significantly contributes to the accessibility of Yalova's central areas. This region is adjacent to both main roads and side streets. Based on the analysis, Region B is positioned at the centre of this road. It is located between three educational institutions and is also densely surrounded by attraction centres, as well as central business and commercial areas. Moreover, in terms of land value, this region is among the highest-valued areas. It also includes first-degree areas in terms of the population-to-vehicle density ratio. Considering that Region B experiences heavy traffic and has a high number of vehicles, it is considered appropriate to establish one of the parking lots planned for Yalova’s city centre in this area. It is expected that a parking lot planned in this region will contribute to solving the parking problems in Yalova’s urban centre.

Region C is located in the square area of Yalova province. This region includes a lot of central business areas, intersections of main and secondary roads, tourism service areas, high land value areas, and locations with high traffic density. For this reason, Region C is considered highly suitable for each of these criteria for parking lot planning. Important attraction centres for the city are located near this area. It is expected that a parking lot planned for this area will make a significant contribution to solving the city's parking and traffic congestion problems.

To support the spatial analysis with field data, images obtained from a field study conducted in 2024 for the specifically proposed Region C are presented (Figure 9a–9d). These images clearly show the high density of vehicle parking in the area and reveal that the existing parking facilities are insufficient to meet the demand. In particular, the photos illustrate improper parking along roadsides and sidewalks, reflecting the increased demand due to the limited parking capacity. This situation aligns with the high parking demand suggested by our spatial analysis and demonstrates the consistency between the site selection process developed in this study and real-world observations.

Figure 9.(a–d) Images Illustrating Parking Problems Caused by Vehicle Density and Insufficient Parking Spaces in the City Center of Yalova. The Photos Correspond to Region C, Which Was Selected as a Sample Area From the Zoning Presented in Figure 8.

4 CONCLUSION

Today, urban areas are developing in almost every field, influenced by technology. These developments directly impact sectors such as education, healthcare, industry, trade, transportation, agriculture, and real estate. Due to the concentration of such sectors in urban areas, rural populations are migrating towards urban areas. These sectors also act as employment opportunities, which thereby have an impact on the growth of the urban population. Furthermore, the development of these sectors generates new attraction centers in cities. This situation significantly increases population mobility. As a result, traffic movements in the city also rise considerably. This intense traffic movement brings about significant transportation problems in urban areas. One of these problems is the issue of urban parking lot. The parking lot problem is an urban transportation issue that significantly affects the transportation comfort within the city. As a result of the study, the map obtained by the weighted overlay of 14 criteria, using AHP and GIS in the QGIS environment, reveals that the most suitable parking lot areas are concentrated in Regions A, B, and C. In addition, it has been determined that suitable areas of the first degree are also located along the main streets of the city, outside of these regions. These areas and streets contain a high amount of residential areas, as well as central business and commercial areas. In this context, since the relevant areas are intense centres of attraction in terms of traffic and travel circulation, it is considered that establishing parking lots in suitable locations within these areas would significantly ease the city centre in terms of travel and traffic comfort. Vacant lands in the first-degree suitable areas identified through the analysis should be utilized as parking lots. For narrow and limited spaces, underground and multi-storey parking lot options should also be considered. It is considered appropriate for local governments to initiate expropriation in relevant areas for the development of new parking lots in regions where there is a demand for parking. However, considering the high cost of land acquisition in central areas and the limited financial capacity of municipalities, alternative strategies should be developed. In compact cities like Yalova, spatial overlap between residential and commercial areas is common, meaning that both first- and second-degree parking zones are often located in similar contexts. Therefore, instead of focusing solely on expropriation, the following solutions may be more feasible and sustainable for local governments:

- Optimization of existing parking facilities through better planning and design,
- Increasing the capacity of existing covered parking facilities by adding underground levels, in cases where it is feasible in terms of technical, legal, zoning

regulations, building permits, ownership status, expropriation potential, and other relevant conditions.

- Promoting private sector involvement with affordable pricing schemes,
- Implementation of smart parking management systems (ITS),
- Creation of Park & Ride facilities at the city's edges,
- Expanding parking for bicycles, scooters, and EVs,
- Allowing public use of institutional and commercial parking during off-hours,
- Encouraging Public–Private Partnerships (PPPs) for construction and operation,
- Use of vertical mechanical parking systems for space-limited areas.

These recommendations are outlined as practical alternatives to address parking demand without heavily relying on expropriation. They also aim to support sustainable urban mobility and minimize traffic congestion caused by drivers searching for available spaces. Furthermore, the city centre is an area with a significantly high stock of old buildings. As these old building stocks are renewed within the scope of urban transformation, it would also be appropriate to make arrangements for parking lots. In the existing parking lots, capacity should be increased if possible, through geometric arrangements or structural innovations. In cases where this is not feasible, these areas should be redeveloped and underground and multi-story parking options should also be considered. Since the study area is located very close to the North Anatolian Fault, which has a high capacity for producing earthquakes, the proposed parking lots in the suggested areas can also help ease traffic flow after a potential earthquake. Additionally, for the proposed first-degree parking lots, in suitable areas, intelligent transportation systems (ITS) should be used for newly established parking lots, and drivers should be directed to appropriate parking lots through notifications on intelligent devices. As a result, the impact of drivers searching for parking spaces on traffic should be minimized, and in addition, more comfortable urban transportation or transport services should be provided.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Taha KAPLAN: Data Curation, Formal Analysis, Investigation, Resources, Software, Visualization, Writing-Review and Editing

Eray CAN: Conceptualization, Investigation, Methodology, Project Administration, Supervision, Validation, Writing-Review and Editing

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